

SUGGESTIONS FOR IMPROVING ANAEROBIC DIGESTION OF SUGAR MILL EFFLUENTS

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Abstract

Mill effluent has been treated in a simple pilot-scale anaerobic digester and the results indicate that anaerobic digestion is capable of reducing the chemical oxygen demand (COD) of the effluent by 80% with a residence time of only two days and without added lime. Advantages of using anaerobic digestion are outlined together with suggestions for increasing its role in effluent treatment.

Introduction

In the South African sugar industry anaerobic digestion of mill effluents is presently playing only a minor role in effluent treatment. The anaerobic dams are generally mere holding dams whose design and operation are not ideal for anaerobic digestion. Despite long residence times of 4–6 days the pollution abatement across most of the dams seldom exceeds 50% in terms of chemical oxygen demand (COD), and in some cases it is negligible. Judging from literature reports (Lettinga et al¹ and Ross²) it should be possible to improve this performance considerably. Some of the existing problems and future potential of anaerobic digestion are highlighted in this paper.

Process Perspective

In comparison with aerobic treatment, anaerobic treatment offers the following advantages:

- (1) No mechanical agitators are required so capital costs and running costs are lower.
- (2) The nutrient requirements are lower so that expenditure on nutrient dosing can be reduced or eliminated.
- (3) Sludge production is much lower thus minimising problems of sludge handling and disposal.
- (4) With proper equipment, very high loadings can be applied so the physical dimensions of the facility can be relatively small.

The major disadvantages are:

- (1) Initial start-up is slow and requires careful control.
- (2) Unpleasant odours may be produced, particularly during start-up.

The slow start-up is a problem only during initial commissioning; most of the active microflora survive throughout the off-crop so subsequent start-ups are not problematic.

Despite such obvious advantages, anaerobic treatment is not accorded much merit in the South African sugar industry because:

- (1) The anaerobic dams presently used are not properly designed reactors and so most of them perform poorly thereby suggesting that anaerobic treatment is an ineffective, unstable and odoriferous process.
- (2) The potential and advantages of anaerobic treatment for industrial wastes have become apparent only in the past 10 years — the first full-scale anaerobic reactor was introduced to the world sugar industry (Holland) only in 1978.

Modern anaerobic reactors are very different from simple anaerobic dams. They have comparatively sophisticated design and operation which enables them to achieve 80–95% COD

reduction with loads exceeding 10 kg COD m⁻³ d⁻¹. Recommended loads for simple anaerobic dams are considerably lower — on the basis of observations at Umfolozi, Cox and Hemens³ recommended a maximum loading of 0,08 kg COD m⁻³ d⁻¹, and in Australia, Parker⁴ recommends a maximum loading equivalent to 0,048 kg COD m⁻³ d⁻¹ for dams 2,5 m deep.

These low loading capacities are substantiated by present experiences at Mount Edgecombe and Umzimkulu where loadings of approximately 0,3 kg COD m⁻³ d⁻¹ are producing symptoms of severe overloading, i.e. very low treatment efficiency, accumulation of volatile organic acids, high lime requirement for pH control and high smell. At Noodsberg, on the other hand, the loading is approximately 0,08 kg COD m⁻³ d⁻¹ and there is consequently no lime requirement, negligible odour and a COD reduction of 40–50%.

The anaerobic dam at Felixton has successfully accepted 0,7 kg COD m⁻³ d⁻¹ (Lewis and Ravnö⁵). This is probably because sludge in the outgoing effluent is settled and returned to the dam. The importance of this will be emphasised later.

To prevent overloading, simple anaerobic dams have to be so large that some mills cannot conveniently accommodate them. In such cases, anaerobic digesters would probably be good alternatives. The design features which enable these digesters to accept much higher loads include:

- (1) Provision is made for separating the active organisms from the outflowing liquid so that the organisms are retained in the digester and can be built up to high concentrations.
- (2) Provision is made for mixing the active organisms with the incoming effluent. Recently it has been shown that adequate mixing can be achieved by directing the incoming liquid through evenly spaced inlets at the base of the reactor, and by achieving high reaction rates so that the evolved gas provides agitation.
- (3) By-pass facilities are provided so that during start-up and during periods of impending malfunction the load on the reactor can be reduced.
- (4) The surface area: volume ratio is relatively low thus minimising heat-loss and the adverse effects of wind aeration. The beneficial mixing effect of evolved gas is increased as the depth of the reactor increases.

These design features were incorporated into a pilot plant to test the performance of a digester when operated on sugar mill effluent.

