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Toxic materials in industrial effluents

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Ultimate disposal to land

Derek Jamieson

Ultimate disposal of sewage sludge to land covers a wide range of alternative methods of disposal including tipping, land restoration, forestry, agriculture, horticulture and allotments. This paper will deal only with the categories of landfill and agricultural use.

In terms of sensitivity to potentially hazardous micropollutants, sludges destined for agricultural use provide the greater cause for concern. Unlike landfill, where if reasonable precautions are taken, problems are few and readily containable, sludges which are used in agriculture expose large tracts of valuable land to the possible risk of contamination. A greater emphasis will therefore be placed on the agricultural use of sludge.

In the UK, the total quantity of sewage sludge produced each year is about 1.25Mt dry solids. Of that total, 75 per cent is disposed of to land in one form or another. Landfill amounts to about 320,000t dry solids per annum, land restoration takes a further 70,000t and agricultural use accounts for the remaining 550,000.[1]

Benefits of sludge

Fertiliser

Sewage sludge has been used for many years as an alternative to chemical fertilisers. Table 1 shows the range of nutrient levels commonly found in liquid digested sludge.[2] Various attempts have been made to quantify the value of these nutrients to the farming community. Typically, these range from about £6/t dry solids for dir-dried digested sludge to about £16/t dry solids for liquid digested sludge. However, because sludging must continue whenever possible throughout the year, there will be certain times when the value to the farmer is substantially less.

Soil conditioner

Liquid digested sludges normally contain between 2 and 8 per cent dry matter of which 50-60 per cent is organic in origin. This can improve the soil structure by increasing the water-containing capability, making heavy soils more friable or adding cohesion to coarse, sandy soils. Moreover, soils with high organic content not only have more microbial activity but also absorb more radiant energy thereby giving warmer conditions.

Trace elements

Sludges contain many trace elements which are important for the promotion of healthy plant growth. Essential micronutrients include Fe, Cu, Mn, Zn, Mo, Co, V, B, Si, Cl and I while Al, Sr, Ru, and Se are considered to be beneficial.[3]

The method by which plants take up trace elements is complex and not fully understood. However, it is known that not all the heavy metal content of the soil is 'available' and that organic matter and high pH tend to act as inhibitors.

Potential hazards

Pathogens

Pathogens are microorganisms or parasites which are capable of infecting humans, animals or plants thereby causing disease. This definition includes bacteria, viruses, protozoa, parasitic worms and flukes. Table 2 gives a list of the more significant waterborne pathogens.[4]

While most pathogens are associated with excreta of humans and animals following enteric disease, those from the processing industries should not be overlooked. For example, *Brucella abortus* can find its way into sludge by disposing of infected, unpasturised milk into sewers; tannery wastes resulting from processing imported hides may contain *Bacillus anthracis*.

Heavy metals

The levels of heavy metals found in sludges vary considerably with location and are influenced to a large extent by the presence and type of local industry. Even in rural areas where the sewage is almost entirely domestic, sludges con-

Table 1: **Nutrients present in liquid digested sludge (kg m^{3})**

Nutrient	Range	Mean
Total N	0.34-3.9	2.1
Ammonium-N	0.12-2.7	1.7
Total P	0.05-2.8	1.2
K	0.04-0.40	0.17
Mg	[illegible]	0.14
Ca	[illegible]	2.2

Dr Jamieson is at Thames Water, Nugent House, Vastern Road, Reading, Berks RG1 8DB

tain significant quantities of heavy metals, particularly lead, zinc and copper. Table 3 gives some indication of the ranges commonly associated with domestic and industrialised sludges.[5,6,7]

Excessive quantities of heavy metals, particularly in those sludges to be used for agricultural purposes, are important from two standpoints: firstly there is the phytotoxic aspect and secondly, the human physiology implications. Information relating to the phytotoxic effects of zinc, copper and nickel is available, albeit fragmented. However, this is not the case for the human physiology aspects where elements such as cadmium, mercury and lead can be translocated without necessarily affecting plant growth itself.

Persistent organic chemicals

Virtually no attention has been given to the effects of persistent organic chemicals which are liable to be present in sludges at trace levels. The classes of compounds which are almost inert to the action of chemical and biochemical degradation processes as used in sewage treatment include aromatic amines, triaryl phosphates, chlorinated benzenes, chlorinated benzotrifluorides, chlorinated toluenes, chlorinated non-aromatic cyclic compounds, chlorinated aliphatics and brominated aromatics.[8] Table 4 summarises the inadequate state of knowledge on persistent organic compounds.

