ULTRASOUND FOR ENHANCEMENT OF SLUDGE DIGESTION

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ABSTRACT

Ultrasound' is the term used to describe sound energy at frequencies above 20kHz. This paper presents results from a large-scale field trial by Wessex Water at their Avonmouth works. It describes how the technology, which involves recently patented developments in design, enables the application of intense and focused sound energy into a liquid at very low retention times of only a matter of a few seconds. The cell lysis induced by focused ultrasound has several notable effects on the availability of substrate to the downstream biology and this paper investigates expectations of enhanced digestion, improved digester stability, greater gas production and improved dewaterability.

Following successful trials in Orange County, CA. by W.S. Atkins in 2000/2001 and application and subsequent selection of Purac Ltd as sole licensee a containerized sonix™ plant was designed and built by Purac Ltd. This plant incorporates all the developmental lessons from the California trials and significant improvements in terms of reactor design, product engineering and control features.

Currently at their Avonmouth works the increasing quantity of "problematic" secondary sludges produced as a function of the greater requirement for secondary treatment, has meant that Wessex Water have been experiencing some operational difficulties with their digestion plant and more importantly the subsequent dewaterability and downstream drying operations. Significant enhancement of gas production and solids destruction readily achievable by pre-conditioning the secondary sludges with sonix™ it is anticipated will enable greater energy recovery and more stable digester operation. The increase in gas production and the commensurate increase in solids destruction is compared with earlier work in Orange County though found, for both, to be typically in the range of 25-50%.

In order that direct comparison can be made between unsonicated feed sludges and sonicated one of the 6 digesters has been used to treat progressively greater quantities of thickened Sonicated SAS upto 100% feed with the remaining 5 receiving only unsonicated feed. Gas yields and solids destruction rates are compared to baseline conditions and conclusions drawn for a full-scale sonix™ plant for the works.

1. KEY WORDS

Enhanced digestion, Fluidsonics, Piezoelectric, Ultrasound, Volatile Solids, sonix™

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2. INTRODUCTION

Ultrasound is the term given to sound energies of frequencies in excess of 20kHz but below 10MHz, outside the audible range (16Hz to 16kHz). Sound waves are propagated via a compression / rarefaction mechanism through any medium; gas, liquid or solid. The energy of these waves can be applied to a number of applications from medical scanners to plastic and metal welding to cleaning baths and sonochemistry applications. Ultrasound when applied to fluids in the chemical and processing industries is often referred to as Fluidsonics (sonochemistry) and requires only the presence of a liquid to transmit its power. The origin of the power of Ultrasound in a liquid is primarily cavitation. Like any sound wave Ultrasound is propagated via a series of compression and rarefaction waves induced in the molecules of the medium through which it passes. At sufficiently high power densities, the rarefaction cycle may exceed the attractive forces of the molecules of the liquid and cavitation bubbles will form, where the internal bubble pressure exceeds the external (atmospheric) pressure. These grow in size until, at the high pressure part of the cycle, the bubble reaches its critical size and implodes exerting violent forces sufficient to provide cleaning / rupturing action as required additionally extremely high temperatures at the foci are believed to aid in the action. Recent developments at the Horn end or Sonotrode have dramatically improved ultrasound's application into a fluid enabling the cavitation energy to be focused by the horn face thereby increasing the cavitation intensity and ultimately reducing the required exposure times. What this paper describes is how this new ability to intensely focus cavitation energy can be used to enhance anaerobic digestion and follows on from earlier work in this area by WS Atkins / FFR et al. reported elsewhere. Other applications of this technology currently being investigated at Anglian Waters innovation center at Cambridge include control of filamentous growth in wastewater treatment plants, BNR enhancement and sludge reduction.

