FACTORS INFLUENCING THE RATE AND STABILITY OF THE ANAEROBIC DIGESTION PROCESS

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ABSTRACT

Three factors affecting the rate and stability of the methane fermentation of a readily-hydrolysable feedstock were investigated. The aim of this work was to develop improved processes and control strategies to facilitate economic treatment of industrial wastes by anaerobic digestion.

A comparison was made between the performance of a continuously-fed digester and semi-continuous digesters slug fed every second day. A semi-synthetic medium with glucose as the major carbon and energy source was used and seed material was transferred between the digesters, which were operated under similar loading conditions. The continuous digester repeatedly failed even when operated at dilution and loading rates much lower than the maximum values commonly reported. In contrast, the semi-continuous units provided satisfactory performance and could be easily and rapidly recovered from retarded operation. Failure of the continuous digesters was characterised by a steady fall in volatile suspended solids concentration followed by a rapid accumulation of acetate, and was attributed to a deficiency in the medium of one or more essential nutrients. These were thought to be provided in the semi-continuous digester by lysis of acidogenic bacteria or luxury uptake from the medium.

Degradation of acetic and propionic acids was investigated in batch culture. Increasing the concentration of either acid from low levels decreased the rate of utilisation of the acid, but the proposed inhibitory role of un-ionised acids was not conclusively supported. Increasing the initial acetate concentration above 1000 to 1500 $mg.l^{-1}$ significantly reduced the rate of degradation of propionate added at 500 $mg.l^{-1}$. When acetate was added at 2000 $mg.l^{-1}$ the rate of propionate utilisation was approximately half of that when acetate was present at 500 $mg.l^{-1}$ or lower.

In batch culture experiments, addition of up to 3.2 mM cysteine-hydrochloride or sodium sulphide, or 4.4. mM sodium thioglycollate did not inhibit total gas production from samples drawn from the continuous digester. However the rate of methane production in effluent samples from a semi-continuous digester was inhibited by 25 % to 30 % by addition of 3.2 mM cysteine or sulphide. Inhibition was attributed to the sulphide ion. Sodium thioglycollate did not inhibit methane production from acetate but propionate degradation was markedly reduced, with increasing inhibition noted with increasing incubation time.

The work adds to a considerable body of investigation into the factors influencing anaerobic digestion and the unresolved problem of process stability in long-term operation of conventional stirred tank digesters has again been highlighted. Indicators and possible causes of process failure have been suggested and further development of these should assist in the continuing increase in the rate of treatment while ensuring acceptable working margins of safety for the process.

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TABLE OF CONTENTS

TABLE OF FIGURES

* large diagram enclosed inside back cover.

TABLE OF TABLES

ABBREVIATIONS

Abbreviations of volatile fatty acid names:

Ac	acetic acid
Pr	propionic acid
iBu	iso-butyric acid
Bu	butyric acid
iVa	iso-valeric acid
Va	valeric acid

Acids will be reffered to by the suffixes "-ate" and "-ic acid" interchangeably.

A subscript "i" denotes the intial acid concentration.

Abbreviation of units:

atm	atmosphere
g	gramme
hr	hour
kcal	kilocalorie
l	litre
mg	milligramme
min	minute
ml	millilitre
mm	millimetre
mM	millimoles per litre
mol	mole
mV	millivolt
r.p.m.	revolutions per minute
µl	microlitre

Other abbreviations:

a	coefficient of the logistic equation (dimensionless)
ATP	adenosine triphosphate
b	coefficient of the logistic equation (day^{-1})
BOD_5	five-day biological oxygen demand ($mg.l^{-1}$)
CDR1	continuous digestion, run 1
CDR2	continuous digestion, run 2
CDR3	continuous digestion, run 3
COD	chemical oxygen demand ($mg.l^{-1}$)
COD_r	chemical oxygen demand removed ($mg.l^{-1}$)
$CODR_s$	specific rate of chemical oxygen demand removal ($g\ COD_r.g\ VSS^{-1}.day^{-1}$)
cyst	cysteine-hydrochloride
E_c	electrode potential relative to the saturated calomel electrode (mV)
E_h	electrode potential relative to the standard hydrogen electrode (mV)
HRT	hydraulic retention time (days)
i.d.	internal diameter
K	coefficient of the logistic equation ($g.l^{-1}$)
K_s	half-saturation constant for sustrate utilisation ($g.l^{-1}$)
NAD	nicotinamide adenine dinucleotide
NADH	reduced nicotinamide adenine dinucleotide
OLR_s	specific organic loading rate ($g\ COD.g\ VSS^{-1}.day^{-1}$)
OLR_v	volumetric organic loading rate ($g\ COD.l^{-1}.day^{-1}$)
ORP	oxidation-reduction potential
pCO_2	carbon dioxide partial pressure (bar)
r_s	rate of substrate utilisation ($g\ substrate.l^{-1}.hr^{-1}$)
$r_{s,max}$	maximum rate of substrate utilisation
r_x	rate of biomass growth ($g\ biomass.l^{-1}.day^{-1}$)
s	substrate concentration ($g.l^{-1}$)
S	total sulphur concentration (mM or $mg.l^{-1}$)
SCDR1	semi-continuous digestion, run1
SCDR2	semi-continuous digestion, run 2

s.d.	standard deviation
SRT	solids retention time (days)
sulp	sodium sulphide
t	time
thio	sodium thioglycollate
TSS	total suspended solids ($g.l^{-1}$)
TVFA	total volatile fatty acid concentration as acetate ($mg.l^{-1}$)
UVFA	un-ionised volatile fatty acid concentration as acetate ($mg.l^{-1}$)
VFA	volatile fatty acid (concentration) ($mg.l^{-1}$)
VSS	volatile suspended solids ($g.l^{-1}$)
Y_{xs}	biomass yield coefficient (g VSS.g COD_r^{-1})
μ	specific growth rate (day^{-1})
μ_{max}	maximum specific growth rate