KALMAR ECO-TECH´03
Bioremediation and Leachate Treatment
KALMAR, SWEDEN, November 25-27, 2003

TREATMENT OF HIGH-STRENGTH LIQUID WASTES BY AUTO-THERMAL AEROBIC DIGESTION

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ABSTRACT

Auto-thermal aerobic digesters comprise a simple, robust, inexpensive technology appropriate for on-site liquid waste treatment by small- and medium-sized enterprises. They have been shown to be effective at treating a wide range of effluents and liquors arising from food processing and chemical plants, especially those with high levels of biological oxygen demand (BOD), or for small-scale sewage treatment.

Liquid circulates around the reactor vessel by pumping through a venturi nozzle, which draws air into the flow. As the microbial community develops, the system self-heats and organic matter is removed as CO_2, NH_3 and water. The temperature of the insulated vessel may rise to 55°C or more as the thermophilic community becomes established. BOD levels typically reduce by 90% over a 3-5 day residence time. Auto-thermal aerobic digestion (ATAD) acts faster than mesophilic or anerobic degradation and is very resistant to organic toxins (pentachlorophenol) or metal pollutants (Cu^{2+}, Zn^{2+}, Ni^{2+}) in the waste.

Examples are shown of wastes and liquors successfully treated by pilot-scale ATAD systems up to 1000 litres in size. These include effluents from food processing (ice-cream, chocolate, egg pasteurisation, brewing), chemical plants (wood processing, phenolic liquor) and silage pit effluent.

Auto-thermal aerobic digestion offers a versatile, cost-effective solution for liquid waste treatment in a climate of increasing demands from Regulatory Authorities and increasing costs of conventional off-site waste disposal such as sewerage or landfill charges.

KEYWORDS

Waste treatment, high-strength effluent, auto-thermal aerobic digestion, biodegradation, bioreactor, venturi aeration, BOD, COD, thermophilic bacteria.

https://doi.org/10.15626/Eco-Tech.2003.040

1 INTRODUCTION

Small and medium sized enterprises (SMEs) are seen by the European Union as the engines of economic advance and recovery. In many instances, however, they are meeting increasing demands from Regulatory Authorities and incurring increasing costs in relation to disposal of both solid and liquid wastes. Trade effluents discharged through the sewer system, to landfill or by specialist contractors all attract increasing direct costs and/or taxes. Introduction of new sewage treatment facilities in the UK following EU directives has seen sewerage costs increase up to ten-fold in comparison to charges when sewage was discharged to sea outfalls. Additionally, companies can seek commercial advantage or may be required by their suppliers, to meet the requirements of an internationally recognised environmental management standard such as ISO13001.

The objective of the studies reported here was to develop a low cost, robust technology for on-site effluent treatment to mitigate the costs of empirical charging formulae now used to calculate sewerage charges of SMEs in the UK. Although methods of charging for sewage treatment may differ between countries around and outside the EU, similar problems of liquid waste disposal face all commercial enterprises, and are likely to be economically acute for all SMEs such as food processing plants now or in the near future.

2 SEWERAGE CHARGES

In the UK, sewerage costs for trade effluent are calculated by the Mogden formula in which the total charge varies greatly with the strength of the effluent (measured by Chemical Oxygen Demand – COD, and Solids), and with the volume discharged.

$$\mathbf{C = R + V + B*(Ot/Os) + S*(St/Ss)}$$

Where C = total charge (pence/m^3) of trade effluent
(current charges in Wales are shown)
R = fixed cost for conveyance (18 pence/m^3)
V = fixed cost for pre-treatment (20 pence/m^3)
B= fixed cost for biological treatment (13 pence/m^3)
S = fixed cost for sludge disposal (10 pence/m^3)
Ot = COD in the effluent (? mg/litre)
Os = COD of "average" settled sewage (500 mg/litre)
St = Solids value in the effluent (? mg/litre)
Ss = Solids value of "average" settled sewage (350 mg/litre)

Illustrative example of Mogden formula charges (based on Dwr Cymru, Wales);

	COD mg/l	Solids mg/l	Charge per m^3
a) relatively weak effluent	5000	20	£1.79
b) strong effluent	100 000	20	£26.89

The commercial importance, especially to SMEs, of minimising both COD and Solids in the effluent is clear, if this can be achieved with relatively low capital and running costs.

