Disinfection of Sewage Sludge: A Review*

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Abstract

Rapid development of urban areas and an increasing awareness of environmental pollution together with rapidly diminishing reserves of energy, have led to a reappraisal of the methods used for treating and disposing of sewage sludge.

The ova of *Ascaris lumbricoides* are still potentially infectious after conventional sewage treatment processes and therefore pose a significant health risk in the reuse of sewage works sludge. This review, therefore, pays particular attention to this problem and also seeks to ascertain the effectiveness of various alternatives in reducing the health risk caused by viruses and bacteria.

The disinfection of sewage sludges may be carried out by a number of different techniques, of which heat treatment and irradiation are considered the most viable economically and which are discussed in detail.

The paper also includes a discussion on the cost of sludge disinfection. Overseas experience is that costs tend to favour radiation. Radiation treatment, however, requires a high capital investment with low running cost, whereas heating equipment is available at lower capital cost but higher running costs. These costs are greatly influenced by the availability of methane from sludge digesters. In this regard cognisance must be taken of the trend in this country towards the establishment of large extended aeration plants which omit the sludge digestion step. In order to make reasonable cost calculations it is necessary to ascertain the cost of each unit process in the purification train and to add these up to obtain an overall treatment cost. In this way more meaningful comparisons with other processes such as Zimpro and thermophilic digestion can be drawn.

Introduction

Throughout the world today considerable attention is being given to the purification of domestic waste waters. Most of the energy expended in this direction has been aimed at the satisfactory purification of the liquid fraction and little attention has been given to the whole question of sludge disposal.

Rapid development of urban areas and an increasing awareness of environmental pollution together with rapidly diminishing reserves of energy have led to a reappraisal of the methods used for treating and disposing of sewage sludge. Furthermore, it is becoming increasingly apparent that sludge will henceforth have to be considered as a valuable resource and recycled into the food chain, necessitating increasing attention to the public health risks involved in such procedures. This aspect has been recognised in the new Health Act (Act No. 63 of 1977) which includes the following provision:

> 38(1) "The Minister may ..... make regulations relating to the control, restriction or prohibition of, ...
>
> (a) ..... the reclaiming of any product from night-soil, rubbish, sewage or other solid or liquid waste and the *utilization* of such product;"

Guidelines for the disposal of sewage effluents already

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exist (Smith, 1969) and it therefore still remains for guidelines to be formulated in regard to the disposal of sewage sludges.

Reference to control procedures adopted in other countries are only sparsely distributed in the literature but those adopted by the Federal Republic of Germany (Bundesgesundheidsampt, 1974) may be of interest in that they provide for unrestricted agricultural use of composted or heat treated sludge.

In South Africa a particular problem arises in that a large number of a section of the population are infected with *Ascaris lumbricoides*. The ova of this worm are still potentially infectious after conventional sewage treatment processes and therefore pose a significant health risk in the reuse of sewage works sludge. Particular attention has therefore been given to this problem in this review which also seeks to ascertain the effectiveness of various alternatives in reducing the health risk from viruses and bacteria.

Disinfection of Sewage Sludge

The disinfection of sewage sludges may be carried out by a number of different techniques, of which heat treatment and irradiation are considered the most economically viable and will be discussed in detail.

Pasteurisation

The basic requirement for this process is a tank in which sludge can be held and heated to at least 80°C (the critical temperature for pathogenic destruction), for a period of ½ to 1h by steam or hot gases. The following problems are associated with pasteurisation:

1. Heat transfer surfaces tend to become readily fouled with deposits. Live steam injection (Triebel, 1967) can be used to overcome this problem but results in an increased volume of sludge for ultimate disposal.

2. Heat recovery by means of heat exchangers can lead to surface fouling and for this reason Dotson *et al.* (1973) have suggested heat recovery by means of vapour heat exchangers but this requires a substantial capital investment.

3. The production of offensive odours, which has been a deterrent to its use. Apparently the degree or the effectiveness of the sludge digestion process before pasteurisation plays a role in the subsequent production of these odours.

4. Heat treatment leads to some degree of solubilisation of organic compounds which can only enhance the putrescibility of the sludge.

5. In low temperature processes dewatering properties of the sludge are adversely affected.

6. In sewage works employing heated digesters just sufficient methane is normally produced to cater for pasteurisation of sludge. With rapidly changing trends towards the extended aeration process this may not necessarily be the case in future — expensive supplementary fuel supplies may be required. These have the added disadvantage of being liable to rapidly escalating prices. An in-depth study of the true costs of pasteurisation is therefore required before its adoption can be recommended.

Enforcement of certain health regulations has resulted in a number of pasteurising plants being built in central Europe but as far as is known none are in existence in South Africa although one is to be installed in the near future at the Cape Flats Works in Cape Town.

Thermophilic Anaerobic Digestion

Capital costs can be reduced if heating appurtenances and digestion processes can be combined into one tank. Furthermore, the pasteurisation step can be omitted if sludge is digested at or above 50°C. For several years Garber *et al.* (1975) ran a full-scale digester at 50°C in parallel with several others operated in the mesophilic range (about 35°C) primarily to determine whether a change was produced in the dewatering properties of the sludge digested at the higher temperature. Steam for the process was derived from boilers fired with cheap natural gas and the additional cost of this operation was estimated to be R1,3 t^{-1} dry sludge.

