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Food Waste Digestate: As an Organic Component of Organo-Zeolitic Bio-Fertilizer

Peter J Leggo^{1*} and Bruce Drew²¹Department of Earth Sciences, University of Cambridge, UK²Agri-Tech Organic Solutions Ltd., Great Dunmow, Essex, UK

*Corresponding author: Peter J Leggo, Department of Earth Sciences, University of Cambridge, UK

Abstract

This paper concerns the use of food waste as the organic component of a highly successful biological plant fertilizer [1]. The original plant fertilizer consists of a mixture of chicken manure and crushed rock having an abundance of clinoptilolite zeolite. This paper concerns the use of a machine to digested food waste that can replace the chicken manure. Converted to a liquid digestate, self - maintained, microbially, at a minimum temperature of 70 °C . After one hour the mixture is self - pasteurised, ensuring, the liquid safe to handle. A plant fertilizer results which is friable and easy to mix with soil. As the mixing ratio is five parts soil to one part fertilizer, its use is commercially viable. Use of food waste in this way, is most desirable as otherwise it would be disposed without any benefit.

Introduction

It has long been known that the continued use of traditional NPK agricultural fertilisers has denuded soils of carbon. Synthetic chemical fertilizers lead to a loss of soil carbon that causes a change in soil structure and an increase in porosity [2]. The result of these changes makes the soil very friable and susceptible to loss in high winds. This effect was seen in the USA and elsewhere, decades ago when large dust storms occurred in areas of aerial crop spraying. This effect has now been brought to public attention in the UK as it is now understood that large scale use of agricultural fertilisers reduces the soil carbon content to such an extent that soils become prone to loss in high winds. It is now time to revise the method of plant fertilisation using scientific methods that have become available [1].

Biological plant fertilisers involving an organic component and Clinoptilolite, a natural zeolite mineral, are able to take up ammonia in the ionic form and enhance plant growth to a high degree. Unlike traditional chemical fertilisers, ammonium ions are released, by ion exchange with soil potassium, slowly at a rate synchronous with plant growth. As a result, nutrients are not lost from the soil during periods of heavy rain, and growth rate and plant quality are sustained to a high degree [3].

Past work [4] used poultry manure as the organic

component. Now a further development has shown that food waste can be used as the organic component. A novel aerobic digestion system has been built that converts food waste to a liquid digestate which may be stored as such or converted into granular presentations. In a period of hours, microbiological activity raises the temperature to 70°C and above, serving to pasteurise the digestate slurry which may subsequently be mixed with crushed zeolitic rock (geological name: zeolitic tuff). The mixture is diluted with five volumes of soil, resulting in an amendment of which zeolitic tuff comprises as little as 6%. Further work has shown that the fertiliser can be pelletised allowing it to be added to soil-based substrates easily and accurately.

Other materials besides crushed zeolitic tuff have been used successfully as the zeolitic component of the organo-zeolitic bio-fertilizer. It was found that activated charcoal played an alternative role behaving similarly, within experimental errors, to that of zeolitic tuff [5]. It has also been found that diatomite can be easily converted to a zeolite that could also be used as an alternative [6]. However, zeolitic minerals being aluminosilicates are far stronger than activated charcoal and will withstand severe climatic conditions and soil attrition. As crushed zeolitic rock is cheaper than activated charcoal or chemically converted diatomite, it is the preferred material. In addition, suitable zeolitic rocks are found worldwide at a cost that is viable in

this application.

