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Accelerated biogas production without leachate recycle

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Abstract

The economics of biogas production remain marginal, even on 'free' substrates such as wastes. However, new insights into the fundamental processes of solid-state digestion promise a much faster and more predictable process. This holds the future prospect of profitable biogas production from anaerobic composters fed with a range of solid substrates, including food industry wastes and biomass crops.

A novel process model proposes that reaction occurs at a well-defined but mobile interface between raw and depleted wastes, forming the boundary of an independent expanding micro-reactor. Very small seed particles cannot establish such micro-reactors. The present paper explores the implications for seeding practice. Leachate recycle might do no more than compensate for erratic seeding, by transporting nutrients into well-seeded zones. Inoculating the waste with well-distributed seed particles of viable size could be more effective — and a great deal simpler and cheaper.

Keywords: Renewable energy; Model; Micro-reactor; Digestion; Seed particle; Biogas; Methane; Landfill

1. Introduction

Variability and slowness in the rate of solid-state anaerobic digestion may be largely due to inadequate seeding. There is good reason to predict the existence of a minimum viable size for seed particles, which may not commonly arise by chance [1]. A new process model on this basis suggests that each viable particle initiates a discrete micro-reactor, which then expands slowly into the substrate [2]. The initial distribution of seed particles is therefore critical.

The main current applications of solid-state digestion (SSD) are landfills and waste digesters. Conventional models of landfills are generally based on exponential decay principles and are restricted to the deceleration phase of the process. Even so, site data often deviate quite widely from their predictions [3]. The micro-reactor model

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is not yet proven but it gives a good fit with both the acceleration and deceleration phases for bench-scale digesters. It does not quantitatively predict the typical 'tail' of slow biogas production that may continue for decades after the peak output. However, it does suggest both a cause and a cure.

The model also suggests that seeding methods have a strong influence on the rate of digestion. If this is correct, SSD could be much more efficient as a route to renewable energy than it is now. Alternative feedstocks might then become economically viable. Consequently, the purpose of this paper is to examine the potential consequences of the model. Quantitative results are not yet available but some general trends and consequences can be predicted.

The focus here is on landfill, since that is the main current use of SSD. However, such feedstock as green biomass crops, agricultural surpluses and food industry wastes could be used. As well as biogas, all would yield a compost-like by-product of better quality than that derived from a typical municipal waste feedstock.

2. Model results

A minimum viable seed size implies that seeding landfills with digested sewage sludge might be of little use, as the floc size is probably too small. However, absorbing the sludge into suitable material of low degradability and adequate size might transform its efficacy. Paper waste is likely to serve well. A good alternative would be previously degraded waste, which has the advantage of a well-adapted, indigenous micro-flora. It is commonly used in waste digesters but never in landfills.

It is possible, however, that digesters are commonly over-seeded. The use of seed particles of optimum size could provide the same effect in a far smaller mass. The core of a large particle contributes nothing to the process, as all the volatile fatty acids diffusing into it are consumed in the outer layers. Typical seeding rates are of the order of 50% by volume, so there might be substantial potential for raising the volumetric efficiency of solid-waste digesters. A much smaller volume of seed material might give equally good results if the seed particles were all of optimal size.

Seed spacing may be as important as size. If the rate of the primary reaction is determined by the rate of expansion of a large number of micro-reactors, increasing the number of viable seed particles will increase the overall rate of reaction. Moreover, the contribution of the 'tail' to the total production of biogas will be reduced by uniform spacing of the seed, which ensures that all of the micro-reactors have much the same 'lifespan'. Some 'tail' is inevitable but better seeding might greatly reduce it. This could greatly reduce the on-going costs of site monitoring.

In landfills, such measures could both accelerate the process and improve its predictability. Agricultural seed-sowing techniques could perhaps be adapted to suit or, with less precision, the seed particles might be sprinkled on to the waste as it is placed. The choice of spacing would furnish a valuable element of process control, enabling a match between biogas production and the installed capacity of electricity generators or other gas-utilizing plant.