Only limited microbiological data is available from this experiment but it would appear that when operating at 47°C there was a complete elimination of *Salmonella* spp and a limited reduction in *Pseudomonas aeruginosa* and faecal coliforms. Similar full-scale experiments carried out at the Johannesburg Northern Works showed that the process was not easily controlled and very precise temperature maintenance had to be adhered to if satisfactory operation was to be achieved.

Thermophilic Aerobic Digestion

The oxidation of 1 g carbon theoretically releases 32,8 kJ so that the addition of pure oxygen to highly concentrated sludges contained in well-isolated closed vessels should provide ample heat for pasteurisation purposes (Environmental Protection Agency, 1974).

Tabasharan (1975) described a process for treating animal excrement in Germany with digestion temperature reaching 45°C. Similar studies are being carried out in the USA by the Union Carbide Corporation whose experiments have shown successful operation at 60°C. Bacteriological data obtained by the Cincinnati National Environmental Research Centre, in a comparative study with Union Carbide showed that pathogenic bacteria were eliminated at this temperature (Farrell and Stern, 1975). No attempts appear to have been made to evaluate parasitic ova.

Laboratory scale experiments with this process, using waste sludge from the Johannesburg Olifantsvlei extended aeration plant were unsuccessful, but this may possibly have been due to heat losses arising from the small scale experiment. Confirmation of overseas results under South African conditions appear to be warranted.

Wet Oxidation

Two wet oxidation processes are considered:

1. Zimpro Process (Raw Sludge)
The Zimpro Wet Air Oxidation Process is based on the fact that any substance capable of burning can be oxidised in the presence of water at temperatures from 120 to 370°C.

When raw sludge is heated under pressure in the temperature range 170 to 200°C in the presence of oxygen, the gel-like structure of the sludge is broken and dewatering, for example by filtration and centrifugation, without the addition of chemicals is greatly facilitated.

If the pressure is increased, no additional source of heat is required and the oxidation of the sludge takes place in the presence of air from about 220°C. The advantage of the process is that it eliminates digesters and produces an easily dewaterable and sterile sludge.

Chicago had the largest high pressure unit in existence until it exploded, killing some of the operators. A disadvantage of the system is that high strength liquors are produced which place an additional load on the biological purification system. Chicago's experience furthermore, indicates a continuous build-up of soluble nitrogen salts in the system.

An example of the low temperature process is to be found at the 18 000 m^3 d^{-1} Kwa Dabeka (Clermont) Works situated near Pinetown in Natal. The overal capital costs of this plant were slightly less than those of a plant equipped with digesters.

Associated appurtenances are fairly sophisticated and include a boiler, water softening plant, vacuum filters, water pressure boosters and heat exchangers and in South Africa, the whole process is subject to control under the Factories, Machinery and Building Work Act.

2. Porteous Process (Digested Sludge)

In South Africa this process is used at only the Northern and Southern Works, Durban and necessitates heating digested sludge to 188°C and holding it at this temperature for 30 min.

Like the Zimpro Process, the basic aim is to produce a material that dewaters easily in filter presses to give a final sterile cake with a solids content of 45%. Similar operational problems and peripheral equipment are used in both processes.

Incineration

Incineration is generally only used as a last resort in disposing of sludge. Only 20% of the sludge produced in the USA is disposed of in this manner and in Great Britain, the newly created Water Authorities are taking a critical look at existing incineration plants. The Yorkshire Water Authority has decided to write off with a loss of about R700 000, its heat treatment and sludge incineration plant at the Knostrop Works in Leeds. This is one of twenty similar treatment plants in the country, fifteen of which have now been shut down (Anon, 1976).

Comparative costs of incineration in relation to other processes are extremely difficult to derive as there are many different incineration processes, including multiple hearth units, fluidised bed plants and other designs, comprising rotary drum or twirl bed furnaces. Furthermore, depending on the moisture content of the feed, the process may be autothermic or may require additional fuel to evaporate the water.

For all practical purposes, a sterile ash is obtained but where caking takes place, this may not necessarily be the case as unburned sludge containing pathogens may be found in the centre of caked material.

Incineration plants generally require specialised staff for their operation and maintenance and are often associated with air pollution problems.

Pyrolysis

This process is in effect a destructive distillation in the absence of air to yield a char, a liquid fuel, a solution of organic compounds and combustible gases. Several systems have been developed using different temperatures and pressures and the presence or absence of additional compounds such as hydrogen. Most systems are still at the pilot plant scale and only a few have reached an industrial scale.

Heat Drying

American experience indicates that sludges which have been heat dried are likely to be virtually pathogen and parasite free but are expensive to produce and are sold at a loss (Osborn, 1975).

Composting

Composting of sewage, often in admixture with domestic refuse, is best carried out at a moisture content of 40 to 60% and often requires a dewatering step. In the manual or semi-automated methods, where heaps are turned over by machine, the compost should reach 70°C and stay at this temperature for many days thus giving rise to a product of high hygienic quality. Public Health Authorities continue to regard the outer layer of the compost pile as harbouring potentially dangerous organisms.

