Session 3

Technology and innovative options related to sludge management

Ecological and economical balance for sludge management options

Jeremy Hall
WRc plc, Medmenham, Marlow, SL7 2HD, United Kingdom

Abstract

The treatment and disposal of sewage sludge is an expensive and environmentally sensitive problem. It is also a growing problem world-wide since sludge production will continue to increase as new sewage treatment works are built and environmental quality standards become more stringent. With some traditional disposal routes coming under pressure, and others such as sea disposal having been phased out, the challenge facing sludge managers is to find cost-effective and innovative solutions whilst responding to environmental, regulatory and public pressures. Recycling and use of wastes are the preferred options for sustainable development, rather than incineration or landfilling, but with sewage sludge this is not straight forward because of perceptions over contaminants, pathogens and its faecal origin, particularly by the food retailers. If future quality standards for sludge and the receiving environment are made too stringent, the agricultural outlet may become untenable for the water utilities resulting in sludge being disposed of by other means that offer the utilities greater operational and financial security, but which may be less acceptable in the long-term. This paper discusses some of the issues relevant to achieving a practicable and affordable balance in sustainable sludge management.

Introduction

There are currently over 50,000 wastewater treatment works (WWTPs) operating in the European Union yielding a total of about 7.9 million tonnes of dry solids (tds) in year 2000. The amount of sludge will continue to increase as the Urban Waste Water Treatment Directive continues to be implemented (CEC, 1991), reaching at least 8.3 million tds/y by 2006. The major outlets for sludge are agriculture and landfill, with only a relatively small amount being incinerated. National measures to reduce the amount of organic matter disposed of in landfill will result in the increased use of the other outlets. From a policy perspective, agriculture is the favoured route, but the question addressed by this paper is whether this outlet can be sustained practically and economically with the prospect of increasingly stringent quality standards.

Farmland has long been the natural outlet for sludge as it contains similar quantities of nitrogen, phosphorus and organic matter as farmyard manure or slurry, making sludge attractive to farmers as a supplement to other fertilisers, particularly in predominantly arable areas. Sludge may also contain lime and other essential trace elements but little potassium. However, there are also well recognised constraints on sludge use due mainly to heavy metals and pathogens that may be present, the occurrence of which reflects the nature of the catchment of the sewage treatment works (i.e. presence of industries, hospitals, abattoirs, combined drainage etc.). Furthermore, there are the potential problems of odour, litter (screenings) and bulk (high water content). While there have been considerable advances in control and treatment technologies in recent years that can reduce potential impacts, albeit with increased costs, sludge quality remains one of the principal constraints on sludge use particularly as quality standards continue to be tightened.

The disposal of sludge always requires very positive and careful management but the ease, or difficulty, with which disposal is actually achieved, and the associated costs depend very much on circumstances. Local and national geographical, agronomic, economic and stakeholder perception factors have considerable influence. The general trend in recent years in most developed countries has been for the disposal of sludge to become more, rather than less difficult, and this has been exacerbated by a considerable increase in EU and national environmental legislation.

With present knowledge, there seems little prospect of developing a cost-effective sewage treatment process which does not transfer a significant proportion of the pollutant load into a concentrated wet solids side-stream requiring off-site disposal. For the foreseeable future, therefore, WWTPs will continue to function as 'sludge factories' with unceasing and unstoppable output. Sewage sludge will also remain a product the quality of which is not strictly controllable, which may have no secure long-term outlet and which usually entails processing, transport and disposal costs of about half the total cost of operating the sewage works. Sludge is thus often regarded as the major problem of water pollution control.

In recent years, sewage sludge has become an international topic with numerous conferences and, in the case of the EU, interstate co-ordinated research and scientific committees focusing on various common problems (Hall *et al.* 1992). This activity reflects the growing realisation that while world sludge production is on a relentless growth curve, environmental quality requirements for sludge are becoming increasingly stringent, disposal outlets are decreasing and yet economic pressures still require low-cost solutions to sludge disposal problems.

The challenge for the policy makers is to balance the preferred policy of using sludge with regard to sustainable development, with quality standards that are achievable and affordable. If this balance is not achieved, it is inevitable that the water utilities will increasingly choose to incinerate sludge due to the greater financial and operational security that this route may then offer.

Sludge treatment and disposal options

Some of the principal treatment and disposal options are shown in Figure 1, which lists the most important conditioning, phase separation and conversion options available for sludge treatment, and shows how sludge may then be integrated or excluded from the material cycle. Sustainable development and the waste hierarchy requires material integration where feasible, and sludge treatment should be applied to achieve this where cost-effective. Some of the treatment options also achieve high removal of pathogens (e.g. thermal hydrolysis, lime addition, thermal drying and composting) and such processes may be increasingly necessary to secure sludge use on land.

The options available for the use and disposal of sludge, and their practical benefits and constraints, may be summarised as follows:

Options	Benefits	Constraints
Sludge use options – *land based*		
• Agriculture • Reclamation • Silviculture • Forestry • Amenity • Horticulture	• Policy • Nutrients • Organic matter • Low cost/low technology	• Voluntary • Vulnerable • Variable demand • Quality • Impacts • Competition
Sludge use options – *fuel based*		
• Incineration • Supplementary fuel for power and processes • Gasification	• 'Green' energy • Transport costs (if on site) • Continuous process	• Public perception • Planning controls • Costs • Emissions • Ash disposal
Sludge disposal options – land based *(not from 2020?)*		
• Landfill - Mono - Co-disposal	• Low cost • Low technology • Fill and forget • Enhanced CH_4 recovery	• Gas emissions • Leachate • Legacy • Resource loss • Void loss
Sludge disposal options – water based *(not from 31/12/98)*		
• Surface waters	• Low cost • Low technology • Biological productivity • CO_2 fixation	• Contaminants • Nutrients • Perception

For the land use options, the relative levels of treatment technology and cost depend on the constraints applied to the specific outlets. For agricultural use, there will be an increasing need to use advanced treatments to provide assured pathogen removal to reassure the food retailers and the public that there are no risks of transfer, due to sensitivities in the wake of a number of recent food scares (e.g. *E. coli* 0157, *Salmonella sp.*, BSE, etc.). Adopting such measures through agreement with the food retailers can be crucial in securing the agricultural route (as in the UK with the 'Safe Sludge Matrix'). Nevertheless, the agricultural outlet is still vulnerable to adverse publicity: it is also voluntary as farmers are of course under no obligation to accept sludge, and their requirements are seasonally variable. These aspects in themselves make agriculture a precarious outlet, and will inevitably be made more difficult and costly by any further tightening of quality standards.

Sludge use in natural forests is generally not acceptable due to their special ecology, but in intensive timber and short rotation coppice wood production, sludge can have beneficial use and being non-food chain outlets, the level of concern for such use should be less. Similarly in land reclamation, although here the need for large one-off applications to rapidly establish soil fertility should be recognised. Sludge intended for amenity and horticultural uses needs to be treated to a high standard of odour, pathogen and litter removal due to the likelihood of public access in treated areas.

Incineration is a high cost/high technology option and is currently only likely to be cost-effective for large cities. It does not have a high level of public acceptability due to concerns over gas emissions and gaining consent to construct new incinerators is often difficult. To be acceptable in terms of the waste management hierarchy, incineration must be done autothermically - i.e. sufficient water must be removed by mechanical dewatering and thermal drying so that the sludge will burn without the use of support fuel. Despite being technically possible, relatively few modern sludge incinerators actually recover energy, other than that which is necessary for process operation, presumably due to cost and the current relatively low price of energy. However, in some countries there is increasing use of sludge (and other organic wastes) in power stations or in cement production as a fuel substitute.

Figure 1: Options for sludge treatment and disposal.

SLUDGE TREATMENT		
Aims of treatment	**Options**	**Examples**
Conditioning	Chemical	Iron salt addition Lime addition
	Thermal	Hydrolysis
Separation of phases	Thickening	Thickener
	Mechanical dewatering	Belt press Filter press Centrifuge
	Drying	Drum dryer Disc dryer
Conversion	Biological	Anaerobic digestion Aerobic digestion Composting
	Thermal	Pyrolysis/gasification Incineration Vitrification

SLUDGE OUTLETS	
Integration in material cycle	**Removal from material cycle**
Use on land Resource recovery	Landfill Atmosphere (CO_2)

Incineration is in effect only a means of sludge minimisation; it is not a means of complete disposal since 30% of the dry solids remain as an ash. The ash is classified as hazardous waste due to its content of heavy metals, and so incurs further expense for its disposal in special landfill sites. However, there are opportunities for utilising ash, such as for construction materials, and when sludge is used as a fuel in cement production, the ash becomes an integral part of the product.

Landfill disposal of sludge has been the most widely used and lowest cost method of sludge disposal in Europe, but it is now widely recognised as being an unsustainable outlet due to concerns over pollution, loss of recyclable materials and loss of void for those wastes which cannot be recycled. The EC Landfill Directive (1999/31/EC) requires all Member States to develop national strategies to reduce biodegradable wastes going to landfill. In fact, a number of countries have already introduced such measures, which when fully implemented in the next few years will effectively ban the disposal of sludge in landfill, unless it is as ash.

Disposal of sludge to surface waters is mentioned here for completeness but this is no longer permitted in the Europe Union under the Urban Waste Water Treatment Directive since 31 December 1998. However, of all of the potential sludge disposal routes, marine disposal is the only one that can potentially fix CO_2 (as carbonate in sediment), where as all of the others are effectively CO_2 neutral in terms of global contributions, although where energy is recovered through combustion of biogas or sludge, this can be regarded as substitution of fossil fuel.

Factors influencing current and future sludge management options

Waste hierarchy

Sludge production cannot be avoided, and as effluent quality standards are tightened to reduce nutrient emissions, sludge production will inevitably increase. Similarly, sludge production cannot be minimised although there are technologies which reduce the mass of sludge for disposal (dewatering, drying, volatile solids destruction). The priority policy is to use sludge on land to utilise the resource value of organic matter and nutrients, and to avoid the use of incineration if possible.

Protection of the environment and health

This is the essential prerequisite for whichever outlet is used. Not only must the means of protection (standards, legislation, monitoring, enforcement, etc.) be effective in the short and long-term, they must also be seen to be so.

Perception (public, political, retail)

Sludge use on land is probably the most researched of all waste management options, yet it still attracts considerable prejudice and low public acceptance due to its faecal origin and fear of industrial contamination, despite the considerable improvements in quality and developments in treatment technologies. There is also a common misunderstanding between hazard and risk. Current food retailer concerns over public perception of crops grown in sludge treated soil will result in increasing restriction of its use and the need for advanced treatment for assured pathogen removal in order to secure the agricultural outlet.

Quality standards

Limit values for heavy metals in sludge have been progressively reduced in many countries in Europe, and this trend is expected to continue. While lower standards are affordable in physical terms due to considerable improvements in sludge quality over the last 30 years, concentrations of some heavy metals are close to the minimum achievable due to the contributions from diffuse sources (plumbing, domestic products, road run-off, etc.). Further significant reductions in metal concentrations are likely to be achievable only at considerable expense to society generally (reformulation of products, separate drainage, etc.).

Reductions in limit concentrations of heavy metals are to minimise accumulation in soil as far as possible, although it will never be possible to achieve a balance of input and output. Atmospheric deposition and the use of fertilisers, farmyard manure and other wastes also contribute to soil loads (and globally considerably exceed those from sludge) but these are currently not well controlled. Since sludge use on land is the only waste that requires monitoring of soil quality, it is inevitable that the water utilities have to accept the liability of other inputs of heavy metals.

Economics

The costs of sludge management are set to increase as the water utilities have to manage greater quantities of sludge within tighter quality constraints. This cost will ultimately have to be carried by the contributing population, and of the available options, those with the lowest cost will be adopted to minimise price rises to the consumers. Investments are usually made with a 20 year horizon and the option selected may be contrary to longer-term sustainable development policy goals.

Proximity principle

There is some ambiguity as to whether sludge is, in practice, a waste or a product. Sludge is defined as a waste and therefore should be disposed of in the region of origin in accordance with the proximity principle, yet transborder movement of sludge occurs which implies that it is a product (secondary raw material).

Competition from other wastes

A wide range of other wastes are used on land. These include industrial wastes (from food processing, paper sludges, abattoirs, composted municipal solid wastes, etc.) and farmyard manure. Such wastes are poorly regulated, or not at all in the case of farmyard manure, yet the latter contributes more nutrients and some heavy metals to soil than sludge.

Landfill disposal

It is now widely accepted that landfill disposal of organic wastes, such as sludge, is not a sustainable option due to concern over gas and leachate emissions and the need to conserve landfill void for those wastes that cannot be reused or recovered. National measures vary but include limits on organic matter, taxes on reactive wastes and carbon taxes, and the separation of municipal solid wastes. Ultimately, the only means of sludge disposal to landfill will be as ash resulting from its thermal destruction.

Conservation of organic matter

There is considerable concern amongst soil scientists in Europe about the loss of organic matter in intensively cultivated soils, with implications for soil fertility, crop production and soil erosion. Use of organic wastes on land is necessary for sustainable agriculture. Furthermore, there are concerns over the continuing loss of peat bogs and their associated unique ecology, and sources of alternative organic materials to substitute peat are actively sought by many suppliers of growing media.

Agricultural outlet

Not only is sludge use on land the preferred option under the waste management hierarchy, but it is also usually the best practicable environmental option (i.e. objective balance of practicability, affordability, sustainability and acceptability). However, the security of the outlet is susceptible to public and retailer perception, and as a consequence, over-regulation. The risks, based on extensive scientific study of the likelihood of sludge doing harm to the environment and health are well characterised, and this should be the basis on which precautionary measures are based to provide long-term protection and public confidence. The degree of precaution required should be considered alongside what is practicable, affordable, desirable and necessary.

Factors affecting security of sludge management operations

One of the major challenges facing the water utilities in providing the public service of collecting, treating and disposing of sewage and sludge, is that not all of the factors that affect their operations are under their direct control. Despite this, the water utilities generally carry the full responsibility of ensuring that environmental, health and economic standards are met. This situation is made more difficult by the generally low public acceptance or appreciation of sludge management.

The main factors affecting the security of sludge management operations (quality, quantity and disposal) that are either under or outside the control of the water utilities may be summarised as follows.

Sludge quality has a major influence on the sludge management options available to the water utilities, but sludge quality is only partially under their control. While there are various technological solutions available to mitigate problems of odour, pathogen

Factors under Water Utility control	
Sludge quality	- sewage treatment
	- industrial effluent control (some countries)
Sludge treatment	- processes, energy, chemicals, manpower, etc.
Sludge disposal	- transport
	- landspreading
Factors *not* under Water Utility control	
Sludge quality	- industrial effluent control (most countries)
	- illegal industrial discharge
	- domestic discharges
	- industrial development
	- changing population
	- diffuse sources
Sludge treatment	- location of WWTP
	- local and national pressures
Sludge disposal	- legislation changes
	- outlet availability
	- local and national pressures

content, physical condition, etc., the chemical quality of the sludge is largely outside water utility control. In most countries, industrial effluent quality standards for discharge to the sewer are not set or controlled by the water utility, and yet the issue of heavy metal concentrations in sludge in relation to its use on land still dominates public and political perception over the acceptability of this outlet.

Sludge quality has improved dramatically over the last 30 years (Hall and Dalimier, 1994; Smith, 1996; Carlton-Smith *et al.*, 1999) since the potential environmental and health problems of heavy metal was recognised in the early 1970s, yet the public and political perception remains that sludge is heavily contaminated by industrial discharges, despite the effectiveness of point source control. Further reductions are probably achievable (e.g. Hg from dental practices) but for most industries, there are likely to be significant cost implications to achieve lower emissions. However, it is diffuse sources of heavy metals that increasingly dictate whether sludge quality meets with the standards for use on land, but such sources are entirely outside water utility control (e.g. zinc and copper are largely derived from water pipes, domestic products, etc.), and by definition are very difficult to control. To reduce such sources of metals would require national and international intervention and would undoubtedly incur significant costs that would ultimately have to be borne by the consumer.