THE PROBLEM

Those sludges containing large quantities of secondary solids from biological treatment are less amenable to mesophilic anaerobic digestion. Frequently encountered problems include reduced gas production, reduced volatile solids destruction, reduced dewaterability and greater instability of digestion performance. Whilst the impact of the former shortcomings can be reasonably accurately assessed commercially the implications of the latter are rather more difficult. Part of the explanation is that water bound up, both within the cells and within the interstitial spaces in secondary sludges make dewatering problematic. Additionally substrate bound up within the cellular material of the secondary sludge is not easily utilized by the anaerobic biology and will not be fully broken down prior to leaving the digester. Therefore as the proportion of secondary sludge increases in a digester feed lower volatile solids loadings can be tolerated for a given degree of destruction. It is regularly reported that SAS exceeding 40% of a digester feed stock can lead to impaired digester performance occasionally resulting in failure. Various methods have been used to breakdown cellular material prior to digestion including treatments such as the thermal hydrolysis, mechanical abrasion and fluidsonics. Earlier work by Chiu *et al* (1997) suggested that ultrasonic pretreatment increased soluble COD and VFA levels and other work by Tiehm *et al* and Clark *et al* has demonstrated both at lab and full scale that sonicating secondary sludges prior to anaerobic digestion can have significant beneficial effects. Full-scale work carried out in California for Orange County Sanitation District (O.C.S.D) in 2000 served to both to reinforce positive findings from the literature and bench-scale research and also demonstrate that certain mechanical and electrical aspects of the system needed further development. This development was needed in order to improve the system reliability / operability and life costs. At the OCSD plant regular probe failures and generator trips had meant that semi constant operational input was required through the trials, which was deemed unacceptable in a full-scale plant that would have to demonstrate favorable payback. Following completion of the OCSD trials WS Atkins seeking licensees for the technology capable of developing it and marketing it commercially appointed Purac Ltd as licensee.

PRODUCT DEVELOPMENT

Throughout the prototype stages various generators or power packs were trialed with varying degrees of success. Additionally the reactor assembly and stack-cradles were cumbersome and made stack inspection and maintenance awkward and time consuming. Due to requirements for continuous operation, (ultrasonic equipment up until now generally semi-continuous duty), overheating of the transducer piezoelectric crystals, stacks and generators was a regular occurrence reducing operational time and degrading the quality of the results. Since license award Purac have developed the reactor design, stack components and cooling system and entered into agreements with key equipment suppliers. The new s**o**nix™ plant consists of a 10 Bar(g) rated polished stainless steel reactor with 5 titanium radial horns installed in series. Each s**o**nix™ horn is part of an individual stack that includes an extender, a booster and transducer. On earlier models these were bolted together by means of threaded studs, which were very prone to breakage. A key aspect of the new design is that each of the stack components are welded to each other to minimize the risk of mechanical fatigue. Each stack is bolted into the reactor in such a manner that the whole assembly resembles a V5 engine hence the term “V5 Reactor”. The horns are placed perpendicular to the flow so that the sludge fluid moves through the center and to a lesser extent around the edges of the horn. An individual 3kW generator running at 20kHz operates each stack. The generators are kept in a chilled cabinet and the transducers are cooled using dried and pre-cooled compressed air. Transducer temperature is detected and controlled separately to improve the operational lifetime.

The rated duty of the basic V5 unit is 8 m^3/h of sludge at 6% DS running upto 24 hours per day. This is equivalent to processing the SAS from a conventional works of 340,000 people. The effective volume of the reactor equates to approximately 1.5 seconds retention time. This standard configuration is modular such that multiple units accommodate higher sludge throughputs. Further developments are also under investigation, chiefly associated with materials of construction, various inserts materials and cooling methods to further increase component life and reduce costs.

UK REFERENCES

In order that a better understanding of process and reliability issues could be gained it was felt important to carryout large-scale field trials in the UK. This would both serve to demonstrate that recent system improvements were effective and once up and running could be used to exhibit the technology to potential future clients.

