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Advanced Digestion in the UK – Technology Developments and Options for Optimisation of Sludge Assets

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ABSTRACT

The potential for improved pathogen reduction; better process stability and increased gas production has led to considerable interest in advanced digestion both within the UK and the US. To date 16 full-scale advanced digestion sites have been commissioned within the UK including pre pasteurisation, thermal hydrolysis, two-stage acid digestion and thermophilic aerobic pre treatment. This paper examines the current state of the art within the UK and discusses why advanced digestion is emerging as the process of choice.

Two case studies are presented demonstrating how the two ideal reactor design configurations, completely mixed and plug flow, have been implemented at full scale. The ability of the two processes to convert the complex organic materials in sewage to volatile acids is reported and the potential to produce Class B and Class A biosolids discussed.

Finally the potential of advanced digestion to increase current digester loading substantially is discussed along with the potential benefits for increased throughput and energy generation using existing assets.

INTRODUCTION

Anaerobic digestion is based on the discovery by Mouras in 1860 that under anaerobic conditions part of the organic fraction of the organic matter in sewage is liquefied. This discovery lead to the common use of the septic tank and later following work in the US (Anon 1899, Clark 1909) and the UK (O'Shaughnessy, 1914) to the development of anaerobic digestion as a separate process for the treatment sewage sludge. Mesophilic digestion dates from 1930's with steam heating being used in the UK, from 1931 at Rochdale (Morgan, 1931) and mechanical screw mixers at Bury in 1934 (Bolton, 1935). During the next 4 decades this single stage Mesophilic Anaerobic Digestion (MAD) process became widely used with increasing application throughout Europe and other parts of the world, but with very little in the way of development in the process.

The conventional MAD process was without doubt successful, and fully satisfied the requirements for sludge treatment and disposal right up until the early 80's, when concerns over the negative impacts of biosolids use in agriculture began to emerge. As a consequence of these concerns, in 1981 the Swiss government enacted an ordinance on sewage sludge requiring hygienisation prior to land application (Anon 1981). This was followed in 1982 in Germany with an ordinance covering biosolids reuse with identical scope (Anon, 1982).

These regulations lead to the development of two stage digesters incorporating pasteurisation with the first stage being either a physical thermal process or a biological thermophilic process. All of the modern day advanced digestion processes can trace their origins back to this pioneering work in Europe which lead eventually to the construction of, in excess of 70 advanced digestion plants between 1982 and 1994 (Zwiefelhofer 1991)

There is a large investment in digestion within the UK with approximately 500 digesters treating approximately 700,000 tonnes of biosolids per year. With few exceptions all the digesters within the UK are anaerobic and mesophilic. As a result of economic drivers the focus in the UK during the 80's was different from that in Switzerland and Germany, with the emphasis being on intensification of the process to maximise the use of existing assets (Brade & Noone, 1981).

This choice between building new assets and intensifying the process has continued to the present day as sewage production has risen with population and rising living standards. Currently UK digesters are operated typically with feed solids from 5% to 6%, and 15 days retention. Assuming 75% volatile solids content in sewage sludge this implies that the current loading of UK digesters is at a maximum of 2.75 $kgVS/m^3$, (170.5 lb $VS/1000ft^3$).
The continuous increase in solids feed and reduction in retention time of anaerobic digestion within the UK has led to the quality of product (in many cases) becoming poorer. In addition the reduced residence time within the digester directly affects the amount of volatile solids converted to biogas, reducing the potential energy recoverable and the quality of the product. As feed solids are increased so the rheology of the digestate becomes more viscous, making the digesters harder to mix, consequently many digesters are not well mixed leading to foaming and short circuiting problems further reducing residence time and quality of biosolids.

Today we once again find ourselves faced with pressures to increase throughput. Phosphorous removal from final effluent, required by European Union legislation has led water companies in the UK to introduce chemical dosing, further increasing the mass of solids to the digesters. Rising population figures are resulting in more sewage coming into the head of the works and higher rate activated sludge processes are producing larger volumes of WAS. At the same time the industry is under pressure to improve the product, to reduce pathogens and improve the product quality for recycling to land.

Public concerns in the UK in the 90's resulted in an agreement being reached between Water UK representing the Water Companies and the British Retail Consortium representing the major retailers covering the safe use of biosolids in agriculture and this came into force in 1998 and will be eventually incorporated into legislation. This lead to the concept of Treated and Enhanced Treated sludges defined as below.

'Treated' – must be treated so as to ensure that 99% (a 2 log reduction) of the indicator pathogen E, coli has been destroyed with a maximum allowable concentration (MAC) of E. coli of 10^5 *per gram (dry solids).*

'Enhanced Treated' – must be treated so as to ensure Salmonella spp. Is absent and be treated so as to ensure that 99.9999% (a 6 log reduction) of the indicator pathogen E. coli has been destroyed with a maximum allowable concentration (MAC) of E. coli of 10^3 per gram (dry solids).

In order to realise the goal of treating more sewage sludges whilst improving the biosolids product, the UK water companies have adopted a number of upfront processes prior to digestion. These can be separated into physical processes, typically using heat to reduce pathogens or biological process to augment the digester, details of which are published below.

Finally the UK government is actively promoting renewable energy and water companies can receive a substantial revenue stream from electricity generated from biogas, hence increasing volatile solids conversion would offer commercial benefit.

