MARKET ANALYSIS FOR UASB SEEDING GRANULES: LOCAL AND INTERNATIONAL MARKETS

Report to the
Water Research Commission

by

N Musee and L Lorenzen
Department of Process Engineering
University of Stellenbosch

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Table of Contents

Abbreviations

AF Anaerobic Filter

BOD Biological Oxygen Demand (mg O2/l)

COD Chemical Oxygen Demand (mg O2/l)

CSTR Continuously Stirred Tank Reactor

EGSB Expanded Granular Sludge Bed

FB Fluidized Bed

HRT Hydraulic Retention Time (hours or days)

HS Hybrid Systems

IC Internal Circulation reactor

MBR Membrane Bed Reactors

SRT Sludge Retention Time (hours or days)

TS Total Solids (mg/l) or (%)

TSS Total suspended solids (mg/l)

TVS Total Volatile Solids (mg/l)

UASB Upflow Anaerobic Sludge Bed

VS Volatile Solids (mg/l) or (%)

VSS Volatile Suspended Solids (mg/l)

1 Introduction

1.1 Problem background

The concept of the upflow anaerobic sludge blanket (UASB) process was discovered by Dr Bill Ross in South Africa in the late 1960s. In the early 1970s, Lettinga and co-workers of The Netherlands (Lettinga et al., 1979) solved the problem of ensuring long resident time for the seeding granules in the reactor. Consequently, the UASB process became the most efficient and highly stable anaerobic wastewater treatment technology for treating high strength effluent.

What made the UASB technology a great success since 1970s up to the 1990s – while many effluent treatment technologies were introduced into the market and vanished within short period of time?

First, the basic knowledge about anaerobic digestion and particularly the UASB reactor was freely accessible to companies interested in producing parts of the reactor – which led to several new firms emerging from the early intensive cooperation between industry and research institutions. Unlike other numerous technological discoveries where companies protect the intellectual property through patent instruments – the UASB technology was never patented. In fact the Biothane Corporation and Paques Inc – the world leaders in this technology – only patented partial improvements to the reactor. Since then, the UASB reactor design continued to be refined (Nederhorst et al., 1986).

Secondly, political-related factors propelled the development and wide application of the UASB technology in Europe and North America. The political reasons are mainly two fold. On the one hand, the energy crisis of the early 1970s resulted in severe fuel shortages in Europe and the North America – particularly the USA which was heavily depended on oil supplies from the Middle East. The actual oil shortages lasted only for a few months, and by March 1974 the supplies were generally back to normal, however, the prices for crude oil quadrupled during the crisis period. The most affected country in Europe was the Netherlands as it was closely linked with the support of the State of Israel, and therefore, was heavily targeted by the OPEC countries in form of oil sanctions. It is in this context that the Netherlands government and industries invested heavily on alternative energy sources. Because the UASB technology proved not only effective in treating the effluent, but also as net producer of energy in form of biogas – huge investments were made to nurture it through experimental phase, hence allowing the technology to mature within a very short period.

On the other hand, the mounting waste regime which begun in the 1960s occasioned by the recovery of OECD states from economic melt down due to the second world to forced companies to seek technologically-driven alternatives that can treat the effluent to acceptable standards before its release into the environment. For the government to compel companies to meet their environmental-related obligations – stringent legislative and high taxes regimes instruments were introduced to force heavily polluting companies to invest in new environmental technologies to address the pollution problem.

In this context, the UASB technology found gradual wide acceptance in diverse industries particularly in Europe. In addition, growing public environmental awareness at the time forced governments to introduce new legislations to protect surface waters, which pressured polluting industries and created incentives for them to explore new methods of wastewater disposal. Again, this propelled the growth of UASB pilot plants together with basic knowledge about anaerobic purification as evidenced by their wide adoption in diverse industries. This aspect will be comprehensively addressed in Chapters 3 and 4.

1.2 Research problem context

In the South Africa context the Water Research Commission (WRC) sponsored research on the development and cultivation of the UASB granules since the late 1990s. This was in response to the limitations identified by the wastewater treatment industrial sector in the country that inhibited full-scale and wide application of UASB for treating high strength wastewater. The most prominent challenge was identified as the inability to easily access high quality granular sludge required for the seeding purposes of new UASB type reactors. The granules comprise of engineered anaerobic consortia needed to expand the catabolic diversity of sludge and shorten the period of adaptation to recalcitrant and toxic substrates (Liu et al., 2003). This symbiotic community of anaerobic microorganisms forms during wastewater treatment in an environment with a constant up-flow hydraulic regime. The granular ecosystems comprise a consortium of diverse bacteria that has the capability to degrade the complex organic waste streams (Liu et al., 2003).

Comprehensive discussions on the challenges facing developing countries in their endeavor to access high quality granular sludge have been well motivated by Britz et al. (1999). In South Africa this challenge was addressed through the development of specialized microbial consortia via induction of desirable biochemical pathway (Britz et al., 1999) as well as designing and fabricating a laboratory-scale reactor to produce the granules (Els et al., 2005).

Notably, the granular sludge constitutes the most prominent characteristic that differentiates the UASB reactors from other anaerobic technologies (Liu et al., 2002). In previous studies, Lettinga and co-workers (1980) demonstrated the close correlation between the efficiency of a given UASB reactor, and the quality of the sludge used for the start-up process. Consequently, access to high quality granular sludge is critical for the optimal functionality of a UASB reactor particularly during the start-up period. It is clear from the foregoing that, reactor start-up is a very important economic process step as it determines the efficiency and success of a given effluent treatment plant using the UASB technology (Els et al., 2005).

However, from these previous studies, due to the small size of the laboratory scale reactors, it is unfeasible to conclusively establish the full-scale operating parameters and conditions of a reactor to fabricate the sludge granules at industrial scale. Therefore, a need to design, fabricate, seed, optimize and commission a pilot-plant for producing UASB granules ranging between 100–1000 kg has been envisaged as the next research phase. The research findings from the pilot-scale plant are envisaged to aid in achieving the long-term goal of designing and developing a full-scale industrial plant. For example, the pilot plant is expected to facilitate in establishing the most optimal operating parameters and conditions suitable for fabricating granular sludge in a full-scale industrial plant.

However, from a strategic and policy perspective on the part of the WRC – it is imperative to establish if the demand for the UASB granules has continued to grow both at national and international markets as was the case in the late 1990s. Consequently, the findings of this study are significant in two ways. On the one hand, to inform the decision processes in the WRC in terms of whether to continue or discontinue funding the UASB granulation projects at the pilot-plant scale phase based on science-driven evidence. On the other hand, use the market demand for the seeding granules to determine the size of the full-scale plant required after future demand market has been well understood.