Zeolite has an unusual crystallography which allows ion-exchange when placed in an aqueous or gaseous environment [7]. The ion-exchange property is central to the function of the organo-zeolitic system which is thoroughly treated in the above work. Unlike other aluminosilicates, zeolites have open pores that pass through the mineral structure allowing the passage of fluids (open framework silicates). As with all aluminosilicates, aluminium partially exchanges silicon leading to an imbalance in electronic charge. This condition is overcome by accepting cations (positive charged particles) from the surrounding environment, in this case water. These cations are loosely bound and can be exchanged by other cations that have higher selectivity. Detailed experimental work has shown that ammonium ions are highly selected by clinoptilolite, the common zeolite mineral used in our work [8]. Caesium, rubidium and potassium are more selective but potassium, as the only one common in soils, takes the role of exchanging the loosely bound ammonium ions held by the zeolite. The organo-zeolitic fertilizer relies on the organic component producing ammonium ions which, on decomposition, are captured by the zeolite. In earlier work, poultry manure has been used for this purpose but in the present study, digested food waste has been found to be satisfactory. In the past, ammonium ions, exchanged by soil potassium, were thought to be oxidized by nitrifying bacteria but it has now been found from our genetic studies on water from the amended soil that the oxidation is caused by Crenarchaeota, a prokaryote from the Kingdom of Archaea, which is now known to be the predominant ammonium oxidiser in soils [9].

Over the past 25 years, research work at the University of Cambridge Botanic Garden has shown that plant growth enhancement is sustainable if an organo-zeolitic bio-fertiliser is used to amend the soil. Experimentation has shown that ammonium ions are slowly released on ion-exchange with soil potassium [1]. The rate of release after fifty to sixty days is synchronous with plant growth [3]. This property allows the plant to consume nitrate without accumulating an excess, thus little is left to diffuse into the soil and reach the ground water table.

To obtain such growth enhancement, the presence of the organic component is essential as phosphorus and potassium are supplied from the digested material. Thus, the three essential plant nutrients, N, P, K are present in abundant amounts. During the oxidation of ammonium ions by the Archaeal micro-organism Crenarchaeota, enzyme reactions produce hydrogen ions in the form of hydronium

(H³⁺) which dissociate metal ions in trace amounts providing a range of nutrients that are beneficial and essential for healthy plant growth.

A series of pot experiments of 85-day duration from

Figure 5: Plant growth comparison in various substrates.

Table 1: Plant Dry Weights.

Set	Number	Weight (g)	Average Weight (g)	± Standard Deviation (g)
1	1/1	1.30	1.29	0.64
	1/2	0.50		
	1/3	2.07		
2	2/1	21.37	32.34	10.97
	2/2	43.30		
	2/3			
3	3/1	4.42	6.40	1.83
	3/2	5.96		
	3/3	8.83		
4	4/1	4.82	5.27	1.60
	4/2	3.68		
	4/3	7.31		
5	5/1	6.99	8.67	1.93
	5/2	11.38		
	5/3	7.64		
6	6/1	1.66	4.97	2.37
	6/2	7.09		
	6/3	6.16		

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germination were carried out, after which the plants were harvested and dried at 65°C for 48 hours. The dry weights are shown in Table 1. It can be seen in (Figure 5) and quantitatively in Table 1 that soil from the Botanic Garden, University of Cambridge amended with a poultry manure/zeolitic tuff mixture [1] produces a growth enhancement greater than that of the digestate/zeolitic tuff amendment but due to differences in manufacturing processes, this mixture has not been pasteurised. When plant waste is used as the organic component, a lower performance is inevitably achieved, due to a lower concentration of ammonium ions produced during digestion. As food waste contains a high abundance of vegetable material, it is not surprising that a lower performance than that obtained using poultry manure is achieved. However, it is demonstrated in (Figure 5) and in (Table 1) that when sufficient zeolitic tuff is added to food waste digestate, see Set 5, a noticeable increase in growth occurs.

In the liquid phase, aerobic digestion has been practised for over a hundred years in sewage purification using activated sludge, promoted by bubbling compressed air through screened sewage. In the solid phase, aerobic digestion has been practiced for even longer in composting vegetable material. Aeration is crucial to the rate of composting and can be affected by mechanical means or by means of in-vessel rotating drums. The above examples exemplify different traditional ways of converting waste products into useful materials; in the case of the above examples, clean water and digested sewage sludge in the first case, and compost for increasing soil productivity in the second case.

