Full-scale experiences with anaerobic treatment of industrial wastewater

R.J. Frankin

Biothane Systems International, P.O. Box 5068, 2600 GB, Delft, The Netherlands.
(E-mail: *r.frankin@biothane.nl*)

Abstract High rate anaerobic treatment for industrial wastewater was first applied on a commercial scale in the sugar industry in the mid 70's. Since that time the technology has developed into a standard method of wastewater treatment for a wide variety of industries. The technology is now functional in over 65 countries and a total of approximately 1,400 plants were build by the 16 leading vendors of such systems. These plants account for approximately 65% of the total number of anaerobic treatment plants for industrial applications, which is estimated to be ca. 2,000. From the analysis from a database consisting of 1,215 plants it appears that the UASB technology as originally developed in the Netherlands is the most predominant process. It is also seen that the higher loaded EGSB type systems are gradually replacing at least some of the UASB applications.

Keywords Anaerobic; EGSB; full-scale; high-rate; industrial; UASB, wastewater

Introduction

Anaerobic treatment has gained tremendous success over the past two decades for treatment of industrial effluents. Apparent advantages are to be found in low operating costs, compact construction, production of energy through biogas, low surplus sludge production resulting in overall favourable economics.

For anaerobic treatment to compete with alternative technologies such as aerobic or physico-chemical treatment, it has to be cost effective (in terms of investment and operating costs), reliable and durable. System designs have focussed on increased process control to secure optimal operating conditions and system "compactness" in order to reduce costs of investment.

From a technological viewpoint, the key to successful application of anaerobic treatment is to un-couple the hydraulic retention time (of wastewater) and the solids retention time (of active biomass) in the reactor system. In order to achieve high system loading rates, short hydraulic retention times should be applied, whilst at the same time maintaining a positive net solids (biomass) retention. Various reactor designs were developed over the past two decades that are based on various ways of retaining biomass within the reactor system. Recently, information on the implementation of anaerobic technologies used for the treatment of municipal and industrial wastes and wastewaters was collected (Hulshoff Pol *et al*., 1998). In this contribution, a detailed overview is given of the anaerobic systems currently used for the worldwide treatment of industrial wastewaters.

Lagoons

For low loaded systems such as anaerobic lagoons this uncoupling of hydraulic and solids retention time is not critical and no active attempt is made to design for biomass retention. The hydraulic and solids residence time in the system is high enough to allow biomass to develop and carry out the conversions. This system is very popular in India and other regions where land is available at low cost and controlled operation is not feasible. Of all systems built the low-loaded lagoon process is the most commonly used (Totzki, 1998).

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Designs vary from simple anaerobic pond type to professionally engineered systems as promoted by e.g. ADI in Canada.

Anaerobic contact process

The anaerobic contact process utilises a clarifier to settle out biomass solids external to the actual bioreactor. These solids are subsequently recycled back to the reactor, hence increasing biomass retention time. This system involves bulk volume tanks and is generally considered not competitive except in those cases of treatment of high solids or high fat/protein content wastewater. Purac from Sweden and Biothane from the Netherlands are active promoters of this process for specific applications.

Upflow Anaerobic Sludge Blanket

The Upflow Anaerobic Sludge Blanket (UASB) design as originally proposed by Lettinga was one of the earliest systems to rely on the establishment of a granular biomass (Lettinga and Hulshoff Pol, 1983). Due to the excellent settling characteristics of this granular biomass, a good sludge retention is assured also by virtue of specially designed three phase (biogas, water and biomass) separators. This technology originates from the Netherlands and is promoted by companies such as Biothane, Biotim (from Belgium), Grontmij, Haskoning, Kurita (from Japan) and Paques.

Fixed film or anaerobic filter

Immobilising biomass on a fixed carrier is an alternative method of retaining biomass. One common system in use is the fixed film system (sometimes referred to as fixed bed) in either upflow or downflow mode. The apparent disadvantage of this system is the cost associated with (bulky) carrier material and its relatively low loading potential. The system is successful in operation e.g. on chemical wastewater (AMOCO system, Van Duffel, 1993). Proserpol from France actively promotes the process.