Up to now, no market research focusing on the UASB granules demand in South Africa has been reported previously. Therefore, in the present study, the objective is to establish the size of the market demand for granular sludge in South Africa and internationally. The study findings will aid in making recommendations for the way forward.

1.3 Anaerobic digestion systems

Anaerobic processes have been used for treating wastewaters from industrial and domestic sources for over a century (McCarty, 1981). The success of the anaerobic processes has been more remarkable over the past three decades (Frankin, 2001). By 2001, since the construction of the first commercial high rate anaerobic treatment plant for industrial wastewater in sugar industry – the technology had been extended to a wide variety of industries in over 65 countries, and 1 400 plants had been commissioned globally (Frankin, 2001). These plants accounted for approximately 65% of the total 2000 anaerobic treatment plants for industrial applications (Frankin, 2001).

The success of the anaerobic treatment systems can be attributed to numerous benefits including: apparently low operating costs, compact construction, energy production in form of biogas, low surplus sludge production, source of re-usable water, fertilizer (soil conditioner), among others – which provide favourable economics. However, for the anaerobic digestion processes to be appealing in wastewater treatment – especially in the developing countries such as South Africa – the systems must be characterized by: minimal need for high skilled manpower, low operating and maintenance costs, low energy inputs, high system throughput, and small 'footprint size' in terms of land requirements for constructing the plant. Hulshoff et al. (1997) highlighted the need for further technical development of small-scale sewage treatment units incorporating adequate post-treatment processes to remove pathogens, residual biological oxygen demand (BOD), and nutrients. Again, these small scale units should be simple, reliable and of low cost.

Generally, the development of anaerobic digestion technology for wastewater treatment has been proven in the developing countries – both for domestic and industrial purposes. This renders the technology a suitable technical and economically feasible solution (Foresti, 2001). In summary, the merits of anaerobic digestion technology in comparison to its close competitor – the aerobic technology are presented in Table 1.

Table 1: Comparison of anaerobic and aerobic systems (adapted from Environasia, 2001; Aiyuk et al., 2006)

	Anaerobic treatment	Aerobic treatment
Operational conditions	Without pre-settling Most suitable for medium to high strength wastewaters Usually for warm wastewaters (> 20 °C) Very few toxic components are allowed Treatment of alkaline wastewaters without neutralization	Preferably after pre-clarification Best for low concentration effluent streams Rather for cold wastewaters (<20 °C) Toxic components tolerable Neutralization for alkaline wastewaters required
Energy	Positive net energy producer during operations through biogas production Not need for external energy sources from fossil or minerals sources	High input energy requirements throughout the process High energy needs from fossil or energy sources
Environment	Very low sludge production (DS/kg $COD_{removed}$ & m3/kg) ~ 10% aerobic No odour problems and waste air in case of systems using closed tanks Excess sludge well stabilized	High excess sludge production Possible odour problems or volumes of waste for treatment Excess sludge not well stabilized
Process operations	Ability to treat seasonal effluents/batch operations feasible Low values only feasible through post-treatment techniques such as aerobic techniques No significant N or P removal, hence need for post-polishing stages High volumetric loading rates No danger of clogging from sludge growth	Must be continuous as shut-downs are not allowed Final low effluent values attainable through multi-stage/cascade design Simultaneous N and P removal Low volumetric loading rates Clogging danger, when using carrier material
Economics	Small plants are economically infeasible High investment costs Low operation costs due to: no power consumption (e.g. 1 kg COD ~ 0.5 m^3 ~ 1 kWh ~ Є0.1 bonus), nutrients removal, no or little excess sludge, Capex/ton COD treated = Є100,000 Opex/ton treated = Є100 bonus	Small plants are economically feasible Relatively low investment costs High operational costs (e.g. ~ 0.4 kg surplus sludge, DM ~ 0.2 Capex/ton COD treated = Є1000,000 Opex/ton treated = Є200 (sludge) + Є100 (electricity)

Despite the merits of anaerobic technology for wastewater treatment, it suffers several delimiting aspects (Lettinga et al., 1999). First, anaerobic systems exhibit high sensitivity of methanogenic bacteria to a large number of chemical compounds. This limits the types of effluents that can be treated by anaerobic technologies. Nevertheless, in many cases the anaerobic organisms are capable of adapting to these compounds. Secondly, the first start-up of an installation without proper seeding sludge is time consuming due to the low growth yield of anaerobic bacteria. In certain cases, this takes up to 12 months. Thus, owing to the slow growth rates of methanogenic bacteria necessitates long retention time before the waste can be stabilized, which leads to high system operational costs.

In treating wastewater containing sulphurous compounds, the anaerobic treatment can be accompanied by odour generation owing to sulphide formation. An effective solution to this problem is through incorporating a micro-aerophilic post-treatment step to convert sulphide into elemental sulphur. Despite of these shortcomings, the performance of the anaerobic reactions can be addressed through advanced reactor design and control of feed rate (Harada et al., 1994; Grant-Allen and Liu, 1998).

The heterogeneity of wastewaters generated (in terms of characteristics, volume, composition, frequency, etc.) from over 30 types of industries (pulp & paper, beverages, breweries, chemicals, pharmaceuticals, etc.) triggered the development of diverse anaerobic technologies as "one technology fits all" approach was found feasibly unattainable. Currently, these technologies are being used for effluent treatment – at different scales worldwide in terms of numbers and size. The anaerobic systems are broadly classified as low-rate (e.g. anaerobic lagoon, ADI bulk volume fermenter (BVF) reactor, continuously stirred tank reactor (CSTR), etc.), high-rate (e.g. UASB, anaerobic contact, anaerobic filter, fluidized-bed system) or ultra-high rate (e.g. expanded granular sludge Blanket (EGSB), internal circulation (IC) reactor, etc.) anaerobic processes.

From market dynamics viewpoint, the growth of the UASB plants globally can be elucidated more profoundly if a comparative study is done against its competitors. Therefore, the growth in UASB plants since 1970s will be compared to those of other technologies such as ADI systems and EGSB subject to available statistics. Only salient features of the most dominant six anaerobic treatment technologies will be summarised in this report. On the basis of how the UASB plants growth has been, its current status, and future anticipated growth – will provide crucial insights on how the seeding granules will grow in the future.

1.3.1 Low-rate anaerobic processes

1.3.1.1 Lagoons

The anaerobic lagoon is the oldest low-rate, and most simple form of anaerobic treatment technology. The hydraulic and solids retention time in the system is sufficient enough (in weeks or months) to allow the biomass to develop and carry out conversions. Owing to inherent limitations of lagoons, they are mostly applied in digesting municipal sludge (Tchobanoglous and Burton, 1991; Grant-Allen and Liu, 1998). Due to odours and the need to control air emissions like methane, an engineered membrane cover is added. Lagoons are widely used outside Europe where land is cheaply available (e.g. in India and Africa) for the treatment of industrial wastes. Anaerobic lagoons are mostly promoted by ADI in Canada. Other forms of low-rate anaerobic processes contribute less than 1% of the anaerobic global effluent treatment capacity, and therefore, will not be discussed in this report.