PHYSICAL PROCESSES – PASTEURISATION

Work carried out in the UK as part of the COST 681 programme, cited by Carrington (1998), produced two temperature correlations for the pasteurisation of sewage sludge. The report highlighted the time temperature correlations of 70°C (158°F) for 30 minutes and 55°C (131°F), for 4 hours as a minimum requirement to produce a sludge 'virtually pathogen free'. Earlier work by Strauch (1991 & 1998) provided slightly different temperature correlations ranging from 7 minutes at 70°C (158°F) to 3 days at 50°C (122°F). This work is summarised below in Table 2 and compared to the treatment times quoted within US EPA 503 regulation.

Whilst no treatment processes are prescribed within either UK or EU legislation it is widely believed that to achieve 'Enhanced' treatment standards the time and temperature correlations described in Table 1 below are required.

Extensive surveys by various water companies highlighted that anaerobic digestion followed by secondary storage could not guarantee the required pathogen reduction to meet 'treated' standard. Hence within the UK various auxiliary processes have been added to digestion to guarantee compliance with legislative requirements (Table 2). Three such systems are based on purely physical processing, and use hot water generated either from low-pressure hot water boilers or from combined heat and power (CHP) plants. Due to the energy balance of digester, biogas production and subsequent conversion to heat in the form of hot water, all such processes require recovery of heat from the treated stream to the cold feed stream (Brade et al, 2000). Without such heat recovery, additional (to biogas production) fuel would be required to provide sufficient heat for the process.

The first type of process is aerobic pre treatment, such as the Alpha Biotherm process, an example of which is located at Ellesmere Port in the United Utilities region. Whilst this is a biological first stage, it can be classed as a physical process, as heat is the mechanism of pasteurisation. The process (at Ellesmere Port) consists of three identical streams each containing a pre heat tank, aerobic pasteurisation tank and heat recovery tank. Sludge passes batch wise in turn through each tank and is then fed to a conventional digester.

The pasteurisation stage consists of a reactor vessel with approximately 18 hours retention, air is injected into the base of the process and hot water is circulated through the outer shell of the vessel whilst the contents are mixed. Pasteurisation is carried out at 62°C (143.6°F), with a batch of sludge being withdrawn from the main reactor every 4 hours and a fresh batch from the pre heat tank pumped in to make up the volume. Therefore whilst the batch time is 4 hours the average retention of sludge within the reactor is 18 hours. (Davies, Messerli 2000)

Table 1 – Summary of Time & Temperature Criteria for Pasteurisation

Temperature	Strauch	COST 681	EPA*
70°C	7 min	30 min	11.4 min
65°C	30 min		57 min
60°C	2 hours		4.7 hours
55°C	15 hours	4 hours	1 day
50°C	3 days		5 days

* Using formula for time required to achieve 'Class A' for <7% Sludge, note minimum time for pasteurisation to be 30 minutes.

To date within the UK there is one operational plant at Ellesmere Port with 2 further plants under construction at Mogden STW and Reading STW both within the Thames Water region. Flow data for these plants and remaining advanced digestion plants in the UK is provided in Table 2.

The second generic process, an example of which is the 'Puriser' plant, is based on holding sludge at 70°C (158°F) for 1 hour. This batch hold period is achieved by using 3 tanks in parallel, one filling, one holding and one feeding to the digester. This allows simultaneous continuous feed to the pasteurisation plant and the digester, and also facilitates heat recovery from the hot treated stream into the raw untreated stream. To date 7 plants have been installed prior to anaerobic digesters all within the Anglian Water region. (Michel, Rooksby 2000)
The third generic process is known as the Hydrolytic Thermophilic Conditioner (HTC) and operates by raising temperature of raw sludge feed to 55°C - 65°C for 4 hours. There are 2 installations at Basildon STW in Anglian Water and Palmersford in the Wessex Water region.

The 3 systems described above were all installed to provide additional pathogen reduction to secure the land disposal route for the site biosolids rather than to improve volatile solids conversion to biogas. Whilst non of the processes described were designed to increase VS conversion, aerobic pre-treatment has the potential to convert more volatile matter due to the aerobic bacteria present in the pasteurisation vessel. It should be noted that aerobic decomposition of organic matter generates carbon dioxide and water, reducing the volatile matter available for methane production. However, aerobic pre treatment contributes to hydrolysis, which could potentially increase volatile solids conversion within the MAD stage. At best it is likely that aerobic pre treatment of sewage sludge prior to digestion has a neutral effect on biogas production.

In addition to the 3 processes already described an additional process, Cambi Thermal Hydrolysis has been installed within the UK. The Cambi process produces a very high quality product with increased gas production and a dewatered final product volume typically half that of a conventional digestion process. This process is a high pressure and temperature treatment route operating at approximately 165°C (329°F) and 8 barg (117.6 psi). Sewage sludge is pressure cooked for 30 minutes and then depressurised rapidly to rupture cell walls and make available the material within. (Jolly, Potts 2001)