An alternative use for vegetable waste has been to incorporate it into animal feed, particularly feed for chickens and pigs. Here again, the vegetable waste was put to good use. Animal waste has traditionally been collected in what were called pig bins and also incorporated into animal feed, often as pigswill. This practice changed in 2001 when a serious outbreak of foot and mouth disease occurred in the United Kingdom. Concerns that the outbreak had started on a farm where pigs had been illegally fed unprocessed restaurant waste led to a nationwide ban in the UK on using unpasteurized waste from homes and catering outlets as animal feed. The UK ban was subsequently extended throughout the EU in 2003. The most efficient carrier of specific pathogens is, by far, the live pig. Pathogens of particular concern in the human food chain are *Escherichia coli*, *Streptococcus pneumoniae*, *Bordetella bronchiseptica*, *Clostridium piliforme* (2), and *Cryptosporidium* sp.

Subsequently, EU legislation was introduced relating to

the digestion of animal and vegetable waste streams under conditions which satisfy the standard set out in 142/2011EC

Figure 1: Overhead view of the food waste digesting machine.

Figure 2: End view of the food waste digesting machine.

Annex V, Chapter III, Section 1. Regulation EC 142/2011 requires the treatment of particles no greater than 12mm to at least 70°C for 1 hour in a closed system, or alternatively to the standards set out in Annex V Chapter III Section 2, permitting alternative methods based on the demonstration of sufficient pathogen destruction. “Sufficient pathogen destruction” is often referred to as pasteurisation and the term “pasteurisation” will be used in this paper. This legislation has encouraged the development of processes

which meet the EU standard for pasteurising animal and vegetable waste materials. Microbial analysis by the private company, NRM Laboratories, has shown that *Salmonella* spp were not found in the digestate liquid samples and *E coli* occurred below 10 cfu (colony forming units). *Clostridium perfringens* per 100 ml digestate liquid recorded between < 1 to 60 cfu which showed that pasteurisation had indeed taken place in the digester.

Pasteurisation processes inevitably add cost to the digestion of animal and vegetable waste, which in turn impacts upon the cost of the pasteurised digestate. Whilst it is obligatory to meet the EU pasteurisation standard, there is inevitable pressure to meet it as economically as possible, which means firstly, using the least possible amount of external energy for heating during the pasteurisation process and secondly, attaining the highest possible rate of pasteurisation in order to operate the process at the greatest possible throughput. In parallel with the EU legislation for producing a digestate which is pathogen-free, agreements at successive world Governmental conferences have required a progressive reduction in the use of carbon-based fuels to generate energy, and a progressive overall reduction in the use of energy.

Method and Materials

The plant growth program was conducted in the Sainsbury green- house laboratory at the Botanic Garden, University of Cambridge. Botanic Garden, soil was used as the plant substrate together with controls as made in earlier works [5]. A patent application WO2019/138205A1 has been filed describing a semi-continuous method of producing a plant fertilizer from liquid organic waste material in which the liquid organic waste material is pasteurised by thermophilic aerobic digestion (the Aerobitherm® process) in a single digester vessel.

Results and Discussion

Introducing a predetermined amount of food waste to the digester (Figures 1 & 2) a liquid phase comprises at least 70% water and can be produced and pumped into a storage tank; wherein the temperature of the food waste digestate is at or above 70 °C. Closing a circuit in the digester for a period of time that maintains the digestate at 70°C or above for at least one hour the food waste is pasteurized and digested to a pre-determined extent, without the need for external heat input.

After a period of time of at least one hour withdrawing a first amount of pasteurized and digested food waste material from the digester; introducing a replacement second amount of organic waste material to the digester

vessel wherein the first amount and the second amount are substantially the same. Preferably the first and second amounts are the same volume percent of the digester vessel such that the efficiency of the thermophilic aerobic digestion is not inhibited. It will be appreciated that if too large an amount of food waste material is introduced, the temperature of the waste organic material will drop too far below 70°C and the digestion efficiency of the thermophilic bacteria will thereby be inhibited.