1.3.1.2 Continuously Stirred Tank Reactor

The continuously stirred tank reactor (CSTR) is the most common form of low-solids reactor feed. The CSTR system has been in operation since 1970s. The feed is introduced into the reactor, which is continuously stirred to maintain a good contact between the biomass and the organic material to be digested. In order to increase the organic load and reduce the retention, biomass is often separated and recycled. As a function of the feedstock characteristics and process temperature, the CSTR retention can be varied, and typically ranges from 2 to 4 weeks. Such systems have low operating costs (Southampton University, 2001).

Generally the CSTR systems are used for treating slurries with total solids (TS) ranging from 2–10% (de Mes et al., 2003). Owing to continuous mixing which creates a homogenous substrate thus preventing the stratification and formation of a surface crust, hence ensuring the solids remain in suspension (de Mes et al., 2003). CSTR systems find wide practical applications in treating sewage sludge, household waste, animal manure, faces, urine and kitchen waste, or a composite of these wastes. Because the bacteria, substrate and liquid have equal retention times, hence the sludge retention time (SRT) equals hydraulic retention time (HRT). Internationally, the CSTR systems are promoted by companies such as the Biothane Corporation and Paques Inc. However, statistically there are very few CSTR plants globally as no more than 3 plants were constructed in any given year.

1.3.2 High-rate anaerobic processes

Sensitivity and the low growth rates of the anaerobic bacteria are viewed as important risk factors of anaerobic systems. The most crucial factors for high rate-anaerobic processes consist of: high solids retention, sludge activity, temperature, and reactor design. The commonly applied technologies in this category include: the air filter (AF), fluidized-bed system (FB), UASB, and hybrid systems which are summarised in the following subsections.

1.3.2.1 Anaerobic filter

The anaerobic filter (AF), also known as fixed film or fixed bed was first commercialized in the late 1980s. The technology is mostly suitable for effluents containing low concentrations of suspended solids (Lettinga et al. 1979; Speece, 1983; Jördening and Buchlonz, 1999). It relies on an inert solid media support (e.g. wood, ceramics, plastics or glass) for growth in order to retain the biomass in the reactor. In an AF bioreactor, a large detention time can be achieved with short retention times. It is mostly used for treating low-strength effluents at ambient temperatures, and has found successful applications in the chemical industries.

The merit of AF system lies in its ability to produce high concentrations of active biomass without the use of a settler (Lim and Lee, 1991). On the other hand, its demerits include the possibility of plugging under high load conditions, or if suspended solids are present as well as high costs associated with bulky carrier materials, and relatively low loading potential. Due to recent modifications of this reactor prompted the development of other diverse reactor configurations (Grant-Allen and Liu, 1998). The AF technology is promoted by Proserpol of France.

1.3.2.2 Fluidized-bed system

The fluidised bed (FB) anaerobic technology was developed in the late 1980s primarily to improve the loading rates and to reduce the reactor size. In FB technology, the biomass is immobilized on a fluidized carrier such as sand, basalt, pumice, etc to retain it in the reactor vessel even against very strong hydraulic flow-through rates. The process usually requires recycling of the effluent from the reactor to keep the medium fluidized (Jördening and Buchlonz, 1999). Typically the retention time in the FB reactor is in order of hours, but the need for "carrier material" can be an operational drawback. The last FB biomass on carrier system was build by Degremont in 1996 (Frankin, 2001).

Nowadays the biomass carriers are rapidly disappearing from the market, most likely because of technology problems in full scale systems (Van Lier, 2008). This led to a new generation of "ultra high-rate" reactors being developed and commercialised during the end of 1990s to eliminate the need for carrier material – but still retain a fluidised bed which facilitates good biomass contact (IEA Bioenergy, 2001). The limitations of this technology comprise of excessive growth on the carrier under mild shear conditions (top part of reactor), no growth on the carrier under high sheer conditions (low part of reactor) as well as elevated operating costs due to high power consumption required for recycling phase of the reactor.

1.3.2.3 Upflow anaerobic sludge blanket

Globally, the upflow anaerobic sludge blanket (UASB) technology is well established technique for treating effluents containing high organic concentrations (Foresti, 2001). This is because of its inherent advantages, which have been extensively discussed in the literature (Lettinga, 1995; Verstraete et al., 1996; Seghezzo et al., 1998; Aiyuk et al., 2006). Most of the merits of this technology are summarized in Table 1. The UASB technology was originally discovered by Dr Bill Ross (South Africa) and latter by Lettinga and co-workers (Lettinga et al., 1979; Lettinga et al. 1980). The first full-scale plant was constructed in the Dutch sugar industry in 1976.

The UASB reactor is a high-rate process that operates entirely as a suspended growth system. Owing to high concentration of biomass renders it more tolerable to toxicants contained in the effluent. In fact, the granular sludge is the most prominent characteristic that differentiates the UASB reactors from other anaerobic technologies (Liu et al., 2002). Lettinga and co-workers (1980) demonstrated the close correlation between the efficiency of a given UASB reactor, and the quality of the sludge used for the start-up process.

Therefore, access to high quality granular sludge is critical for the optimal functionality of a UASB reactor particularly during the start-up period. Due to excellent settling properties of the granular biomass good sludge retention is assured by virtue of specially designed three phase (biogas, water and biomass) separators. In the global market for the anaerobic technologies, the UASB is promoted by several companies, viz.: Biotim, Paques, Kurita, Biothane, Haskoning and Gromtmij.

1.3.2.4 Hybrid Systems

The development of hybrid systems (HS) was motivated by the drawbacks of the UASB and AF systems. For instance, in an AF reactor, the presence of dead zones and channeling in the lower part of the filter generally occurs. Moreover, in UASB systems, sludge washout may be a problem in wastewater containing large fractions of suspended solids. Thus, the hybrid technology combines the features of AF (in the top of the reactor) as well as the UASB system (use of granular biomass) as means of eliminating these problems. The filter zone in the hybrid reactor retains the biomass as a biological activity contributing to the COD reduction (Elmitwalli, 2000).

The widely proven hybrid system technology is the ADI-hybrid reactor – which is highly suitable for treating chemical and chemical-type wastewaters. As such, the hybrid reactor has been successfully applied at several complex chemical plants globally. A good example is the treatment of chemical effluent from the purified terephthalic acid (PTA) plant in Taiwan (Paques ADI, 2001). The hybrid is promoted by ADI Systems.