A composting process tried in Munich and currently being evaluated by the Council for Scientific and Industrial Research at their Cape Regional Laboratory, Bellville, is claimed to produce temperatures exceeding 80°C which would effectively reduce the pathogen risk (Nell and Wiechers, 1978).

Although composting is a logical way of disposing of both domestic refuse and sewage sludge, the lack of suitable market outlets has resulted in the closing down of all composting plants in the USA (Nell, 1975). The US Agricultural Research Service has developed a modification of the conventional process by composting together digested sludge and wood chips in windrows which were frequently mixed (Epstein and Wilson, 1974). Temperatures in excess of 60°C are reached in the centre of the windrow and the wood chips are recycled after screening the product. The estimated cost is R26 t^{-1} (dry).

Radiation Treatment Methods

Microwave Radiation

Small scale laboratory experiments have been carried out by the Johannesburg City Health Department Laboratories using a small microwave oven to inactivate *Ascaris* ova in reasonably dry sludges. The efficacy of this process proved to be very low and furthermore, the temperature in the irradiated sludge was found to vary with depth and distance from the radiation source. This work has therefore not been pursued in greater depth.

Radiation with High Energy Electrons

1. The choice of an energy source for radiation of sludge lies between an electron accelerator and a gamma ray source of radio-active cobalt or caesium. Accelerators offer a sixfold advantage in initial capital cost and a twofold advantage in overall operating costs (Ballantine, 1976). Fur-

ther consideration is, therefore, limited to consideration of electron accelerators in the 0,5 to 3,0 MeV range.

2. Farrell and Stern (1975) presented the following advantages of low voltage electron accelerators:

   i The energy requirements are estimated to be fifty times less than the energy needed for steam (thermal) pasteurisation.

   ii Sludge odour is less unpleasant than with thermally pasteurised sludge and corrosion problems are less.

   iii Sedimentation and dewatering rates are enhanced.

   iv The unit can be switched on when required, is safe, has a potential for operating continuously on a three-shift basis and has a down time of 2 to 7%.

   v Free radicals produced can initiate auto-oxidation decomposition of organics, leading to greater stabilisation of the sludge.

   vi Very high dose rates are possible.

3. Disadvantages of low voltage electron accelerators:

   i Higher initial capital costs are involved compared with those of thermal pasteurisation plants.

   ii Accelerators are characterised by low penetration capability and have a usable depth range of 3,5 mm MV^{-1}, i.e. 10 mm for a 3 MV machine.

   iii They are inflexible in design.

   iv Deposition of magnesium ammonium phosphate is encouraged (Lessel *et al.*, 1975).

4. The design of an electron accelerator pasteuriser must necessarily be centred around the need to present a thin film to the electron beam. The ease of achieving this requirement is in turn dependent on the viscosity of the material to be irradiated. In the case of sludge, radiation costs will decrease as the solids concentration increases but this in turn may make it more difficult for a uniformly thin film to be maintained under the electron beam.
   It is essential that optimum solutions be found to these problems as soon as possible, as sludge concentrations ranging from 1 to 40% solids can be obtained in a wastewater purification plant with costs rising rapidly as the percentage solids increases.

Effectiveness of Irradiation Disinfection

The chief source of infectious organisms in wastewater sludge is human faeces. Other sources are, for example factory effluents, and abattoirs. Four broad groups of human and animal pathogens or parasites can be present in sewage sludge *viz.*, bacteria (particularly *Salmonella* spp.), viruses, cysts and oöcysts or protozoa, and parasite eggs.

Some of the studies reported upon below relate to the effect of irradiation on pathogens found in contaminated waters. They are included because they provide an indication of radiation doses required for effective elimination of pathogens. Sludge studies are hampered by the technical difficulties associated with enumerating residual organisms, particularly viruses, in sludge after treatment and attempts at improving isolation methods are constantly being made.

Bacterial Studies

Hess and Breer (1975) investigated the effect of radiation of sewage sludges and concluded that a total radiation dose of 3000 Gy resulted in a death rate of 10^4 to 10^8 cells of the *Enterobacteriacea* and that less than 10 such cells g^{-1} remained in 97,2% of the samples thus dosed. The sanitary effect of 3000 to 3500 Gy dosages on *Enterobacteriacea* was equivalent to the effect of heat treatment by pasteurisation. For purposes of comparison, it should be noted that this quality can be equated to certain Swiss regulations for milk products which require a contamination of less than 10 coliforms g^{-1}.

Hess and Breer (1975) concluded that radiation of sludges with 3500 Gy would make them suitable for use as a fertilizer for grasslands. Similar results were achieved by heat sterilisation at 80°C for 30 min.

Wizigman and Würsching (1975) found in practice that a dose of 2600 Gy for 210 min produced a 2 log reduction in the enterococcal content of sewage sludge and a 5 log reduction in *Enterobacteriacea*. However, the counts of bacteria increased to their original values when the irradiated sludge was stored on drying beds. They also observed that *Ascaris* eggs were damaged but presented no information as to whether these eggs were viable or not.

Sinskey *et al.* (1975), in studies on the biological effects of high energy electron radiation of municipal sludge, found that a dosage of 3000 Gy was sufficient to produce a 99,99% kill in the total population present in sewage sludge. The coliforms and other Gram-negative bacteria in sludge proved to be most susceptible to irradiation. A 100% inactivation of these bacteria was obtained with a total dosage of less than 1500 Gy.