Desirably the temperature of the digester is 67 °C or higher immediately after addition of the second amount of replacement organic waste material. Keeping the temperature of the single vessel digester at 67°C or higher immediately after the second amount is added maintains the temperature of the food waste material in the digester in the comfort zone of thermophilic bacteria for efficient digestion of the food waste. Desirably from 1 to 5% of the volume of the digester vessel is withdrawn and replaced. In a preferred embodiment the first amount is about 3% of the volume of the digester.

It will be appreciated that the process of the present invention may thus be described as semi-continuous inasmuch as small quantities of pasteurized material are removed from the digester “continuously” albeit at discrete intervals at least one hour apart. The method is semi-continuous in that the first amount of pasteurized and digested organic waste material is removed from the single digester vessel continuously after the period of time.

Preferably the method further comprises combining the organic waste material with a microporous adsorbent (natural zeolitic tuff). The microporous adsorbent will be described in more detail below. It will be appreciated that pasteurization and digestion are separate processes. For the purposes of clarity, the use of the term pasteurization within this application is taken to mean compliance with EU Regulation EC 142/2011. The term “proper digestion” is taken to mean that bacteria have consumed at least 50% of the organic matter in the waste, converting it to carbon dioxide and water. Pasteurization and proper digestion of the food waste are taking place independently of each other so that whilst the material within the digester vessel may have been pasteurized, it may not have been properly digested, and vice versa.

As an illustration of the way in which the present invention can be practiced under typical conditions within the digester vessel, let it be assumed that:

- I. With the organic waste feedstock being provided,

Figure 3: Schematic illustration showing the throughput of the Machine

Figure 4: Schematic the steps in the working of the machine.

digestion of the organic waste would be complete in 3 days, and

II. Pasteurization is complete within an hour whilst the temperature is maintained no less than 70°C, and

III. We remove 3% of the digester vessel volume every hour, and

IV. The contents of the digester vessel re-attain a temperature of 70°C within an hour and a quarter of fresh feed being admitted to the digester vessel, so that pasteurization is complete within two and a quarter hour of fresh feed being admitted,

then, $3 \times 24 \div 2.25 = 32\%$ of the volume of the digester vessel would have been withdrawn as pasteurized product during each period of 24 hours, and the average residence time in the digester vessel of the withdrawn product would have been 67 hours, allowing a concurrence of “proper digestion” and “pasteurization” to be provided.

The process will now be described in detail with reference to the accompanying figures in which:

(Figure 3). is a schematic illustration of an arrangement for carrying out the method of the invention, and

(Figure 4). is a scheme of the steps of the invention. The present invention is able to confirm and record by appropriate instrumentation that material withdrawn from the digester vessel complies with the EU pasteurisation standard, namely that it has been treated at a temperature of at least 70°C for at least one hour. Many analyses have demonstrated that the digestate provided by the present invention is free of pathogens, even after six months of storage at ambient temperatures.

It has been found that the present invention enhances the rate of pasteurization and the overall productivity of the digestion process by controlling the temperature variation in the digester vessel to 71.5°C +/- 1.5°C and thereby providing optimal conditions for the thermophilic micro-organisms to digest the organic waste material. By controlling the temperature of the material in the digester vessel in this way and by regular replacement of a second amount of pasteurized material with a first amount of unpasteurized feed, the present invention has shown that the thermophilic micro-organisms are able to thrive and hence substantially eliminate the need for external heating of the digester vessel, thereby reducing the cost of digestion.

The organic food waste material in the digester vessel can be passed through a macerator to reduce a size of

particles of organic waste material in the liquid phase. The organic waste material is supplied from a hopper and passes through a macerator before entering the single vessel digester. In some embodiments, the macerator is arranged in a closed circuit with the digester. The organic waste material in the digester can be passed through the macerator in the closed circuit with the digester. The macerator and the pipes in the closed circuit are lagged and insulated in order to restrict heat loss from the organic waste material. Where the organic waste material is loaded into the input hopper in polymeric bags certified to comply with European norm EN13432 which requires at least 90% to be biodegradable within six months under conditions defined by the norm, it has surprisingly been found that such polymeric bags, after passage through the pump macerator along with their contents, can be completely digested by the present invention within a residence time of 48 hours.