Methods and Materials

Two pilot-plant digesters, each consisting of plastic tubes 3 m long and with a capacity of 87ℓ were assembled as shown in Fig. 1.

A 15ℓ inoculum consisting of 5ℓ of sludge from a previous experiment and 10ℓ of sludge from anaerobic dams at Mount Edgecombe was used to start each digester. Effluent from Mount Edgecombe mill was fed to each digester to give a hydraulic retention time (HRT) of 6 days. After 26 days the HRT was reduced to 4 days and after a further 14 days it was reduced to 2 days.

The effluent used to feed the digesters was stored in drums for up to 8 days. During the initial stages of the experiment it

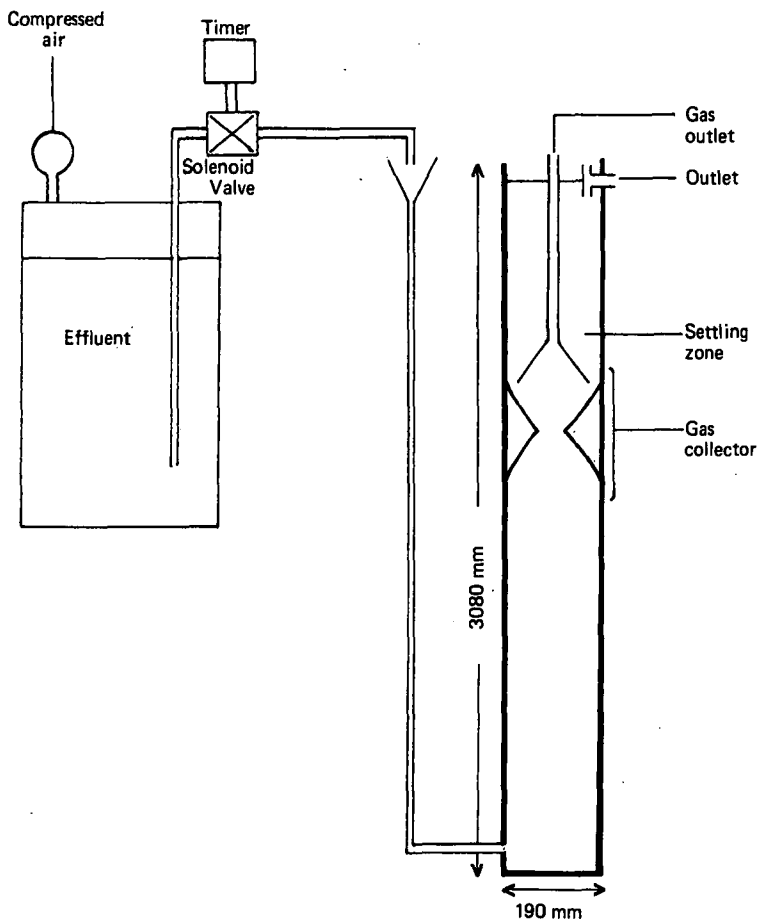


FIGURE 1 Diagram of pilot plant anaerobic digester.

was collected from after the point of lime addition. The pH of this effluent was occasionally above 8 and in such cases it was adjusted to 7 with hydrochloric acid. Ultimately, unlimed effluent without pH adjustment was used.

For nutrient supplementation some treated domestic sewage was added intermittently to the effluent at the mill but no other sources of nitrogen or phosphorus were added. The COD:N:P ratio varied widely from week to week but over one representative period it averaged 100:1,8:0,6.

The effluent was sometimes supplemented with a combination of sucrose and molasses so as to increase its COD and to cause fluctuation in the COD input.

For the determination of volatile organic acids in the effluent the samples were stabilised with 10% formic acid and then injected into a gas chromatograph with a 1 m × 3 mm column of Carbowax B, H₃PO₄ washed; 3% Carbowax 20M. The column temperature was raised from 120°C to 180°C at 8°C/min.

Results and Discussion

The performance of the pilot plant digesters is indicated in Figs. 2 and 3. These results show that a COD abatement of about 80% can be achieved consistently with an HRT which averaged 1, 8 d, and with genuine mill effluent of fluctuating concentration and no pH control.

When effluent from the same source was limed and fed to anaerobic dams with an HRT of approximately 7 days there was very little COD abatement, but plenty of smell, throughout the two crushing seasons. The COD of samples from the outlet of the anaerobic dam was often higher than that of inlet samples. This is probably because catch samples were involved and so batches of high COD effluent entering the dam over short periods (e.g. weekend washings) would usually escape sampling at the inlet but would disperse in the dam and be included in the outlet sample.