1. ***Resistance***

   Micro-organisms may acquire a resistance to radiation. Davies and Sinskey (1973) and Davis *et al.* (1973) reported that *Salmonella typhimurium* LT2 acquired an increased resistivity of up to 20 times that of the wild type. It is also well known that the bacterium *Micrococcus radiodurans* is fairly resistant to gamma radiation. Simon and Tamasi (1975) concluded from their studies that anaerobic bacteria were more radio resistant than aerobic bacteria and that sporulation played an important role in this respect. They were also not in favour of the use of radiation to destroy Mycobacteria since too high a dose was required for this purpose.

2. ***Synergism***

   Tests on the synergistic effects between radiation with chlorine, zinc chloride and ultrasonic vibrations have been carried out on samples in various liquid media by Sidorenko *et al.* (1963), Dharkar (1964), Kiortsis (1968), Basson and Melmed (1970), Woodbridge *et al.* (1975) and Vajdic (1971). These treatments are not however, suitable for sludge. A combination of heat and radiation can be used effectively for sludge disinfection. Stehlig and Kaindi (1966) found a 10^2 synergistic effect of heat combined with radiation in food irradiation for survival of *Saccharomyces cerevisiae*.

Sivinski (1975) investigated the treatment of sewage sludge with a combination of heat and ionising radiation (thermoradiation). He believed that if the synergistic effect of heat and radiation could be successfully transferred to sewage sludges, a cost effective alternative to heat alone for sludge disinfection could be obtained. For instance, he found that *Ascaris* ova could be inactivated by a temperature of 47°C and 400 Gy.

Virus Studies

As far as public health is concerned, only animal viruses are of importance since neither plant viruses nor phages can infect animal cells (Lemke and Sinskey, 1975). A great deal has been written on the effects of ionising radiation on viruses but most of the work has been done on wastewater. These effects cannot easily be applied to sewage sludge since analytical methods for determining viral concentrations in sludges and water still need improvement (Lemke and Sinskey, 1975).

Sullivan *et al.* (1971) tested in liquid media some thirty different viruses of the groups adeno, polio, echo, coxsackie, herpes, reo and myxovirus and have found a reduction rate of about 90% at a radiation dose of 3900 Gy.

Lund (1975) reported that a temperature of 70°C for a period of ½ to 1 h should inactivate parasite eggs and viruses with the possible exception of hepatitis virus which cannot at present be cultivated.

Adeno and poliovirus are likely to be of direct concern in the wastewater treatment field and of these, adenovirus has been found to be more resistant to the effects of radiation and could perhaps be used as an indicator organism.

Epp (1975) reported that it was very difficult to isolate virus from sludge and therefore investigations into radiation were inconclusive. He inoculated virus into sludge by planting capsules containing virus in the sludge and followed this by radiation with 3000 Gy in 3½ hours. He found that only two capsules out of a total of thirty three showed the presence of virus. Under natural conditions the sewage sludge contained four times less virus after radiation.

Parasitological Studies

Roundworm infection appears to be endemic to certain sections of the population in South Africa and it therefore appears to be prudent to rely on local work in evaluating the effect of radiation on the ova of *Ascaris lumbricoides*.

Muller (1975) reported that eggs from these worms could be recovered from digested sludge which had been buried in soil for seven years. Melmed (1976) found that waste activated sludge taken from a Johannesburg sewage works contained an average of 2 200 eggs g^{-1} dry mass with 85% of the eggs potentially infectious. Similarly, digested sludge from the same works contained 2 900 eggs g^{-1} dry mass of which 44% were potentially fectious. After irradiation with a dose of 1000 Gy, the residual potentially infectious numbers of ova dropped to 0,7 to 1% in both types of sludge. At 5000 Gy a complete kill was not achieved. Animal infectivity studies are currently being undertaken to determine whether the apparently infectious ova after irradiation are in actual fact infective. Additional work is also currently in progress to confirm the synergistic effect of thermoradiation found by Sivinski (1975). Experiments with batches of sludge exposed in a microwave oven for 2 min have shown that the sludge reached a temperature of 70°C giving a 99% kill of *Ascaris* ova. In summary therefore, it would seem that a dose of 1000 Gy would appear to give effective reductions in *Ascaris* ova at a realistic price.

Verster *et al.* (1976) and Verster *et al.* (1977) found that beef and pork carcasses infested with cysticercosis can be rendered fit for human consumption by exposing them to radiation doses of 200 to 600 Gy.

Practical Applications of Radiation Technology

Jackson (1970—71) described a plant to irradiate poultry wastes for re-use as animal feed. It would treat 60 t of slurry daily containing 17 to 18% solids at a total dose of 1200 Gy which was expected to kill most of the bacteria and enhance solids separation.

Compton *et al.* (1969) drew attention to the possibility that disinfection of sewage sludge by irradiation may be beneficial when it is disposed on land, since its effective disinfection with chlorine is known to be difficult.

