An Investigation into the Bioprocesses of DiCOM®: A Technology Combining Composting and Thermophilic Anaerobic Digestion for the Treatment of Municipal Solid Waste

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It is difficult to understand that ...
High value fossil fuel and nuclear energy is invested to destroy the renewable solar energy which is fixed in the chemical compounds in biogenic waste.
(Edelmann *et al.,* 2000)

God gave men and women a privileged place among all creatures and commanded them to exercise stewardship over the earth (Genesis 1:26-28). Stewardship implies caretaking, not abusing. We are to intelligently manage the resources God has given us, using all diligent care to preserve and protect them.

To My Darling Wife, Mandy … I love you!

I declare that this thesis is my own account of my research and contains, as its main content, work that has not previously been submitted for a degree at any university.

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The aim of this study was to investigate a novel municipal solid waste (MSW) treatment system called DiCOM®. This process diverts organic waste from landfill and consequently abates the adverse environmental impacts associated with the practice. The DiCOM® process exposes the mechanically sorted organic fraction of municipal solid waste (OFMSW) to sequential aerobic, thermophilic anaerobic and aerobic conditions in a sealed vessel during a twenty one day batch treatment cycle. The outputs of the technology are renewable energy, in the form of biogas, and compost.

The features that differentiate DiCOM® from other waste treatment systems include:

- Treatment is performed within a sequencing batch reactor.
- During the aerobic treatment the internal pressure is raised to enable hyperbaric composting in an attempt to maximise oxygen availability and consumption.
- Some of the bio-methanation potential of the OFMSW is sacrificed to enable aerobic microbial metabolism to raise the temperature of the OFMSW to that required for thermophilic anaerobic digestion (AD), minimising the need for external energy input.
- The residue of the thermophilic AD phase is composted within the vessel, minimising the plant footprint and the generation of off-site odours.
- The anaerobic liquid is reused thus minimising the production of wastewater.
- The small plant footprint can allow for processing of MSW close to its source in an attempt to minimise transport costs.

The DiCOM® process vessel is loaded with organics over a five day period during which the material is exposed to aerobic conditions. Aeration consists of cyclically pressurising the vessel with air to 25kPa, holding the pressure to maximise oxygen

consumption, followed by vessel depressurisation. During aeration microbial metabolism raises the temperature of the organics to that necessary for the thermophilic AD phase.

The 7 day thermophilic AD is initiated by flooding the reactor with anaerobic liquor from a previous batch thus inoculating the system with a viable and active methanogenic culture. The biogas produced can be captured and used to meet the energy requirements of the process. As the anaerobic liquor is reused, the production of a wastewater stream can be minimised.

Aerobic maturation of the compost occurs after the anaerobic liquor has been drained from the vessel and the organics mechanically dewatered. After 5 days of aerobic treatment the vessel is unloaded (2 days), completing the treatment cycle, with the vessel ready to receive the next charge of organics.

The study of the transition from aerobic to anaerobic conditions was of interest, as methanogens are known to be oxygen sensitive. A laboratory–scale DiCOM® reactor demonstrated a seamless transition from aerobic to anaerobic metabolism with methane being produced within 4 hours of the establishment of anaerobic conditions. The reuse of anaerobic liquor improved bio–methanation as noted by, a more rapid onset of sustained methane production, an increase in mean biogas production rate (from 18.2 to 28.7 L/kg of TVS/day) and an increase in total solid degradation (from 41 to 45% of TVS) during the anaerobic phase. An electron balance showed that the direct liquor transfer provided a 50% increase in electron flow during the digestion phase and provides a significant energetic advantage to the process. The compost was found to be

more stable (self–heating test) than the control, which is consistent with greater destruction of organics.

Inevitably the liquor reuse led to ammonia accumulation. While the higher levels of ammonia were shown to inhibit methanogenesis, the process of ammonia release had the benefit of providing alkalinity and hence decreased the risk of acidification. Modelling of ammonia and propionate accumulation suggested that the methanogens in the DiCOM® process were, to some degree, always inhibited, by either free–ammonia or free propionic acid, and that a “pH window” could be defined within which this inhibition was minimised.