1.3.3 Ultra-high-rate anaerobic processes

Owing to the evolution of the anaerobic processes, the high-rate anaerobic processes were found inadequate for certain applications because their inflexibility and small range of COD concentrations they can handle. This led in the development of ultra-high rate and high capacity anaerobic models characterized by improved sludge-wastewater contact and the use of entire reactor volume efficiently.

1.3.3.1 Expanded granular sludge Blanket and Internal Circulation

The expanded granular sludge Blanket (EGSB) technology is an anaerobic process – which is an out growth of successful operating experience with UASB technology. The EGSB technology incorporates the best features of two technologies, namely; the growth of granular sludge (from UASB) and high loading rates (three-phase fluidized bed technology) (Versprille et al. 1994; Zoutberg and de Been, 1997). Thus, the EGSB system does not require carrier material in order to retain the biomass within the reactor. Thus, the ultrahigh loading rates of the fluidized bed process are achieved with granular biomass, while no carrier material is required for start up or operation. Generally this process is widely perceived either as an ultra high rate UASB, or a modified conventional FB. EGSB is applied in treating effluents from breweries, chemical plants, fermentation industries and pharmaceutical industries. The system is designed to operate at high COD loading (up to 30 kg COD/m^3 day); it is very space efficient – requiring a smaller footprint size than a UASB system. Among the key merits of EGSB process comprise of (Gavrilescu, 2002):

- Simplicity – the Biobed EGSB process (although extremely effective), consists of only two major components within the reactor: the settlers at the top of the tap and feed distribution in the bottom of the tank.

- Flexibility – the influent feed distribution system in the bottom of the reactor has a several feed inlet points to ensure the maximum wastewater to sludge contact. This ensures that channelling or "rat-holing" of the sludge does not occur.

- The settler in the top of the reactor has been designed to accept high liquid and gas velocities, without the need for external clarification.

- Has high volumetric loading rates ranging from 15 to 30 kg COD/m^3 and even higher rates are feasible as function of wastewater characteristics. Consequently, this lead to a small footprint.

- High circulation ratios create inherent hydraulic balancing capacity, and allow for treatment of wastewaters inhibitory, but not biodegradable.

The EGSB is currently marketed globally by the Biothane Corporation as the Biobed process and the IC process known as BiopaqIC (Pereboom and Vereijken, 1994) promoted by Paques.

The BiopaqIC is a very popular ultra-high rate anaerobic reactor (Habets 1999; Grant-Allen and Liu, 1998), and from late 1990s became, for some industrial sectors (e.g. pulp & paper and breweries), the preferred technology over the standard UASB. The reason being, the cylindrical design of this reactor makes it very suitable for applications where land is a premium especially in Europe.

1.4 Historical factors for UASB development

Because the thrust of this project was to analyze the market trends for the seeding granules, it is important to first establish the historical factors that led to the development and inception of the UASB technology in the 1970s. To this end, historical push-factors that influenced the UASB technology development, introduction into the waste treatment markets, wide acceptance, and success in diverse industries are summarized. Recently Raven and Verbong (2004) presented historical reasons for the development of UASB technology, push-factors for its rapid growth in the wastewater industry as well as wide adoption in diverse industries. In this report, only the most salient drivers are summarized.

The first push-factor was the global energy crisis of early 1970s to mid-1980s. Because of the high energy demand by the aerobic technologies – commonly used for effluent treatment in the 1970s and 1980s – led to the development of alternative treatment technologies – characterized by low energy demand per unit throughput. Consequently, the UASB became a highly attractive alternative owing to its ability to produce useful energy in form of biogas, and very low energy demand per unit throughput of the treated effluent (see full comparisons in Table 1).

This viewed in the context of rising energy prices in the early 1970s fuelled rapid introduction of UASB technology for effluent treatment in the 1980s. Estimates of the early 1980s indicated that Dutch farms produced biogas equivalent of about 800 million cubic meters of natural gas, or roughly 1 percent of total gas production in the Netherlands (de Boks and Nes, 1994). Furthermore, the energy crisis of 1973 stimulated energy-saving projects – which played a critical role especially during the experimental phase allowing the UASB technology sufficient time to mature. By the end of energy crisis, the UASB technology was already an established purification method for treating diverse industrial and municipal wastewaters.

Secondly, the waste age begun in the early 1960s after numerous western countries recovered from economic collapse occasioned by the World War II. For instance, many of the European and USA economies were rapidly growing in the 1960s and 1970s – but accompanied by parallel growth in waste quantities. Consequently, growing concerns surfaced from citizens regarding rapidly increasing quantities of waste from industries, and after end of products life span. This culminated to the birth of environmentalism and demand for accountability by enlightened society forcing industries to seek alternative technologies to aid in improving their waste management practices.

In response to the new forms of environmental challenges, the first UASB plant was constructed by a beet sugar company in 1976. Its primary aims were to eliminate odor, and reduce levels of organic carbon in the effluent before it was disposed into ecological systems. Since then, the UASB technology has been applied in diverse industries as will be illustrated in Chapters 3 and 4.

And finally, increasing social pressure and mounting evidence of pollution's ill effects on public health prompted the government to introduce new environmental legislations. In the Netherlands, a law protecting surface waters was enacted in November 1969– followed by a portfolio of new laws in the 1970s and 1980s. For instance, in the Netherlands, in 1976, a law governing chemical waste products was passed (Stb, 1976, 214), followed in 1977 by a general law regulating waste products (Stb, 1977, 425). This, with stringent taxation regime on dumping of waste together with tight regulations for dumping waste introduced between 1980 and 1985 forced industries to adopt technologies – particularly in the European community – that offered superior performance in addressing the pollution problems. In the light of these drivers, among others, the UASB technology has grown in the wastewater treatment industry from less than five plants in the 1970s to over several thousands worldwide.

1.5 Study objectives

In this project, the study objectives comprised of, *inter alia;*

- To establish the suppliers of UASB granules for wastewater treatment in South Africa, for industrial and municipal treatment plants.

- To establish a comprehensive database for the companies that use (industrial sectors) that use UASB technology for wastewater treatment in South Africa.

- To establish the producers and suppliers of UASB granules internationally.

- To establish the market size of the UASB granules, both in South Africa and the international markets through market trends analysis.

- Investigate new technologies that may have been introduced into the wastewater treatment market as potential competitors to UASB technology.