Constraints

ADAS Advisory Paper No. 10

There is general agreement that sludge disposal on productive land should be in accordance with 'good agricultural practice'. It is in defining such practice that opinions have differed. An initial attempt at defining quantitative limits for phytotoxic metals commonly associated with sludges is contained in ADAS Advisory Paper No. 10.[9]

The approach was to define the maximum concentration tolerable in soils using the concept of 'zinc equivalent'. This was taken to be an additive measure of phytotoxicity based on the assumption that copper is twice and nickel is eight times more toxic than zinc. Notwithstanding that the validity of this concept has been questioned,[10] the resulting recommendations on limits were considered in some quarters to be rather conservative.

DoE/NWC Guidelines

More recently, the report of the Working Party on the Disposal of Sewage Sludge to Land[11] extended the range of potentially hazardous constituents to include consideration of nitrogen in addition to those metals such as cadmium which fall into the category of impinging on human health without necessarily harming crop growth.

The resulting 'Guidelines' for disposal of sludge to agricultural land are not mandatory in any sense. However, most agencies responsible for sludge disposal have internal codes-of-practice which at least to some extent are based on the Guideline recommendations.

Table 2: **Some of the more significant water-borne pathogens**

Group	Genus
Bacteria	*Salmonella, Shigella, Escherichia, Vibrio, Clostridium, Leptospira, Mycobacterium*
Viruses	Poliovirus, Coxsackievirus A, Coxsackievirus B, Echovirus, Adenovirus, Rotavirus, Reovirus, Hepatitis A virus
Protozoa	*Entamoeba, Giardia*
Trematodes (flukes)	*Schistosoma*
Cestodes (tapeworms)	*Taenia*
Nematodes (roundworms)	*Ascaris, Anchylostoma, Heterodera*

Table 3: **Ranges of heavy metal levels commonly found in sludges**

Metal	Domestic sludges (mg/kg dry matter)	Industrialised sludges (mg/kg dry matter)
Lead	50-200	300-1250
Zinc	40-650	850-7000
Copper	30-200	290-3550
Nickel	10-60	20-1350
Cadmium	1-10	15-100
Chromium	10-35	90-3200
Mercury	—	4-20

Table 4: **Concentrations of certain persistent organochlorine compounds found in sewage sludges.**

Compound	Range of levels observed (mg/kg dry matter)
Aldrin	0- 16.2
Dieldrin	0.03-2.2
PCBs	0-352
Chlordane	3-32
Total DDT isomers	0.1-1.1

Present legislation

It is argued that while sludges are spread in accordance with 'good agricultural practice', they are not a controlled waste subject to the waste-disposal licensing provisions. Therefore, at the present time, legislation is confined to those activities which involve tipping of sludge. In particular, the Town and County Planning Act (1971) can be invoked to ensure compliance on land-use matters and the Control of Pollution Act (1974) requires waste tips to be licensed.

Options

Trade effluent control

Trade effluent control provides an opportunity of reducing the level of heavy metals in industrialised sewage sludges. While this can be effective, particularly for specific metals such as cadmium, it does not reduce the large contribution from domestic sources. Moreover, the cost to industry must be borne in mind and therefore it is important that any conditions imposed should be realistic and not unduly penalise manufacturers.

Conditioning

Sludges can be conditioned to make them more environmentally acceptable especially from the odour standpoint. At larger works, anaerobic digestion has been used extensively to reduce the lipid fraction of sludges prior to disposal. Elsewhere, the tendency has been to dispose of raw sludge, except for a few isolated instances of lime stabilisation.

Dewatering

Untreated sludges typically have a solids content within the 2 to 5 per cent range making transportation expensive on anything but a local scale. There are many different ways available for reducing the water content of sludges including lagooning, drying beds, vacuum filtration, centrifuging, band/belt pressing and filter pressing. Cost and effectiveness vary enormously and therefore decisions on dewatering must be considered in association with transportation costs.

Pathogen destruction

Besides exposure to the natural effects of ultra-violet and the shorter wave-lengths of visible light, there are a number of alternative processes for killing off pathogens in sludges including pasteurisation, disinfection and irradiation.

Pasteurisation destroys *vegetative pathogens* but not bacterial spores: disinfection by liming kills off vegetative pathogens but not worm ova and spores; irradiation using either sealed radioactive sources or high-voltage electron accelerators appears promising except for perhaps viruses and certain worm ova. However, the least expensive and equally effective way of *overcoming most pathogen*-related problems is simply to store the sludge by lagooning or stockpiling for periods of a year or more.