3 AUTO-THERMAL AEROBIC DIGESTERS

Auto-thermal aerobic digestion represents an innovative and unique system for treatment of high strength wastewaters. It benefits from many of the characteristics of thermophilic composting and sludge digestion. These include faster degradation rates, more efficient removal of free ammonia to the gas phase, inactivation of pathogenic micro-organisms, and a general insensitivity to exposure to heavy metal and organic toxicants when compared to activated sludge processes and anaerobic digestion. The mean residence times for ATAD are substantially reduced when compared to mesophilic processes, which leads to a significant reduction in the size of bioreactors required [1]. The main disadvantages of the process are the expense of tank aeration (electricity), poor bacterial flocculation (but relatively little sludge is produced), and foaming problems (may be overcome with anti-foaming agents).

The bioreactor consists of an insulated barrel shaped vessel, the liquid contents of which are pumped around rapidly near the base [2]. Just prior to re-entry the liquid is forced through a venturi nozzle with air pipe attached (*Figure 1*). This has the effect of allowing air to be self-entrained into the vessel, maintaining a high concentration of dissolved oxygen. Air is exhausted through a pipe at the top. The random microflora, which develops in such digesters, responds with rapid growth and typically the temperature is elevated (to a maximum of 70°C) by self heating [3,4,5]. The organic component of the feedstock is used for microbial growth but most is exhausted as CO_2, some ammonia and water. Model reactors can be 50-100 litres using a 90W pump (domestic central heating pump). A larger experimental scale is 1000 litres, requiring a pump of about 500W [6].

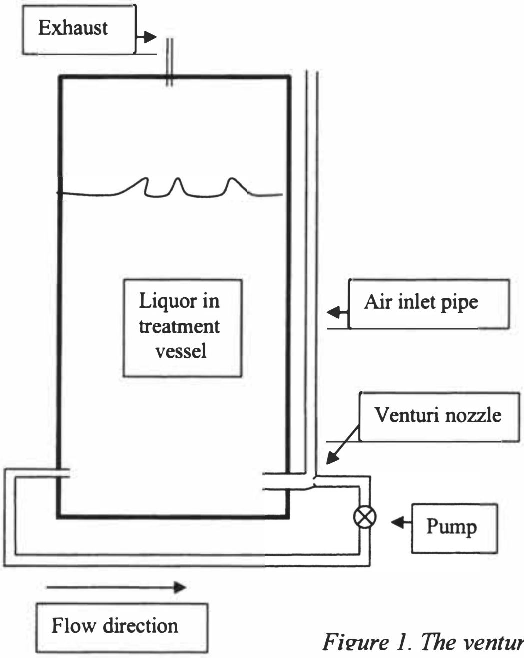

Figure 1. The venturi-aerated digester [2,6]

The thermophilic microbial community that develops is capable of reducing biological oxygen demand (BOD) by up to 90% within a 3-5 day residence time in optimised conditions. Such reactor vessels can therefore be much smaller than anaerobic digesters (typically 15-30 days residence time), with savings in land and construction costs. In many trade effluents BOD comprises a very high proportion of the total organic matter (COD), on which sewerage charges would be based. Digesters, if adequately insulated, can be used all year round even in cold climates because of self-heating. Where human or animal waste material is included in a waste stream, strict regulations govern its disposal, requiring heat treatment at more than 55oC. ATAD systems provide such conditions and hence can inactivate potential pathogens and infective agents.

The microbial community has been shown to be resistant to additions of heavy metals (Cu2+, Zn2+, Ni2+) and organic toxicants (phenol, pentachlorophenol) at concentrations ten times higher than would poison an activated sludge plant or anaerobic digester [1]. The organic pollutants became rapidly metabolised.

Effluents from food processing often contain high concentrations of sugars and starch which are readily metabolised to organic acids, reducing pH rapidly below 4 and inhibiting further biodegradation. Adding calcium or sodium carbonate immediately raises pH and re-starts bacterial degradation, enabling the bacteria to metabolise acidic compounds (lactate butyrate, propionate) and maintaining alkaline pH.