2 Methodology

To investigate the market dynamics of the UASB technology locally and internationally and to meet the study objectives – three methodological approaches were employed. This was to facilitate robust collection of data, information and knowledge essential in arriving at informed conclusions and recommendations on the economic feasibility of generating UASB granules commercially in South Africa. The methods employed comprised of: literature survey, questionnaires, and interviews. The different choice of approaches was aimed at complementing and cross-validating data and information derived from each method. In the following sections, each methodology will be briefly described.

2.1 Questionnaires

To assess the market dynamics of the seeding granules, a written survey was conducted using two forms of questionnaires. The first questionnaire focused on soliciting information from the current industrial users of UASB technology for effluent treatment in South Africa (Type- I questionnaire: Appendix A).The second questionnaire was designed to solicit data and information from experts in UASB technology in South Africa on both local and global market trends of (Type- II questionnaire: Appendix B). Both questionnaires were sent to the targeted recipients, and follow up telephone calls were made later. The companies and experts identified for the exercise were identified through websites, literature reviews, and personal contacts.

The motivation for designing and developing two forms of questionnaires were three fold. First, to ensure optimal acquisition of data and information essential in arriving at informed conclusions and recommendations. Secondly, to minimize the possibility of lacking sufficient data particularly through reliance on a single source (industries or experts), and thirdly, to cater for different perspectives of the study which could not be met through soliciting data and information from a single source (experts or industries).

2.1.1 Type – I Questionnaire

Type-I questionnaire was sent to 13 plants – in diverse industrial sectors such as breweries, food and beverages, municipal treatment plants, chemical and petrochemical, etc. – presumed to be using UASB technology effluent treatment according to information supplied by various experts knowledgeable on the wastewater treatment industry in South Africa. The questionnaire primary aim was to solicit data and information in the following aspects:

- The suppliers of UASB seeding granules to a particular plant.
- Operational base of the suppliers – either in SA or overseas.
- Cost of the granules (rands per tonnage).
- Trends on the quantities of effluent treated using UASB over a certain period of time.
- The performance of the granules and possibly if other alternative technologies are being considered in place of UASB.
- Information on readily availability of seeding granules in SA.
- The type of industrial processes generating the effluent treated using the UASB technology, among other forms of data and information.

2.1.2 Type – II Questionnaire

Type-II questionnaire was designed to facilitate structured interviews with experts in UASB technology in South Africa. 18 experts were identified based on the database compiled through telephone calls and interviews with the initial experts in the wastewater treatment industry known to the researchers. Each expert was mailed a questionnaire, and a follow up call was made to arrange for an interview. The experts were distributed in different among sectors namely academic, consulting, government as well as research and development.

2.2 Desktop literature survey

The first part of the project focused on establishing the existence of reported findings on the market dynamics for the UASB technology since its inception in the late 1970s. Very limited findings were found in the literature characterized by varied degrees of data gaps. From the literature survey, several researchers have addressed the market dynamics of anaerobic treatment systems, and these results will be summarized in Chapter 3. To broaden the scope of our literature survey, representative companies in South Africa of the major suppliers of UASB technology internationally were conducted to provide more information in this respect. Primarily, literature survey provided crucial data on growth of UASB technology from its inception in the 1970s. These findings will be summarized in Chapters 3 and 4.

2.3 Interviews

To expand the knowledge on the workings and the current status of the UASB technology, structured interviews were conducted with the experts, and companies operating UASB technology systems in South Africa. Prior to the actual interviews, a set of questions were sent to the individuals to be interviewed, highlighting the data and information relevant to the objectives of this study. The study findings arising from the interviews will be summarized in Chapter 4.

2.4 UASB granular sludge in South Africa

In the late 1990s, the wastewater treatment sector in South Africa identified several challenges that inhibited its full- and wide-scale application of UASB in treating high strength wastewater (Britz el al., 1999; Britz et al., 2002). The most prominent challenge was the inability to easily access high quality granular sludge required for the seeding purposes of UASB type reactors. Typically, the granules consist of engineered anaerobic consortia needed to expand the catabolic diversity of sludge and shorten the period of adaptation to recalcitrant and toxic substrates. A comprehensive discussion on the challenges facing developing countries in their endeavor to access high quality granular sludge have been well motivated by Britz et al. (1999). However, recently a breakthrough in addressing this problem was achieved in South Africa through the development of specialized microbial consortia via induction of desirable biochemical pathway (Britz et al., 1999) as well as designing and fabricating a reactor at laboratory scale to produce the granules (Els et al., 2005).

To ensure constant and guaranteed high quality supply of seeding granules for the existing UASB reactors and new plants in South Africa – the Water Research Commission (WRC) initiated a research project with the purpose of enhancing the anaerobic sludge granulation process. Primarily this was aimed at meeting the expanding needs for high quality granular sludge in the South African market for treating high strength wastewaters. On the other hand, such supplies were deemed necessary in the event that existing reactors were poisoned through acidification process, or owing to the presence of foreign chemical contaminants in the effluent. The initial studies (Britz el al., 1999; Britz et al., 2002) yielded promising laboratory scale results in terms of artificial enhancement mass of the bio-granulation process (Britz et al., 1999; Els et al., 2005). The scaling up results reported by Els et al. (2005) illustrated that mass culturing of granules holds great promise for application in the UASB technology, specifically in the developing countries like South Africa.

However, from these previous studies – the small size of the laboratory-scale reactors – made it infeasible to conclusively establish full-scale operating parameters and conditions for a commercial-scale reactor for fabricating the seeding granules. Therefore, to realize the initial goals, objectives and aspirations of funding this project by the WRC – first it is essential to design, fabricate, seed, and optimize a pilot-plant for producing UASB granules ranging between 100 – 1000 kg before designing and developing a full-scale plant. Such approach will facilitate undertaking additional research in establishing, first, the optimal operating parameters, and secondly, the environmental conditions suitable for fabricating granular sludge at a full-scale industrial plant.

For the commercial-scale plants to operate economically, it is imperative to ascertain if the demand for the UASB granules – both in local and international markets still exists as was the case in the late 1990s and early 2000s. Such findings are crucially necessary as form the basis in informing decision making in relation to: the size of the full scale plant required, the projected UASB granules demand, and, the underlying market drivers for the granules demand both locally and internationally presently as well as the foreseeable future. Such information and knowledge is important in ensuring long-term success of the granules manufacturing business.

Presently, there is no market research data in South Africa elucidating the extent for the UASB seeding granules demand in the wastewater treatment sector. Therefore, in this study the objective is to establish the size of the market demand for the granular sludge in South Africa and internationally. Notably, several authors have presented global trends on the growth of UASB technology from the late 1970s to early 2000s, and such data will be used to elucidate the granules demand. The findings from the study will then aid in making recommendations on the way forward, specifically in terms of the feasibility of such an industry.