Throughout the recent system developments up until the end of 2000 the research was part funded by various water companies. These stood to gain a royalty payment from future production units but more importantly were party to the results and implications for their own future business. One of the sponsors Wessex Water, keen to improve wastewater treatment wherever possible and receptive to emerging technology were interested in trailing a pilot unit at their Avonmouth works. The Avonmouth WWTW, PE 1.2 million has 6 mesophilic digesters treating blended sludges from conventional primary treatment and increasing quantities of secondary sludge from their SBR plants. Digester performance was being adversely affected as SAS quantities exceeded 25-30% of the sludge feed. As the digester performance deteriorated downstream dewatering operations were not achieving sufficient cake dryness for final drying in their large drum-dryer. With this inability to process all secondary sludge through the above preferred route alternative treatment methods were being undertaken chiefly alkaline stabilisation. This was having a serious cost implication for operations and resolution of the problem was becoming a matter of priority.

Clearly the design of the trials needed to demonstrate that sonicated secondary sludge was more amenable to digestion, the improved sonix™ equipment would operate reliably with minimal operational input, the cost of a full-scale system could be recovered from operational and disposal savings within an attractive time period and if possible the installation of the sonix™ plant in the interim period would help to alleviate present operational difficulties. The demonstration plant was therefore installed on a new feed line to one of the 6 digesters (digester No. 5) drawing from the thickened SAS tank. The existing thickened SAS tank feeds the digester ring main and therefore as the quantity of Sonicated SAS was increased to the trial digester as the trials progressed less SAS would be available for the other digesters thereby improving their performance. As the maximum rated duty of the sonix™ plant would enable the processing of the test digester's entire feed, SAS proportions to the other 5 digesters could be reduced from a maximum of 39% feed down to 23% and thereby potentially alleviate their problems.

The 340,000 PE containerized sonix™ plant arrived at the Avonmouth works on the 11th July. The entire plant is held inside a mobile ISO container and once on site only needed coupling up to the SAS tank and Digester inlet pipework. The plant started running 24 hrs/day on the 23rd July. Over a period of weeks the feed rate was ramped up in order not to overload the digester and at the time of writing Digester 5 is operating at 60% Sonicated SAS feed.

3. DISCUSSION

The key operational parameters that will be studied in order to derive a fair comparison between sonicated and unsonicated fed digesters are gas production / solids destruction and digester stability. Additionally some means of accounting for varying hydraulic retention times / feed rates is essential as these will have a direct effect on the above.

FEED RATES AND DIGESTER HYDRAULIC RETENTION TIMES

A sustained historical comparison prior to sonix™ startup between the test digester and digester 6 proved to be difficult. This was due to a one-month shutdown of digester 5 (test) between January and February and an inaccurate inlet flowmeter on the feed to digester 6 (control) around the same time. Figure 1 shows feed rates of digesters 5 and 6 illustrating a close agreement in their feed rates following digester 5 being brought back on-line at approximately the end of March.

DIGESTER STABILITY

Figure 2 illustrates how the proportion of SAS to the test and control digesters was changed over the early period of the trial. As Digester 5 (test) received more and more sonicated SAS from the sonix™ plant the quantity that the control digester (6) received dropped off. Due to vagaries of secondary processing operations elsewhere on the site quantities of SAS for digestion dropped off during August resulting in the control digester receiving even less SAS than anticipated. When the intended quantity of SAS returned for processing in early September and was duly fed to all digesters via the ring main (including the test digester in an unsonicated form in addition to its Sonicated feed) all digesters started to foam. The test digester however foamed least and recovered quickest even though by that stage its SAS proportion was upto 60%, a level normally associated with very high instability at these retention times (12-13 days).