Table 2 – Summary of Advanced Digestion Plants in UK

Site	Capacity (TDS/pa)	Start Date	Feed Rate	Dry Solids	1st Stage		2nd Stage			Biological / Thermal
			m^3/day		Temp	Retention	Temp	Volume (m^3)	Retention	
Palmersford	1,971	Operating	120	4.5%	65°C	4 Hours	35°C	1 x 1200	10 days	Thermal
Nigg	18,000	Operating		9% to 12%	165°C	1/2 hr (Hydrolysis)	39°C	2 x 4000	15 days	Thermal / Physical
Ellesmere Port	8,000	Operating	1,077	5% - 7%	62°C	18 hr (4 hr batch)	35°C	3 x 3367	16.8 days	
Reading	8551	April 04	335	7%	65°C	18 hr (4 hr batch)	35°C	4 x 1800	20 days	Thermal/ Biological
Mogden	53000	2005	4780	6.5%	65°C	18 hr (4 hr batch)	35°C	16 x 4500	20 days	Thermal
Macclesfield	2,993	Operating	207	6%	42°C	2 days	35°C	2 x 1800	17.4 days	Biological
Bromborough	9,5810	Operating	375	6%		2 days	35°C	2 x 2250	12 days	Biological
Crew	11,826	2005	568	6%		2 days	35°C	3 x 2520	13.3 days	Biological
Swindon	9672	Operating	379	7%	32°C	2 days	35°C	3 x 1769	17	Biological
Gt Billing	19,809	Operating	442*		70°C	1hr	35°C	5 x Digesters Total 17,045	18 Days*	Thermal
Cambridge	5,522	Operating	442*		70°C	1hr	35°C	3 x 2650	18 Days*	Thermal
Cliff Quay	7,184	Operating	317*		70°C	1hr	35°C	3 x 1900	18 Days*	Thermal
Bedford	8,477	Operating	306*		70°C	1hr	35°C	3 x 1836	18 Days*	Thermal
Caister	5,840	Operating	333*		70°C	1hr	35°C	2 x 3000	18 Days*	Thermal
Lowerstoft	8,384	Operating	244*		70°C	1hr	35°C	2 x 2200	18 Days*	Thermal
Chelmsford	6,466	Operating	433*		70°C	1hr	35°C	2 x 3,900	18 Days*	Thermal
Basildon	6,570	Operating	450	4%	55°C	4 Hours	35°C	2 x 2500	11 days	Thermal

Biogas production is increased due to the rupturing of cells. A biological cell wall is constructed from protinacious material called Murein that is difficult for anaerobic bacteria to degrade (quickly) within a MAD. By rupturing the cell walls the internal cell material, which is relatively simple to degrade can be used as a food source for the anaerobic bacteria. In addition the cell walls would have more surface area available following rupture, allowing better degradation.

At present there is one operational Cambi plant within the UK at Aberdeen (Nigg STW) in Scotland. The Cambi process whilst delivering a high quality product has an associated higher capital cost and greater level of complexity compared with the other physical processes. Since privatisation of the water industry in 1989, operator-staffing levels in the UK have progressively decreased with water companies generally preferring low technology applications to those they perceive as complex. More recently interest has turned towards biological processes upfront of anaerobic digestion in particular the 2-stage acid gas process.

BIOLOGICAL PROCESSES – ACID GAS

Acid gas digestion was developed in the US in the 1970's and is gaining popularity both in the US and in Europe for the ability to optimise the anaerobic digestion process by separating the hydrolysis and acidogenesis stages from the methanogenesis stage. For a full explanation of this process see Ghosh (2003). In essence, acidogenic bacteria prefer an environment of pH 5 and 1 to 3 days retention whereas methanogenic bacteria prefer pH 7.5 and +7 days retention, acid gas digestion provides both environments consecutively.

When looking at the fundamentals of reactor design there are two options for any 'ideal' reaction, completely mixed and plug flow. A typical digester is an example of a completely mixed (when mixing is adequate) reactor and this is the standard reactor design for both 1st stage and 2nd stage tanks both in the US and in Europe.

Thames water have constructed the first UK Acid Gas plant at their Swindon STW comprising of a completely mixed acid digester operating at mesophilic temperature followed by MAD and this process is described below.

The second option for reactor design is plug flow. Plug flow reactors (PFR) are quite common in the pharmaceuticals, petrochemical and other chemical engineering industries, but the nature of municipal sludges presents a unique challenge to the PFR designer. The presence of rag and grit combined with the rheological nature of sludge, and the propensity to gas, make the use of most commercial PFR's impossible.

United Utilities (UU) have developed and commissioned 2 sites incorporating the advanced digestion process, 'Enzymic Hydrolysis' (patent pending), which utilises a plug flow reactor operating at mesophilic temperatures followed by MAD.

COMPLETELY MIXED – ACID GAS

Following a two-year bench scale investigation of various processes to reduce pathogens within their treatment flow sheet, Thames water selected an acid-gas two stage digestion process for the Swindon STW. The reactor design selected for the first stage acid digester was a completely mixed stirred tank (CSTR) similar to the typical anaerobic digester in the UK and typical of acid gas digesters in general (Wilson 2003). For a more detailed account of the bench scale work carried out by Thames Water, see Shana et al (2003).