For a review on radiation treatment of sewage for the period 1948 to 1970 see Newland (1970). Gerrard (1971) suggested in her literature survey, while accepting the present cost penalty of radiation treatment, that there are areas where no other treatment method is currently feasible, for instance, in Arctic regions. Friedman and Albrecht (1968) also considered that radiation treatment might have a part to play under such conditions and considered electron beam sources to be most suitable. More recently, Okun (1973) estimated the overall potential of radiation treatment of wastewaters.

For the disinfection of sludge, in which Chicago has been especially interested because of its land reclamation programme, the penetrating power of radiation may have an advantage over chemicals, but must compete with anaerobic digestion and with heat. Etzel *et al.* (1969) had found a 99,99% kill at 2000 Gy in activated sludge. A positive step has now been taken by the Federal Republic of Germany which has largely financed the construction of the first sludge disinfection experimental facility, near Munich. Describing this, Suess *et al.* (1974) stated that, in future, before sewage sludge is used in agriculture, more stringent requirements will have to be applied to the destruction of the eggs of the parasites, *Salmonella* spp. and other pathogens. Studies have shown that the sterilising efficiency of 3000 Gy dose was the same as that of standard pasteurisation (80°C for 30 min) without its attendant odour problem. The capacity of the Munich plant is 30 m^3 d^{-1}, but this can readily be increased by a factor of 4 to 5. Radiation costs amount to about DM2m^{-3}. The comparable thermal treatment cost was DM1,84 m^{-3} in 1972 and will certainly be higher today. Advantages indicated are improved sludge dewatering which reduces volume and handling costs, no noxious odours, very low staffing costs and prevention of seed germination in the final product. An extensive research programme using the facility is proposed under the guidance of the Bavarian State Institute of Soil Cultivation and plant Breeding.

Safety Aspects of Sludge Irradiation

The use of radiation brings about the question of the safety of its use. Trump *et al.* (1975) summarized these aspects as follows:

1. No increase over the natural radio-activity of sludge is in-

duced by electron irradiation at any of the doses or energies reported upon in this manuscript.

2. Electron irradiation initiates instantaneously a complex chain of energy transfers and transient chemically active states of the material being treated and its components. These react vigorously with entrained micro-organisms and molecules which are also affected by direct action of the radiation. The end result is a rapid return to normal state with an increase in temperature of about 1°C, i.e. appropriate to the energy adsorbed.

3. In contrast to long-lived artificially radio-active sources of gamma rays, electron accelerators can be turned off instantly and totally inactivated.

Notwithstanding the extensive investigations that were carried out on the wholesomeness and toxicology of a very wide variety of foodstuffs that were irradiated to doses far in excess of what is envisaged for the treatment of sludge, no evidence has been presented on any harmful effects that resulted from the consumption of irradiated food. This has led to the situation that five food items (potatoes, wheat, chicken, paw-paw and strawberries) were declared 'unconditionally safe' for human consumption by the World Health Organisation at a meeting held during September 1976 in Geneva. At present a whole list of other food items is at the point of being given a similar clearance (Du Plessis, 1977). It thus follows that no evidence exists that the irradiation of food can lead to unwanted properties with regard to its wholesomeness and toxicology.

In the case where irradiated sewage sludge is to be used for agricultural purposes there is correspondingly less reason to believe that the irradiated sludge will have any detrimental effects on the crops grown on it. All evidence indicates that the application of irradiated sludge for growing crops for human consumption will be just as safe as the radiation of food is at present.

Cost of Sludge Disinfection

Pasteurisation

Many of the references quoted in this review contain statistics relating to the costs of pasteurising sludge by various means. After careful consideration of this data it was concluded that no meaningful purpose would be served by attempting to summarize it into one comprehensive table. Some of the reasons are:

1. The data relates to plants of vastly different sizes and constructed in different years.

2. Inflation and changing rates of exchange make comparisons on a common baseline impossible.

3. Cost of land, interest on capital, amortization rates, cost of labour and electricity vary tremendously from place to place.

4. In some cases a completely different purification system must be compared with a pasteurising system added on to the end of an existing process.

Under these circumstances it is felt that consideration

TABLE 1
OPERATION AND COST DATA FROM SIX SWISS SLUDGE PASTEURISING PLANTS
(LESSEL *ET AL.*, 1975)

Plant	A	B	C	D	E	F
Inhabitants	3 500	25 000	12 000	5 000	1 000	6 000
Population equivalents		170 000	7 000	30 000	30 000	11 000
Batch volume	2 x 2,5	2 x 10	17,5	2 x 3	cont.	2 x 3
Investment cost (S.Fr.)	190 000	280 000	104 000	237 000	104 300	278 000
Operation period	Feb.—Sep.	Mar.—Sep.	Mar.—Oct.	Mar.—Oct.	Apr.—Oct.	Mar.—Oct.
Pasteurised sludge volume (m^3)	390	2 690	1 170	1 095	1 890	4 200
Total sludge (%)		46	69	100	43	100
Fuel oil costs (S.Fr.)				1 820	2 500	4 880
Methane consumption (m^3)	3 900	39 600	14 800			
Specific heat cons. (10^6 joules m^{-3})	272	400	338	362	289	254
Total operation costs (S.Fr.)	860	5 520	3 940	3 730	5 470	10 720
Capital cost (10% a^{-1}) (S.Fr.)	9 500	28 000	10 400	9 500	20 860	27 800
Total specific costs (S. Fr. m^{-3})	26,20	12,50	12,30	12,00	13,90	9,20
Estimated total specific costs at full performance, 1975 (S. Fr. m^{-3})	10,30	3,50	6,80	7,00	7,50	7,50

should only be given to the relative costs of radiation techniques versus heat treatment processes, where these figures relate to data obtained in the same country and over a comparable period of time and where both techniques are used on mesophilically digested sludge. Data relating to six sludge pasteurising plants in Switzerland are given in Table 1.