Fluidised Bed system

The Fluidised Bed (FB) system as developed in the early eighties uses the phenomena of immobilisation of biomass on a fluidised carrier material (like sand, basalt, pumice and the like). The problems encountered in this system were based on excessive growth on the carrier under mild shear conditions (top part of reactor) and no growth on the carrier under high shear conditions (low part of reactor) necessarily required to fluidise the carrier. The last FB biomass on carrier system build was by Degremont in 1996. Nowadays the biomass on carrier system seems to be disappearing from the market place.

Hybrid

The hybrid system combines both features of the fixed bed system (in the top of the reactor) as well as the UASB system (use of granular biomass). ADI is actively promoting this process e.g. for chemical applications.

Expanded Granular Sludge Bed and Internal Circulation systems

The latest generation of anaerobic treatment system is the Expanded Granular Sludge Blanket (EGSB) process (Zoutberg and de Been, 1997) and Internal Circulation (IC) process (Hack *et al*., 1987).

To cope with the aforementioned problems with the FB system Biothane turned the FB system, initially developed by Gist brocades (Heijnen, 1983) into an Expanded Granular Sludge Bed (EGSB) system (Versprille *et al*., 1994) making use of a granular biomass rather then fixing to a carrier. This system uses a granular biomass, which is expanded by gas and hydraulic forces. Biothane actively promotes it as the Biobed process. The IC system makes use of an internal circulation driven by a gaslift and is known as the BiopaqIC (Pereboom and Vereijken, 1994) promoted by Paques.

The advantages of these systems are found in its small footprint and high loading rates. These high rate systems appear to be outcompeting more conventional systems from an economic and performance standpoint as will be seen in the analysis (this article). Both systems are categorised as EGSB in this article.

In this article a historical overview will be presented of the success of various processes, their application areas and their geographic distribution.

Method

A database was compiled using the reference lists from the relevant vendors. In case no reference list could be obtained, data for plants will be under the heading of "others". Totzki (1998) presented a similar overview in 1998 for a large number of different vendors. Actual data not obtained directly from the vendors were taken from the Totzki analysis to estimate total number of plants operational worldwide.

Results and discussion

Table 1 shows the vendors that provided their references including the number of plants to which the results and information in this article relate. Plant information obtained on plants not directly provided by the vendor are accumulated under "others".

From the Totzki article referred to above it is noted that a total of 7 vendors exist with each more then 10 plants constructed which are not included in the current database. The total of plants realised by these 7 vendors was 243 in 1998. It is estimated that the top 16 vendors (some of which have already disappeared from the market or were merged into larger groups) have built a total of 1,400 plants. With the current database 1,215 plants represent approximately 80–85% of all plants realised by the top 16 vendors.

Totzki estimated in 1998 the total number of plants operational in the world at 1,700+. The number should at the current time be estimated to be around 2,000 so the current database represents probably some 50–60% of the total plants currently in operation (engineered systems). This obviously is excluding thousands of anaerobic lagoons installed in Latin America, China and India.

For the analysis of trends we have assumed that the current database represents a good overview of "engineered systems" applied for anaerobic industrial wastewater treatment.

Historic growth of number of anaerobic treatment plants

Figure 1 shows the cumulated number of anaerobic treament plants installed by the vendors in the database. The total number is 1215 installed in 65 different countries.

Table 1 Full scale plants for Industrial applications

Vendor	Number of plants	System
ADI	98	Lagoon, hybrid
Biothane	297	Contact, UASB, EGSB
Degremont	94	Contact, FB, Fixed Bed, other
Grontmij	38	UASB
Kurita	53	UASB, EGSB
Paques	370	IC, UASB
Proserpol (SGN)	48	Fixed Bed
Purac	67	Contact
VA TECH (CT Umwelt/Sulzer)	62	Fixed Bed, Lagoon
Others	88	Mainly UASB
Total in data base	1215	

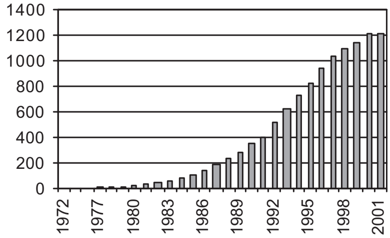

Figure 1 Cumulative number of anaerobic treatment plants for industrial applications

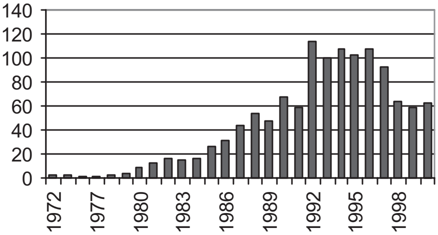

Figure 2 Number of plants installed per year

The total number of plants built was ±100 per year from l992 to 1997. At present this number seems to be reduced to around 60. This is mainly caused by a reduced number built in Asia.