Heavy metal removal

It is now possible to remove the bulk of heavy metals from sewage sludge. Recent laboratory and pilot-scale trials suggest that upwards of 90 per cent of lead, zinc and cadmium, together with 75 per cent of copper and chromium can be removed by a process involving solubilisation followed by double laundering.[7] However, the cost is prohibitive if the sludge is merely disposed of to land.

Disposal strategy

Approach

The over-riding objective in any sludge treatment and disposal strategy must be to develop and maintain secure long-term means of sludge disposal, within the constraints imposed, at *minimum overall cost. Utilisation* of sludge should be regarded only as a potential way of achieving that end and not an end in its own right. However, with increasing pressures on natural resources, the value of reclaimed waste can be expected to rise and if this can be recouped through selling sludge or sludge-based products, then utilisation will make an increasing contribution to sludge disposal.

In any planning process, different sources of uncertainty must be recognised and wherever possible allowances made to counteract their impact. Firstly, there is the uncertainty in quantitative data, ranging from sludge volumes, solids content and quality to the various costs associated with sludge treatment and disposal. Secondly, there is the uncertainty regarding future environmental standards in terms of national or international legislation. Thirdly, there is technological uncertainty in both new industrial processes which may appear, threatening existing practices and also any new innovation which may offer improved ways of processing sludge.

Within this framework, the aim of the planning process is to choose the optimal mix of treatment, disposal and utilisation methods from a limited number of the more cost-effective alternatives to cater for variations in scale, location, prior investment and sludge characteristics. In the past, it has not been necessary to consider more than one works at a time since the interaction between works has been minimal. However, this is unlikely to continue in the future and the resulting complexity suggests the use of more rigorous analytical techniques.

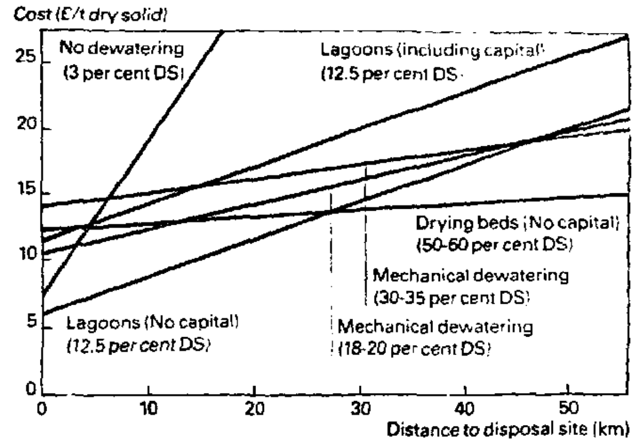
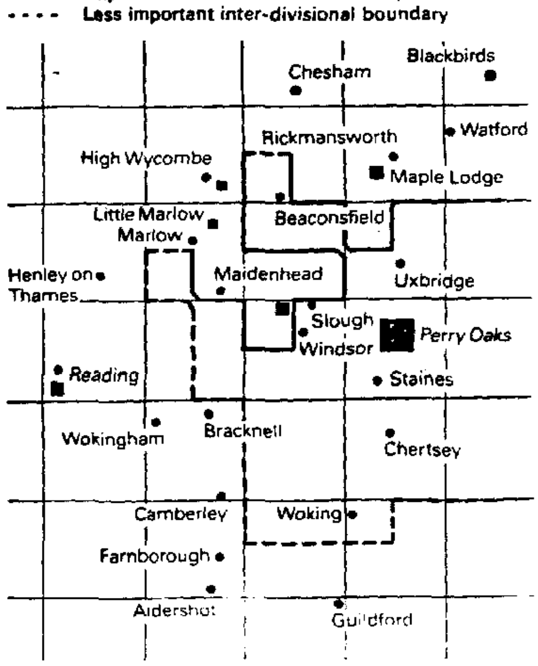


Fig 2 Medium-term possibilities (expected combined dewatering and haulage costs; haulage by conventional road transport; figures in parenthesis indicate final sludge dry solid (DS) content)

Fig 1 Short-term rationalisation (proposed basis for access to agricultural land)

■ Major sewage or sludge works: area proportional to annual cadmium quantity in sludge
—— Important inter-divisional boundary
- - - - Less important inter-divisional boundary



Short-term rationalisation

Any strategy will be subject to continual review but the ability to introduce changes will be influenced largely by existing commitments or capital investment having worthwhile life. In the short term, it may be possible to rationalise only existing practices. For example, adoption of the DoE/NWC Guidelines' recommendation for cadmium has led to a dramatic increase in the requirement for additional agricultural land which in Thames Water has resulted in different works competing for the same area. The main regional aim has been to arrange an equitable distribution of suitable disposal areas between works, consistent with minimising the overall cost of sludge-to-land operations.