This leads to the possibility that the progress of digestion might be pre-determined by selecting different seeding patterns. The above discussion assumes a dispersed, particulate seed, which would give rise to a peaked curve for biogas production. However, a sandwich construction could be used instead, alternating thick layers of waste with thinner layers of seed.

For this planar geometry, the model predicts a constant-rate process. The area of the reaction front does not increase as it advances, so the resulting production profile approximates to a plateau. This would be bounded by sharp transitions: (1) there would be an indeterminate steep rise (from zero to high gas output) at the end of the lag phase; (2) there would be an indeterminate steep fall (from high to low gas output) at the end of the productive phase.

This operational mode would be much easier to match with generator capacity. The seed could be applied as a closely spaced layer of particles or as impregnated slabs or carpets of a suitable carrier material. A prolonged period of roughly constant gas production would be far more conducive to its efficient and economic utilization than a peaked output.

A planar seeding pattern would also enable the site operator to select the lifespan of the site as an active bioreactor, zone by zone. The reaction front appears to advance at constant speed, so the number of seed layers in a given depth of waste will determine the overall reaction rate. This too would facilitate gas utilization. As conventional operation generally entails the placement of waste in thin layers, the adaptations needed to deploy this seeding method might be quite minor.

3. Discussion

The micro-reactor model is not likely to replace the established models of biogas output from existing landfill sites, although it may shed useful light on their deficiencies. Although it matches both site and laboratory data well for the acceleration phase. It predicts a sharp peak and a *convex* curve for the deceleration phase, almost a mirror image of the apparent exponential decay observed on site. This seeming inconsistency arises because it predicts the performance of an individual micro-reactor, whereas site data represent the aggregate performance of millions of asynchronous micro-reactors of diverse size.

There are many potential sources of such differences between micro-reactors, most of them capable of wide variation: seed particles usually vary in size and spacing; they might also vary in viability; inhibition might vary locally. Thus the micro-reactor model is unlikely to prove directly useful in predicting the performance of existing landfills. However, the operational modifications it suggests could lead to much faster and less variable landfill processes.

Its implications for the 'flushing bioreactor' mode of operation are not yet clear. Where the proposed multi-layered reaction zones become established *within* a waste particle, the flow of recycled leachate around it might have little effect. However, waste is not homogeneous in reality and the contact between seed and waste particles is rarely perfect. The stimulatory role of irrigation might thus be largely through improving the transport of substrates between particles. Irrigation would therefore be redundant if the seed particles were initially well distributed.

A recent experimental study appears to confirm that viable seed particles are too large for distribution by recycled leachate [4]. This showed that methanogenesis occurred in seed-rich material but not in waste-rich material. It follows that either the leachate velocity was too low to transport any methanogens or, more probably, that the single cells and small particles transported were too small to survive in the more acidic conditions of the waste-rich zones.

This observation is as relevant to digester design as it is to landfill construction. The most costly digesters employ mixing and/or leachate recycle to achieve short residence times. If better seeding alone could greatly accelerate digestion, it might be more economic to use a much simpler but rather larger digester. There is no obvious reason why digestion could not be carried out in a polythene bag, similar to those used for ensiling baled crops — providing the feedstock was well seeded beforehand.

4. Conclusions

The micro-reactor model could clearly have major implications for landfill operation. It presents possibilities of much faster stabilization at modest initial cost, transforming landfill into a reliable, controllable, more sustainable waste disposal process. Of course, the idealized patterns of seed and waste placement described above could never be closely approached on landfill sites. However, even a rough approximation to the ideal might confer great improvements in performance.

Similar techniques might also be applicable to engineered digesters, and so could also find uses in those countries where legislation limits the use of landfills. Stabilization in digesters is very much faster than in landfills, so the scope for process acceleration is limited. However, optimization of seed particle size might allow a substantial reduction in the seeding rates. Moreover, simpler digesters might give acceptable performance at much lower capital cost. This might make it economically viable to generate biogas from a variety of renewable resources.

Leachate recycle might confer no benefit on a well-seeded landfill or digester. Its only role may be to compensate for erratic seeding by transporting substrate into clusters of seed particles.

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