A study into the presence and survival of methanogens indicated that endogenous thermophilic acetoclastic and hydrogenotrophic methanogens in OFMSW were found to survive the 5 day pressurised aeration phase of the process and resumed methanogenesis upon initiation of anaerobic conditions. Characterisation of the laboratory–scale anaerobic liquor identified the key methanogen present to be *Methanoculleus thermophilus*, a hydrogenotrophic methanogen. Maintenance of the anaerobic liquor is critical to efficient DiCOM® processing as the bulk of the methane produced (79%) was via hydrogenotrophic methanogenesis. Toward the end of digestion however, acetoclastic methanogenesis was found to be the dominant pathway for methane production. The dominant acetoclastic methanogen, *Methanosarcina thermophila*, was attached to the solid organics. Hence, the use of stabilised digested solid, as an inoculum, improved AD of OFMSW in DiCOM® trials resulting in a decrease in volatile fatty acid accumulation (44%) and the time required for solid stabilisation (3.5 days).

Laboratory trends could be observed at pilot–scale however, the performance of an optimised laboratory–scale DiCOM® reactor was not able to be reproduced at pilot–scale, as AD was incomplete within the DiCOM® timeframe. The high temperature predicted, from modelling of the initial aeration phase, was confirmed at pilot–scale (85°C) and may hold the key to understanding the observed variation in the micro–flora between laboratory and pilot anaerobic liquor. Solids degradation during the initial aerobic phase, measured as electron flow, was found to be significantly less (70%) than optimised laboratory trials, which resulted in a greater proportion of easily degradable organics introduced into the AD phase. Pilot–scale DiCOM® trials suggested that for sustainable operation, under test conditions, either a longer AD phase and/or an improved inoculum transfer may be necessary.

This study has contributed to the optimisation of the DiCOM® process by providing critical information to enable rapid waste processing and energy self sufficiency.

Contents

$\Delta G^{\circ\prime}$	Change in Standard Gibbs Free Energy (Adjusted to pH 7.0)
AD	Anaerobic Digestion
ATP	Adenosine Triphosphate
CSTR	Continuously Stirred Tank Reactor
COD	Chemical Oxygen Demand
DI H_2O	Deionised Water
DNA	Deoxyribonucleic acid
GI	Germination Index
HRT	Hydraulic Retention Time
K_I	Inhibition Constant
k_s	Half Saturation Constant
LCFA	Long Chain Fatty Acid
mg/L	milli Grams per Litre
mM	milli Moles per Litre
MPN	Most Probable Number
MPR	Methane Production Rate
M_s	Endogenous Decay Coefficient
MSW	Municipal Solid Waste
mV	milli Volt
μ_{max}	Maximum Specific Growth Rate
NH_3 –N	Ammonia Nitrogen
NAD^+	Nicotinamide Adenine Dinucleotide
NADH	Reduced NAD^+
OFMSW	Organic Fraction of Municipal Solid Waste
OHPA	Obligate Hydrogen Producing Acetogen
OUR	Oxygen Uptake Rate
pKa	Acid Dissociation Constant

PAH	Polycyclic Aromatic Hydrocarbon
pressate	the liquid mechanically squeezed from the stabilised solid at the conclusion of the anaerobic phase of the DiCOM® process
recyclate	the anaerobic liquor which is recycled through the previous, mature reactor
RNA	Ribonucleic acid
SC	Spontaneous Combustion
SRB	Sulfate Reducing Bacteria
SRT	Solids Retention Time
TAN	Total Ammonia Nitrogen
TOC	Total Organic Carbon
TS	Total Solids
TVS	Total Volatile Solids
UASB	Up–flow Anaerobic Sludge Blanket
VFA	Volatile Fatty Acids
Y	Biomass Yield Coefficient
VS	Volatile Solids