To this end, a mathematical model based on a form of linear programming was developed. On the basis of available land estimates and assumptions about sludge quantities, cadmium contents, dosage rates, road conditions and haulage costs, the programme was capable of optimising the allocation of sewage disposal areas to various works (Fig 1). The results indicate that if the cadmium limit remained unchanged and trade-effluent control lives up to expectations, there should be no need for haulage distances to exceed 30km during the [illegible]

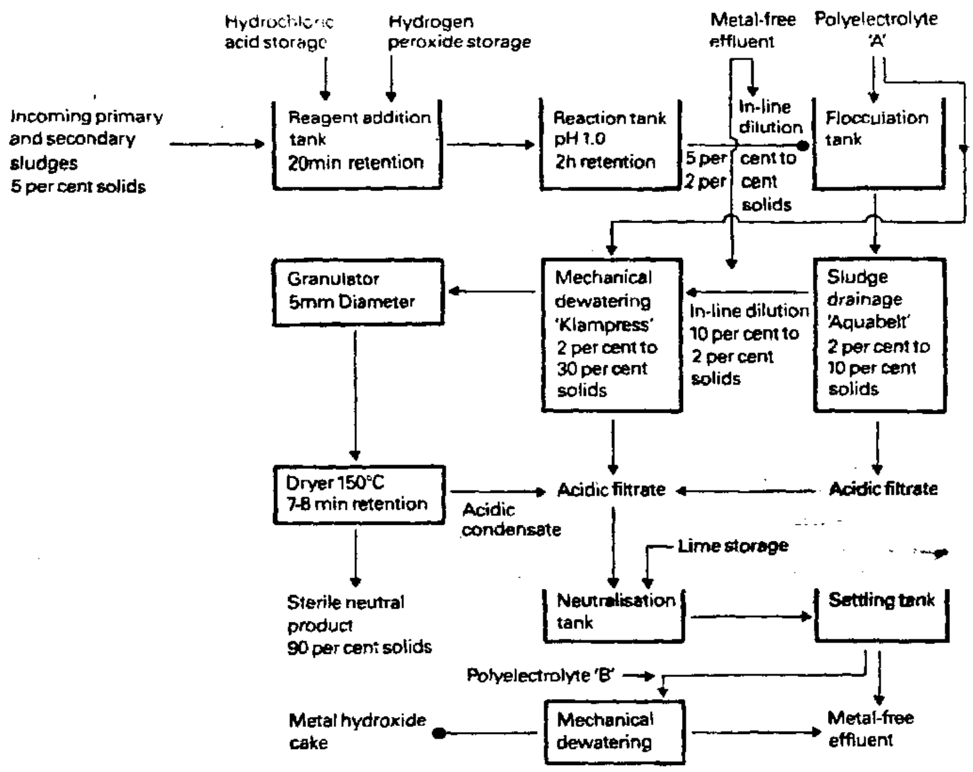


Fig 3 Longer-term aspirations (detoxification process route)

Medium-term possibilities

The medium term has been defined arbitrarily as the period between the ending of constraints imposed by existing commitments and a time horizon dictated by the availability of new technology. During that period, there is the opportunity of redirecting resources, insofar as existing technology permits, should there be merit in doing so. For example, it would be possible to invest additional capital in conventional treatment equipment, consider alternative means of transport or investigate further outlets for disposal (Fig 2).

Where non-realisable assets have been invested already in treatment processes, it is only the present operating costs which have any relevance, providing the existing plant continues to function satisfactorily and that environmental constraints are met. Nevertheless, with continual amendments to guidance on what is environmentally acceptable, and movements in the real cost of essential commodities, the relative merits of alternatives may change with time.

Longer-term aspirations

The reason for speculating on the longer term is to ensure that steps taken in the short and medium terms do not preclude the eventual introduction of new technology. This includes the possibility of over-investment in conventional plant which is inflexible and cannot be adapted or incorporated into new treatment processes.