A direct comparison of heat treatment and irradiation costs as obtained at the Geiselbullach pilot plant (near Munich) is given in Figures 1, 2 and 3.

The radiation costs at Geiselbullach are based on the use of ^{60}Co as a radio-active source and are therefore much higher than those for an electron accelerator. When costs are recalculated based on the latter, it seems likely that they will be of the same order as those encountered for secondary heat treatment processes.

Stern (1974) estimated the fuel costs for pasteurising digested sludge containing 5% solids to be \$14 t^{-1} (dry) with no allowance being made for the recovery of heat. Where methane from anaerobic digestion can be used this cost is likely to drop to \$10 t^{-1} (dry) for small plants with a flow up to 10 000 m^3 d^{-1}. These costs include amortization plus operating and maintenance costs.

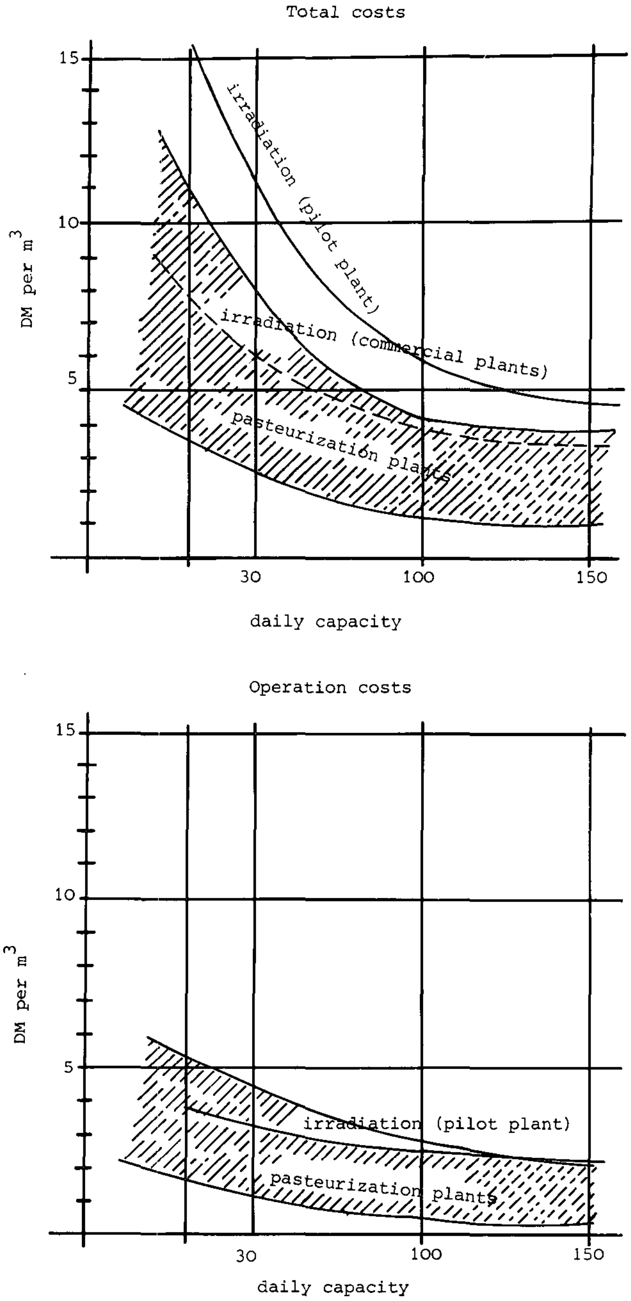

Figure 1
Costs calculation for various sewage treatments
(From Lessel et al.*, 1975)*

Fluidised Bed Incinerators

Fluidised bed plants have been installed at both the Durban Central Works and at Port Elizabeth. Everitt and Gaillard (1976) gave the estimated running costs of the Durban plant as:

R12 t^{-1} (dry) assuming autothermic conditions,

R24 t^{-1} (dry) assuming additional fuel is required,

plus R 9 t^{-1} (dry) for pre-conditioning the sludge by centrifugation.

All figures are based on the use of primary clarifier sludge.

Zimpro Process

Antoni (1976) estimated that the total cost of operating this process at the Kwa Debeka Works (near Pinetown) in South Africa was currently R100 t^{-1} (dry), dropping to an estimated R50 t^{-1} (dry) when the plant reaches its design capacity.

Porteous Process (using digested sludge)

Everitt and Gaillard (1976) reported that the operating costs for the locally installed plants in Durban were:

1. Running costs only, using digester gas to heat boilers: R16 t^{-1} dry
2. Additional cost if alternative fuel is required: R12 t^{-1} dry
3. Cost of subsequent filter pressing: R15,7 t^{-1} dry

These costs did not include the price of any additional biological oxidation plant required to handle the high strength liquors arising from this process.