This situation has been further exacerbated by the attention that in recent years has been given to organic contaminants in sludge, such as dioxins, despite the fact that there is ample evidence to demonstrate that these are unlikely to represent a risk. Because of the media and public interest in such issues, it is likely that EU-wide limit values may be introduced despite that fact that the concentrations of compounds such as dioxins have been in rapid decline since their peak in the 1950s (see Figure 2). Furthermore, a review of the compounds currently controlled by national legislation in

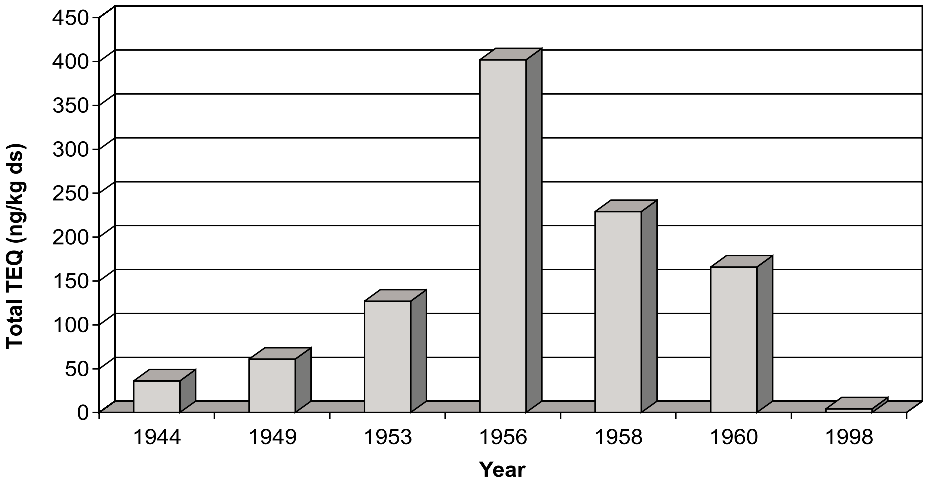

Figure 2: Changes in dioxin concentrations in Mogden sludge, UK (archived samples, ng TEQ/kg ds).

Europe clearly shows the lack of scientific evidence since there is little agreement on which compounds and limit concentrations. Some countries have focused on labile compounds that can occur at relatively high concentrations (such as LAS), while others have set limits for recalcitrant compounds that occur at very low concentrations (e.g. dioxins/furans, PCBs).

The setting of the standards that regulate the use or disposal of sludge are outside the control of the water utilities, but such controls have a significant impact how they are required to manage sludge. More restrictive standards to provide greater margins of safety to the environment and human health inevitably increase costs through the need for further sludge treatment, accessing additional land or development of new outlets. Setting standards is a complex and difficult issue and a balance should be made between the desire to minimise environmental contamination on the one hand and what is achievable and affordable on the other. This is particularly difficult for the agricultural outlet since, for instance, setting limit values for heavy metals too low may well make the outlet impracticable. Undoubtedly, lower heavy metal limits for sludge are practicable in Europe as significant reductions in sludge concentrations have occurred since Directive 86/278/EEC was implemented, but as discussed above, further large reductions will be much more difficult to achieve due to the predominance of diffuse sources. In setting standards, a holistic and scientific approach should be adopted, taking into account:

- Environmental effects
- Benefits
- Perspective against other inputs
- Impact on other outlets
- Precautionary approach
- Cost

The question here is whether heavy metal limits should be set as low as possible (close to background) or whether increases should be permitted to proven safe levels. There has been a clear trend in a number of countries for progressive reductions in sludge and soil metal limit concentrations, driven largely by a policy to reduce metal inputs wherever possible. Such a policy is not inappropriate when considering the long-term sustainability of European agriculture, but only where it is achievable and applied across all materials applied to the land. The potential problem with this type of precautionary approach is that it only considers the specific sludge outlet; it does not necessarily address the issues in a more holistic way, such as if limit values are set too low and sludge has to be disposed of by some other means, is the overall effect of using the alternative outlet more or less acceptable or damaging to the environment?

Diffuse sources ultimately restrict how far a policy of progressive reductions in metal limits can be achieved, otherwise sludge will have to be managed in a less desirable way (i.e. incineration). Furthermore, sludge is still the only waste applied to land that is subject to EC quality standards, monitoring and reporting requirements. This is despite the fact that other wastes applied to land, particularly livestock manures, as well as fertilisers and aerial deposition, add far larger quantities of heavy metals overall. It would be logical to include all of these materials within common standards and controls so that more detailed assessment of metal loadings from different sources can be made, and balanced and practicable solutions identified.

Common quality standards for all wastes should also be extended to treatment for pathogen removal, since livestock manures effectively are untreated when spread on land and can contain significant pathogens loads compared with sludge, such as *Cryptosprodium, E. coli 0157* and *Salmonella*, that can infect humans.

Sludge is the most intensively researched of all wastes, and has been subject to EC co-ordinated activities over many years on potential environmental and health effects (Hall *et al.*, 1992), from which scientifically derived quality limit values and treatment standards can be derived. The potential environmental and health impacts of other wastes or inputs to agricultural land are much less well characterised, the quantities are largely unknown, and there is little if any monitoring or recording of their use. This lack of information needs to be addressed if the potential impacts of sludge are to be placed into a proper context, but more importantly, the potential effects of the large quantities of other wastes used on land need to be quantified and action taken to minimise impacts in line with those applied to sludge.

It is not surprising that sludge use in agriculture is the most sensitive of outlets for sludge, despite the fact that this is considered to be the most sustainable management option, but it is the one over which the water utilities have the least control. It is inevitable that as the constraints on this outlet accumulate and there is no uniformity of approach to waste use on land, other outlets such as incineration over which the water utilities have more direct control, will become increasingly attractive both economically and practically.

Costs of sludge treatment and disposal

Direct costs

It is generally accepted that sludge treatment and disposal account for about half of the total costs of sewage treatment and disposal. This makes sludge management very expensive as the volume of wet sludge accounts for less than 1% of sewage.

The most significant cost is for sludge treatment, and this will increase further as more stringent hygiene standards are introduced. Dewatering and drying of sludge is also very costly, although this is off-set by savings made in the high cost of transporting wet sludge.

Figure 3 compares the generalised treatment and disposal costs for some management options. For each of these, the spread of costs is large and overlap with those of other options, due to the influence of local circumstances on investment and operating costs. As can be seen, conventional treatment (digestion) and use in agriculture or disposal to landfill are the lowest cost options, although both can be more expensive than more technical solutions due to the high operating costs of small WWTPs, and in the case of landfill where full site construction costs are included for mono-disposal. Composting, thermal drying and incineration are generally much more expensive than the basic options but still have wide range of costs, reflecting size of plant, type of technology, etc.

In the future, sludges will need to be treated to higher standards, particularly with regard to assured pathogen removal for sludge use in agriculture. This will inevitably increase the costs of the agricultural outlet, and will make the water utilities re-evaluate whether the agricultural outlet remains financially viable, compared with, say, incineration. Where high capital costs are involved, the water utilities will need to

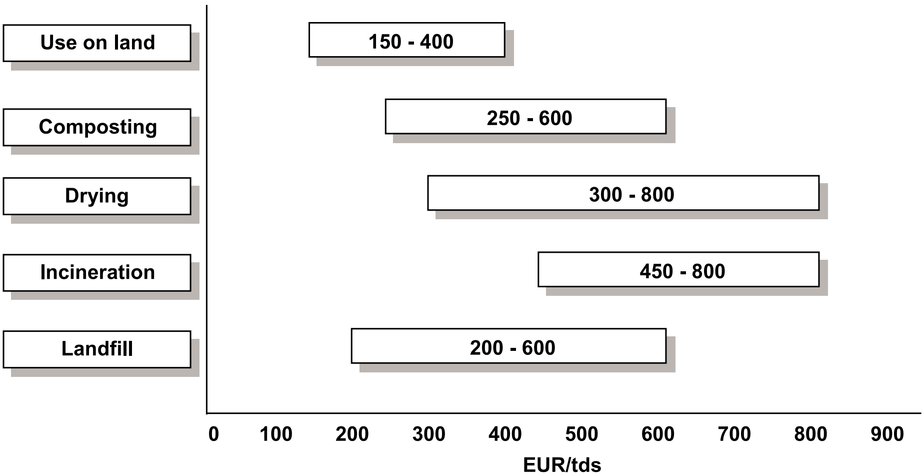

Figure 3: Sludge treatment and disposal costs (Euro/tds).

be confident that the investment period is secure. Table 1 provides indicative costs of the likely capital and operating costs for a WWTP to achieve the advanced sludge treatment requirements of the 'Safe Sludge Matrix' before sludge can be used in agriculture in the UK.

Table 1 shows that lime addition has the lowest capital cost but has the greatest operating costs. Thermal drying and composting have the greatest capital cost (3 – 5 times more than lime treatment) but operating costs are up to half that of lime treatment. In this comparison, thermal hydrolysis of sludge provided the most cost-effective treatment option, with reasonably low capital cost and the smallest operating costs.

Table 1: Costs of pathogen reduction technologies (£UK).

Treatment	CAPEX[1] £	OPEX[2] £/tds
Liquid heat[3]	750,000	20
Liming	600,000	60
Drying	2,000,000	40
Composting[4]	3,000,000	35

[1] Assumes addition to existing digestion plant (5,000 tds/y, ~250,000 pe)
[2] Assumes existing cost of dewatering and use on land
[3] 70 °C for 30 minutes
[4] Assumes green waste delivered free and product removed free

Indirect costs

Conventionally, when calculating and comparing the costs of different sludge treatment and disposal options, only the direct capital and operating costs discounted over an appropriate investment period are considered, and the indirect benefits or external costs are usually ignored. Such externalities can have significant implications and should be taken into account when evaluating sludge management options. Non-exhaustive lists of the externalities for use of sludge on land and sludge combustion are given below:

BENEFITS	COSTS
Externalities - Land Use	
• Reduced reliance on inorganic fertilisers • Resource conservation (P minerals) • Soil conservation (organic matter)	• Legacy of soil 'contamination' • Implied liability for other wastes on land • Reformulating domestic products (Zn, LAS) • Replacing domestic plumbing (Zn, Cu, Pb)
Externalities - Combustion	
• Reduced use of non-renewable fuels • CO_2 neutral • Reduced road transport • Construction materials	• Increased fertiliser use (CO_2 emissions) • Ash (hazardous waste) • Emission control

The obvious benefit of using sludge on land is the potential reduction in the quantity of commercial fertiliser used by the farmer, provided the farmer is informed about, and is confident in, the fertiliser replacement value of sludge. By relying more on sludge nutrients, there are likely to be local benefits (reduced nitrate emissions) and the organic matter added may improve soil conditions. In a wider context, the reuse of the phosphorus content of sludge (and other wastes) on land is becoming an increasingly important issue for the sustainability of agriculture as there are only finite global resources of mineral phosphate.

There are potential long-term consequences and cost implications of adding excessive amounts of contaminants to soil after regular sludge applications for the sustainability of soil fertility. However, by setting allowable concentrations at very precautionary levels, this will have two possible consequences: either the use of sludge in agriculture will not be feasible, or can only be sustained by action to reduce diffuse sources of contaminants. This issue has to be considered with care since an action to achieve one objective could have unforeseen costs and environmental implications elsewhere. An example of this may be the removal of lead in petrol which has resulted in a reduction of lead in sludge in combined catchments, but there are concerns that the substitute anti-knock chemical may have other adverse environmental or health effects. Also if all zinc galvanised or copper pipes were replaced, there would be a dramatic reduction in the concentration of these elements in sludge, but the only feasible replacement plumbing material is plastic with the consequent risk of increasing the content of plasticisers in effluent and sludge, with potential concerns for their potential oestrogenic effects.

Another hidden cost for the water utilities is the potential liability that they have to accept when spreading sludge on land from other wastes that may also be applied to the same area. This is because of all the wastes that are permitted to spread on land, only sludge is subject to a statutory requirement to monitor soil quality. Therefore there is a natural assumption that any increase in heavy metal concentrations is due to sludge, yet many other wastes, including animal manures, contain significant amounts of heavy metals, the concentrations of which, and their application to land are under very limited control compared with sludge.

Where sludge is incinerated and there is energy recovery, the external benefit is the reduction in the quantity of fossil fuel that would be burnt and the corresponding net addition to CO_2 emissions. Incineration is CO_2 neutral thus can contribute to CO_2 reduction when energy is recovered, although a negative aspect of this is that the nutrients are not being used in agriculture and therefore there is the lost saving in fossil fuel used for the winning and manufacture of commercial fertiliser.

Other energy and resource related benefits often overlooked are that the transport implications for sludge are generally nil or small when comparing incineration with other outlets, as incineration is usually carried out on the WWTP. Also ash can be used for construction materials: this not only reduces the need for quarries for ballast, etc., but it is also a means isolating contaminants in sludge from the environment, thus avoiding the need for disposal in hazardous waste landfill.

Selecting and assessing sludge management strategies

The objective in developing a sludge management strategy is to identify the best practicable environmental option (BPEO). This approach has been developed into a strategic management methodology by WRc for identifying the optimum sewage sludge treatment and disposal strategy (Powlesland and Frost, 1990). The essential criteria in the selection of the BPEO is that it:

- Represents that which is on balance the best for the environment as a whole, is secure and sustainable, and does not incur excessive cost;
- Observes all regulatory standards for emissions to air and water, reuse on land and disposal to landfill, and improves upon them if practicable; and
- Incorporates safety factors to overcome uncertainty about any environmental impacts or their scale, and to reduce the possibility of inadvertent pollution transfer between different environmental media.

The process of evaluating the BPEO may be summarised as follows:

Establish options →	**Evaluate against standard criteria** →	**Rank options** →	**BPEO**
- Treatment - Land use - Fuel - Novel use - Disposal	- Practicability - Impacts - Security - Costs	Process and site related	Usually agriculture

In developing the BPEO, the following aspects are essential:

- All potential options are evaluated, including minimising sludge and pollutant generation, co-treatment and disposal with other wastes and fuels, novel and conventional methods;
- All decisions are taken primarily on environmental grounds, and that all short and long-range effects (distance and time) are considered;
- A reasonable and justifiable balance is made between benefits and costs.

The evaluation should consider all input and output flows (see Figure 4) and be subjected to the following assessment criteria:

- Legal - local, national, international
- Policy - political, social
- Environmental - air, water, noise, ecology, safety, energy
- Planning - landscape, space, infrastructure
- Technical - flexibility, complexity, reliability
- Financial - capital and operating costs, costs of non-action, external costs

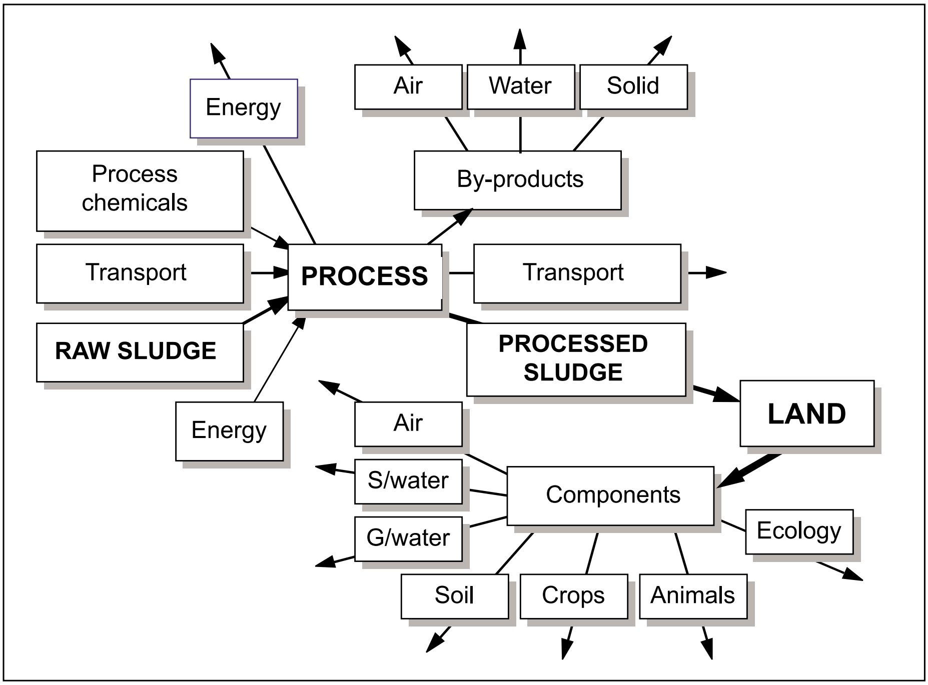

Figure 3: Input and output flows for treating and using sludge on land.