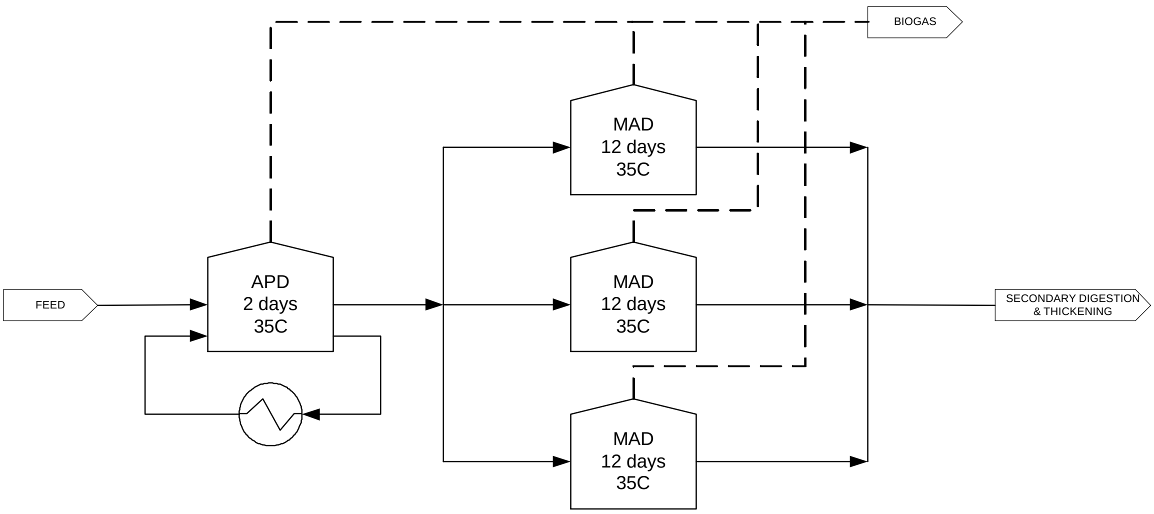
Laboratory trials indicated that the first stage reactor could be operated at between 1 to 3 days retention and at feed dry solids of 6%. The plant could operate with a volatile solids loading of 15 to 24 kg/m^3.day (930 to 1,488 lbVS / 1000ft^3), approx 2 days retention at 6% DS, and that the first stage of acid digestion, would generate volatile acids at a concentration of between 8,000 mg/l and 9,000 mg/l

Following the successful trials a full size plant was constructed at Swindon STW. The first stage acid gas digester has a volume of 1000m^3 (35,315ft^3) and operates at variable level to maintain a retention time of upto 2.5 days dependant on loading. When full the tank has an aspect ratio of 1:1, and is heated by external spiral heat exchangers. Following the 1st stage tank are 3 number anaerobic digesters each of 1,769m^3 (62,472ft^3) with a minimum of 12 days retention. Both stages operate mesophilically at 35°C (95°F), Figure 1.

The 1st stage tank and all 3, 2nd stage tanks are heated by external heat exchangers and all tanks are mixed. The acid digester is currently mixed by a large blade impeller mounted on a fixed roof, although there are plans to jet mix the digester in future. The 1st stage provides a significant proportion of the 2nd stage heat demand with the existing heat exchangers, for the MAD's, only having to replace thermal heat losses.

The 1st stage is fed between 10 and 20 minutes per hour through the side wall and, as stated above, the tank volume is varied to maintain a loading of approximately 20 kgVS/m^3.day (1240lbVS/1000ft^3), the plant has been found to operate stablely with a retention time of 2.4 days and a volatile solids loading of 18 to 24 kgVS/m^3.day (1,116 to 1,488 lbVS/1000ft^3). Whilst the 2nd stage anaerobic digesters operate with 12 days retention and with a loading of 2.4 kgVS/m^3.day (148.8 lbVS/1000ft^3).

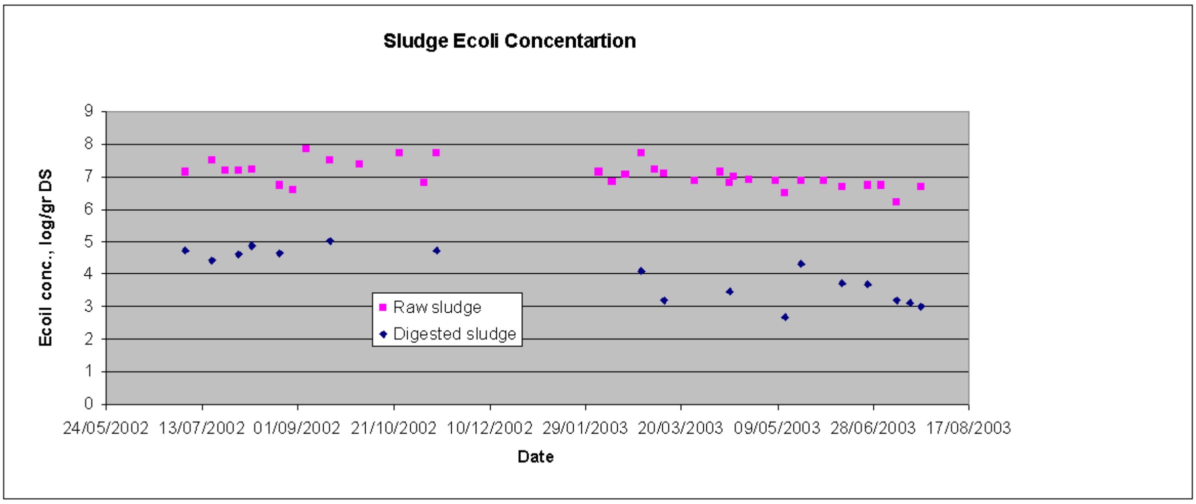
Fig 1 – Schematic Flow Diagram Swindon AG / MAD



Sampling of the plant at Swindon has shown the process to be effective at producing a Treated standard biosolids, with E Coli reduction of approximately 10^4 log reduction. Figure

2 below shows the pathogen reduction across the digestion process between May 2002 and August 2003.