Figures 3 and 4 show the number of plants built per year by the vendors in the database in N-America and in the EU. It appears that the number of plants built has stabilised in the EU to a level of 20–30 per year, whilst in N-America the number seems to be reducing since 1997. Given the size of the N-American market and its industrial activity it can be concluded that the potential for anaerobic treatment has not yet been fully exploited in this region.

From Figure 5 it can be seen that the economic crisis which emerged in Asia in 1997 impacted implementation of anaerobic treatment drastically. It can be seen however that the region under "normal" economic circumstances is good for 40–50 plants per year. For this analysis India is also considered part of Asia. S-America saw a nearly linear growth of number of plants until 1997 (Figure 6). Of all plants approximately 70% were built in 12 countries. These are listed in Table 2.

Process selection

Table 3 shows the number of plants categorised per type of process. In earlier investigations in 1997 we found that UASB occupied some 62% of all plants. This number has reduced to 56% due to the growing number of EGSB plants. At present 50% of all plants built by vendors in the database is based on the EGSB type process. Over the past 4 years (1997–2000) the average of granular technology based installations (UASB and EGSB)

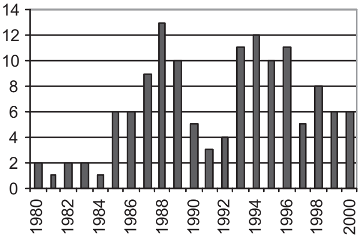

Figure 3 Anaerobic plants built in N-America

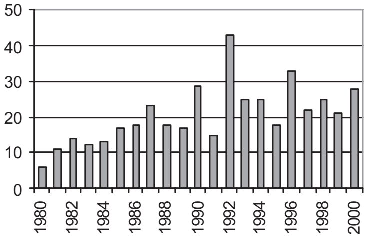

Figure 4 Anaerobic plants built in the EU

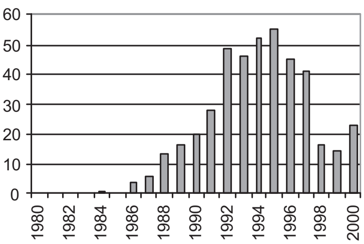

Figure 5 Anaerobic plants built in Asia

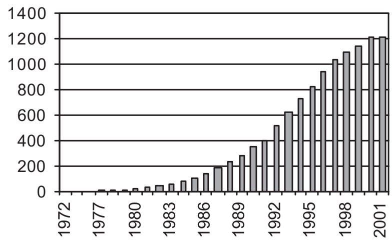

Figure 6 Anaerobic plants built in S-America

Table 2 Number of plants in various countries					
India	150	Germany	94	Mexico	27
Japan	122	Brazil	82	Canada	26
USA	108	France	49	Taiwan	25
Netherlands	98	China	36	Philippines	22

Table 3 Processes used by vendors in database

Process	Number of plants	% average in database	% average over 1990–1996	% average over 1997–2000
EGSB	198	16	8	50
Low rate (lagoon/contact)	187	15	12	8
UASB	682	56	68	34
Fixed Bed	54	4	4	3
Fluidised Bed	16	1	2	1
Hybrid	12	1	1	2
Undefined/unknown	66	5	6	3
Total in database	1215	100	100	100

has increased to 84%. This is a significant increase relative to the percentage of 76% over the period of 1990 to 1996. Overall granular sludge systems are gaining popularity over other processes.

Figure 7 shows the development regarding changes of process selection in granular sludge systems over time. It is apparent that the traditional UASB system is gradually being replaced by ESGB type systems. This is due to the effectiveness and competitive advantages of the EGSB system.

Industrial applications

Table 4 shows the industrial applications where plants were built by the vendors in the database.