Fig. 4 shows the results of organic acid analyses of samples from the inlet to and outlet from the dam. It is clear that the concentration of acids increased considerably as the effluent passed through the dam. In a properly functioning anaerobic system these acids are generated in the first stage of sugar degradation but they do not accumulate because methanogenic bacteria convert them to methane gas. The methanogenic bacteria grow much more slowly than the acid forming bacteria,

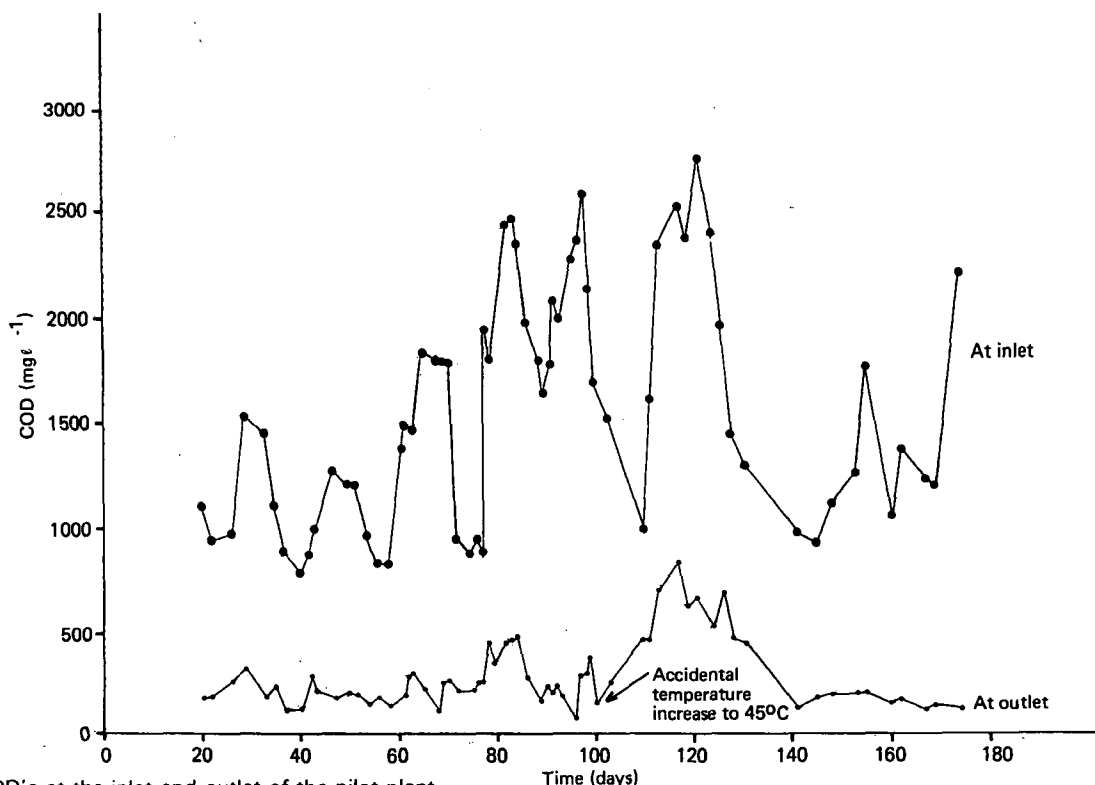


FIGURE 2 COD's at the inlet and outlet of the pilot plant.

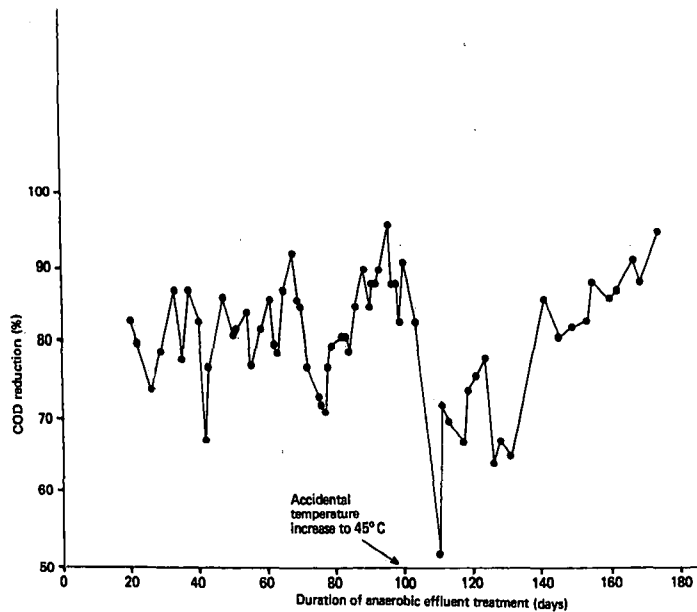


FIGURE 3 Performance of the anaerobic digester.