BIOGAS PRODUCTION

Solids destruction is directly associated with gas production. Improvements in gas production will be accompanied by increased volatiles destruction for any given mass feed rate. Figure 3 shows the 7 day averaged gas production of the test and control digesters since the middle of March 2001. As Figure 3 shows both digester 5 and 6 were producing similar quantities of biogas prior to trial commencement. Following the start of the sonix™ trials however Digester 5 has produced substantially greater quantities of biogas than digester 6. Whilst, at the time of writing Sonicated SAS feed as a percentage was between 50 and 60%, gas production has increased some 32% on average without adjustments for volatile matter feed rates. Additionally as digester 6 started foaming in August Figure 4 shows gas production of the test digester compared to digesters 6,7 and 10 in order that a better comparison can be made. Figure 5 illustrates the increase in gas production adjusting for feed rate between the test digester and the three control digesters. Over the period of the trial mean gas production per m^3 of sludge for the control digesters 6,7 & 10 were $21.74m^3$, $21.3m^3$ and $21.85\ m^3$ respectively per cubic meter of sludge fed. Given that the mean ring main dry solids feed concentration has been 5.45%DS and that mean volatile solids concentration has been 77.3% (VS/TS) from January to October, total solids and volatile solids destruction prior to the trial in the control digesters (No.6,7 & 10) can be calculated as 32.9% and 42.5% respectively. For the test digester, prior to the trial, these figures were slightly better, possibly on account of recent refurbishment / de-gritting etc, 35.6% and 46% respectively. It is important to note that these figures derived from gas production are broadly in line with general expectations from a sludge digestion plant of this type. Once an increasing proportion of SAS was removed from the control digesters and diverted to the test digester (5) via the sonix™ plant the performance of the control digesters improved in terms of total solids destruction and volatile solids destruction to 39.7% and 51.3% respectively. This increase in biogas production from the control digesters is accounted for by a) an increase in the feed proportion of readily digestible primary sludge and b) a consequent reduction in the more problematic secondary sludges as these are diverted off to the test digester. Again generally in line with expectations from earlier studies. If these problematic secondary sludges were digested to an equal degree the overall improvement would be significant in itself. However not only are the performances of the remaining digesters improved by reducing the amount of secondary sludge in their feed but also the performance of the test digester receiving Sonicated feed sludge improves dramatically. Prior to the trials the performance was very similar to the control. Over the period of the trials from 23rd July up until 29th Sept (time of writing) taking into account the increasing quantity of the reduced SAS feed thickness to the test digester, mean total solids destruction and volatile solids destruction has been 61.7 % and 78.7% respectively. Figure 5 illustrates the higher gas yield from the test digester compared to the control digesters through the period of the trial, unadjusted for reduced SAS feed thickness. These destruction rates are expected to improve further as the percentage of sonicated SAS to the test digester is increased upto 100%. Figures 7 and 8 illustrate biogas production as a function of total and volatile solids loadings respectively.

Wide fluctuations in gas production early on in the trials are a function of variable feed rates. During the start-up period of the sonix™ trials only partial control over the feed quantities to the test digester could be gained, as a large proportion of the feed stock was still from the ring main and the cycle timer control was not directly interfaced with the sonicated feed rate, additionally downstream final sludge processing difficulties meant that from time to time large quantities of secondary sludge had to be removed for alkaline stabilisation. As the trials have progressed the feed rate to the Test digester has been brought under more direct control of the sonix™ plant and gas yields have stabilized. Also less SAS needs to be stabilized using lime and therefore more consistent quantities are available for sonix™ treatment. Figure 6 illustrates this increasing stability from the end of August.

COMMERCIAL IMPLICATIONS

Prior to trials any secondary sludges produced on site over and above that which could be treated by digestion were stabilized by lime. To process the entire secondary sludge make the SAS had to make up approximately 40% of the digester feed, 26,000kgDS.d as SAS. Prior to sonix™ installation the digesters were accepting between 20% and 25% feed as SAS, a 152 m3.d shortfall which at £40.00 per tonne DS liming cost might cost anything upto £132,000pa. If the feed proportion to the test digester was maintained at only 60% SAS, the surplus drops to 86m^3.d still requiring lime treatment, amounting to approximate savings of £57,000pa. If however as expected SAS feed proportions are sustainable upto 100% savings in the order of £123,000 per year are realizable from the demonstration plant alone.