Problems of foaming can be managed during start-up using anti-foam agents and typically diminish on reaching steady state. A special design was developed for effluents rich in water-immiscible oils and fats.

4 EXAMPLE APPLICATIONS OF ATAD

Pilot scale trials (50 to 1000 litre vessels) using a range of effluents arising from food processors and chemical manufacturers have demonstrated the potential of ATAD reactors to achieve substantial and rapid reductions of COD/BOD. In most cases, greater efficiency could be achieved by optimising operating conditions, so reducing residence time. This would occur along with scale-up to accommodate the rate of production of a particular effluent. The following examples, shown in summary, illustrate the operation of ATAD systems with a variety of trade effluents. The systems were initially primed by adding a small amount (5% volume) of waste to water or sewage and running the reactor for a few days, after which a substantial amount (25% volume) of waste was added. Levels of COD, solids, pH, temperature, *etc* were monitored as the reactions proceed in batch mode. In some cases, regular additions of waste were made, to produce a semi-continuous process. Additions of carbonate or growth nutrients were made as appropriate. Initial levels of pollutants refer to the waste before adding it to the reaction vessel.

4.1 Chocolate factory effluents

Battermix waste	Comments
50 litre small scale trial. Initial: pH 6.9 COD 87 000 mg/l Solids 334 000 mg/l	After addition of waste - pH dropped to 4.0 (inhibitory) due to acid production. Carbonate added to re-activate. After 13 days temperature dropped - N & P nutrients added – high temperature restored.
Final (16 day): pH 9.5 COD 7725 mg/l Solids 9600 mg/l	Mogden sewerage costs: initial £171, final £23 per m^3.

Marshmallow waste	Comments
50 litre trial Initial: pH 6.4 COD 302 500 mg/l Solids 4872 mg/l	Wash-down from production line (large volume, intermittent flow). pH dropped to 3.3. Carbonate added to re-activate. N & P nutrients added (day 8).
Final (15 day): pH 8.6 COD 1550 mg/l Solids 4444 mg/l	Installing an equalisation tank would even out wash-down discharges.

4.2 Ice-cream factory waste

Spillage onto factory floor	Comments (see *Figure 2*)
40 litre trial Initial: pH 6.6 COD 254 600 mg/l Protein 22 260 mg/l	In first 24 hours, COD reduced by 53%, protein by 90% and pH dropped to 4.0 (lactate production), then little change.
Final (8 day): pH 7.5 COD 3890 mg/l Protein 222 mg/l	$CaCO_3$ added (day 6) – re-starts reaction; pH increased to 7.6, and further COD reduction. Would give Mogden cost saving per m^3 of c94%.