Fig 2 – Pathogen Profile for Acid Gas Digester at Swindon



It can be seen, from Table 3, that the process produces volatile acid levels of 7,551 mg/l in the 1st stage and that the VA levels in the MAD are almost zero. This indicates that the 1st stage reactor is very effective at carrying out the initial hydrolysis and acidification stages of digestion.

PLUG FLOW – ENZYMIC HYDROLYSIS

The development and testing of the chosen design, is outlined in Mayhew et al (2003) and elsewhere, but in brief the plant consists of 6 CSTR tanks with a retention time of 2 days. Raw sludge is fed every hour to tank 1 and raised to 42°C (107.6°F), passing through all the tanks in series to tank 6. From tank 6 the treated sludge is pumped directly to MAD, see Fig 6 below.

To date, 2 plants are installed and operational. The first plant at Macclesfield STW was commissioned in 2000, with a treatment capacity of 207 m^3/day with feed dry solids of upto 8% giving a total treatment capacity of 16.5 tonnes per day (36,432 lb/day). The second plant at Bromborough was commissioned in 2003 and has a treatment capacity of 375m^3/day at 8% dry solids giving a capacity of 30 tonnes per day (66,000 lb/day). A third plant for Crewe STW is currently at design stage, and will be under construction at the time of conference, treating a flow of 560m^3/day at 8% dry solids, 44.8 tpd, (98,560 lb/day).

Initially the process was developed solely to reduce pathogen content across the treatment process to comply with the UK's Treated standard, the results from Macclesfield have been published extensively Mayhew (2003), and are summarised in Figure 3 below.

Table 3 – Sample data from Swindon STW 2 stage digestion process

Determinand	Unit	Raw sludge	Stage 1	Digester
E.coli	log/gDS	7.9-7.4	4.0-5.0	3.40
E/coli wet count	MPN/wet g	-	-	-
Alkalinity	mg/l	1238-2560	2042-5187	4017
Ammonia	% g/g	-	-	-
Ammonia	mg/l	-	-	-
DS	%	4.84-6.5	4.47-6.2	3.55
VM	%	78.5-80.8	78	60.9
pH		5.3-6.2	5.2-5.5	7-7.3
VFA total	mg/l	2738	7551	63
Ethanoic	mg/l	1404	3608	4
Propanoic	mg/l	860	2061	46
I-Butyric	mg/l	38	228	<2
N-Butyric	mg/l	298	769	11
I-Valeric	mg/l	79	434	<2
N-Valeric	mg/l	59	451	<2

As can be seen from the MAD + EH pathogen reduction (Figure 4) for E Coli is sufficient to meet the legislative requirements, however initial laboratory work suggested that pathogen reduction could be even better than demonstrated at Macclesfield.

It was felt that one reason for this was due to the degree of plug flow within the reactor and so to assess this, a lithium trace test was carried out at Macclesfield. Plug flow was assessed and the measure of $T_{10/}$ ô was applied, where T_{10} is the time in hours for 10% of feed to pass through the reactor and ô is average residence time in hours.

For a ‘perfect’ Plug Flow Reactor (PFR), following an infinitely short pulse of tracer, T_{10} / ô would be 1 i.e. all feed remains in the reactor for the retention time. The closer to 1 the result is the better the degree of plug flow.

The aim in the design of Macclesfield was to balance the degree of plug flow whilst providing an economic, and practical design. Therefore whilst the retention time of the plant was designed for 2 days it was considered that a minimum of 1 days retention within the reactor for all sludges was sensible and therefore a T_{10} / ô value of 0.5 was acceptable

During the test at Macclesfield the reactor operated with 5 tanks in series rather than 6 as the final tank was being used as a pilot thermophilic digester. The tracer results, shown in Figure 5 below show that the actual response of the system was very close to 5 ‘ideal’ CSTR’s in series. Furthermore the values for T_{10} / ô, T_{10} & ô were calculated and these are given in Table 4.

Whilst the Macclesfield lithium trace test successfully validated the initial design it was decided to modify the second plant at Bromborough slightly to improve performance. The length of time between tank transfers was increased and minor changes made to the mixing regime. In addition to this the retention time at Bromborough was increased due to the design for a higher future loading.