Heat Treatment Costs

Sludges which have been heat dried are likely to be virtually pathogen and parasite free but are expensive to produce and are sold at a loss as indicated below:

	Trade Name	Production $t\,d^{-1}$	Sold $t\,a^{-1}$	Cost \$ t^{-1}	Revenue \$ t^{-1}
Chicago		165	61 000	106	15
Milwaukee	Milorganaite	185	670 000	90	54

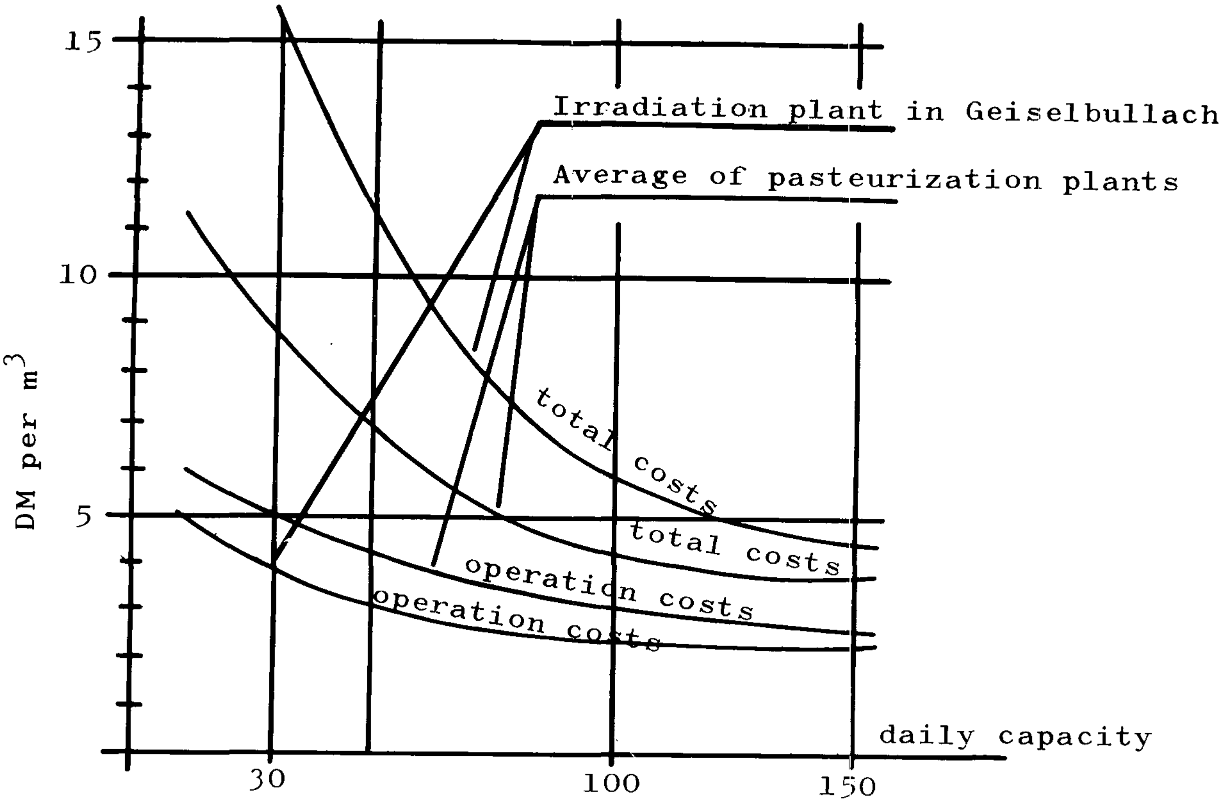

Figure 2
Comparison between the costs calculation for the irradiation plant in Geiselbullach and pasteurization plants, including the effect of different sedimentation
(From Lessel et al., *1975)*