3 Literature Review: UASB Plants Distribution

In this section, the market growth for seeding granules since the inception of UASB technology in the water treatment sector is presented. The market growth demand for the granules is based on the assumption that it is directly proportional to the increase of the UASB plants built locally and internationally. However, though in certain UASB plants the granular sludge ceases activity in the course of the effluent treatment, and therefore necessitating re-seeding of the plant, such demand is deemed insignificant. The reason being, experience shows that globally such cases only occurs twice or thrice in about 10 years[1]. Also, for an optimally operated UASB plant, it produces excess seeding granules, and consequently may not require externally sourced seeding granules.

To establish the size of the granular sludge demand currently in South Africa and globally – a brief historical trend on the growth of UASB plants built globally is presented. Such findings are viewed as essential in terms of providing concise insights into the dynamics of the granular sludge markets over a specified period of time. Equally important, we state right on the onset that data on the annual growth of the UASB plants globally was found to be scarce, erratic, and to a certain extent exhibiting varied degrees of inconsistencies. This point will be become clear as the results of literature review are presented in the next section.

In this review, statistics of the UASB plants globally reported in peer reviewed journals and reports up to 2000 are summarized – to provide preliminary growth trends on the demand for seeding granules. The findings presented in this section do not entail a comparison of the UASB and other anaerobic effluent treatment technologies. Such findings will be presented in Chapter 4. The case studies reported in the literature are described briefly in the following sections.

3.1 Nederhorst et al. (1986)

Recently, Raven and Verbong (2004) summarized the findings of Nederhorst et al. (1986) originally published in Dutch. In 1985 a committee of experts from industry, research institutes, and government concluded that anaerobic treatment was a valuable technology for industrial wastewater carrying easily decomposed organic material (Raven and Verbong, 2004). By then about thirty anaerobic reactors had been built in several countries. With the

[1] Personal Communication, 2007. Interview with Dr Talbot of Talbot and Talbot (Pty) Company.

exception of one fluidized-bed system at Gist Brocades (a biotechnology company that produced yeast), all were UASB reactors. The distribution of the UASB plants globally based on the industry and country distribution are presented in Table 2. Note that, of the total 51 UASB plants operating globally by 1984, 27 of them were in The Netherlands, and none had been constructed in Africa by then.

By broadly grouping industries operating UASB by 1984, the market distribution of these plants can be summarized as follows. The food-related industries commanded a market share of 59% whilst the brewery and alcohol-related industries had only 31%. The rest of effluent treated using UASB technology from other industries accounted for about 10%, mainly from the paper and meat industries.

Table 2: The distribution of UASB plants globally by 1984 (Nederhorst et al., 1986).

Industry Source	Country	Number of Plants
Beet Sugar	Netherlands	7
	Germany	2
	Austria	1
Liquid Sugar	Netherlands	1
Potato Processing	Netherlands	8
	USA	1
	Switzerland	1
Potato Starch	Netherlands	2
	USA	1
Corn Starch	Netherlands	1
Wheat Starch	Netherlands	1
	Ireland	1
	Austria	1
Alcohol	Netherlands	1
	Germany	1
Yeast	USA	1
Brewery	Netherlands	1
	USA	1
Crustaceans	Netherlands	1
Abattoir	Netherlands	1
Dairy Products	Canada	1
Paper	Netherlands	2
Preserved Food	Netherlands	1
Alcohol Production	Thailand	12
Total		**51**

3.2 Lettinga and Hulshoff Pol (1990)

Lettinga and Hulshoff Pol (1990) provided UASB plants statistics constructed before September of 1990[2]. The plants were estimated to be at least 205 with a total effluent treatment capacity of 339 600 m^3, as shown in Table 3. These statistics did not provide UASB plants distribution by country, or by the continent. However, the plants classification was based on wastewater industrial source – and most plants were mainly in alcohol, brewery, pulp and paper as well as food-related industries. These figures were collaborated by Grotenhuis (1992) who summarized the plants distribution as follows: "the UASB technology gained rapid popularity worldwide and there were over 200 full-scale installations by 1992 worldwide".

Table 3: Full-scale UASB plants constructed before September 1990 (Lettinga and Hulshoff Pol, 1990).

Wastewater	**Number**	**UASB-Volume (m^3)**
Alcohol	20	52 000
Baker's yeast	5	900
Bakery	2	347
Brewery	30	60 600
Candy	2	350
Canneries	3	2 800
Chemical	2	2 600
Chocolate	1	285
Citric acid	2	6 700
Coffee	2	1 300
Dairy and Cheese	6	2 300
Distillery	8	24 000
Domestic sewage	3	3 200
Fermentation	1	750
Fruit juice	3	4 600
Fructose production	1	240
Landfill leachate	6	2 495
Paper and pulp	28	67 197
Pharmaceutical	2	400
Potato processing	27	25 610
Rubber	1	650
Sewage sludge liquor	1	1 000
Slaughterhouse	3	950
Soft drinks	4	1 385
Starch (barley, corn, potato, wheat)	16	35 500
Sugar processing	19	23 100
Vegetable and fruit	3	2 800
Yeast	4	8 550
Totals	**205**	**339 609**

[2] The figures reported here were obtained from an anonymous source (Anonymous 1988).

3.3 Fang, Chui and Li (1994) and Alves et al., (2000)

Fang et al. (1994) reported that by 1994 there were over 300 UASB plants globally treating effluents from different plants such as brewery, potato, starch and sugar processing. However, their statistics did not provide a concise distribution of the UASB plants in terms of industrial sectors, or by country. Nonetheless such data clearly points to rapid growth of UASB plants globally over a short period of time. In 2000, Alves and co-workers (Alves et al., 2000) reported that UASB reactors represented more than 65% of all the anaerobic digesters installed for treating industrial wastewater globally. In numerical terms, this translates into more than 900 UASB units operating worldwide. Nevertheless, the authors did not provide the statistics breakdown in terms of the country or industry.

Though these sources did provide plants distribution in terms of country or industry but they serve two important issues in context of this study. First, they indicate rapid growth of the UASB technology globally in terms of few plants in the 1970s to close to 1000 plants by 2000. Again, this attests to wide acceptability of this technology in the wastewater treatment industry. Secondly, it shows rapid growth of the UASB technology within fairly short period of time. This is mainly true given that many effluent treatment technologies are introduced into the market and within five years they are completely phased out or only two to three plants are constructed globally annually. Nevertheless, this is not case for the UASB technology.

3.4 Full-scale anaerobic digestion plants globally

Ross (1994) provided a detailed breakdown of the anaerobic digestion plants in various parts of the world. According to Pauss and Nyns (1990) report, in the 1980s there were three main companies supplying the UASB technology worldwide namely; Paques BV (The Netherlands), Biotim (Belgium) and SGN (France). For instance, in October 1991, 106 full-scale Paques BV UASB plants were in operation globally, and their distribution according to countries is provided in Table 4.