so if the system is overloaded the acids accumulate. When the concentration of acids exceeds about 300mg l^{-1} they inhibit the methanogens, thus preventing the development of an active system for the consumption of COD. Anaerobic digesters are particularly prone to overloading during start-up and from the foregoing discussion it can be appreciated that they are unlikely to ever start-up if the overloading continues. If they can be started slowly and a population of methanogens capable of handling peak loads can be built up then they are tolerant of fairly rapid fluctuations in loading.

The anaerobic dams at Mount Edgecombe are divided into 3 compartments which are operated in series. This compartmentalisation effectively increases the loading to each compartment because whereas the HRT across the whole system is approximately 7 days, the HRT across the compartments is

approximately 4,2; 1,4 and 1,4 days respectively. Thus the COD loading on the first compartment is about $0,5\text{ kg m}^{-3}\text{ d}^{-1}$ and because this is far too high there is little COD abatement so almost the full load is passed on to the next compartment. This illustrates the need for complete mixing rather than plug flow in anaerobic digesters. Where a number of dams are involved the load is best distributed by feeding in parallel rather than in series.

General Discussion and Conclusions

There is potential and incentive to increase the role of anaerobic digestion of mill effluents in South Africa. The high-performance, gas-trapping anaerobic reactors which are presently finding increasing application in the European beet industry are probably not appropriate to South Africa. The main advantages of these reactors is that they require very little space and do not produce smells so they can be located in built-up areas. They are also small enough to be heated if necessary and the methane produced can be used as a boiler fuel. None of these advantages is particularly important in South Africa because the mills are not in built-up areas, heating is not necessary and bagasse provides adequate boiler fuel.

A design which is intermediate between a simple dam and a sophisticated reactor seems most appropriate to South Africa. The design must provide for:

- (1) Maximum possible mixing (i.e. greatest possible depth with feed dispersed at the bottom, so that rising gas will provide agitation, and no compartmentalisation to interfere with mixing).
- (2) Facilities for controlling the load on the digester.
- (3) Settling facilities for sludge retention.

These facilities are provided for in the so-called "damgester" (Fig. 5) which has recently been constructed at Mount Edgecombe for testing. The damgester is constructed almost entirely from earth and should be much less expensive than an aerobic system for equivalent COD consumption.

In cases where the treated effluent is discharged to a stream its COD must normally be below 75 mg l^{-1} . In such cases a small aerobic plant will be necessary after the damgester because