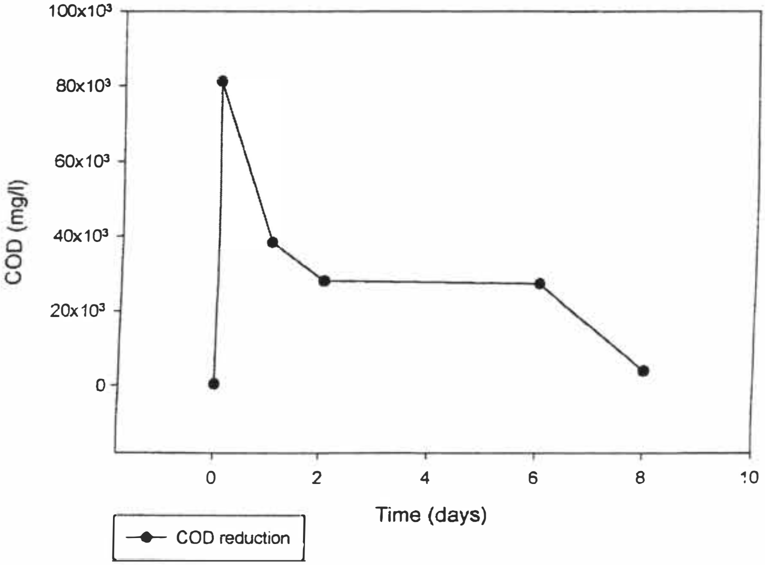

Figure 2. Biodegradation of ice cream waste

4.3 Egg processing plant effluent

Pasteurised egg waste	Comments (see *Figure 3*)
1000 litre pilot scale trial Initial: pH 12.6 COD 21 000 mg/l Solids 5244 mg/l Protein 17 mg/l	High pH due to betol sanitizer used in cleaning process. Continuous input of waste from holding tank (up to 500 litres/day). Max. temperature of reactor 51°C at day 2. Waste temperature 80°C, hence use of fresh waste would assist in generating high temperature (cost-free).
Final (5 day): pH 9.6 COD 5980 mg/l Solids 1860 mg/l Protein 2 mg/l	5-day reductions relative to initial reactor concentrations: COD 49%, Solids 64%, Protein 25%. Foaming was a problem with this proteinaceous waste. Use of 2 reactors in sequence would reduce foaming.

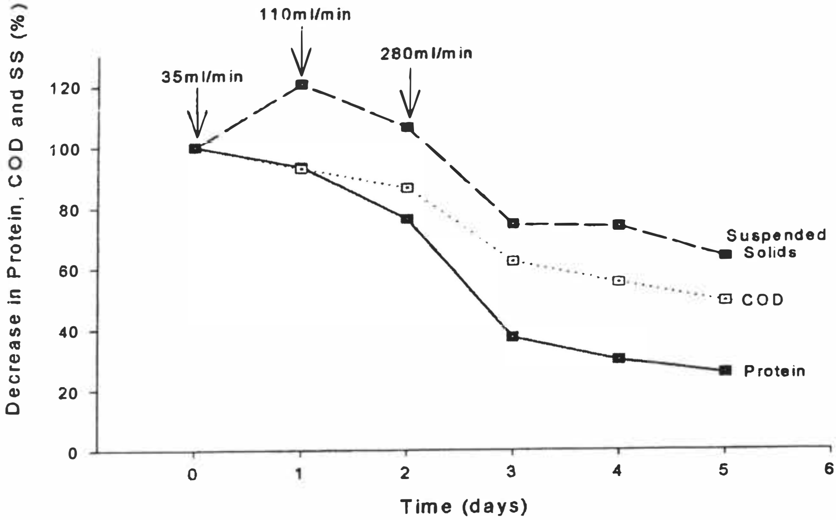

Figure 3. Pilot scale degradation of egg waste

4.4 Chemical effluent from plastic manufacture

Due to high levels of methanol and p-hydroxybenzoate, this waste cannot be discharged to sewer and is sent for incineration. Phenolic compounds (degradation products) would inhibit activated sludge plants and anaerobic digesters.

Fresh waste (no phenolics)	Comments
50 litre trial Initial: pH 7.3	Initial large reduction in COD and total organic carbon (TOC) over 8 days.
Final: pH 9.6 COD 1650 mg/l TOC 1100 mg/l	Very efficient overall reduction – 95% over 16 days.

Stored (phenolic) waste	Comments (see *Figure 4*)
50 litre trial Initial: pH 5.4 COD 51-54 000 mg/l	Rapid decrease in methanol and phenol (4 days), eliminated over 11 days, followed by slower reduction of COD (95%) over 11 days.
Final: pH 8.3 COD 1600 mg/l TOC 600emg/l	Presence of phenol reduced bacterial numbers (total viable counts, TVC) but remaining organisms degraded it using phenol mono-oxygenase enzyme and TVC rose again.