Fig 3 – Schematic of Macclesfield EH Plant

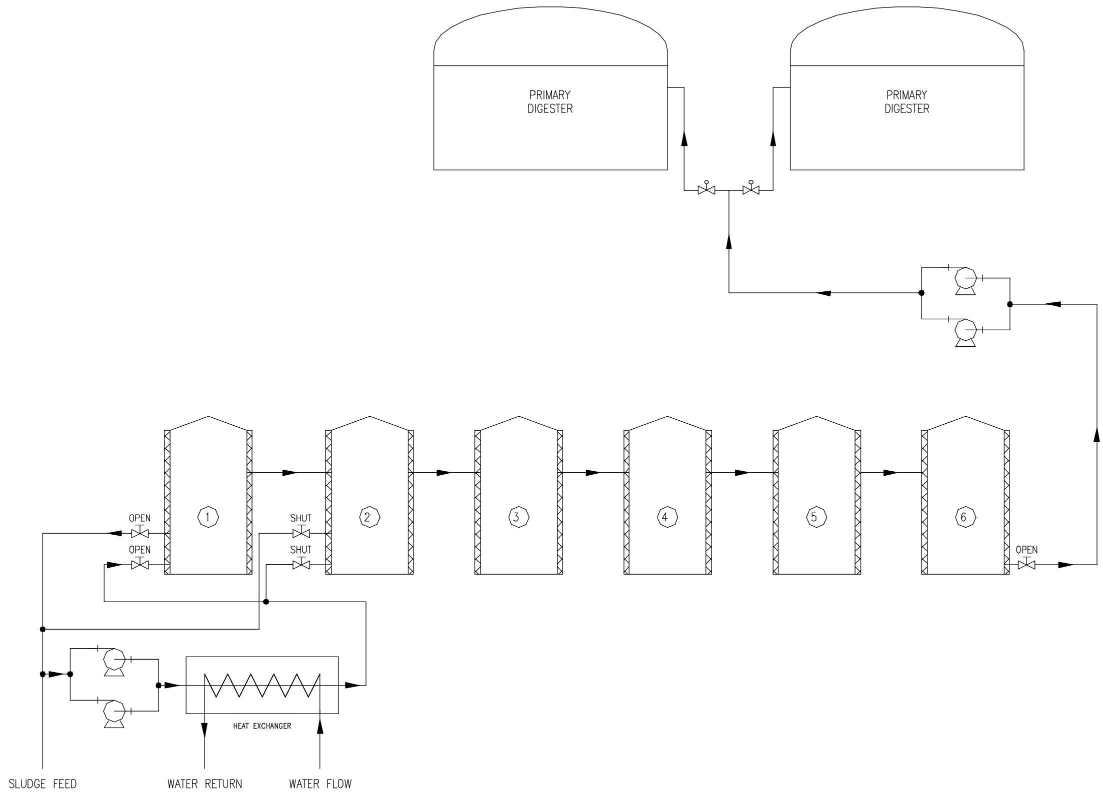
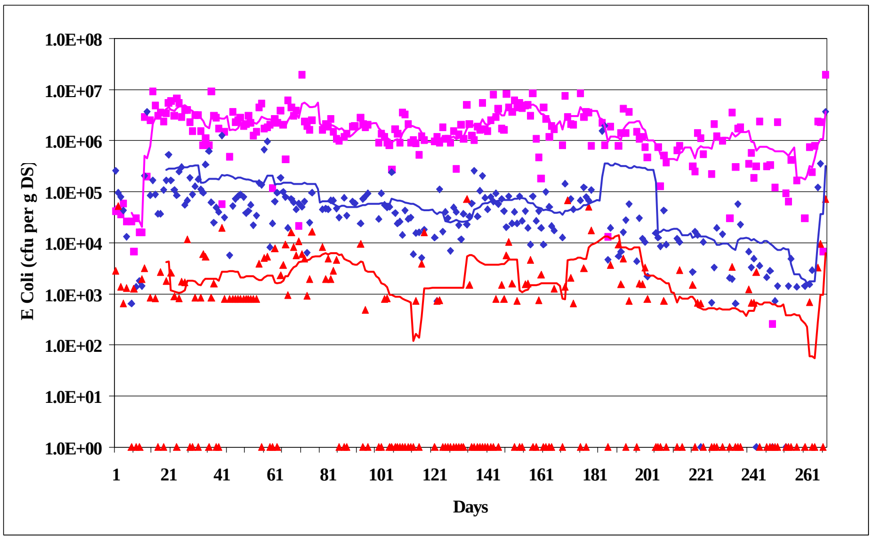


Fig 4: Pathogen Profile for Macclesfield PFR.



(◆Raw sludge, ■Control MAD, ▲ MAD with EH feed)