Together with ancillary treatment cost savings the increased gas production will contribute to further cost savings. Based on current gas production figures without sonix™ the digestion plant produces approximately 17,600 m^3 biogas per day with 25% SAS feed to all digesters. With the sonix™ at 60% feed in the test digester this rises to approximately 19,700m3 and can be extrapolated to 22,000m^3 biogas per day with 100% sonicated SAS feed to the test digester. A full-scale sonix™ plant in the order of 4 times the size would produce something in the order of 30,000m^3.d biogas. Using a Calorific value for biogas of 22.5MJ/m^3, a kWh$_e$ cost of 4.5pence, a CHP plant electrical efficiency of 34% (current efficiency level of new plant) and added to this an allowance for hot water generation savings (CHP 41.5% thermal efficiency, NB this excludes any savings that could be made from low grade heat utilisation), current savings with sonix™ at 60% are £9.00per day (£3,285 pa.), at 100% £19.00per day (£6,956 pa) and extrapolated to full-scale £54.71per day (£19,968pa.). Whilst savings / income associated with biogas generation are highly dependent on the sites ability to utilise the gas perhaps the greatest benefit of enhanced digestion with sonix™ are those derived from reduced downstream solids handling and disposal costs.

Greater destruction means less sludge to dewater and dispose of. Clearly the more comprehensive downstream treatment the greater potential for cost reduction. If all the sludge produced on the site (64.5Tonnes per day) were digested obtaining historical levels of solids destruction (33%), dewatered, dried and disposed of to land, the current intended practice and, using typical industry costs of £40.tds dewatered, £64.tds drying and £35.tds final disposal, the daily cost would be of the order of £6,292 per day. By installing a full-scale sonix™ on thickened SAS feed to the digestion plant and getting 48% total solids destruction thereby having to dewater, dry and dispose of only 35tds.d c.f. 45.2tds.d, a daily saving of £1,432 or £522,760 per annum could be realised. Care needs to be exercised here, as all sites will have their own treatment costs some of which will significantly affect the economics. The drying cost here for example accounts for almost 50% of the treatment costs after digestion.

Running costs of the sonix™ plant range between 30p and 52p per m^3 of sludge treated Cost variations are due to ambient temperatures on account of cooling requirements and size of plant. Annual running costs are therefore anything upto £18,000 pa. Excluding maintenance and spares.

Further investigations into dewaterability will enable a more complete picture to be obtained.

4. CONCLUSIONS

- sonix™ treatment enables stable digester operation even on very high levels of SAS feed.
- Significant increases in methane production from test digester receiving sonicated SAS feed.
- In excess of 60% total solids destruction from digesters receiving high percentage levels of secondary sludges.
- By concentrating problematic sludges into Sonicated fed digesters the performance of other digesters receiving higher proportions of primary sludge are also improved.
- Proportion of SAS fed to the test digester to be increased upto 100%.
- Further containerised demonstration plants are being built.
- Significant mechanical and electrical developments have transformed a prototype technology into a reliable, robust piece of process plant. This has significantly improved the operability of the process and the economics, translating into very attractive payback periods for full-scale projects.
- Technology now ready for commercial market