Quality assurance in sludge management

It is widely recognised that the implementation of Directive 86/278/EEC in 1989 (CEC 1986) provided much needed confidence both for the producers and users of sludge due to the imposition of a common mandatory framework. However, in recent years, further concerns have been raised, often associated with food quality scares and exploited by the media, that have linked sludge to public health issues. This has undermined public and farmer confidence and as a reflection of this, some farming groups and food retailers throughout Europe have increasingly taken cautious positions regarding the use of sludge on the land growing the crops that they market. Since sludge is applied to such a small proportion of agricultural land, farming groups and retailers are in a strong position and this potentially makes sludge use on land very vulnerable. A consequence of this is likely to be the adoption of increasingly precautionary standards that are not necessarily wholly scientific and risk-based, but nonetheless are essential for the security of the agricultural outlet. The response from the water utilities has been to focus on their sludge management systems and the growing recognition that quality assurance (QA) is an essential sludge management tool if the confidence of stakeholders is to be maintained. Aspects of QA that should be implemented and adopted by water utilities include:

- Appropriate legislation and policy
- Industrial effluent control
- Proven treatment processes
- Monitoring protocols
- Standard analytical techniques
- Management systems
- Training
- Record keeping
- Openness
- Communications (customer, regulator, public)
- Remedial action plans
- HACCP (Hazard Analysis & Critical Control Point)
- ISO 9000
- Certification
- Independent audit

The food retail industry has well developed QA systems, based on HACCP, and the adoption of this type of approach to sludge management by the water utilities will become increasingly important in securing the confidence and co-operation of this important stakeholder. This approach certainly appears to have worked in the UK, through the development of the 'Safe Sludge Matrix', where the water utilities have voluntarily committed to increased restrictions on sludge use and higher levels of sludge treatment in order to secure the agricultural outlet.

An important maxim is: Credibility + Reliability = Security. However, this is likely to be achievable only within a statutory framework of common standards encompassing all waste used on agricultural land, and where the quality standards for waste and the receiving environment provide appropriate but achievable levels of protection to ensure that such wastes are used beneficially, and that their disposal is not forced down less acceptable or sustainable routes.

Role of regulations in retaining ecological and economical balance

Sludge is a waste that has, and will, never enjoyed high public esteem or confidence, and it is well recognised amongst all of the stakeholders that sludge issues are now predominantly driven by perception. It is increasingly the case that the scientific basis for sludge use and control is no longer sufficient to satisfy such concerns. Undoubtedly there are likely to be gaps in scientific knowledge on the potential effects of sludge on the environment that may warrant changes in standards and control procedures in the future, but recent extensive reviews have not revealed major short-comings in the standards as currently adopted (Carrington *et al.*, 1998).

Heavy metals in sludge have received an immense amount of research investment over the last 30 years, and will rightly continue to attract attention due to the long-term nature of the potential hazard from heavy metals. Reductions in sludge limit values for heavy metals are currently easily affordable as concentrations in sludge are general well below the maxima of Directive 86/278/EEC, but a practical barrier to continuing reductions of heavy metals in sludge is being approached, as diffuse sources increasingly dominate sludge quality. Furthermore, reductions in permitted rates of addition and soil concentrations have to be approached carefully to avoid unnecessarily restrictive measures being adopted.

For instance, soil concentrations of heavy metals are naturally highly variable across Europe for geochemical reasons, although their bioavailability is usually very low.

Common soil quality limit values based on total soil values are always likely to be more restrictive in areas naturally rich in heavy metals. However, it is the amount of sludge heavy metals added by sludge (and from other sources), rather than the total achieved that is the potential environmental concern. This is particularly the case for light textured soils as these generally have the smallest concentrations of geochemical trace elements, and such soils are likely to be the most sensitive to potential long-term effects on soil fertility where anthropogenic heavy metal additions are high.

If the maximum rate of sludge addition is set too low on a precautionary basis, the consequence is likely to be a lack of take-up of sludge by farmers. This is due to the fact that if the agronomic value of individual applications of sludge is too limited, then it would not be worthwhile for the farmers to spread sludge, i.e. the fertiliser and organic matter additions and benefits from the sludge would be too small, compared with the costs and inconvenience of spreading and associated soil compaction damage. Furthermore, very restrictive limit values would not assist in the general policy of improving the organic matter status of arable soils in Europe through the use of organic wastes.

Setting high treatment standards and very low heavy metal limit values for sludge may be very attractive, as this would meet with public and political expectations, and if achievable, would provide a strong basis for sustainable sludge use. However, such an approach carries the risk of regulating out the practicability of the agricultural outlet for sludge. A pragmatic balance has to be maintained between minimising risks to health and inputs to the environment on the one hand, whilst on the other, facilitating the use of sludge on land as being the most desirable means of managing sludge. Tighter quality standards are inevitable, indeed essential, to secure the use of sludge on land in the future, but it is equally essential that such standards are scientifically justifiable, achievable and affordable.

Concerns have been raised periodically over the occurrence of organic contaminants in sludge and as a consequence, some Member States have adopted limit values for various groups of compounds, although there is little agreement on which are important. The scientific evidence suggests that at the concentrations commonly found in sludge, there is no basis for imposing quality standards, and that the adoption of common standards throughout Europe is likely to be complex, very expensive and unnecessary, with no tangible environmental or health benefits. However, with the level of public (and media) interest in organic contaminants generally, such as dioxins, it is becoming almost inevitable that the water utilities should demonstrate that sludge does not represent a source of such compounds. The prudent solution would be to identify a compound that is easy to monitor and occurs at reasonable concentrations which can act as a sentinel, such that if a guideline limit value was exceeded, a more detailed examination of the organic components of the sludge could be carried out before the sludge is permitted to be used on land.

Sludge treatment and pathogen removal are being re-evaluated so as to reduce further the risks of disease transmission (e.g. the Safe Sludge Matrix in the UK). However, it should be noted that there have been no reported incidents of infection of animals or man from sludge spreading on land where the appropriate treatment standards and land use restrictions have been followed. The need for higher quality standards has been an inevitable and essential consequence of the sensational media reporting of recent health scares and market retailer concerns, in order to provide much needed confidence on a sensitive aspect of sludge use. The cost implications for the water utilities in achieving this additional security will be substantial but necessary to secure the continuation of the agricultural outlet.

The water utilities (both private and public) have to be financially responsible, and where the operational security of the agricultural outlet is challenged (i.e. requirement for advanced treatment, reduced land bank, increased operating costs, unachievable sludge or soil quality limits, etc.), it is inevitable that alternative outlets will be considered and selected where these offer greater operational and financial security. The most insecure scenario for the water utilities is where quality standards for agricultural use are likely to be progressively tightened over a period of years. Capital investment for sludge treatment is usually based on at least a twenty year asset life, and the risk of having to make major reinvestments during that period is likely to seriously erode the confidence of water utilities in the agricultural outlet.

The future direction of sludge management in Europe at this moment is uncertain. The decisions to be taken by the water utilities, national governments and the European Commission on policy, standards and affordability will dictate how sludge will be managed for many years to come. It is essential that a holistic approach is adopted to enable a broad and balanced view of the benefits, impacts and costs (direct and indirect) of all of the potential outlets and management and control regimes to be taken.

Agriculture is widely regarded as the best practicable environmental option, provided it is used safely. The risk is that in trying to ensure its long-term sustainability by setting stringent standards, the water utilities may lose confidence in the agricultural outlet, and thus revert to alternative solutions (most likely incineration) in which they may find greater security in their costs and the control regime.

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Problems about sewage sludge incineration

Director Dr.-Ing. Dieter O. Reimann
Müllheizkraftwerk Stadt und Landkreis Bamberg
Rheinstr. 6, D-96052 Bamberg, F.R.G.

Abstract

From the 55 million Mg sewage sludge (5% dry solids (DS) = 2,7 Mg DS/a), produced per year in the FRG out of 10,273 sewage plants, 13% are dumped, 68% agricultural used or composted. The remaining 19% are being thermally treated (data 1997). Municipal sludge which has been pre-treated in different ways is currently being incinerated on its own (mono) in thirteen fluidised bed incinerators and one multi-stage furnace as well as one combination of these two types. Another fluidized bed incinerator is planned for the near future.

Domestic refuse and sewage sludge are co-incinerated (mixed) in twelve grate fired incineration plants in Germany.

The combined incineration of sewage sludge and brown or hard coal as an acceptable solution for a high throughput is practised in 3 power plants and planned in another 11 plants.

For all the different kinds of sludge utilization, thermal treatement and disposal or dumping the main problems are created by the pollutants in the sludge. Not only salts and organic pollutants may be critical in their content but specially the heavy metals. The content of these pollutants may cause environmental dangers on soil, plants, ground-water and into the air. On the other hand a big advantage must be seen in the content of nutrients (P, N, organic matter) usable for soil improvement.

The advantage of the thermal sludge treatement in opposite to dumping and utilization must be seen in the thermal destruction of the critical organic matter and pollutants the disadvantage in the destroying of fertilizing matter. By the incineration process a great part of the heavy metals are evaporated by the high burning-temperature, they run into the flue-gas and can be captured by condensation (cooling down) on the filterash as well as by wet, dry or semidry flue gas cleaning systems.

The situation of sludge utilization and incineration has become even more pressing after enactment of the German Technical Guidelines for Municipal Waste on February 12, 1993 which stipulate in Annex C that by the year 2005 only waste not exceeding loss of ignition (LOI) of 5% may be landfilled.

Important for the sludge-combustion is its heat-value, which is depending from the organic matter and the water content of the sludge, which can be influenced by dewatering and drying systems.

The results of these investigations and the evaluation of possible problems by the incineration process will be presented and should serve as basic for the choice of treatment-system and for the prevention of negative environmental influences by the burning of sewage sludge.

General

Refuse incineration plants, including sewage sludge incineration plants, may only be operated if they comply with technical guidelines for incineration plants and if emissions do not exceed the levels permitted by decress or laws, or the restrictions for incineration plants stipulated in legislation currently being drawn up.

Precise knowledge of pretreatment and of the calorific content of sewage sludge are therefore needed before appropriate thermal processing can take place. The same applies to mixed refuse, if sewage sludge is incinerated together with other substances such as household refuse, RDF, coal, shredder waste etc. The content of organic pollutants in sewage sludge are of only secondary importance for thermal processing, as they are destroyed by the high temperatures during the incineration process. Closer investigation is only required if extremely high concentrations of inorganic or organic pollutants such as PCB, PAH, PCDD or PCDF mean that the sewage sludge must be classified as hazardous waste.

Assesment of future technologies for sewage sludge disposal

The main problem confronting the incineration process is how to reduce the high water content of the sewage sludge. Water reduction means energy demand. Raw as well as oxidises and digested sludges have a natural water content of between 92% and 99%, the sludge water being well combined with the solid particles.

The separation process of the liquid and solid content can be facilitated by biological, chemical, physical and thermal means. Biological methods achieve the lowest and thermal methods the highest dewatering rates, though it should be borne in mind that the degree of dewatering depends on such factors as the type of energy (steam, electricity) used, processing pressure and reaction time.

Water extraction can be divided into two main stages:

- Single-stage, mechanical dewatering to app. 20-35% DS. The energy required to raise the dry solid content of the sludge from 5% to 35% is approximately 3-5 $kWh_{electr.}$. In order to achieve these levels of dry residual content, organic coagulating or other precipitating agents are usually added. The consistency of the thickened sludge is vitally important. Those methods which result in a well-structured and ideally crumbly thickened sludge with a high particle surface are preferable. Redilution by the filtrate or concentrate (sludge water) should be kept as low as possible. All these requirements are met e.g. by the centripress. Filterpresses and belt filter presses produce similarly good dewatering rates except that they require a large amount of space, some of them operate discontinously and the throughput is lower.

At a dry solid content of above 25%, the thickened sludge can be dewatered to 60-70% in a second stage. The dewatering technology for this process is currently still undergoing pilot testing.

- Another well-established method is drying the sewage sludge; it is possible to reduce the water content to a few percent. However, the critical factor is the energy required to dry sewage sludge. To dry thickened sludge from 25% to 90% DS, it takes app. 70-80 $kWh_{therm.}$/kg evaporated water. Drying is carried out at various temperature ranges. At relatively high drying temperatures (>300 °C), care must be taken to ensure that no organic compounds such as dioxins and furanes occur in the vapours. Unpleasant odours are frequently unavoidable; dust explosions may also occur. On the other hand, low-temperature drying by the thin-layer method (slightly above 100 °C) appears to have established itself, as it produces rolls of sewage sludge which can be stored well for some time but generates only little dust or vapour.

  Every desired degree of dewatering can be achieved by controlling the drying process accordingly. The critical water content around 60% should be avoided because of a glueing effect which causes clogging of the sewage sludge.

  Further dewatering in addition to sewage sludge drying is only justifiable if subsequent utilisation systems necessitate modification of the consistency or structure and a high dry residual content. The final product takes the form of either dusts or pellets.

- For the same reasons that apply to dumping, the individual products such as pre-dewatered sewage sludge and domestic refuse should be intensively mixed before incineration. At a high level of sewage sludge and a limited piling capacity, the ideal solution is to spread well-structured, pre-dewatered sewage sludge continuously on the refuse in the bunker with a spreading machine. This spreading process can be carried out either in the refuse bunkers and the product then displaced and mixed with commercial and domestic refuse with the aid of a grab, or by spreading onto the continuous-operation hoppers feeding the incinerators. The effectiveness of mixing in the waste bunker can be optimised by a skilful crane operator.

At the waste to-energy heating and power station in Bamberg, this processing technique with pre-dewatering in a centripress and subsequent spreading had been used for the entire sewage sludge output for the past 12 years, without any problems.

The thin partly digested sludge volume amounts to app. 130,000 m^3 (3% DS) compared to 115,000 Mg refuse/year, equivalent to a mixture ratio of dewatered sludge (30% DS) to domestic refuse of about 11:89 x 100 = 12%. Even after intensive research, no negative effects on incineration, burning out, smell and emissions have been identified.

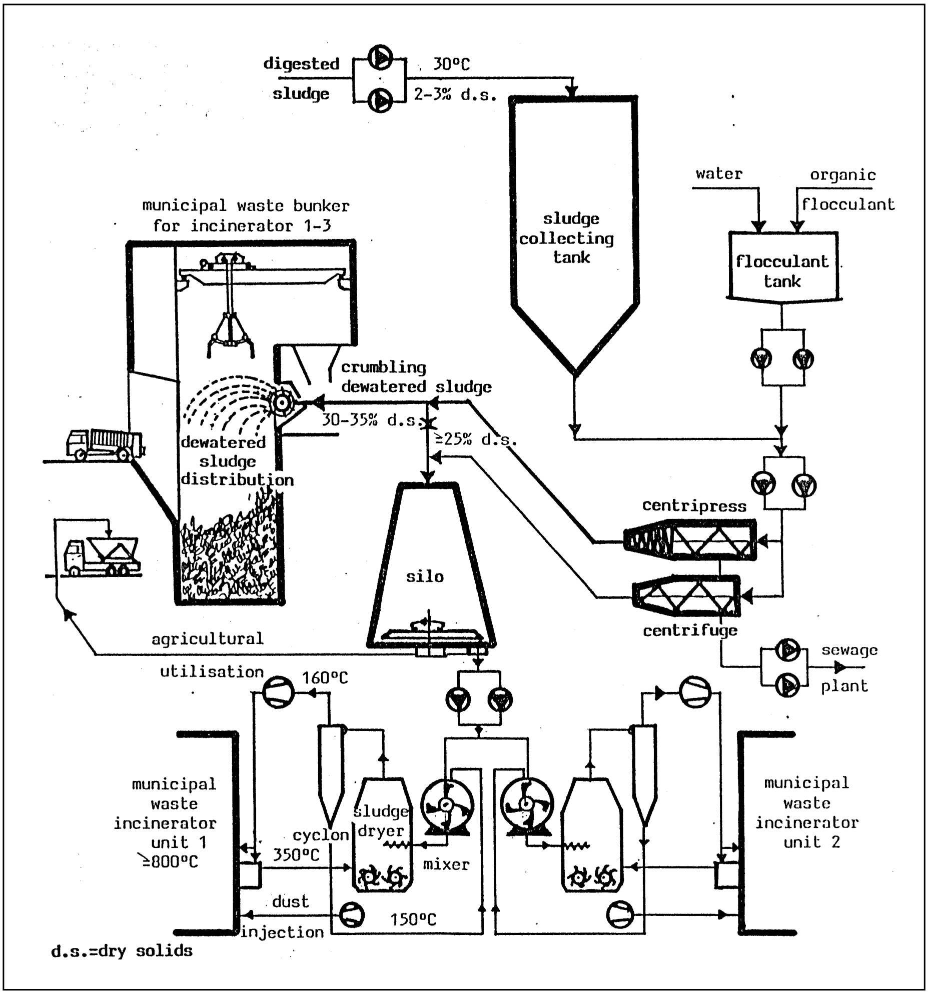

Figure 1: Waste-Fired Power and Heating Plant Bamberg - Sludge Treatment Facilities.