Fig 5 – Lithium Trace Results for Macclesfield vs 'Ideal' Response

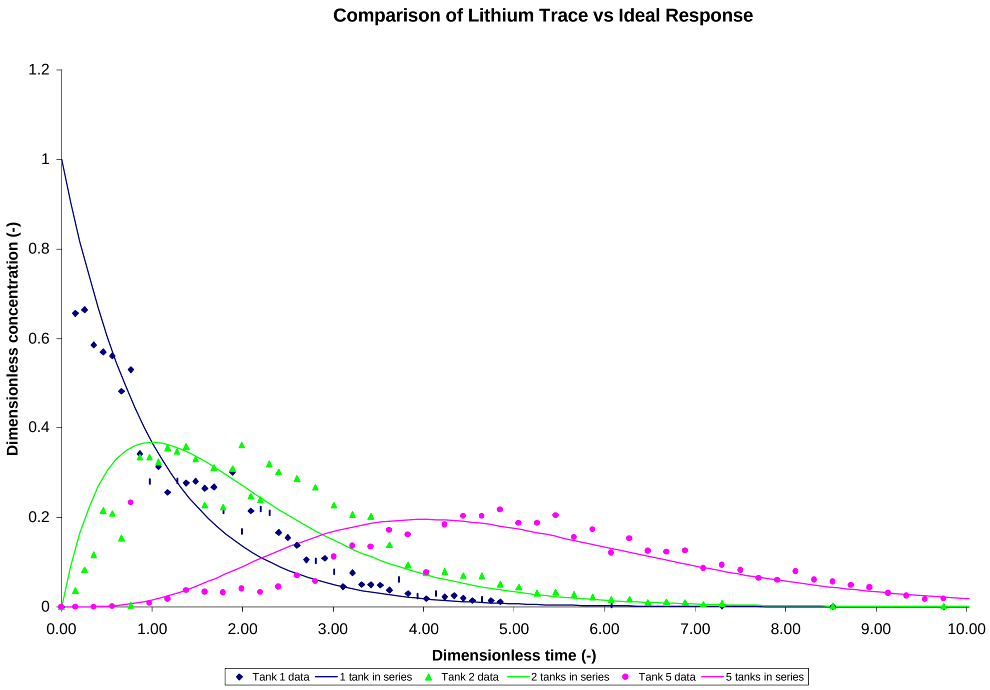


Table 4– Summary of Lithium Trace Results

	Tank 1	Tank 5
Mean Residence Time (ô)	9.8 Hours	49 Hours
Time for 10% of Feed to Short Circuit (T_{10})	1.5 Hours	23.5 Hours
Degree of PF (T_{10} / ô)	0.15	0.48

The result of these changes was marked; it was observed that hydrolysis within the reactor increased markedly, so much so that operational staff decided to temporarily reduce the operating temperature to 32°C (89.6°F). Table 5 below shows the pathogen and volatile acid profile for the plant taken on April 14th 2004.

The results show an E Coli reduction of 10^4 across the EH plant alone easily meeting both the UK's and US legislation for 'Treated' and 'Class B'. Once these results had been received it was decided to operate the plant at 42°C again to investigate what effect this would have at longer retention. The results given in Table 6 below show that the process not only met a Treated standard but also met the UK's Enhanced treated standard, approximately equivalent to the US EPA 'Class A'.

Table 5– Sampling Results from Bromborough EH Plant (32°C)

Determinand	Unit	Raw sludge	Tank1	Tank3	Tank5	Tank6
E.coli	log/gDS	6.00	5.67	4.45	2.91	2.16
E/coli wet count	MPN/wet g	68300	24192	1414	41	10
Alkalinity	mg/l	2482	2264	2392	2545	2485
Ammonia	% g/g	0.99	1.63	1.79	1.9	1.62
Ammonia	mg/l	669	841	904	960	1115
DS	%	6.76	5.16	5.05	5.05	6.88
VM	%		75.6	75.9	72.2	71.7
pH		5.3	5.6	5.3	5.2	5.2
VFA total	mg/l	6310	6826	3126	9989	11432
Ethanoic	mg/l	2530	2376	3136	3581	3940
Propanoic	mg/l	1886	1899	2730	3429	3723
I-Butyric	mg/l	165	232	251	279	365
N-Butyric	mg/l	1154	1374	1407	1575	1912
I-Valeric	mg/l	261	404	417	459	637
N-Valeric	mg/l	315	542	582	666	855

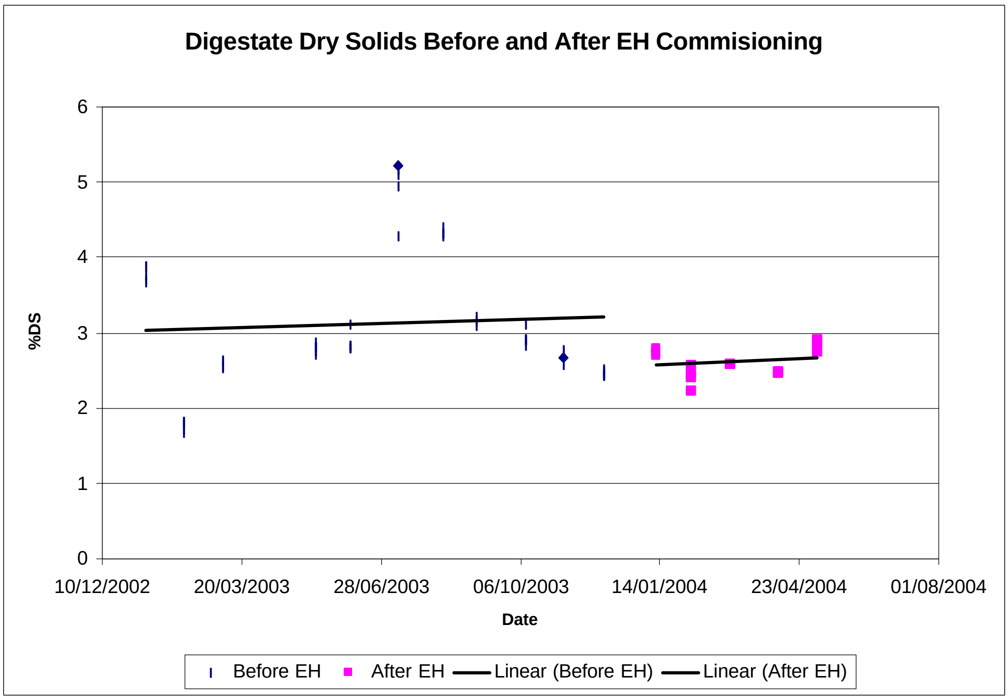
Table 6 – Sampling Results from Bromborough EH Plant (42°C)