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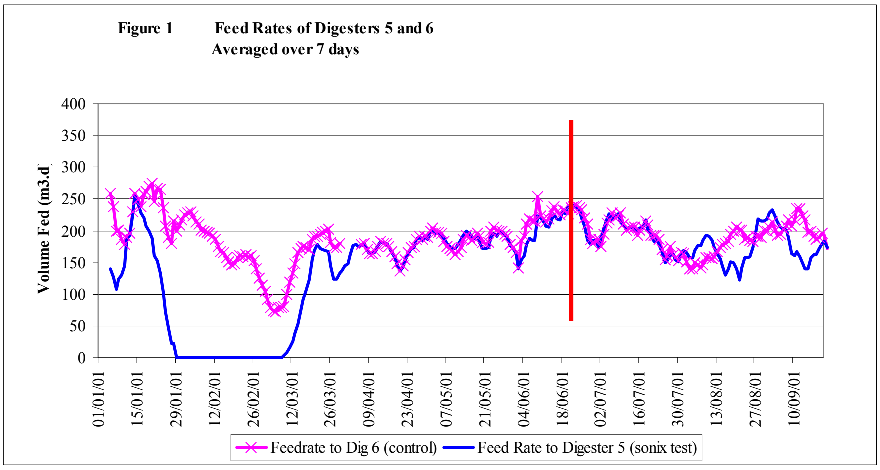
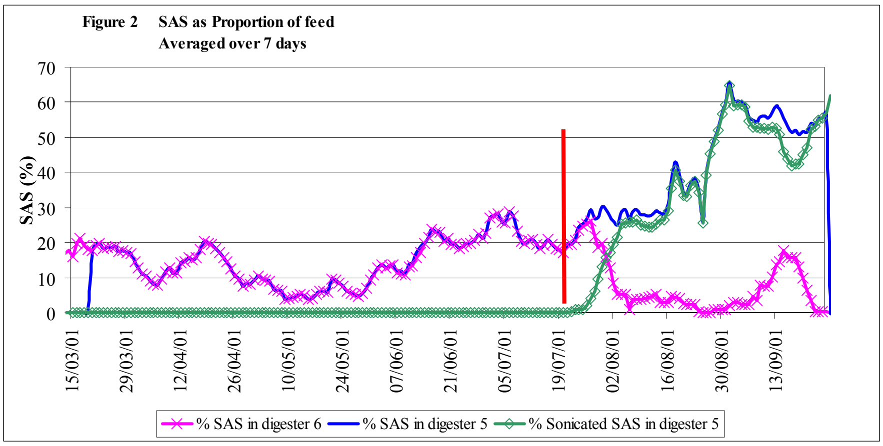
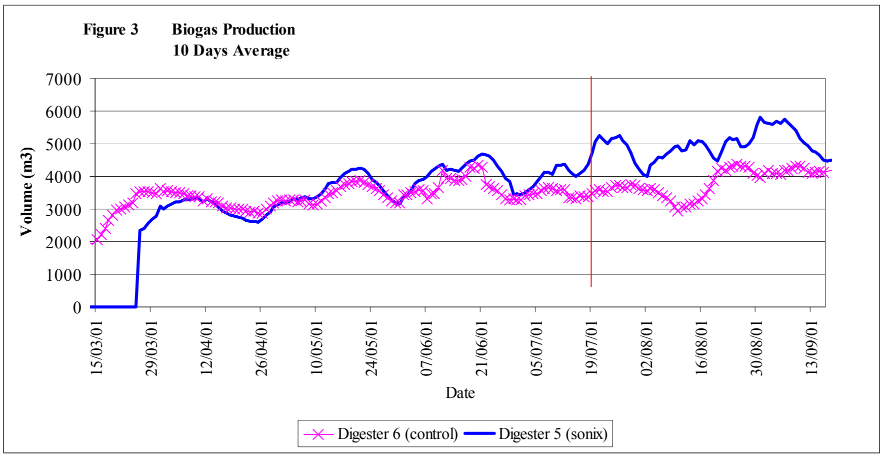
Figures:







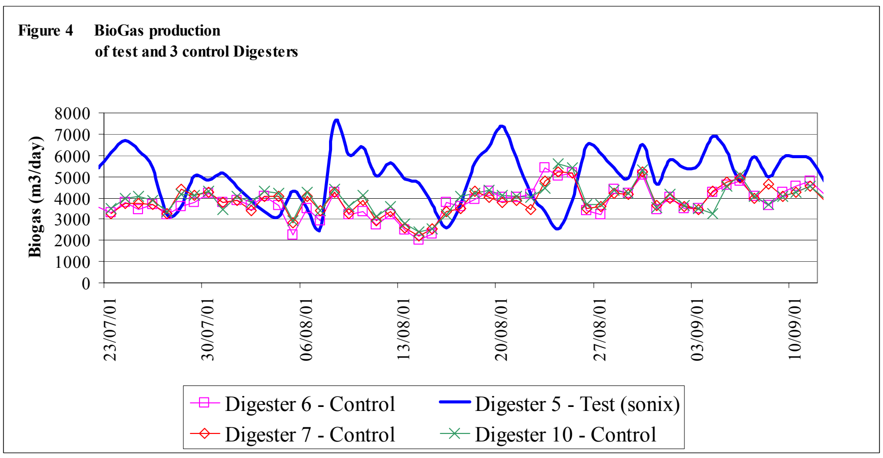


Figure 5 Biogas Produced per m3 of Sludge Fed

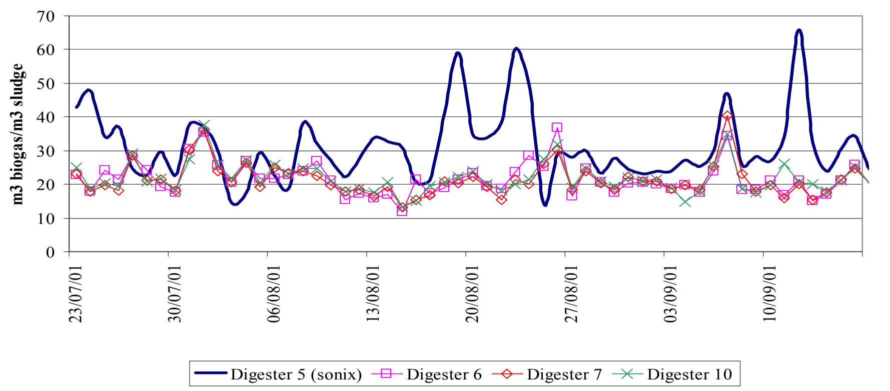


Figure 6 BioGas production and % SAS Feed

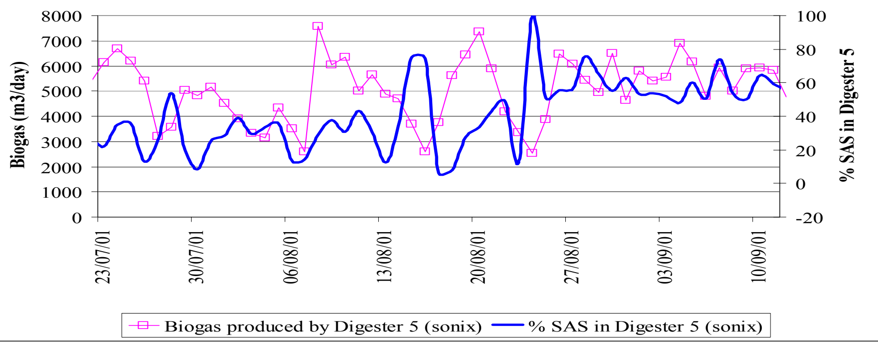


Figure 7 Biogas produced as a funtion of the total solids loadings

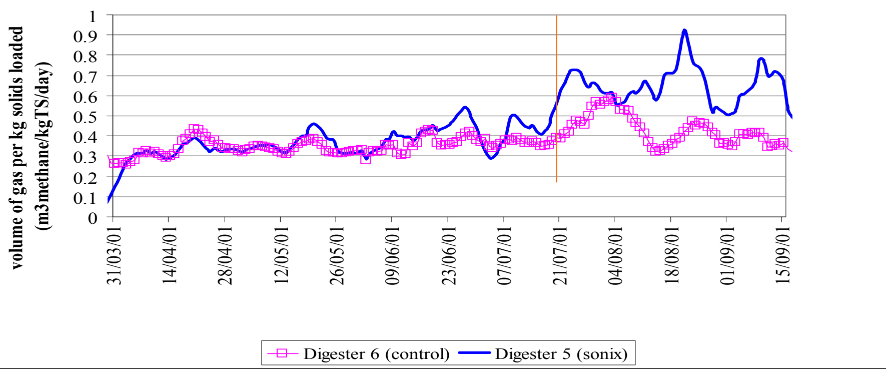


Figure 8 Biogas production as a function of the volatile solids loadings as a 7 day average