If the sewage sludge proportion rises considerably, a drying stage can be integrated between the dewatering system and spreader in order to obtain any desired dry residual content.

This solution may be expensive of all the sludge will have to be dried.

Meanwhile problems can be caused by the phosphorus-content if a catalyst for denifrification is used. The reaction time of the cat-material may be shortened from 40,000 to 20,000 h by the phosphorus content of sewage sludge.

Ammonia out of the sewage sludge may increase the leachibility of copper in the bottom ash by the formation of copper-tetra ammonia complexes with high water solubility. This may cause a problem if bottom ash will be used as a building material.

Calorific value of mono and mixed sewage sludge

The calorific value of sewage sludge depends exclusively on the amount of organic matter in the dry solids (DS). An average calorific value of 23 MJ/kg can be assumed for 10% organic matter.

Municipal sewage plants generate raw, oxidised or digested sludges. As Table 1 shows, crude sludges exhibit a low DS (2.5% on average) at a high loss on ignition (LOI) of 60-90%. The digestion process converts part of the organic content of the sewage sludge, and the calorific value falls by this proportion. The dry residual content of the digested sludge is higher, at app. 4-8%; the level of LOI of 45-55%, however, it is approximately 1/3 lower than for raw sludge.

Table 1: Comparison of dry solid content, loss of ignition and calorific value for predominantly municipal sewage sludges (raw/dewatered) and domestic refuse.

Product		**Raw sludge**			**Digested sludge**			**Domestic refuse**	
Data	**Dimension**	**from - to raw**	**average raw**	**average dewatered**	**from - to raw**	**average raw**	**average dewatered**	**from - to**	**average**
Dry solid content (DS)	%	0,7 - 4,0	**2,5**	25	4,0 - 8,0	**6,0**	**30**	65-75	**70**
Water content (WC)	%	99 - 96	**98**	75	96 - 92	**94**	**70**	25-35	**30**
Ash content of DS	%	40 - 10	**25**	25	55 - 45	**50**	**50**	45-25	**35**
Loss of ignition (L.O.I.) of DS	%	60 - 90	**75**	75	45 - 55	**50**	**50**	55-75	**65**
Calorific value of DS	MJ/kg	13,8 - 20,7	**17,3**		10,4 - 12,7	**11,5**		15,0-17,3	16,1
Calorific value of sludge/refuse (L.O.I.) of DS (with 23 MJ/kg LOI)	MJ/kg	0,09 - 0,83	0,43	4,3	0,51 - 1,0	0,69	3,5	8,22-12,94	10,47
WC heating up and condensation energy demand (with 2,673 MJ/kg H_2O)	MJ/kg	2,65 - 2,57	2,61	2,00	2,57 - 2,46	2,51	1,87	0,67-0,94	0,80
Total	MJ/kg	**-2,56 - 1,74**	**-2,18**	**2,31**	**-2,06 -1,46**	**-1,82**	**1,58**	**7,55-12,00**	**9,66**
Average product quantity of sludge/refuse kg waste/for 1 kg org. C (referring to averages)	kg org. C.		**53,0**	**5,3**		**33,0**	**6,6**		**2,1**

For a raw sludge with 75% organic content, an average calorific value (low heat value) (C_v) of app. 17.3 MJ/kg can be calculated, and an (C_v) of app. 11.5 MJ/kg for digested sludge with 50 % organic matter, on the basis of 100% DS.

Table 1 also lists comparative data for domestic refuse. Due to the fact that domestic refuse exhibits a relatively high dry residual content of app. 70%, at a LOI of 65% it has an average calorific value of 10.5 MJ/kg. The average calorific values stated refers to the calorific value of the dry mass and not to the calorific value of the sewage sludges or moist refuse. If for instance the calorific value of the dry mass of domestic refuse refers to the moist product, the C_v is app. 9.6 MJ/kg domestic refuse. By way of comparison, a minimum calorific value of 5 MJ/kg is required for the self burning process of domestic refuse at incineration temperatures of >850 °C that means without the need for other primary sources of energy such as oil or gas. In contrast to sewage sludge, domestic refuse is a heterogeneous product. In view of quality fluctuations an exaggerated excess of air (λ=1.6-1.8) must therefore be applied to ensure more or less complete burning out. The excess air can be reduced when incinerating sewage sludge in view of the product's homogeneity, with the result that the excess air ratio is lower and thus selfcombustion is achieved at a lower calorific value.

The bottom row in Table 1 shows the specific amounts of the initial product required to obtain 1 kg of organic substance-equivalent to 23 MJ/kg. If this value for domestic refuse is app. 2 kg, the amount of digested sludge rises to 33 kg at 6 % DS, and to as much as 53 kg for raw sludge at 2.5% DS. The ratios, which depend on the dry content among other factors, illustrate that effective dewatering is necessary before sewage sludge is incinerated in order to achieve a sufficient calorific value.

These specific product amounts are of decisive importance for the design of dewatering units and the assessment of thermal processes.

The abscissa in Figure 2 indicates the water content of sewage sludge from 100% and 0%, the ordinate showing the calorific value C_v in kJ/kg of sewage sludge. The total energy demand stated above the abscissa largely depends on water evaporation from the sewage sludge and, to a minor extent, on the degree to which the dry content heats up. The figures for 100% and 0% H_2O are only theoretical values for the purposes of the graph. A 100% H_2O content in the sewage sludge means that the substance is water, not sewage sludge; water requires app. 2,673 kJ/kg (1 ata) for heating up and evaporation at 100% efficiency.

In addition to energy demand, the energy content for the three types of sewage sludge which generally occur refers to the relevant organic content. A distinction has been made here between organic contents of 70%, 50% and 35% (crude sludge, digested sludge and stabilised sewage sludge). If the energy demand and energy supply from the organic content are superimposed, the excess energy which depends largely on the degree of sewage sludge dewatering can be calculated. A loss of efficiency in the thermal conversion process must be taken into account when assessing the process. The sewage sludge pre-treatment process selected should always assure an energy excess for the thermal processing of sewage sludge.

Following Figure 2 illustrates the calorific values sewage sludge dewatered to 35% DS, i.e. 65% H_2O, for the various types of sewage sludge. In order to dry sewage sludge dewatered to 35% DS, app. 1,800 kJ/kg are required. If this sewage sludge has an organic content of 35%, there remains excess energy of app. 1,020 kJ/kg; this value is theoretical app. 3.835 kJ/kg for crude sludge with 70% organic content. Due to the excess air ratio and to fluctuations of such aspects as the composition, dry content and consistency of the sewage sludge, and in the efficiency of the heating and water

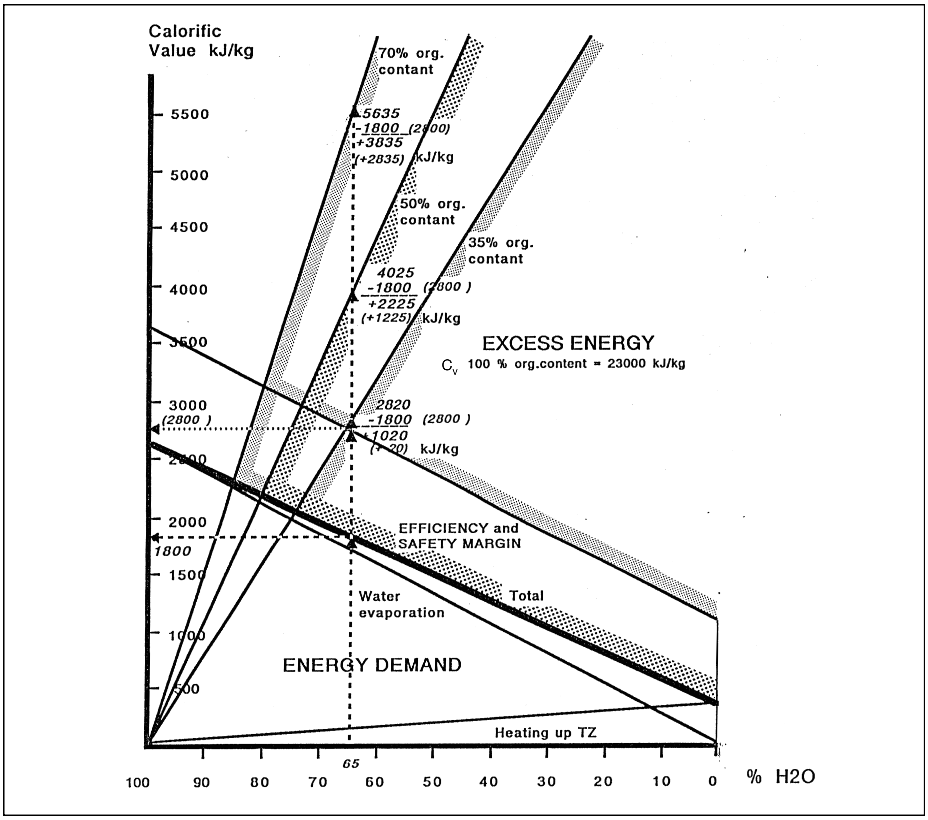

Figure 2: Energy demand and energy excess for the incineration of sewage sludge in relation to organic content and the degree of dewatering.

evaporation process, the theoretical energy demand stated for water evaporation must be increased by a safety margin plus app. 1,000 kJ/kg for incineration losses. The excess energy for the self-burning monotype incineration of sewage sludge with a 35% organic content is therefore still insufficient; with an organic content of 50% or 70% available excess energy permits self-burning reaction. In monotype sludge incineration plants, the energy demand is often improved by feeding hot combustion air back so that sufficient excess energy is also obtained for thick sludge with a 35% organic content, once the process has been started with the aid of primary fuels.

Figure 2 does not include the energy required to achieve the desired or necessary degree of sludge dewatering. The preliminary single-stage or multi-stage dewatering processes require very varied operating materials and levels of energy, which must be calculated in each individual case. The energy required for mechanical dewatering is much lower than for drying (see before).

The data in Figure 2 are based on a product of equivalent combustibility and only apply to a limited extent to sticky, pressed and tightly-packed sludge products with a low exposed surface. Such products should be prepared if necessary, otherwise they could cause difficulties mainly in the burnout quality of the bottom ash, which could increase the level of L.O.I. permitted up to 5%.

Calorific value of sewage sludge/domestic refuse mixture

In addition to monotype sewage sludge incineration, the co-incineration of sewage sludges together with domestic refuse, coal or other high-energy substances (shredder and special waste etc.) is gaining importance.

For this reason, it is necessary to calculate the influence of adding sewage sludge to the basic product and assess the resulting new mixed products according to sludge type, dry residual content, amount and composition.

If a complete mixture cannot be achieved problems can even be caused by unsufficient burn out of the sewage sludge.

The abscissa of Figure 3 represents the mixture of sewage sludge and domestic refuse in proportions ranging from 0:100 (no sewage sludge) to 50:50 (1 part as weight sewage sludge to 1 part as weight domestic refuse). The ordinate above the abscissa indicates the calorific value of the sewage sludge as a function of dry residual content and percentage of organic content in the dry substance; the ordinate below the abscissa shows domestic refuse types with a C_v between 7,000 and 9,000 kJ/kg. The calorific value of other fuels such as brown coal (8.3-15.5 MJ/kg) or hard coal (28-30 MJ/kg) and the influence of adding sewage sludge could also be represented instead of domestic refuse.

Problems can be caused if a good mixture of the different products particular with sewage sludge cannot be achieved, because in this case the self burning process of the fire cannot be guaranted.

The appropriate calorific value for freely-chosen mixture ratios of sewage sludge and domestic refuse or other fuels can be read off from Figure 3. For instance, if domestic refuse (calorific value 8,000 kJ/kg) is mixed in a ratio of 19:81 with a sewage sludge which contains either 25% DS with 70% organic content or 35% DS with 50% organic content, an C_v value of 7,000 kJ/kg is achieved. If a minimum calorific value of 6,000 kJ/kg is specified for the mixture, a mixture ratio of 35 parts sewage sludge to 65 parts domestic refuse of the same nature (i.e. basically 1:2) is possible.

In this way, the ideal recipe for various types of sludge, degrees of dewatering and mixture ratios of sewage sludge and domestic refuse can be calculated, bearing the minimum calorific value in mind. The calorific value of mixtures of other types of sewage sludge and domestic refuse or other fuels can also be determined by interpolation.

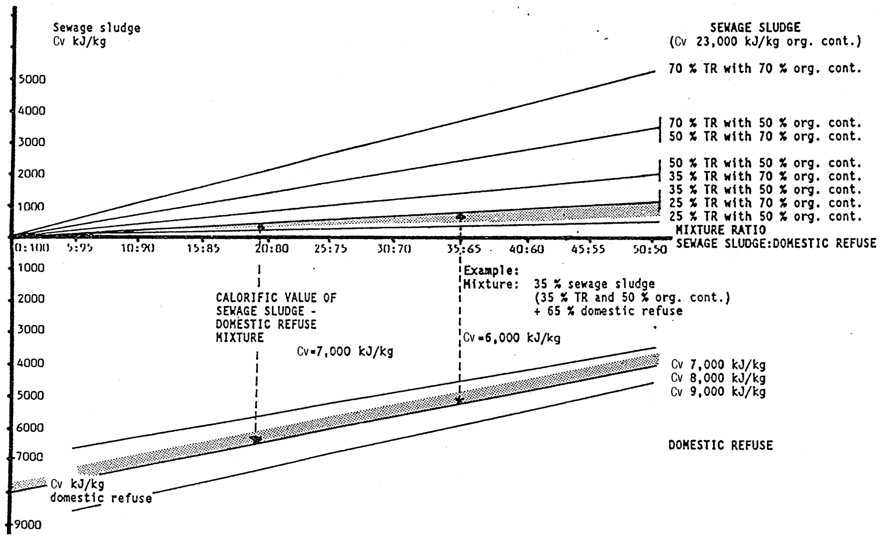

Figure 3: Calorific value of a sewage sludge/domestic refuse mixture depending on C_v (kJ/kg) for domestic refuse, organic content and degree of dewatering.

Summary

The calorific value of sewage sludge largely depends on the type of sewage sludge and its degree of dewatering. Very simple, reliable dewatering facilities should ensure that the dry residual content required for subsequent processing is achieved.

As mono-incineration of sewage sludge cannot be carried out at an ideal excess air count of λ=1.0, and since every incineration plant generates app. 25% energy loss in addition to the energy required purely for drying and burning there must be app. 20-25% excess energy for the self-burning effect of sewage sludge. The excess energy represented in Figure 2 is therefore partly used up again. To achieve self-propagating incineration, a minimum calorific value in the sewage sludge app. 2,500 kJ/kg above the energy required for drying should therefore be aimed at.

In assessing every aspect of energy and operating media, all process steps preceding self-propagating incineration should be compared. If high investment is devoted to advance dewatering, the energy demand for subsequent drying is reduced. It should be borne in mind that mechanical dewatering methods require less energy and are less complex for separating out large amounts of water than energy-intensive evaporation.

If a mixture of substances such as sewage sludge and domestic refuse/coal or other high-calorific residues is co-incinerated instead of only one type of sewage sludge, the calorific value of the dewatered sewage sludge becomes correspondingly less important. For instance a mixed product consisting of one part 35% DS sewage sludge mixed with 4 parts domestic refuse has an average C_v value of app. 7,000 kJ/kg, far in

Table 2: Heavy metal and organic contents in digested sludge from the Bamberg Sewage Plant compared to municipal solid waste.