Ross (1994) reported that 80 full-scale anaerobic plants were constructed by Biotim of Germany and SGN of France worldwide mainly comprised of all types of digesters (e.g. UASB, anaerobic contact, upflow anaerobic contact, anaerobic filter, etc.). However, it is unfeasible to elucidate what percentage of these plants were UASB technology-based plants.

By 1991, South Africa had 12 full-scale plants in operation for treatment of industrial effluent using anaerobic digestion technology (Ross, 1994). Only two plants were UASB type reactors namely; the South African Breweries Prospecton in Durban with a daily wastewater flow of 2 600 m^3, and apple processing plant at Ceres with a daily flow of 430 m^3. On the basis of global statistics on the UASB plants in full-scale operation by 1991, it is evident that UASB technology had been established and rapidly expanding as a preferred wastewater treatment technology, hence providing a significant contribution to the international pollution control and energy conservation.

3.5 UASB plants in South Africa and Africa

To establish the market size of the seeding granules in South Africa, it is imperative to examine the growth of the UASB plants in the country. The time line of the UASB reactors growth in South Africa will extent from the inception of the first plant to date. According to Ross (1989), the South African Breweries at Prospecton in Durban had the first UASB plant in South Africa for treating high strength brewery wastewater since in 1985. The growth of UASB reactors in other sectors in South Africa has also grown over the years. To fully understand the market growth for seeding granules in South Africa, we are in the process of establishing the number of UASB plants currently in operation, when they became operational, quantity of effluent treated monthly or annually, among other sets of parameters to be examined.

It is from such data and information on the growth of UASB reactors in South Africa that the future demand for the seeding granules can be established. Likewise, the data and information makes it feasible to postulate future anticipated growth on seeding granules demand in the country. Thorough attempts were made to solicit information on the extent at which the UASB technology has permeated the African continent; no such data was readily available.

Moreover, attempts through interviews with experts working in companies supplying UASB technology in South Africa – to establish the extent this technology has permeated into other African countries – indicated that only less than 10 plants were build in countries out side South Africa in the continent. Other countries in the continent where UASB plants are operated in the Africa continent include; Angola, Ghana, Tanzania, Nigeria, Kenya, Uganda and Mauritius mainly in the industrial sectors related to manufacturing of alcohol, foods and beverages fermentation-related industries. Therefore, in lieu of very low demand for UASB technology in other African countries there is strong evidence pointing towards a low demand for the seeding granules.

Table 4: Distribution of the UASB plants commissioned by Paques BV (The Netherlands) for the treatment of industrial effluents (1981–1991) (Ross, 1994).

Country	Total UASB Vol. (m^3)	Total COD load ($kg.d^{-1}$)	Number of Plants
Australia	2 635	36 500	4
Austria	2 300	3 000	2
Brazil	31 615	294 585	27
Canada	10 000	186 000	2
Finland	1 520	39 500	1
France	3 194	30 050	4
Germany	4 122	34 714	5
India	22 500	225 000	5
Ireland	2 200	17 000	1
Israel	750	7 200	1
Italy	5 375	29 660	4
Japan	100	1 500	1
Korea	754	9 338	2
Mexico	1 330	19 800	1
Netherlands	18 670	128 220	25
Portugal	1 323	15 000	1
Philippines	2 280	34 470	1
Spain	4 900	?	2
Switzerland	1 300	13 200	3
Taiwan	1 963	> 4 800	5
United Kingdom	2 480	23 000	2
USA	2 000	33 000	2
Venezuela	11 889	184 800	3
Yugoslavia	600	?	1
Total	***135 791***	***1 370 337***	***106***

3.6 Summary

In this chapter, brief statistics on the growth of UASB plants globally were presented to illustrate the technology reliability and acceptability for treating effluent from over 30 different industries. This has been feasible after Lettinga and co-workers (1979) provided a solution to the design problem of how to keep the seeding granules into the reactor as long as possible. Evidence of UASB technology growth is shown by the rapid increase of UASB plants of fewer than five in 1979 to 51 plants by 1984. This indicates the UASB plants grew by over 160% annually from 1979 to 1984. However, these plants were distributed in other continents globally – but none had yet been constructed in Africa and Australasian continents till late in the 1980s and early 1990s.

From the onset of UASB technology growth globally, South Africa and entire African continent in general have insignificantly contributed to the overall market size of the UASB technology. This can be attributed to two fundamental reasons. First, it is because of the high cost of constructing the UASB plant. In fact, the cost of the granules is viewed by the experts in the effluent treatment industry as negligible in comparison to the overall cost of building a new UASB plant. Typically, the cost of the seeding granules accounts for less than 1% of the total cost, and usually it is offered as a free service to the client[3]. Secondly, owing to poor or none existence of environmental legislations – in the African continent – compelling companies to treat their effluent to environmentally acceptable standards as is the case in the developed countries. Therefore, the demand for seeding granules appears to be minimal in the continent.

[3] Personal Communication (2007) with an expert in the field of UASB technology involved in designing, constructing and commissioning of wastewater treatment plants in South Africa.

4 Results and Discussions

4.1 Contextualization of study findings

In this section, the study findings are presented and discussed. Notably, in the process of gathering the data and information on the growth of the UASB plants globally – since the inception of the UASB technology – was found to be scanty, inconsistent in certain instances, and very limited. Several reasons can account for this phenomenon.

First, the propriety nature of the data and information held by the technology vendors – makes it difficult to verify the overall accuracy and completeness of the data and information reported in the literature. Second, values for the same year on the number of EGSB or UASB plants installations – even from the same technology vendor differ in certain instances for the same year. This appears to be depended on the source of the data, that is, the vendor supplied statistics appearing in their website, or data sourced from peer reviewed articles. It was also noted that data on the number of installations per year from the same vendor differed considerably after revisiting the website after several months though in reference to the number of plants installed in the same year. Thirdly, worldwide data and information related to many aspects of waste management are limited and incomplete, and from this study, the statistics on the anaerobic digestion systems in general and the UASB technology specifically were not an exception.

To elucidate the growth trends of the UASB technology and indirectly the demand for the seeding granules, the study findings will be presented from four perspectives. The first perspective entails examining the UASB plants growth worldwide as a function of the number of plants supplied by the most dominant market technology vendor suppliers for the AD systems mainly the Biothane Corporation, Pagues Inc., and the ADI Systems Inc.