A further aspect of the present invention, a microporous adsorbent is added to the digestate either to the digester vessel during pasteurization, or to the pasteurized material after it has been withdrawn from the digester vessel. As examples, the microporous adsorbent may be a natural zeolite mineral such as clinoptilolite, mordenite, phillipsite, chabazite, or diatomite or mixtures thereof and/or vegetable such as biochar wherein the particle size of the microporous material is a powder of particle size up to 700 microns (0.7mm), or a granular material of particle size between 400 and 2000 microns (0.4-2.0mm).

When added to the digester vessel during pasteurization, the microporous material (Zeolitic Tuff) is preferably a powder of particle size up to 400 microns (0.4mm) in order that the majority of the microporous material may be held in suspension in the agitated digester vessel. The appropriate dosage of microporous material to be added during pasteurization has been determined by experiment to lie between one half part and one and a half parts by weight of the solid content of the material being digested.

When added to the pasteurized material after it has been withdrawn from the digester vessel, the microporous material should preferably be a granular material of particle size between 400 and 2000 microns (0.4-2.0mm). The relative quantities of microporous material and aerobically digested organic material will depend upon the type of organic material being aerobically digested, its solid content and the ultimate use of the soil remediant. Excellent agronomic results have been obtained where the dosage of microporous material added post-pasteurization lies between 0.5 and 1.5 parts by weight of the solid content of the digestate slurry.

The digestate can be converted into a pelleted or granular presentation. In this aspect, it is important to retain the beneficial components contained within the liquid phase and hence the liquid digestate cannot be simply filtered and then pressed into a pellet presentation due to the loss of beneficial components present within the liquid phase. In this regard, the present invention differs significantly from the aerobic digestion utilised in the purification of screened sewage where the objective is to produce as clean a liquid effluent as possible. In the present invention, the objective is to produce a soil remediant of greatest efficacy from a feedstock of waste organic material wherein the composition can comprise widely variable materials. It will be noted that the liquid effluent from the present invention is rich in beneficial components of value in soil amendment which are preferably retained in any subsequent conversion of the liquid digestate into a granular product.

Results of the Plant Growth Experiments

The plant growth experiments, after many trials showed that the digestate was adequate in functioning as an organic component of a bio-fertilizer, (Leggo and Lédésert, 2009 op cit) Having the additional function of producing a material that was safe to handle which is a vital part of the process. Plant Dry Weights (g) are given in (Table 1).

Conclusion

An excellent process and associated equipment have been developed providing simultaneous digestion and pasteurization of food waste to produce a digestate that can be used as the organic component of a biological plant fertilizer. An integrated equipment system has been designed and built to digest waste food to produce a liquid product. On entering the digester storage tank microbial activity elevates the temperature to 70°C and above, thus pasteurizing the product in a matter of hours in compliance with EU regulations. Pasteurisation was found to have been maintained even after the product had been stored at ambient temperature for six months.

When mixed with crushed zeolite tuff, an organo-zeolitic bio-fertilizer is obtained that has been found to enhance plant growth. The bio-fertiliser is mixed with soil to make a plant substrate which finds greatest use for potted plants or in situations where the soil substrate is mixed on site e.g. by nurseries.

In broad acre agriculture, the digestate can be used economically, applied as a slurry, either alone or after an application of zeolitic tuff.

Use of food waste in this way at an attractive capital

investment is more environmentally friendly than burial at land sites, and more sustainable than the continued use of synthetic fertilizers. When mixed with crushed zeolitic tuff to produce the bio-fertilizer, the tuff absorbs water and the material becomes dry, friable and odourless and so easy to mix into a soil substrate.

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*Corresponding author: Mbah Relean-Jeans, Email: releanjeans@gmail.com

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