Elements	**Sewage Sludge Utilization Order 92**		**Actual concentrations in sewage sludges**				**Municipal Waste**
	max. permissible concentration in sewage sludge for agr. use mg/kg DS	**max. permissible concentration in soil mg/kg DS**		**Range of fluctuation mg/kg DS**	**average values 100% DS**	**33% DS**	**content of pollutants (Bamberg 1998) mg/kg DS**
Lead (Pb)	900	100	MWC Bamberg* Germany**	97 - 720	485 61	162 20	719
Cadmium (Cd)	10 (5,0)	1,5 (1,0)	MWC Bamberg* Germany**	1,6 - 4,1	2,8 1,5	0,9 0,5	11
Chromium (Cr)	900	100	MWC Bamberg* Germany**	31 - 50	35 53	12 18	86
Copper (Cu)	800	60	MWC Bamberg* Germany**	280 - 390	327 281	109 94	855
Nickel (Ni)	200	50	MWC Bamberg* Germany**	26 - 64	39 24	13 8,0	47
Mercury (Hg)	8	1,0	MWC Bamberg* Germany**	1,7 - 8,4	4,2 1,2	1,4 0,4	2,0
Zinc (Zn)	2500 (2000)	200 (150)	MWC Bamberg* Germany**	808 - 1100	962 840	320 280	1114
AOX	500	n.a.	MWC Bamberg* Germany**	202 - 500 148 - 258	253 196	84 65	n.a.
PCB	0,2	# 28, 52, 101 and # 138,153,180	MWC Bamberg* Germany**	-	n.a. 0,15	n.a. 0,05	n.a.
Dioxin TE	100 ng/kg	n.a.	MWC Bamberg* Germany**	28 - 38 9 - 24	33 17	11 5,7	60

* Bamberg - research from 1990 - 1998 ** Federal Republic of Germany - R.+D. sewage sludges investigation program 1996

excess of the minimum calorific value required for self-sustaining combustion (app. 5,000 kJ/kg) in a grate firing system.

Thermal refuse processing plants for domestic refuse or coal, with controlled incineration technology and highly effective flue gas cleaning systems, can normally be operated on both domestic refuse and sewage sludge from the same area dewatered to app. 30-35% DS, without any significant fall in capacity. This assumes that it does not serve any major industrial plants or sites which would exert a negative effect on the volume and composition of the sewage sludges or domestic refuse.

The following difficulies and problems must be taken in account:

- The water content of sewage sludge is the main problem for incineration. To burn water you produce a negative energy balance. Pretreatment e.g. dewatering and/or drying device are needed.
- Dried sludge as powder is difficult to store (self-ignition) and could be explosive if the atmosphere is not inert.
- Mono-incineration of dewatered sludge is expensive and limited in its capacity.
- Co-incineration is depending on the kind of fuel and needs an optimal mixture.
- Sewage sludge is varying because of its pretreatment in the sewage plant - raw, oxidise, digested sludge - with different composition, C_v and pollutants.
- Ammonia from the sludge may cause problems in the bottom ash by increasing the leachability of copper.
- Phosphorus by sewage sludge needs a special care and a coating of cat-material for denitrification.
- Incineration is always an expensive solution, even if it is the most effective method to destroy critical organic pollutants and give the possibility to separate out salts and inorganic substances as well as heavy metals and to collect this substances separatly in the residues of the flue gas cleaning system.

As shown with this paper there exist problems about the sewage sludge incineration but they can be solved by state of the art techniques as incineration or co-incineration plants in operation confirm.

Alternative waste water treatment processes to reduce sewage sludge production

Andrea Tilche[1], Giuseppe Bortone[2] and Michal Dohányos[3]
[1]European Commission – Research DG – Bruxelles, Belgium - E-mail: andrea.tilche@cec.eu.int
[2]ENEA – Section of Wastewater Treatment and Water Cycle – Bologna, Italy - E-mail: bortone@bologna.enea.it
[3]Dept. of Water Technology and Environmental Engineering – Prague Institute of Chemical Technology – Prague, Czech Republic - E-mail: dohanyom@vscht.cz

Abstract

The expected increase of sewage sludge production in the European Union, due to the application of Directive 91/271/EEC, can be counterbalanced by the application of wastewater treatment processes with low excess sludge generation.
The biological removal of nutrients in general give rise to a lower sludge production respect to the sole COD removal, but some processes, like the ones described below, can present more advanced sludge reduction properties.
Anaerobic treatment of sewage, combined with aerobic post-treatments, can also reduce to about 50% the excess sludge generation.
Zero-sludge or very low-sludge processes can also be possible, like in the case of new membrane bioreactors and in the case of constructed wetlands, both processes that today can find application only for the treatment of small communities.
For reducing sludge production from existing large wastewater treatment plants, stimulation of anaerobic digestion through sludge pre-treatment can be able to achieve even 30 to 40% improvement of organic matter degradation.
Of course, each sludge reduction option will end up with the generation of different sludge qualities, with consequent implications on the final disposal options.
The 5th European RTD Framework Programme, in its Key Action Water, considers sludge minimisation, safe valorisation and disposal within its research priorities.

Introduction

Sewage sludge originates from the sum of particulate material that is present in sewage and of excess biomass produced in the biological wastewater treatment processes. In fact, in order to remove pollutants that are present in the water, these are degraded biologically; the generation of energy leads to the formation of new biomass. Biomass, particularly if carbon source is well available, tends to produce exopolymers which help to stick bacteria together with suspended particulate material, in a process called "bioflocculation" that drives to the formation of activated sludge.

The instruments for reducing the generation of excess sludge acting on the wastewater treatment process, without changing the composition of sewage, can be of different kind:

1. To use the biochemical energy contained in the wastewater for conversion processes that need energy (denitrification, P removal) and not only for carbon oxidation;
2. To apply waste water treatment processes that are characterised by low biomass growth;
3. To apply long sludge age systems (extended aeration, membrane bioreactors, biofilm processes);
4. To manage the activated sludge food chain, stimulating the balanced growth of bacterial predators (with the warning of not grazing the slow growers, like nitrifiers);
5. To enhance biological sludge stabilisation (pre-treatments, termophilic anaerobic digestion, etc.)

Nutrient removal wastewater treatment processes with reduced sludge production

In general, biological nutrient removal systems need longer sludge age respect to COD removal systems; this could alone help in slightly reducing the overall excess sludge generation. Moreover, in order to better use the available carbon sources for nutrient removal, most of the more advanced configurations do not place a primary settler ahead of the biological treatment, therefore degrading part of the suspended organics. In other case, primary clarifiers are mantained but the primary sludge is biologically hydrolysed to produce volatile fatty acids, necessary for the nutrient removal process. All these options can result in some sludge production savings, but better results can be obtained with new configurations which make better use of the available electron sources for non-heterotrophic processes.

In this concern, Wanner *et al.* (1992), Bortone *et al.* (1996) and Kuba *et al.* (1996) have oriented their research work in the integration of denitrifying dephosphatation micororganisms in P and N removal treatment plants.

In most common modifications of nutrient removal activated sludge plants the anaerobic zone is placed ahead of the anoxic zone. Thus the organic substrate sequestered by Polyphosphate Accumulating Organisms (PAO) under anaerobic conditions is not available for denitrifiers under anoxic condition. However, this would be the case only when PAO are completely different from denitrifiers. The occurrence of denitrifying phosphorus removing bacteria (DPB) has been nowadays clearly demonstrated in several studies (Kuba *et al.* 1993, Bortone *et al.* 1996). It has been shown that DPB have similar capacities and characteristics as fully aerobic PAO. Plant configurations that exert selective pressure in favour of DPB are strongly recommended, since the competition between PAO and denitrifiers can be drastically reduced.

A better use of electron donors is also necessary and, in this concern, those configuration driving electrons to the reduction of nitrates are favoured. On the contrary, single sludge treatment plants do not avoid the use of carbon source in oxic condition, while two-sludge systems (anaerobic/anoxic and oxic) could lead to better performances.

Recently, Kuba *et al.* (1996) have reported a stoichiometric mass balance of the required COD, consumed oxygen and produced sludge for P and N removal in single sludge conventional systems, alternating anaerobic/anoxic/aerobic conditions, and in two-sludge systems, alternating anaerobic/anoxic condition with a separated oxic phase. From the stoichiometric calculation it follows that 50%, 30% and 50% of respectively for the COD requirement, oxygen consumption and sludge production can be saved using two-sludge systems.
Moreover, such kind of plants are particularly suitable for low COD/TKN Chemical Oxygen Demand/Total Kjeldhal-N ratio wastewater, where the lack of carbon affects the nutrient removal efficiency. It has been experimentally proved that best performances can be obtained with only 3.4 COD/N ratio (Kuba *et al.* 1996), while in conventional systems COD/N ratio should be higher than 4.5, up to 8.6 to take into account the aerobic COD "loss" in oxic condition.
In Figure 1, the innovative process scheme (DEPHANOX) is reported. This process proved to be very efficient because drives the utilisation of organic substrate either for phosphorus and for nitrogen removal. The process solves the competition for organic substrates among Poly-P organisms and denitrifiers as well as the problem of overgrowing of slow nitrifiers by faster organotrophs, typical of activated sludge.

The benefits of two-sludge systems for P and N removal in comparison with single - sludge systems are summarised as follows:

- smaller reactor volumes
- separate optimisation for P and N removal possible
- lower energy requirements: utilisation of oxygen for nitrification only, minimal utilisation of oxygen for P removal, no large recycling for denitrification (being in a post- and not in a pre-denitrification configuration)
- minimal loss of COD by aerobic oxidation

As it can be noticed, two settlers are used instead of one in conventional configurations. This might make this configuration not competitive with regards to the higher investment cost, which might be not justified by the higher efficiency that can be obtained.
A bottleneck could be NH_4-N residues in the sludge bypass stream. If the NH_4-N concentration is balanced with the ammonia requirement for growth in the anoxic zone, nitrogen removal is full, otherwise NH_4-N effluent concentration might to high.

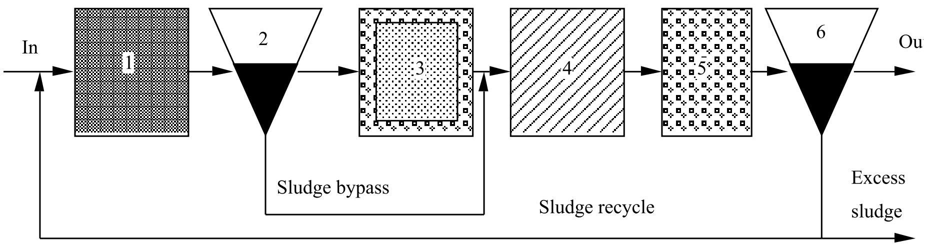

Figure 1: Innovative nitrification-denitrification-enhanced biological P removal (NDEBPR) plant configuration: 1) Anaerobic P-release; 2) Sludge and settleable organic matter separation; 3) Fixed-film nitrification; 4) Denitrification combined with luxury P-uptake; 5) Re-aeration; 6) Final settler.

Generally, the lower is the sludge bypass flow rate, the higher is the N removal efficiency. This is facilitated by the very high settleability of the activated sludge of this configuration only alternating anaerobic/anoxic condition.
It has been quite well proved (Bortone *et al.* 1996), that combined kinetic and metabolic selection in that system improves sludge settleability. In spite of the fact that DEPHANOX was started up with an activated sludge characterized by high abundance of filamentous microorganisms (*Microthrix parvicella*), a rapid decrease of Sludge Volume Index (SVI) values was recorded during the start up period and, for the entire experiment, SVI-values have been usually lower than 50 mL/g.

Wastewater treatment processes with intrinsic low sludge production

The amount of sludge produced by a given biological process is related to its typical yield. Yield is usually experimentally determined, even if there are methods – still experimental – to predict it, knowing the macrochemical equation and the type of electron transport system involved in the biochemical reaction.
Without entering in theoretical matters, it is possible to generalise that aerobic heterotrophic growth is characterised by high yield factors (~0.63 g $COD_{biomass}$/g $COD_{consumed}$), while denitrification has slightly lower yield (~0.57 g $COD_{biomass}$/g $COD_{consumed}$). Nitrification is characterised by a low yield in the conditions of wastewater treatment, even if, as a chemioautotrophic process, cannot be compared directly to heterotrophic growth, being referred to g $COD_{biomass}$/g $N_{consumed}$. Anaerobic digestion is then characterised by a very low yield, in the range 0.05-0.1 g $COD_{biomass}$/g $COD_{consumed}$. The reason for this stays mainly in the fact that in anaerobic digestion one of the products of the reaction (the methane) still contains most of the energy present in the original substrate.

Anaerobic treatment of sewage

The very fast development of anaerobic techniques since the end of the 1970s, that was mainly concentrated on industrial wastewater treatment, resulted in processes and technologies that, being able to ensure a very long sludge age, could be adopted also to treat cold and diluted effluents at ambient temperature. This was the basis of the development of a series of anaerobic processes for the direct treatment of municipal wastewater, resulting in much lower sludge production and energy consumption respect to traditional aerobic treatments. Of course, being anaerobic processes conservative for nutrients (nitrogen is mostly transformed into ammonia and phosphorus is mostly transformed in soluble ortophosphate), adequate post-treatment is needed to match European effluent standards.
The ANANOX process is an example of process integration conceived for obtaining good effluent characteristics while minimising sludge production and energy demand. The ANANOX process (Garuti *et al.*, 1992 a and b) is based on the direct anaerobic treatment of raw sewage, subjected only to fine screening, removal of grit, sand and oils. The anaerobic treatment is carried out into a three chamber anaerobic baffled reactor (three upflow sludge bed reactors in series), where the first two chambers work

in full anaerobic conditions, while the third one works in anoxic conditions for denitrification (Figure 2). A final sludge trap is designed to avoid massive sludge escape from the reactor. The effluent goes to an aerobic nitrification unit, typically on biofilm (a submerged aerated biofilter); the final effluent is partially recycled to the anoxic stage for denitrification. The anaerobic stage removes great part (60 to 80%) of influent COD, while transforms organic nitrogen into ammonia and reduces sulphates to sulphides. In the anoxic section of the reactor, recycled nitrates are denitrified at the expenses of residual organic matter and of sulphides that act as electron donors and are re-oxidised to sulphates. In sludge bed denitrifying reactors, where sludge retention time is quite long, it may also happen to create a favourable environment for the so-called ANAMMOX process (anaerobic ammonia oxidation, i.e. the formation of molecular nitrogen from the oxidation of ammonia with nitrite), that has been recently hypothesed to happen under these conditions (Sanchez-Guerrero, 1999).
With a non-optimised system, having an activated sludge reactor for nitrification, it was calculated that the ANANOX process is able to perform like a nitrification-denitrification activated sludge process with at least 50% reduction of sludge production. However, this process can be better favoured by mild climatic conditions and it is not recommended for very cold sewage temperatures. Research on the anaerobic treatment of very cold effluents has anyway pointed out the potential of new reactor concepts, like the EGSB (Expanded Granular Sludge Bed), for which research on its application to sewage is in course.

Constructed wetlands

Another treatment system that is characterised by very low (or zero) sludge output is based on the use of constructed wetlands, in one of their many possible typologies, like surface flow marshes, vegetated sub-surface flow beds (horizontal or vertical flow), submerged aquatic beds and floating leaved ponds.
All these systems have the common characteristics to behave very actively as influent suspended solids traps, and they do not generate biological solids in excess, apart the

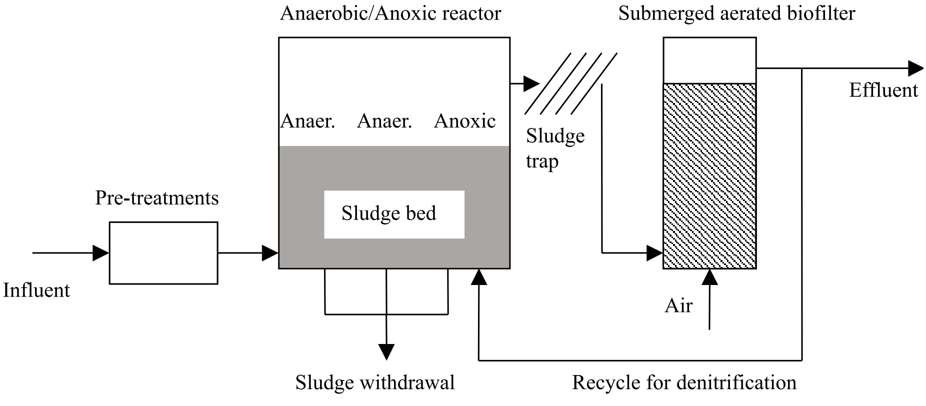

Figure 2: Schematic drawing of the ANANOX process.

vegetative growth of the plants, that depending on the typology will need to be removed, usually not frequently.
Of course, due to the extensive nature of these systems and to the high footprint, they are only suited for the treatment of single households or small communities. This can still represent a consistent fraction of the whole population load, if we consider that in Europe the rural population accounts for 12% and great part of the 19% of the population still not served by wastewater treatment plants belong to small communities (EEA, 1999).