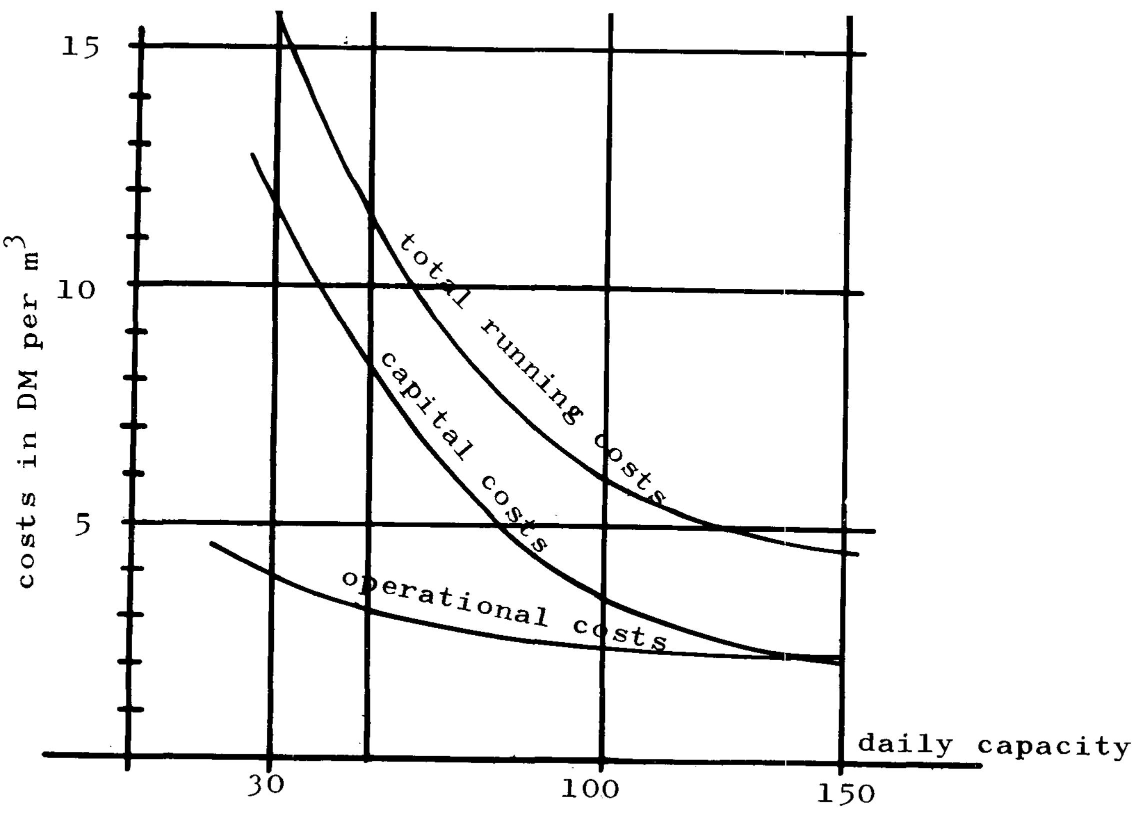

Figure 3
Costs calculation for the irradiation plant
(From Lessel et al., *1975)*

Composting

Current (1975) costs of producing compost from refuse in Europe vary from R6 to R13 t^{-1} compared with incineration cost without energy recovery of R15 t^{-1} of refuse received (Nell, 1975). In the Western Cape with reasonably developed markets, it appears to vary from R10 to R15 t^{-1} and is sold at a loss of R6 t^{-1}.

Electron Accelerators

Ballantine (1976) estimated the capital requirement of a 3 MV accelerator to be \$5 000 kW^{-1}. Running costs depend on:

1. The mass of material to be irradiated
2. The dose of radiation
3. The efficiency of absorption of radiation energy in the system.

The Deer Island Plant, Boston, USA, treats 1 136 $m^3 d^{-1}$ of 2% sludge which is dosed with 4 000 Gy making the total daily requirement 455 x 10^4 Gy $m^{-3} d^{-1}$. At 75% efficiency the capacity requirement becomes 606 x 10^4 Gy $m^{-3} d^{-1}$. The radiation power requirement is obtained by dividing the latter figure by 8,73 x 10^4 Gy $m^{-3} d^{-1}$ which is equivalent to 1 kW. The cost of electricity can be calculated from this figure.

Total costs can then be obtained by summating amortization and interest charges with running and estimated maintenance costs.

Conclusions

Hard and fast conclusions are difficult to draw from such a broadly based literature survey. Researchers may report disinfection efficiencies in terms of percentage reduction in bacterial numbers without giving the initial concentration and may perform their experimental work with synthetic sewage media under laboratory conditions. Virus estimations are both difficult and costly and this has led to the addition of viruses to sewage sludges under highly artificial conditions which may not necessarily bear any relation to practice.

In order to make cost effective decisions on the type of disinfection process to adopt, it is very necessary to have quite clear-cut objectives regarding the ultimate use of the disinfected sludge and the minimum acceptable bacterial, viral and parasitological quality.

Auxiliary heat treatment of sludges to 80°C for 30 min and irradiation with a total radiation dose of 3 000 Gy appear to have proven equivalent performance, *viz.* a reduction of intestinal micro-organisms by a factor of 10^6 to 10^7 leaving a residual of less than 10 enterobacteria g^{-1} in 97% of irradiated sludges (Hess and Breer, 1975). The same radiation dose reduces the potentially infectious *Ascaris lumbricoides* ova content to about 1% (Melmed and Comninos, 1977).

Costs, in overseas experience, tend to favour radiation. Radiation treatment however, requires a high capital investment with low running cost, whereas heating equipment is available at lower capital cost but higher running costs. The latter are greatly influenced by the availability of methane from sludge digesters. In this regard cognisance must be taken of the trend in this country towards the establishment of large extended aeration plants which omit the sludge digestion step.

If the organism reductions achieved by a 3000 Gy radiation dose are considered to be acceptable from a public health point of view, then the cost of such treatment is likely to be R12 t^{-1} for a sludge containing 5% solids. In the case of an activated sludge plant where waste sludge concentrations may be of the order of 0,4% solids to bring this sludge up to 25% solids by means of air flotation and belt pressing operations may cost about R30 t^{-1} (dry) but radiation costs may drop to about R3 t^{-1} (dry).

In order to make reasonable cost calculations it is necessary to ascertain the cost of each unit process in the purification train and to add these up to obtain an overall treatment cost. In this way one can then make more meaningful comparisons with other processes such as Zimpro and thermophilic digestion.

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