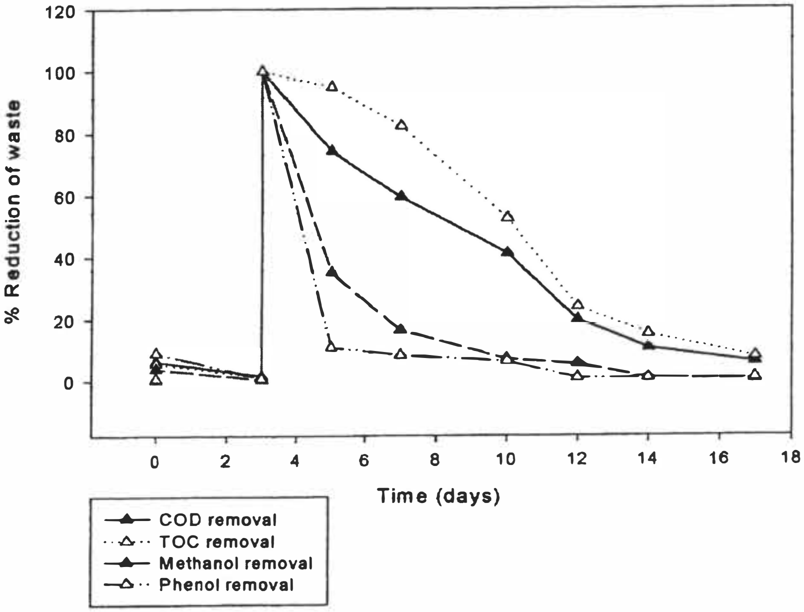

Figure 4. Treatment of phenol-containing chemical waste

4.5 Wood waste effluent from a board-making factory

Three distinct effluents were produced by different stages in the manufacturing process. In addition a very strong and acidic evaporate waste was produced (pH 3.6, COD 221 200 mg/l). Problems of foaming prevented processing of this waste.

3 distinct effluents	Comments (effluents arise at different stages in process)
Initial; pH 5.9-8.2 COD 1475 –7875 mg/l	COD reduction in reactors 80-89%; 50% reduction typically in first 3 day period.
Final: pH 8.7 – 9.0 COD 160 – 380 mg/l	Indication of nutrient limitation (if added, would increase degradation rates) – further trials needed to optimise growth.

4.6 Silage effluent

On-farm storage of silage often results in surface leakage of highly polluting effluent. The acid constituents (lactic, butyric and propionic acids) are highly corrosive to concrete containers and silage effluent has extremely high BOD values (up to 90 000 mg/l). Pollution of surface waters poses a great danger to local aquatic life, and on-site treatment of leachate would mitigate such hazards.

Silage effluent	Comments
Initial pH 3.8	No change after extended aeration (microbial inhibition)
Added 2% $CaCO_3$ to raise pH to 4.8	Reactor functioned – temperature raised to 58°C and pH raised to >8.0. Bacteria now able to metabolise organic acids (*e.g. Bacillus sphaericus, B. subtilis, B. licheniformis*, known to grow on lactate, acetate, etc).
To maintain alkaline condition:	A continuous feed system could be devised, based on the rate of acid degradation, with treated effluent applied safely to land.

4.7 Brewery waste

Spent brewery liquor may contain more than 50 000 mg/l BOD. Experimental treatment of weaker effluent (initial BOD after dilution in reactor, 1100 mg/l BOD) achieved a reduction of 50% over 4 days but the temperature rose to a maximum of just over 50°C, reflecting the low strength of this effluent.

5 CONCLUSION

Auto-thermal aerobic digestion has proved to be effective for initial treatment of a variety of trade and process effluents including food waste, chemical waste and silage effluent with, potentially, significant savings on sewerage charges. This novel and versatile technology is characteristically:

- Robust – resistant to contamination by metals and organic poisons;
- Low capital cost – simple to construct, requires relatively small housing space;
- Low running costs – electricity for continuous pumping;
- Rapid degradation rate compared to mesophilic aerobic or anaerobic digestion;
- Removal of pathogenic micro-organisms (requires >55°C).

In view of these features ATAD is particularly appropriate for SMEs requiring on-site pre-treatment of liquid wastes before discharge to municipal sewerage. Two-stage treatment for strong effluents with ATAD followed by "polishing" in reed or willow beds (constructed wetlands), is proposed where direct discharge to environment is required. Further work in collaboration with industry is needed to prove the efficacy and cost-effectiveness of full-scale installed ATAD systems.

6 ACKNOWLEDGEMENTS

The trials reported here were funded by European Regional Development Fund (ERDF) and Welsh Industry, in support of Cardiff University's Clean Technology Group.

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