Long sludge age systems

Extended aeration processes (full oxidation) are well known to produce little amount of sludge, because they extend the oxidation to the stabilisation of sludge. Of course, these systems are accustomed only for little or very little plants, due to their large footprint and to the relatively higher energy demand.
The only possibility to achieve full oxidation in a more compact plant is to be able to retain higher quantity of sludge per unit volume or to increase the oxidation. While the latter can be obtained adopting pure oxygen processes (which however are frequently not designed to reduce sludge production) or deep shaft technologies, the long sludge age strategy can be today implemented adopting membrane bioreactors.
Membrane bioreactors (Figure 3) can be generalised as biological reactors - usually completely stirred – that are coupled to a membrane microfiltration device that extracts a particle-free effluent and restitutes to the reactor the biological solids. Excess sludge can be managed depending on the needs, but it has been demonstrated

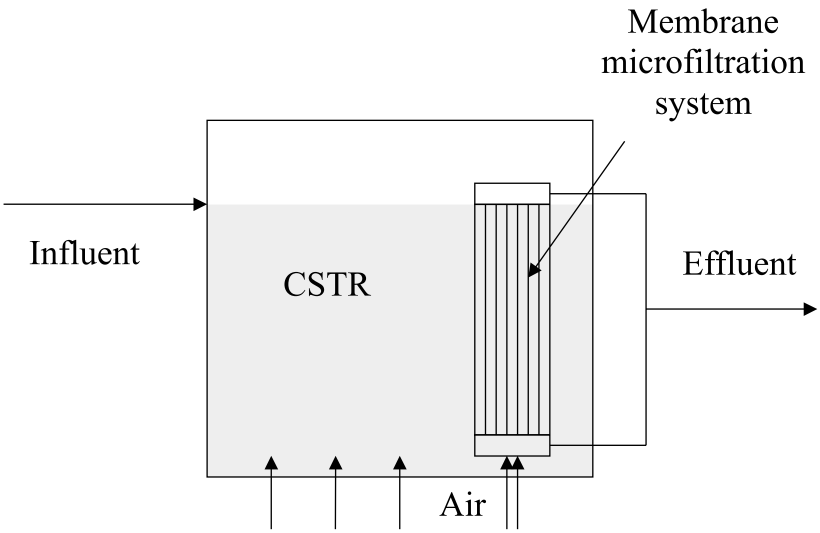

Figure 3: Schematic drawing of a membrane bioreactor (MBR).

the possibility to reach conditions of equilibrium at very high sludge age, approaching zero sludge production. Recent results (Rosenburger *et al.*, 1999), obtained with a bioreactor with immersed hollow fibre membranes for effluent extraction (Zenon Zee Weed®, 150) show that for municipal wastewater zero sludge production can result from the equilibrium between biomass growth and death, that was experimentally reached at a F/M (Food/Micro-organisms) ratio of approx. 0.07. Some limitations can occur when the MLSS (Mixed Liquor Suspended Solids) go over 25 g/L, due to the increase of viscosity and the decrease of oxygen mass transfer.

Apart the zero option, that could be difficult to reach and quite expensive in terms of energy, membrane bioreactors can be managed also for a reduced sludge production. Another advantage of long sludge age systems is that, allowing the growth of slow-growing biomass, that can contain specialised populations able to degrade recalcitrant compounds, the resulting sludge will contain a lower amount of organic micropollutants. The proof is the very fast diffusion in the last few years of immersed membrane bioreactors for the treatment of pharmaceutical effluents.

Ecological manipulation of the activated sludge environment

A different approach was proposed by Lee and Welander (1996), who obtained in the treatment of paper mill wastewater an apparent sludge yield between 0.01 and 0.23 kg TSS/kg COD removed, far below the values of 0.2-0.4 that with the same wastewater are usually obtained with traditional activated sludge system.

Their approach is based on the division of the biological treatment in two compartments:

- the first one, a completely mixed aerated reactor without biomass retention, favours the growth of fast-growing dispersed bacteria; typical conditions were HRT (Hydraulic Retention Time) = SRT (Solids Retention Time) = 1 to 2 hours, depending on the loading rate;
- the second one, equipped with biofilm supports, is designed to favour the growth of bacterial predators, like protozoa and metazoa, including even oligochaetes (worms), that remove the dispersed bacteria from the effluent

It should anyway be noticed that the very low sludge age makes this approach unsuitable for nutrient removal, and that the increased mineralisation is obtained, like in extended aeration, at the expenses of a considerably higher oxygen consumption.

Enhancement of sludge stabilisation

In most large wastewater treatment plants the raw sludge is stabilised using a biological process, that in the vast majority is anaerobic digestion.
The methanogenic process is generally limited by the rate of hydrolysis of suspended matter and organic solids. This is of particular importance during the anaerobic treatment of solid wastes, slurries and manure. By means of an efficient pre-treatment,

the substrate can be made better accessible to the anaerobic bacteria, optimising the methanogenic potential of the waste to be treated. The objective is to accelerate the digestion of sewage sludge, to rise the degree of degradation and consequently decrease the amount of sludge to be disposed of.
Low biogas yield from excess activated sludge is caused by the low biodegradability of the cell walls and of the extracellular biopolymers formed in activated sludge.

The enhancement of the biodegradability of particular substrate is mainly based on a better accessibility of the substrate for enzymes. There are several ways how this can be accomplished:

- *mechanical methods - the disintegration and grinding of solid particles present in sludge*: releases cell compounds and creates new surface where biodegradation take place (Eastman & Ferguson, 1981; Dohányos M & Zábranská J, 1991; Kunz & Wagner, 1996; Baier & Schmidheiny, 1997; Dohányos *et al.*, 1997; Kopp *et al.*, 1997);
- *ultrasonic disintegration*: (Tiehm *et al.*, 1997)
- *chemical methods*: the destruction of complex organic compounds by means of strong mineral acids or alkalies (Mukherjee & Levine 1992);
- *thermal pretreatment*: thermal hydrolysis is able to split and decompose a remarkable part of the sludge solid fraction into soluble and less complex molecules (the thermal pre-treatment of excess activated sludge is used in some cases to improve its biodegradability), (McCarty *et al.* 1976; Haug *et al.* 1983);
- *enzymatic and microbial pre-treatment*: a very promising method for the future for some specific substrates (e.g. cellulose, lignin etc.) (Knapp & Howell 1978; Hakulinen 1988; Lagerkvist & Chen 1993);
- *the stimulation of anaerobic micro-organisms*: some organic compounds (e.g. amino acids, cofactors, cell content) act as a stimulating agent in bacteria growth and methane production (Gossett & Belser 1982).

Most of the above methods occur at the premethanation step and result in a better supplying of methanogenic bacteria by suitable substrates.
The most promising method of disintegration is the mechanical one. This method creates new surface and releases cell compounds. A released content of bacteria cells into a bulk liquid after the destruction of cell walls has been known as cell lysate. Cell lysate represents not only better accessible and degradable organic compounds, but contains some enzymes, part of enzymes and co-factors with still residual activity. Cell lysate can accelerate degradation reactions and consequently saves energy for biosynthesis. The presence of cell lysate in sludges that have to be digested supports anaerobic bacteria growth and methane production.

Many methods of mechanical disintegration were developed and tested, such as ball mills (Baier, U. and Schmidheiny, P., 1997; Kopp *et al.*, 1997), high-pressure homogenisers (Kopp *et al.*, 1997) and ultrasonic disintegration (Tiehm e*et al.*, 1997). The main problems of the application of the mechanical pre-treatment in a full-scale methane digester are the costs of the cell disruption and the quality of the lysate produced. For a full-scale application a new method of cell disintegration by means of a lysis-thickening centrifuge was developed (Dohányos *et al.*, 1997). The objective of

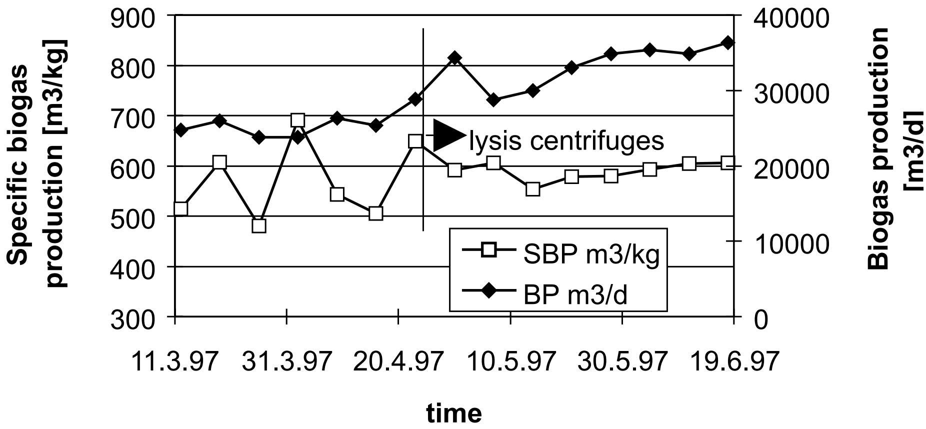

Figure 4: Increase of biogas production at the Prague wastewater treatment plant after the installation of lysis thickening centrifuges.

this method is a partial destruction of excess activated sludge cells during the thickening. A benefit of the procedure is that the cell destruction proceeds after the thickening in the thickened sludge flow only, which avoids centrate water loads. A relatively small amount of the lysate present (4 -10% related to incoming solids) is enough to cause a significant stimulation of the methane fermentation process.

The operation of lysis-thickening centrifuges in Central Wastewater Treatment Plant in Prague proved possibility of full scale application of the disintegration method. The improvement of methane yield and sludge biodegradability are influenced by the quality of input excess activated sludge and by the working conditions of the thickening centrifuge. The improvement of methane yield from thickened activated sludge was in an average 11.5 -31.3% dependent on the sludge quality. This results in a corresponding increase of the destruction of Volatile Solids and in an overall reduction of the amount of sludge to be disposed of (Figure 4).

The advantages of the activated sludge disintegration are the following: the improvement of the anaerobic biodegradability, the acceleration of the degradation process, the increment of methane production, the lowering of digested sludge amount and the improvement of the energetic balance of the process. (Dohányos *et al.*, 1997; Kopp *et al.*, 1997; Tiehm *et al.*, 1997).

Another method for improving the sludge digestibility is based on the addition to the mixture of primary and secondary excess sludge of a 10% of lysate obtained from rapid thermal treatment of digested sludge (Zábranská *et al.*, 1997). The rapid thermal treatment, performed into a reactor with a retention time of 1 minute at 170 °C, allows to obtain a cell lysate that has the property of stimulating the anaerobic digestion process, obtaining more than 40% increase of biogas production.

A further increase in digestion efficiency can be obtained using thermophilic digestion processes.

Conclusions

From this very synthetic review it can be concluded that a series of alternatives exist for minimising the excess sludge production, thus offering a counterbalance to the very considerable growth in sludge production that could derive – at today processes and technologies – from the complete application in Europe of the Urban Wastewater Directive.

The range of possible choices can be divided into two major categories: 1) processes to be applied to new wastewater treatment plants; 2) processes to be applied to existing treatment plants.

The first category is larger, but the large availability of choices does not correspond to a similarly large application in the reality. This is mainly due to the resistance of engineering companies to propose innovations on the market (the time passing from the research phase and the application is frequently very long), but also to the relatively higher investment cost of the new processes.

Among the technologies of the second category, simple devices that do not alter the existing configuration, like the thickening lysis centrifuge described before, have the chance to find broad application.

The growth of sludge production has to be accurately monitored in order to be able on time to propose eventual limitations to the amount of sludge to be generated, forcing wastewater treatment companies towards the application of the best available technologies, as it is already for many industrial sectors after the application of the IPPC Directive. Municipal wastewater treatment is becoming an industry itself, and therefore it could in the future be included in the IPPC system. Market oriented economic instruments can also work in the sense of promoting the application of technologies and practises resulting in lower environmental costs.

Of course, sludge reduction can cause also a change in its quality, which can affect final disposal options. The right answer should therefore combine sludge reduction with the removal of pollution at the source.

The Fifth Framework Programme of research, technological development and demonstration of the European Union, with its Key Action "Sustainable management and quality of water", is addressing research in the field of sewage sludge minimisation, by its workprogramme in the area of waste water treatment and reuse.

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Examples of good practices for reducing waste water and sludge contamination – the case of Sweden

Lars Ulmgren
International Director at Stockholm Water Co, Sweden
Torsgatan 26
S-10636 Stockolm

Early environmental efforts in Sweden

Sweden is well endowed in terms of both surface and ground water as far as its water resources are concerned. This means that the need for steps to be taken to protect our water was not taken seriously until late 1960s. A number of evident incidents with a negative effect on the environment occurred during the 1950s and 1960s, which resulted in increasingly polluted receiving bodies. The following examples can be mentioned:

- Severe eutrophication of lakes and watercourses: phosphorus from detergents;
- Mercury poisoning of fish: discharges from chloralkali plants;
- Oxygen-deficient water: major fibre discharges from paper mills
- Deaths of seals and sea-eagles: high discharges of toxic substances, PCB, DDT, etc;
- Work with asbestos tubes which caused cancer;
- Impregnating agents which caused pollution of nature.

The cases mentioned above started an intensive environmental debate in Sweden. We learned then that many aspects have to be taken into consideration to be able to solve environmental problems. In Sweden we have up to now worked with these questions for nearly 40 years and have seen good results on the environment, but there is much more to be done in the future.

Swedish legislation and administration

All the above incidents meant that an extensive environmental work started in Sweden during the 1960s. One clear indicator was the establishment of the Swedish Environment Protection Board on 1 July 1968 through the merger of a number of smaller authorities, and at the same time considerable resources were set aside for the funding of appropriate measures. The first national environmental legislation was also adopted on 1 July 1969, supplemented by an Environmental Notice, which regulated particularly pronounced environmentally hazardous activities within almost 40 industrial specific areas or the corresponding.

There is a long Swedish tradition in relying on tough legislation. One of the main problem within the environment field is, however, the difficulties in proving a crime for not taking necessary steps according to set up environment conditions for a permitted activity. There are very few verdicts of guilty at the Swedish court of justice.

In late 80’s one found it necessary to look over the total package of laws within the environment field. One aim was to give the one responsible for an environment disturbance to prove that they are not causing any harmful effects on the environment. The new Environmental Code came into force on 1 January 1999 and the aim is to encourage sustainable development and to ensure that future generations enjoy a healthy and sound living environment. To reach the goals reuse and recycling of resources shall be the guideline in all work and efforts. There is also a greater freedom to **r**estrict or completely halt environmentally hazardous waste.

Local authorities responsible for the water business and sludge

Municipal associations, public companies or local authorities handle all questions in the municipalities referring to water supply and waste water. A water organisation of interest – VAV - was established during the 1950s with the task to safeguard and support the water interests of the municipalities. VAV (the Swedish Water and Wastewater Works Association), where all municipalities are members, is an organisation of public servants.

There is a special WA-Act (Water and Wastewater Act), which regulates the operation and the conditions between the municipality and the private consumers. This means that a field of activities is defined, within which the municipality is obligated to serve the households, but not the industry. All questions relating to water and wastewater have to be dealt with to the best of its ability and in accordance with the applicable laws and regulations. All costs are based on the principle that prime cost must be met by the water collective through a system of charges in accordance with a tariff laid down by the Municipal Council.