Applied loading rates

From Figure 8 it follows that the average (design) loading rate for the EGSB plants in the database (N = 198) is somewhat over 20 kg COD/m^3.day. This is two times higher then the average loading rate for UASB which is 10 kg COD/m^3.day (N = 682).

The higher design loading rates determine lower cost for reactors, which contributes to the overall cost competitiveness of the process. This explains further the trend as observed in Figure 7.

Table 4 Applications served by vendors in database

Application	Number of plants	%
Breweries & beverages	329	27
Distilleries & fermentation	208	17
Chemical	63	5
Pulp & Paper	130	11
Food	389	32
Landfill leachate	20	2
Undefined/unknown	76	6
Total in database	1215	100

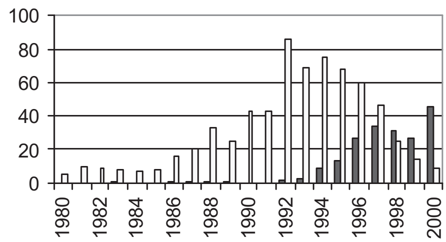

Figure 7 Total number of UASB plants (open bar) and EGSB plants (filled bar)

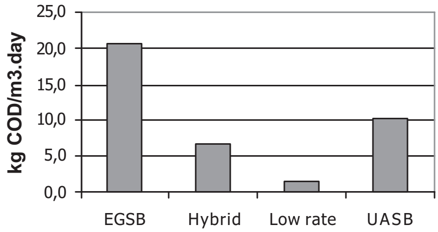

Figure 8 Design loading rates for various processes

Conclusions

From the data presented it becomes clear that anaerobic treatment is an established technology for a wide variety of industrial applications. The technology is accepted in the industrialised western world as well as in less developed countries. The granular sludge based processes UASB and EGSB gradually take a large portion of applications. And although UASB still is the predominant technology in use, at present ESGB type processes are gaining more popularity driven by economics. The data evidence that the design load for EGSB systems is approximately double that of the UASB process, which results in a competitive advantage over lower loaded systems. It should however be noted that the data presented represents approximately 50–60% of total anaerobic systems installed and contribution of EGSB and IC systems may be relatively high in the current database relative to total number of systems installed.

Acknowledgement

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References

Duffel, J. van (1993). *Anaerobe behandeling van organische zuren*. Presented at the national conference on Anaerobic Treatment of Complex Wastewaters, Breda, The Netherlands (in Dutch).

Hack, P.J.F.M., Vellinga, S.H.J., Habets, L.H.A. (1987). *Growth of granular sludge in Biopaques IC-reactor*. Proceedings of the GASMAT workshop Lunteren, The Netherlands, 25–27 October 1987, ISBN 90-220-0936-X.

Heijnen, J.J. (1983). *Development of a high rate Fluidized Bed Biogas reactor*. Proceedings of the Eur. Symp. November 23–25. Noordwijkerhout, The Netherlands.

Hulshoff Pol, L.W., Euler, H., Schroth, S., Wittur, T. and Grohganz, D. (1998). *GTZ sectoral project "promotion of anaerobic technology for the treatment of municipal and industrial wastes and wastewater"*. Proceedings of the Fifth Latin-American Seminar on Anaerobic Wastewater Treatment, Vina del Mar, Chile, 27–30 October 1998.

Lettinga, G. and Hulshoff Pol, L.W. (1983). *UASB process design for various types of wastewater*. *Wat. Sci. Tech.* **24**(8), 87–107.

Pereboom, J.H.F. and Vereijken, T.L.F.M. (1994). *Methanogenic granule development in full scale internal circulation reactors*. *Wat. Sci. Tech.* **30**(8), 9–21.

Totzki, D.E. (1998). *Anaerobic treatment technology overview*. Paper presented at Anaerobic seminar, Milwaukee, USA.

Versprille, A.I., Frankin R.J. and Zoutberg, G.R. (1994). *Biobed, a successful cross breed between UASB and fluidised bed*. In 7th Int. Symp. On Anaerobic Digestion, RSA(pty) Ltd, Goodwood, 587–590.

Zoutberg, G.R. and de Been, P. (1997). The Biobed EGSB (Expanded Granular Sludge Blanket) system covers shortcomings of the UASB reactor in the chemical industry. *Wat. Sci. Tech.* **35**(10), 183–188.