In the past, sludge was deemed a disposal problem and treated accordingly: little attention was paid to the marketability of the end product as, more often than not, it was simply given away or dumped. However, consideration is now being given to ways of either presenting the traditional sludge products in a more saleable form or exploiting the constituents of sludge where this appears commercially feasible. This includes supplementing the nutrients in sludge to form a more balanced fertiliser and pelletising sludges for ease of application. While these processes are more expensive than the conventional routes, the anticipated return through sales would hopefully offset the increased cost. However, these alternatives would require a greater degree of quality control than hitherto has been practised. Moreover, the problem of heavy metals remains. Fortunately, there is now the prospect of removing heavy metals from sludge (Fig 3), albeit at a substantial cost. While this additional cost is unlikely to be recouped from the sale of sludge as a fertiliser or soil conditioner, there are potentially valuable ingredients in sludge, such as lipids and protein, which may justify that level of expenditure.[12]

Conclusions

Future legislation

Looking to the future, it seems inevitable that disposal of sewage sludge to agricultural land will be subject to tighter restrictions. At the present time, government involvement is confined to guidance, but within the foreseeable future, there is the distinct possibility of formalising this guidance into a code-of-practice, if not actual legislation.

If legislation were to materialise, it is likely that it would originate within the EEC which is currently supporting a high level of research activity in this area. Should that be the case, it is of interest to note that continental practices tend to be more stringent in terms of tolerable heavy metal limits than this country's.

Likelihood of continuance

Disposal of sewage sludge to agricultural land represents a substantial outlet and is likely to remain so in the foreseeable future despite the possibility of severer restrictions. Even if a more positive approach is adopted towards recovering the valuable components of sludge, the indications are that this would only be attractive at large urban works. Elsewhere, particularly for small-to-medium sized works in rural areas, the expectation is that sludge disposal to land will continue, albeit perhaps in a modified form.

This continuation is conditional upon the containment of potential problems associated with micro-pollutants. Sludging has increased the amount of certain heavy metals to levels greater than the original natural background concentration. Whether or not these increases are significant in terms of contaminating food chains is less certain. More research is required, full consultation is essential and limits must have regard for the economic implications as well as the risks. Only in this way will realistic limits emerge which while protecting the environment, do not unnecessarily penalise either those responsible for disposing of sludge or their customers.

Acknowledgements. While this paper is published with the permission of the Director of Planning, the views expressed are those of the author and not necessarily of Thames Water.

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Amounts and effects of toxic materials discharged to sewers

See next article

Robin Chalmers

An assessment of the effects of toxic materials discharged to sewers is complicated by the fact that the toxicity of materials varies not only according to the nature and concentrations of the materials themselves, but also according to the nature of the receiving environment. Sewers may discharge to treatment works or directly to surface waters or the sea.

Manufacturing operations vary with the nature of the product made, the size of the manufacturing operation, the degree of application of good practice in minimising discharges and the extent of water recycle or re-use adopted. The amounts of wastes then discharged to sewers is further influenced by the extent of pre-treatment prior to discharge, which is dictated by the standards required for those effluents, which vary from location to location.

In practice however, the amount of toxic materials actually discharged by an industry, is determined in most countries by the limits prescribed by the sewerage authorities. These limits are derived either from an approach of using the 'best available technology economically achievable' for elimination of pollutants by pre-treatment of the wastes (the USA's aim for 1983) or from an assessment of the amounts of a substance which can be accepted into sewers without damage to a sewage treatment system or to the ultimate receiving environment. This approach, based upon environmental quality objectives, is the one currently adopted in the UK and some other European countries. It is therefore the effects of toxic materials which should, and generally does, determine their amounts in discharges to sewers, and examples of these are given later. According to recent WHO estimates (1979) about 60,000 chemicals are frequently used in daily life, and this number increases at the rate of some 200 to 1000 new chemicals per year. Knowledge of their toxicity, particularly chronic toxicity, is not always complete and limits have to be framed with some factor of safety.

Some interplay exists between what is achievable and what is desirable in limiting discharges to sewers. It is therefore important to know how wastes arise and how effectively they can be minimised at their points of origin. Limits can then be determined more or less realistically and where this is desirable, as in some developing countries, introduced in phased stages. For this reason, some attention is given to the amounts of wastes, and their variability, as they arise.

Mr Chalmers is a consulting chemist and chairman of International Consulting and Laboratory Services, Birmingham. He is also senior consultant of its Bostock Hill and Rigby Division, 288 Windsor Street Birmingham [illegible]

What is toxic?

Toxicity may be defined as the ability of a chemical molecule or substance to produce injury once it reaches a susceptible site in or on an organism. The word is derived from the Greek. *Toxikon* - poison for arrows. Toxicity is a chemical phenomenon and may be [illegible] local or system[illegible]