Development of waste water treatment and production of sludge

The development of the treatment of domestic wastewater in the Swedish municipalities can shortly be summarised as follows:
- Mechanical treatment: from the 1930s
- Biological treatment: since the middle 1950s
- Chemical treatment: since early 1970s
- Filtration: since late 1980s
- Nitrogen removal: since early 1990s

Biological treatment reduced the content of heavy metals to less than 25–40%. That meant that the amount of metals in the sludge was low at the start, but on the other hand operational disturbances on the biological processes occurred from hazardous waste and peak loads of BOD (Biological Oxygen Demand) coming from local industries connected to the sewerage system. The introduction of chemical treatment in Sweden was normally as a post precipitation step, which did not protect the biological step. On the other hand the amount of metals and organic solvents etc. raised considerably in the sludge.

The effect could easily be seen when analysing on certain heavy metals in the sludge. The content of metals in mg/kg of dry matter in the sludge were 5–15 times higher than the values valid today. The metals of special interest were: mercury, chromium, zinc, lead, nickel, copper and cadmium. In the table below one can see the metal concentration in milligrams per kilogram of dry matter at different years. The limit values for the time being are also given. The values are average for Henriksdal and Bromma waste water treatment plants.

Metal	1973	1983	1993	1998	Limit 98
Lead	350	150	50	40	100
Cadmium	25	4	2	1.5	1.75
Copper	1400	650	450	500	600
Chromium	550	150	60	30	100
Mercury	7	5	2.5	1.8	2.5
Nickel	300	80	40	25	50
Zinc	2500	1000	600	550	800

Already in the early 1970s a national decision was taken that all industries connected to a domestic sewage system had to have a pre-treatment for their effluents. It also in many cases resulted in a change of the processes including internal re-circulation of process water. The claim on pre-treatment was valid for both industries with effluents containing hazardous waste and the one with high content of organic materials. Activities of the first kind were for instance; metallic industries, photo and dental laboratories while the latter represents dairies and slaughterhouses.

Parallel to the program of treatment of the waste waters one had to work with the sludge evaluating if there were any risks in spreading it on the farmer land. An ambitious research program started and has continued for more than 35 years. The results have been used for calculating the amount of sludge which can be spread. The base was to optimise the amount of phosphorous and minimise the amount of added heavy metals and other added substances.

Examples from the work with harzadous wastewater in Stockholm

The problem with harzadous substances in the domestic waste waters causes still many problems as many new substances have come into use. The questions have in many cases been described in connection to the use of sludge in agriculture. Eventual risks have not always been possible to foreseen or perhaps even neglected. At these occasions one has talked mostly about the existence of heavy metals and not so much about other toxic substances. The latter has, however, been more evident lately. The sludge has certainly not a positive image today and perhaps it is a natural phenomenon as sludge has to be regarded as a waste according to the EU Directive from 1986.

During the years 1990/92 Stockholm Water Co carried through an intensive investigation program aimed at reducing discharges of hazardous substances into the sewerage system; toxic substances and metals such as lead, cadmium and mercury.

The work was carried out by Stockholm Water Co and at the same time involving other actors in the city, such as;
- the city council,
- neighbouring municipalities,
- small businesses - industries,
- professional associations,
- local households,
- NGOs

The efforts were divided into four major groups based on the source of the pollutants, namely:
- small industry generators,
- waste water from municipal activities,
- household waste water, and
- storm water.

To change attitudes and behaviours of the one mentioned above, we used a consistent strategy of coupling new discharge standards and operational requirements with cooperative research, product development, and education programs to encourage voluntary improvements in waste water pre-treatment. Appropriate methods – treatment technologies – for minimising pollution discharges from each source were developed and implemented in co-operation with the different parties/industries involved. Stockholm Water furthermore carried out the analysis of pollution levels, prescribed limits, conducted information campaigns, and evaluated environmental friendly products in co-operation with the producers.

Local businesses and small industries showed a great interest in a co-operation with Stockholm Water Co to create less polluting production. For example, the Swedish Dental Federation co-operated to address the problem of mercury discharges from dental practices. We also imposed the pollution limits determined to be appropriate in the purchase of preferred products, purchased environmentally friendly products endorsed by Stockholm Water for its own use.

The intensive program above and earlier efforts during the 1980s achieved substantial reductions of various metal contents in sewerage sludge – from 50% to 85% during the years up to early 1990s. The result was achieved in spite of the City's lack of regulatory powers to impose penalties or to close down polluting industries. We were probably successful due to a good confidence from the one responsible for the polluting industries after positive discussions about sewage treatment facilities in order to achieve the compliance of businesses and small industries to the imposed limits.

Special activities around mercury during the 1990s in Stockholm

Our efforts to reduce mercury discharges provide an excellent example of combined regulatory and co-operative approach. In Stockholm, the sludge produced at the

Henriksdal wastewater treatment plant, the largest of Stockholm Water's three treatment plants, had a particularly high mercury concentration in the late 1980s. The concentration was so high that, if left unabated, it would come to exceed the limits set by new national standards coming into force in 1995. So in 1987 Stockholm Water co started extensive investigations to identify the reasons why mercury loads in Henriksdal were higher than in other treatment plants.

The investigation process involved identifying all possible sources of mercury. An inventory started at small and medium sized companies that used mercury in their production or trade, such as companies manufacturing fluorescent tubes, dental materials laboratory devices and instruments. Heavy industries were ruled out as potential sources of mercury discharges because they were not connected to the sewage system.

The investigation concluded that the processes used by eighteen identified companies were operated in such a way that either no contamination of the wastewater could occur or that mercury discharges by accident were highly unlikely. Thus they were eliminated as possible sources of mercury.

Analyses conducted during the investigation showed that about 20% of the total mercury load came from storm drains. These loading were largely traced to the smoke emitted by crematoria and contained some 50 kg of mercury each year.

Samplings of household wastewater indicated that about 15% of the total mercury levels entered the sewerage system through the use of mercury thermometers in the home and from small amounts of mercury in food and amalgam fillings in teeth. Samplings of discharges from hospitals demonstrated that these institutions emit some 10% of the mercury loading.

A very specific campaign was carried through in Stockholm seven years ago. We offered all people having a mercury (fever) thermometer to hand it over to a pharmacy. They received then 15 SEK per thermometer. We collected about 190,000 thermometers, which corresponds to about 380 kg of mercury. This shall be compared with the fact that one sold some 70,000 thermometers up to 1992, when it was prohibited to sell them any longer.

Based upon these findings we hypothesised that the main part of the remaining mercury discharges came from the more than 1,100 dentists in the Henriksdal area, which meant three times the number of dentists connected to other treatment plants. An investigation showed that sewage water from the dental clinics had a mercury concentration of up to 1,300 times higher than levels found in domestic sewage. An investigation in 1988 showed that the amalgam separators used in dental offices did work poorly due to bad construction and insufficient maintenance.

Due to the results it was decided to implement local developed standards and jointly the cities of Stockholm, Malmoe and Gothenburg required that by 1 January 1994 all dentists must use amalgam separators that have passed the German or Danish national standards for amalgam separators. The clinics must also connect their washing machines, sinks and dental chair drains to the amalgam separators. The goal was essentially to eliminate mercury discharges from dental practices by 1995. Stockholm Water conducted also an information campaign to increase awareness of the problem as well as to promote the proper handling of amalgam. We maid also a visit to all dentists to inform and control.

An unexpected event happened three years ago, when we suddenly observed metallic mercury to Henriksdal. It showed to origin from an area containing dental laboratories and originated from many years of uncontrolled effluents in the past. The mercury had been stored in some part of the sewage system and when flushing the system after it had cloughed a release of about 100-kilogram of mercury occurred. The sludge was polluted for half a year and not suitable for agricultural purposes.

Investigations during the last years in sewage pipes at schools, hospitals and other institutions have also found many sources of mercury. The amounts found have been taken care of and transported to a special destruction company, SAKAB. This work is to prevent any uncontrolled release of mercury to the sewage system connected to Henriksdal and Bromma.

Cadmium – a metal in focus

Cadmium has during the last 20 years been in focus as one of the heavy metals which is debated regularly in the media. In Sweden cadmium is often presented as the substance causing cancer. The result is that it all the time raises the question, if one can use sludge on farmer land.

In Stockholm one has worked hard in finding eventual sources of cadmium. The result is that one reached a level of 1.5–2.0 mg per kg of DS already 10 years ago. The level is still the same today. The cadmium is mostly coming from diffuse sources, which are the food we eat, storm water, armatures and car repair shops. One important source is, however, paints for artists. Recently we started an investigation in the sewerage system to find out if we can trace any source in the collecting system.

Toxic discharges from “smaller” industries

The control today of toxic discharges into the sewage system from small businesses is an important component in all anti-pollution measures. In this effort concentration is on surface finishing industries, graphic and photo laboratories, automotive repair shops, service stations, restaurants, car wash shops, and food processing industries. The approach to the problem is guided by the following objectives:

- to get a shift to chemicals which are safer to the environment,
- no toxic substances to the domestic wastewater,
- adoption of process containment technologies to reduce the amount of disposed wastewater, and,
- to introduce extensive internal purification of wastewater before it is released into the sewage system.

According to Swedish Water Law, municipalities are only obligated to provide sewage treatment services to private households, which means that they are not forced to provide treatment services to industrial users. While pollution standards and discharge limits for businesses are established by the Swedish Environmental Code, depending upon the size of the industry, regulations are set by either the national or regional authorities or by the local environmental authority. In the process of establishing regulations, the sewage treatment plants are given the opportunity to make their own demands. The smaller municipalities are relying on a special publication from VAV presenting limit values in the effluents. The larger cities on the other hand have set their own demands, which means that one decide of the limit values in each case separately.

In many cases their is today a need for special solutions, which in many cases are equivalent to collecting the waste/waste water by special companies and transporting it to destruction companies such as SAKAB.

A special interest has during the last years been focused on the car service stations, including car washing, which have been obligated to treat their wastewater internally and circulate it. New techniques have come into practice and the results are very promising. The result is presented in a special report.

To be able to carry through the above work Stockholm Water Co has a special department consisting of about 10 persons. Their main task is to work direct with the industries in the area with the goal to stop as many pollutants as possible at the source. The work shall be done in a positive mood to built up confidence within the industries.

Although a City does not have the authority to impose penalties on an industry the responsible operator can cut the violator´s connection to the sewage system. In the case of damage to the treatment plant or the sewage system because of non-compliance by an industry legal action can be taken against the party involved. In practice, however, it has shown to be very difficult to prove an environmental crime so in reality very few punishments have been the results from taking the responsible person to the court.

Household discharges

Already during the 1970s we started in Sweden efforts to reduce or even change the content of phosphorous in detergents. Many new substances were introduced, but not always harmless for the environment. It showed instead how difficult it is to find other products if you do not have a dialogue with manufacturers.

A shift to safer chemicals especially detergents was achieved after discussions with product wholesaler and manufacturer from the 1980s. These discussions focused on the issue of harmful substances in dishwashing, laundry and cleaning detergents, such as EDTA (a chelating agent) and nonylphenol (a surfactant). The result has been that the manufacturer has developed environmentally safe detergents. In Scandinavia these products among many others have got “the Swan”, which is the symbol for safe environmentally products. The consumers have pushed for the introduction of new products. An effect was that local households switched to products which have been determined to be environmentally superior and reduced usage of household products containing polluting substances.

The most important result of a higher environmental consciousness among the consumers is that products, which are excluded from the list of suitable products, have lost market shares. The manufacturers are therefore forced to change their products or come with new ones.

During the work one found that there was a need for an alternative for taking care of household hazardous waste instead and flushing it directly into the sewer system. Ten years ago environmental stations or collection points were opened in the Swedish cities, where the citizens could dispose their hazardous waste instead of putting it into the sewage system. During the last ten years the municipalities have also launched extensive information campaigns aimed at influencing the behaviour of the public towards purchasing of household products that have adverse environment impacts.

The campaigns were directed towards large consumers besides every household. One used information pamphlets, advertising and poster displays on public places. The result has been successful with respect to a change in the use of products, which are environmentally safe. “The Swan” mark has been a good support. The personnel staff of Stockholm Water Co have also met the citizens in the streets in connection to the Stockholm Water Festival.

The role of the citizens/consumers

There are no possibilities to fulfil established environment goals if the individual is not informed and educated. Every consumer of drinking water is a vital part of the water cycle in the capacity as producer of wastewater. During the 1970s it started with different types of campaigns. One of the first steps was to get people to reduce the dosage of detergents to be able to have less phosphorus in the waste water. Today, it is quite common in most Swedish municipalities to arrange information campaigns.

This work is also connected to Agenda 21, which was adopted and recommended by United Nations at a conference in Dublin, Ireland nearly 10 years ago. The base is that the individual shall be involved in the decisions and work for a sustainable environment in the future and at the same time take their part of the responsibility. This is important in raising the quality of the sludge through a better understanding in not throwing all type of pollutants in the waste water.

A very important group to inform and educate is the young people so today we start at a very low age or in kindergarten. In the primary and secondary schools there are many activities around the environment. The young school children are then supposed to have influence on the older generation. To reach the established environmental goals one has to change the attitude of the people, which at the far end perhaps even means a change in lifestyle for many people. One has to get the ordinary man to understand the necessity of saving resources and not polluting for a sustainable development.

Sludge and its use for agricultural purposes

Sludge for agricultural purposes was a reality very early or already during the 1960s. From the beginning it was an easy way to dispose sludge at a low cost. It is also to notice that it was free for the farmer to get the sludge on his land. That went on well for many years and was confirmed during the 1970s through a research program started and led by the University of Agriculture in Uppsala. The aim was to find out the uptake of toxic substances and estimate the possible amount of sludge which can be added per hectare. A reasonable amount as an average over a period of seven years was set to one ton of dry solids per hectare and year. It also ended up in a list showing the maximum concentration with respect to certain metals. The actual values set up in 1985 and 1995 were as seen below. The new limit values in year 2000 are also presented.

Metal	g/ha/y		
	1985	1995	2000
Lead	100	100	25
Cadmium	2	1.75	0.75
Copper	600	600	300
Chromium	100	100	40
Mercury	2.5	2.5	1.5
Nickel	50	50	25
Zinc	800	800	600

PCB, DDT and the corresponding have been focused on even if the reduction of these substances was significant depending on an early total prohibition to use them in all activities. One has here chosen indicator substances, which must be analysed regularly in sewage sludge. The four indicators are shown below with actual values. It is now, however, recommended to delete toluene from the list.

Indicators	Lower than mg/kg DS (dry solids)
Nonyl Phenol	50.0
Toluene	5.0
PAH	3.0
PCB	0.4

The question of introducing methods to get a better hygienic level was discussed and the decision was that there was no need for a special treatment such as pasteurization. One result from that was that it was not allowed to spread the sludge on pastureland.

A national sludge agreement

Everything seemed to be under good control and the sludge was spread on the farmer's land and to an increasing amount. During the late 1980s, however, individual researchers stressed that there were many substances in the sludge, which could among others cause cancer. It resulted in a boycott from the Federation of Swedish Farmers in using sludge for agricultural purposes.

One important result from this was that the three main partners concerning sludge decided to start a co-operative work, which ended up in an agreement in 1994. The three partners are:

- LRF The Federation of Swedish Farmers
- SEPA The Swedish Environmental Protection Agency
- VAV The Swedish Water & Wastewater Association

Others interested in the use of sludge had also possibilities to influence the work that produced an agreement. In February 1995 a report was presented containing the rules for using sludge in the future. The amount of sludge in the agriculture started from that point to increase, but the amount used for this purpose is still not higher than around 40% out of the total amount produced in Sweden. The rest are used for covering disposal areas, incineration, composting or just disposed. 2003 is the time set for an evaluation of the agreement and deciding on necessary changes.

At the same time it was established a National Group for Sludge Consultation with members involved in setting up the agreement. The group has worked in a positive way and many minor questions and/or problems have been possible to solve jointly. For the time being the group works in the direction of agree on a revised sludge agreement. An active part in this work is the Association for the Food Industry, which has set up a special sludge policy/rules for spreading sludge as a fertiliser. The policy contains 8 points and is shown shortly below. One result is that the connection to the food production is more evident and strengthens the conditions for the use of sludge.