Determinand	Unit	Raw sludge	Tank1	Tank3	Tank5	Tank6
E.coli	log/gDS	7.36	3.97	2.35	2.21	2.24
E/coli wet count	MPN/wet g	1046240	464	10	10	10
Alkalinity	mg/l	2007	2456	2631	2733	2861
Ammonia	% g/g	0.97	1.97	2.35	1.85	2.26
Ammonia	mg/l	441	969	1050	1130	1313
DS	%	4.55	4.92	4.47	6.11	5.81
VM	%	71.7	78	75.1	70.3	72.4
pH		5.9	5.5	5.7	5.5	5.2
VFA total	mg/l	3595	8352	8968	10365	144744
Ethanoic	mg/l	1978	2638	3002	2758	4427
Propanoic	mg/l	868	2819	2707	4051	5240
I-Butyric	mg/l	127	287	356	358	456
N-Butyric	mg/l	305	1341	1408	1664	2437
I-Valeric	mg/l	203	498	628	642	788
N-Valeric	mg/l	114	768	867	891	1069

The results from Bromborough confirmed that the EH process was highly effective at converting complex organic molecules to volatile fatty acids. The plant operating at 32°C generated VA's in excess of 11,000 mg/l and at higher temperature (42°C) the plant generated greater than 14,000mg/l.

An additional benefit of the pre hydrolysis and acidification of the digester feed was that following commissioning of the EH plant (December 23rd 2003), the digester solids were seen to stabilise considerably relative to their previous values, see Figure 6 below. This data indicates that digester performance was greatly improved by the addition of pre treatment. It should be noted that no physical changes were made to the digesters themselves.

Fig 6 – Digester Dry Solids Samples (Bromborough), Pre and Post EH Commissioning



DISCUSSION

Physical processes such as pasteurisation are well established within the UK for the reduction of pathogens in biosolids to meet legislative requirements. Yet whilst these processes have worked, with greater or lesser degrees of success, they do not (with the exception of thermal hydrolysis), satisfy the economic drivers requiring greater solids throughput and increased gas production.

Separating the phases of digestion process, has allowed both Thames Water and United Utilities to increase the loading of their existing digester assets. Comparing the normal digester loading (within the UK industry) of 2 to 2.75 kgVS/m^3.day, Swindon operates with a maximum feed dry solids of 6% at 14.4 days retention (3.1 kg/m^3.day / 194 lb VS/1000ft^3), whilst the 2 EH plants operate at 14 days retention with upto 8% feed dry solids (4.3 kgVS/m^3.day / 266 ld VS/1000ft^3). Figure 13 below shows the comparison between conventional UK digestion practice and the acid phase digesters in Thames and UU. It is believed that conversion from conventional MAD to separate phase digestion followed by anaerobic digestion will allow a 50% increase in digester loading.

The loadings quoted in Table 7 are design loads, however there is preliminary data, particularly from Macclesfield, Mayhew (2003) that these loadings can be increased further. During March and April 2003, the anaerobic digesters at Macclesfield were operated at 7 days retention with approximately 5%DS feed with no ill effects, giving a digester loading of approximately 6kgVS/m^3.day (372 lb VS/1000ft^3**).**

Table 7– Comparison of Current UK Practice with 2 Stage Digestion Plants

Item	Typical UK MAD	Swindon (CSTR)	EH (PFR)
Feed	5% – 6%	5.5% - 6%	6% – 8%
Retention (days)	15 – 18	12.4	14
Volatile Loading (kgVS/m^3.day)	2 – 2.75	3.3 – 3.6	3.2 – 4.3
Operating Temperature	35°C (95°F)	35°C (95°F)	42°C (107.6°F)
Pathogen Reduction	10^1 to 10^3	10^4	10^4 to 10^6

In addition to the improved digester loading achieved with advanced digestion all 3 sites where the technology has been installed have reported an increase in biogas production. Although this has not been quantified reliably, the reports are of an increase between 15% and 40%. Should this increase in gas production prove reliable this would provide a strong economic driver for advanced digestion within the UK and Europe where renewable energy is increasingly important.

Comparisons between the CSTR reactor and the PFR must be done with care. Whilst there are 2 operational PFR reactors with a further plant in design, only 1 CSTR acid digester exists in the UK. Initial data however indicates that a plug flow design is better suited to breaking down the complex organic molecules in sewage sludge to volatile acids. It is also evident that the greater the degree of plug flow the more VFA’s are produced and the greater the pathogen reduction achieved. In addition PFR’s appear to produce more of the longer chain VFA’s, namely Butyric & Valeric acids than the CSTR, which could be an indication that more complex organic molecules are being hydrolysed and entering into the beta-oxidation cycle, which in turn will end up as acetate for biogas production by methanogenesis.

CONCLUSION

Legislative and economic drivers originating from the European Union have driven the UK water industry to examine numerous forms of process enhancement. Both physical and biological processes have been installed to reduce pathogens and to improve the quality of biosolids.

Whilst physical process can guarantee pathogen reduction, and indeed these processes are still the asset standard for ensuring enhanced biosolids, they do not facilitate greater loading or improved biogas production.

In order to meet all legislative and economic drivers, two of the largest UK water companies, Thames Water & United Utilities, have turned to advanced biological processes. The plants at Swindon, Macclesfield and Bromborough have proven effective at increasing digester loading whilst improving biosolids quality.

Early indications are that improving the degree of plug flow within the digestion process improves both volatile acid production from complex organic molecules and also has the potential to provide an Enhanced, (Class A) biosolids solution.

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