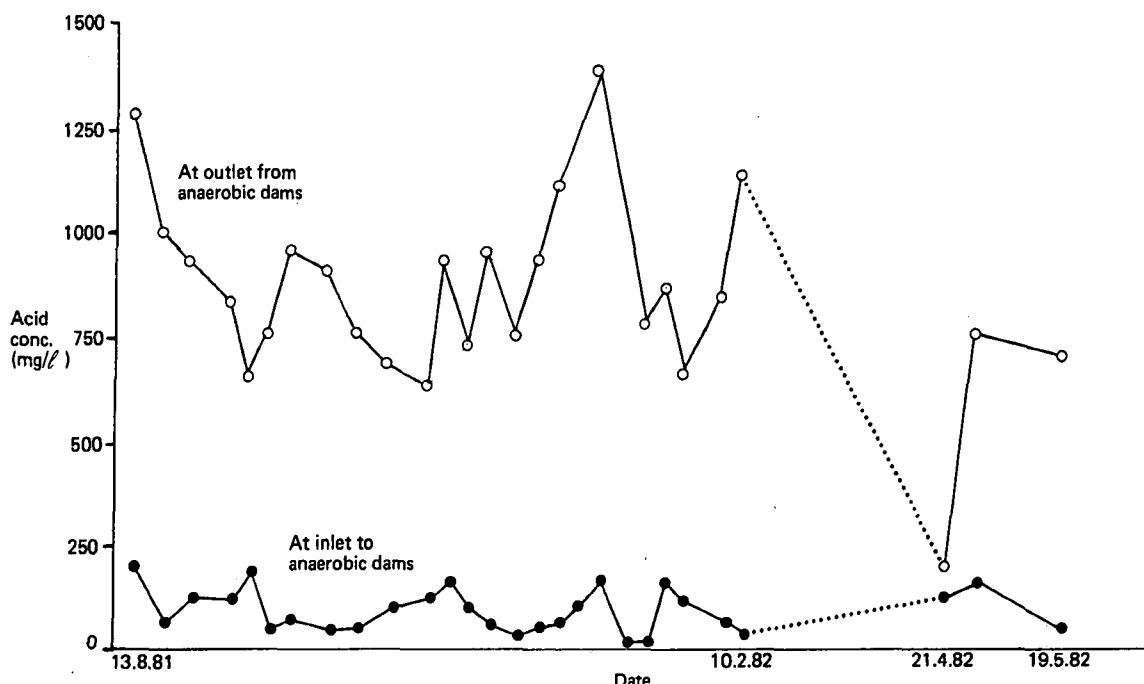


FIGURE 4 Volatile organic acids at Mount Edgecombe anaerobic dams.

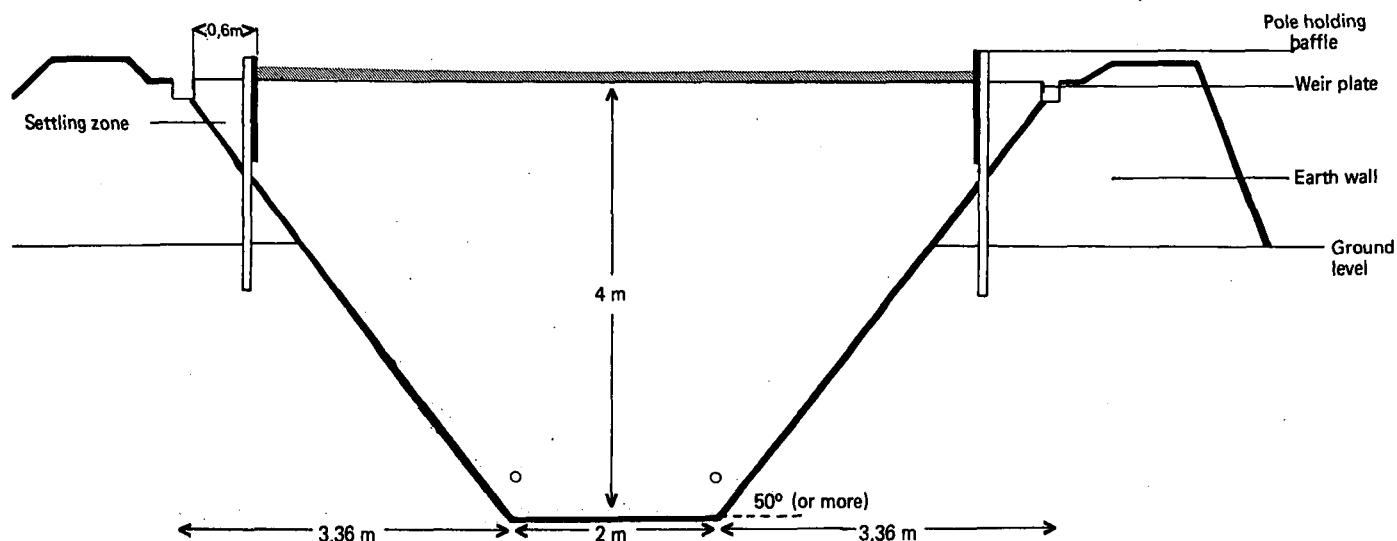


FIGURE 5 Cross-section of pilot-scale damgester.

the outlet from the damgester is likely to have a COD of about $200 \text{ mg } \ell^{-1}$.

During start-up of a damgester and during occasional periods of malfunctioning it is necessary to divert most of the effluent to an alternative system. Such a system must be regarded as a necessary ancillary to a damgester. In most cases it could merely involve by-pass facilities for temporary direct irrigation to cane. A dam capable of holding all effluent produced over about a 5 day period would however be useful. Initially it could serve as a buffer to smooth out flow rates to the damgester and to irrigation. Later, when the damgester accepts the full flow, the holding dam could be used, after the damgester, as a maturation pond. If used in conjunction with floating aerators it might provide a relatively inexpensive aeration facility for reducing the final COD to below $75 \text{ mg } \ell^{-1}$.

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