1 The domestic wastewater shall be "protected" from wastewater from undesired industrial effluents and waste waters from disposal areas are not allowed to connect. Special efforts shall be put on the storm water question.
2 Documentation of all sludge use: where it is used and its origin.
3 Analyse of the soil is needed to verify set limit values.
4 The sludge shall be satisfactory from hygienic point of view.
5 The sludge are not allowed to be spread on pastureland or in connection to vegetables.
6 The sludge shall have product certificates and one shall all the time try to raise the quality of the sludge.
7 A continuos raising of the knowledge at the one working with sludge shall be aimed.
8 A scientific council shall be established.

Parallel with the work during the last two years the debate about cadmium and other substances has started again. This has furthermore stressed the Food Industry allowing the use of sludge on areas, which are producing foodstuff for the clients within the food industries. They are anxious to loose market shares, if their good reputation are tarnished. This has of course effected LRF´s point of view and their possibilities to act otherwise than being restrictive.

With a start in early October 1999 some events have occurred, which once again have stopped the use of sludge in agriculture. The first one, which caused the stop, was a media presentation about Bromide-biphenyl-esters, which had been found in sludge in small amounts. It is a group of substances to get flame protection, which is quite common in computers and curtains. The amount imported to Sweden is estimated to about 520 tons per year. The amount coming to the sludge with the wastewater is calculated to be very small or about 100 kg in all sludge in Sweden. The effect of this is that LRF has made a recommendation to the farmers for an immediate stop for spreading the sludge. It is also said to be a temporarily stop, but that means probably at least half a year. It is very important to come to a quick solution. Will it be a use as fertiliser or do we have to look at incineration as the most realistic alternative.

The second event, which occurred at the same time, was a doubt on the hygienic quality of the sludge. Researchers announced that they were very anxious about the risk for *Salmonella* in the sludge originating from for instace hospitals.

The effect from the above means probably that we are back some five years or perhaps even more. We thought from all partners side that we had come to a stable situation in dealing with the sludge questions. Instead we are reminded on the uncertainty we have depending on new detected toxic substances in the sludge, which are not known today. Furthermore it is very difficult to inform all people about this complex questions. The normal result is that people get very anxious in most cases due to insufficient knowledge what is a risk.

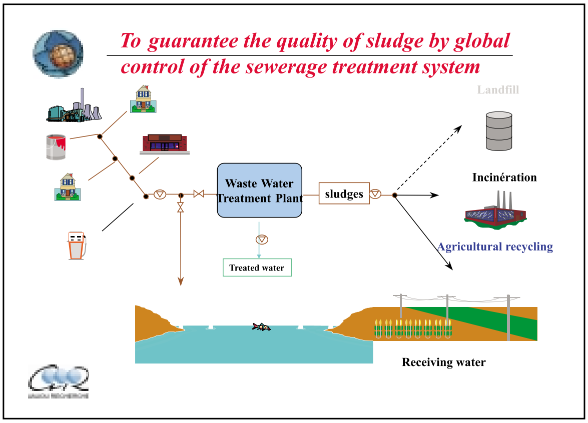
New rules in Sweden for handling organic material

In 2000 a landfill fee of 250 SEK per ton of wet sludge (organic material) has been established. That corresponds to about 250 million SEK per year. Furthermore from 1 January 2005 it will not be allowed to dispose any organic material. The goal is instead to recycle all rest products. There are going to be problems for the wastewater treatment plants producing sludge. There are no alternative solutions ready for treatment of the sludge if the farmers will not accept the sludge in the future. For the moment incineration is one way, but it takes time to built new plants. There are also other possible methods for separation of the phosphorous, which then can be recycled as a “clean” product. The remaining fractions have to be taken care of through incineration and/or other form of treatment. The cost will probably be very high. There is an urgent need for a long-term solution aiming at reaching a sustainable development.

Control of industrial discharges and quality assurance system for sludge reuse in a Life project in France

Laurent Phan
Anjou Recherche
1, Place de Turenne
F-94417 Saint Maurice Cedex

The actual name of the project supported by the Life program of the European Commission was "To guarantee the quality of sludge by global control of the sewerage treatment system". This project has been also supported by the Seine-Normandie Water Agency which conducts several actions for the Waste Water Treatment and the improvement of sludge disposal.



Among the solutions that will be still available, agricultural recycling is viewed as the cheapest way and (the most) compatible with the idea of sustainable development.

Overall objectives

To develop upstream preventives actions

- To reduce pollutant discharges from economic activities

To address European and French legislation on urban effluent management

- European Guideline of May, 21st 1991
- French Water Act of January, 3rd 1992
- French & European regulation for biosolids land application
- Municipalities sewerage laws (Special discharge agreements)

To achieve environmental protection and comply to the attached legal requirements, the communities and their operators will have to master their sewage systems and insure a cheap and sustainable way for sludge disposal. This pass also through a risk assessment process. But if we want to keep agricultural recycling as acceptable and that means acceptable to all the stake holders, from the community to the end consumers of agricultural produce we all are, a series of strong objectives will have to be completed and insured.

Objectives

- - Remove unacceptable components
- - Warrant sludge quality
- - No phytotoxic effect
- - Soil preservation
- - Efficient as a fertilizer
- - Usable product
- - Nuisance limitation

- Remove unacceptable components, of course, to have a safe products
- Warrant sludge quality, that means give to the public and the user the guarantee that that product is safe, this is a quite different task
- No phytotoxic effect
- Soil conservation
- Efficiency as fertilizer
- Good usability as fertilizer
- Limit the nuisance to reduce the social cost supported by the neighbouring inhabitants and the farmer

Technical partnership

ANJOU RECHERCHE

- For Sewerage System Control

Générale des Eaux - S F D E

- Sludge recycling and control

S E D E

- Agronomic qualities

ORVAL

To complete this task a pluridisciplinary partnership has been formed with:
- Anjou Recherche, Center of Research and Development of Vivendi Water

Service provider for water supply and sewage operation
- Générale des Eaux, the operator in France
- SEDE for sludge recycling and control
- ORVAL for agronomic engineering

Project stages

- 1- Diagnosis
  Risk study and assessment
- 2- Analysis and conception
  Actions and methodology
- 3- Validation

On its different aspects the study has been organized into three phases :
- Diagnostic and Risk assessment
- Analysis and conception of solutions (Action and methods)
- Validation of the above

Study development

STEP 1 - Diagnosis of the sewer and sludges networks :

- micropollutants and microorganisms analyses on water and sludges
- Method development to identify critical elements of the treatment process

STEP 2 - Development of management tools :

- Control procedures for the sludge network
- A user-friendly software, ACTIPOL ®, used to identify companies that might discharge pollutants into the sewer network

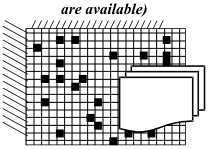
Application site: St Thibault des Vignes (Disneyland Paris)
200 000 Population Equivalent
23 towns
6900 companies

The upstream of the process is of course the effluent generation and treatment at the sewage system. The problems is how to avoid or limit the risks of effluent and sludge contamination through a risk assessment study on a first stage either for pollutant sources or sludge production, followed, on second stage, by the establishment of methodological solutions, quality assurance, study tools. This was conducted on the town of St Thibault des Vignes near Paris which has many industries.

Data used

696 economic activities (French, European and International Classification are available)

73 Pollutants



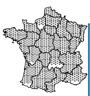
Matrix

+

List of economic activities connected to the sewer system

National Institute of Statistics and Economic Studies

+



Public Offices / WWTP Operator

Additional informations
- *Water consumption*
- *Private treatment device*
- *Network connection conditions*

For pollution risk assessment, the association of economic activities with the possible presence of peculiar components has been developed.

Sources used to create the matrix

Technical notes on economic activities (industrial countries):

- EPA sector notebooks
- British Department of the Environment - Industry profiles
- Canada Environment - National Inventory of Pollutants Release
- French Minister of the Environment - Annual data from the supervision programme

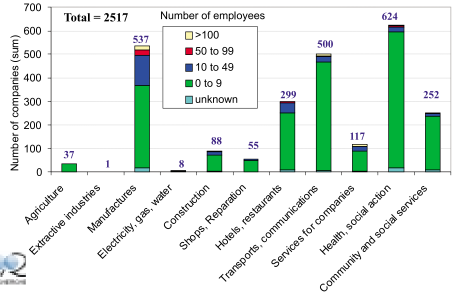
Litterature survey on pollutants :

- Scientific papers and communications
- Merck Index, toxicological notes of the French Science & Research National Center (CNRS)
- French Water Agencies studies
- Laboratory analyses

By using an exhaustive bibliography study and a campaign of measurement and analysis.

Results (1)

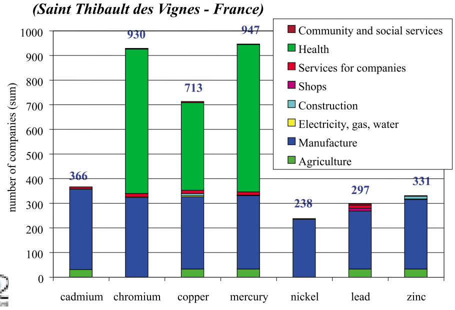
Distribution, by activities and number of employees, of the companies that might discharge at least one pollutant considered in the database (sewerage system of St Thibault des Vignes - France)



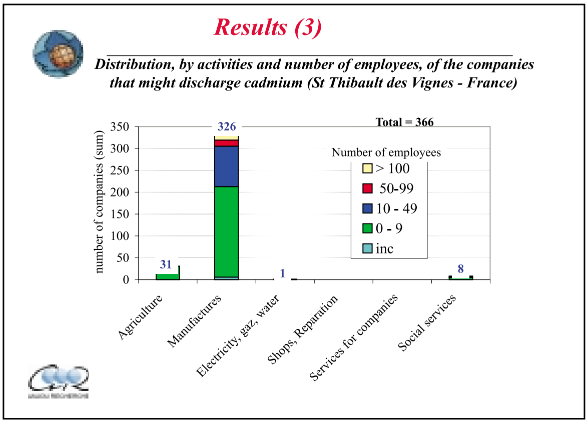
This led to the development of a database called Actipol which on a peculiar site allows to screen the activities and determinate which components could be discharged or on the other side, in case of peculiar pollution which factory could be the source. Other information that can help to assess the risk of pollution are also used. If we take the example of St Thibault des Vignes, among the 6900 companies working there, 2517 could discharge some of the components considered, 366 could discharge Cd.

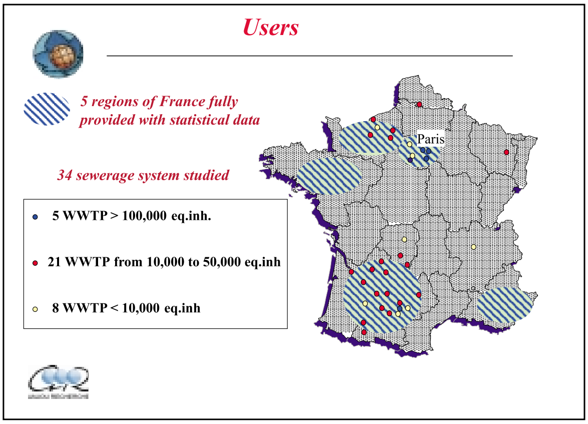
Results (2)

Distribution, by activities, of the companies that might discharge at least one of the 7 main metals considered in the database (Saint Thibault des Vignes - France)

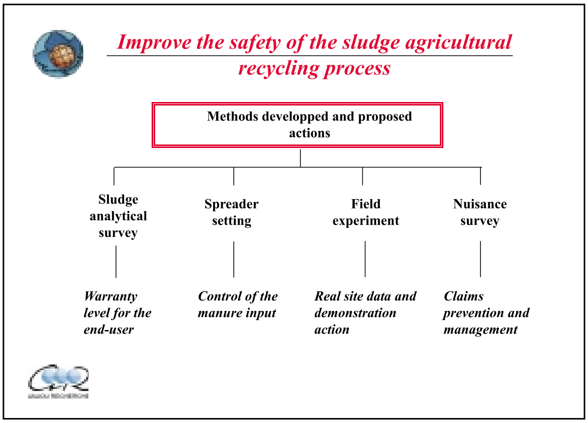


This helps at least the operator of the community to assess the risk of pollution to point out where the strongest one are originating from and to prioritize the enquiries to be conducted to find out potentiel pollution sources and, most of the time, to seek with the industrials the solution or a procedure that could limit pollution risks. This much more rapidly that could be done before.



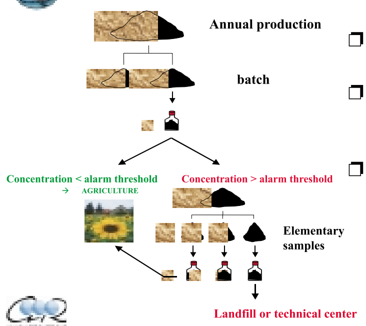


That data base has been validated and used operationaly on several sites in France for diagnosis and pollution prevention.
The sludge production, control and use process has also be reviewed



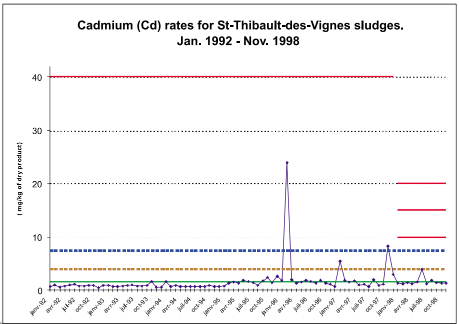
- through a quality insurance approach of the sludge production with a survey of quality and procedure of management.
- improvement of the spreading process
- method of Field Test - for demo aspect
- treatment of the claims
For the sludge production we have seen how a contamination by industrial could be prevented.

Stages of the analytical survey



- Batch processing
- Alarm thresholds determination
- decomposition into elementary samples

Another problem was the survey afterwards and the management of the sludge once a contamination would be detected.
The need was a sustainable survey procedure and the necessity to limit the quantities to be picked up from the recycling process.



This was obtained by organizing the sampling and the defining a level of warning..
That has been applied in the case of St Thibault des Vignes.
Another procedure was defined to improve the information process of the population, including in case of nuisance the rapid and correct treatment of claims.

Agronomic testing

To guarantee the agronomic value through adapted testing tools

EXPECTED RESULTS	ASSOCIATED TEST
Organic value	➩ Analysis of the organic matter 's composition
Soil pH correction	➩ Analysis of the soil 's reaction to the manure in terms of pH
Fertilizing value	➩ Test on biodisponibility of nitrogen and phosphorus
Innocuousness toward crop growth	➩ Global test of phytotoxicity

Last but not least agronomic testing were completed to verify innocuousness as product and efficiency as fertilizer.

Sludge value as fertilizer

- Definition :
  - CAU = (Q1-Q2) / Q3
  - IU = (Q1-Q2) / (Q4-Q2)

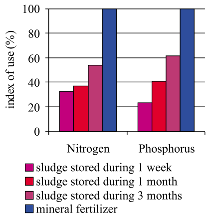
where

Q1 : quantity of N/P used by the plants with a sludge fertilized soil.

Q2 : quantity of N/P used by the plants on an untreated soil.

Q3 : quantity of N/P brought by the sludge

Q4 : quantity of N/P used by the plants on a soil fertilized with a mineral fertilizer



⇨ **- the sludge behaves as an organic fertilizer for Nitrogen and Phosphorus.**

- the storage improves the performance.

- lower N/P biodisponibility comparing to a mineral fertilizer but equivalent to other organic one 's.

The performances were to be compared to those of organic fertilizer.

Conclusion of the agronomic testing

- **Agronomic value of the sludges from St Thibault des Vignes**
  - good effect on soil acidity
  - to be compared to an organic fertilizer for nitrogen and phosphorus
  - innocuousness of CaO- treated sludges toward crop growth (20 t/ha)
- **Interest of the used approach**
  - transposability of the method on other products
  - Reproductibility of the results

The study achieved satisfying methods with the development of tools and methods transposable to other applications.

CONCLUSION

- Multi-result study for a multi-partnership induced by the committment of numerous stakeholders
- Tools and methods transposable to other domains

It's also a good example of a multi-partner study in response to a multi-domain and multi-stakeholder problem.