The second perspective will focus on the UASB technology growth annually in comparison to other AD systems since its inception in the 1970s to 2007 based on the accessible data for the three dominant technology vendor-suppliers (Biothane, Pagues, and ADI). Thirdly, data will be presented to illustrate the growth of UASB plants in different continents, and hence elucidate where feasible markets for the technology may lie in the future. And finally, the data will be examined in relation to the UASB plants distribution as a function of industrial sectors (e.g. breweries, chemicals, pharmaceutical, pulp and paper, food and beverages, etc.). Also, the trends on the number of UASB in these industries in comparison to the EGSB will be presented to show how the future market may be affected by the aggressive introduction of the latter technology.

On the basis of the foregoing stated data analysis approach, it will be feasible to transparently examine past market demand trends for the UASB seeding granules. And secondly, using the findings on the market trends of AD systems – specifically the UASB technology – the most plausible future demand for the seeding granules will be postulated. Finally, market predictions for the future seeding granules demand based on oral interviews with UASB technology experts in South Africa will be summarized. These interview-based results will be compared to the trends established through historical data analysis, and then derive overall conclusions and recommendations of this study.

4.2 AD Plants Distribution Globally

To conceptualize the contribution of the UASB technology for the treatment of industrial and municipal effluent streams, the growth statistics of the AD plants globally are summarized[4]. The growth of the AD technology for the treatment of effluent from industry and other sources has grown dramatically in the last two decades. According to recent findings of Van Lier (2007), there were over 1900 vendor-supplied systems in operation worldwide by 2004. Table 5 provides the categorization of the AD systems as a function of the process type.

In Table 5, UASB technology appears to be the dominant technology in the development and application of AD systems. Figures 1 provides the distribution of AD type systems for effluent treatment constructed and implemented from 1981 to 2004. From these results, the UASB technology dominated the wastewater treatment sector with a market share of about 55% based on 1902[5] vendor-supplied systems. Also, for the purposes of this evaluation – the high-rate systems had the highest market penetration of 68% of the total AD systems. These results are similar to those reported by IEA Bioenergy (2001) – where the high-rate systems had market dominance of 67% based on 1300 vendor-supplied AD systems[6]. The market dominance of the UASB technology will be illustrated in section 4.3 in reference to the number of plants constructed

[4] However, considerable discrepancies were noted in the data as a function of the sources used.

[5] The statistics reported here are based on systems supplied by major global suppliers (e.g. Paques, Biothane, ADI, etc) and the number is much higher if the systems developed by local suppliers in each country are taken into account.

[6] In the findings of IEA Bioenergy (2001), the UASB technology had market dominance of 60%.

annually in comparison to other AD type technology systems. Note that the UASB and the EGSB/IC systems had a combined market share of 74%.

Table 5: Distribution of the AD technology systems from 1981 to 2004 (adopted from Van Lier, 2007).

Technology	1981-2004*	1981-1997*	1998-2004*
UASB	1046	853	193
EGSB/IC	362	87	275
AF	152	147	5
CSTR	152	142	10
Lagoon	95	74	21
Hybrid	57	47	10
FB	38	33	5
Totals	**1902**	**1383**	**519**

* Values presented in this table were provided as percentages in Van Lier (2007).

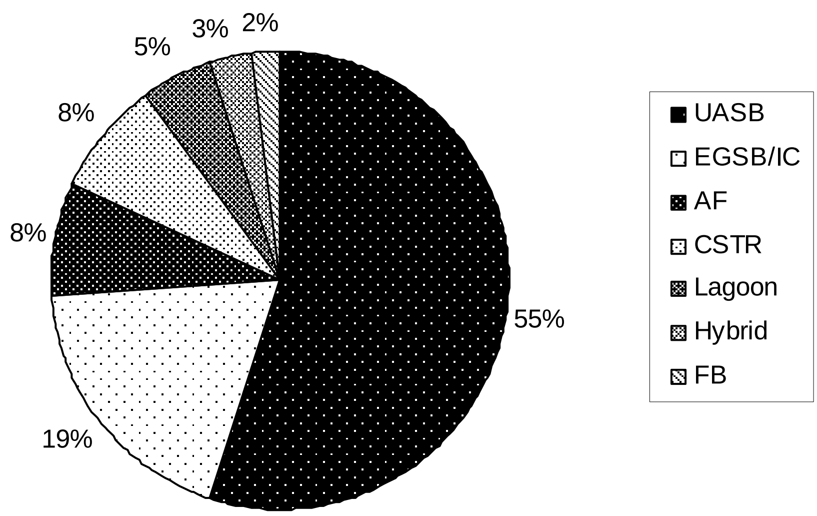

Figure 1: Types of AD systems used for industrial and municipal effluent treatment from 1981 to 2004 globally.

Figure 2 examines the market share for the AD systems from 1998 to 2004 where a total of 519 vendor-supplied systems were implemented. The analysis shows that the ultra-high rate systems (EGSB/IC) gained great popularity over this period with a market share of about 53%. Concurrently, competitive technologies like high-rate systems such as fluidized bed (FB) and anaerobic filters (AF) almost disappeared from the market with each technology having 5 plants constructed over the seven year period. This translates into less than one plant annually in either of these treatment technology systems. The inability of some high-rate technologies in terms of consolidating their market share in the wastewater treatment industry can be attributed to technical problems experienced in various full-scale plants – which rendered them unappealing to the clients.

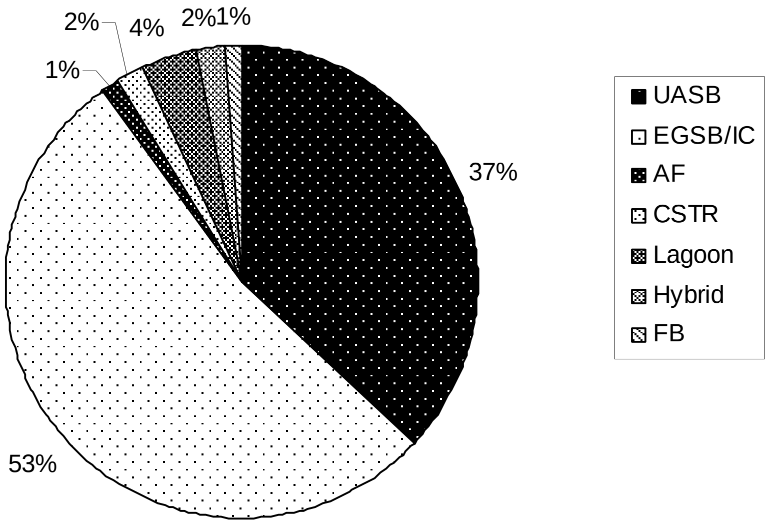

Figure 2: Distribution of AD systems used for industrial and municipal effluent treatment from 1998 to 2004 globally.

On the other hand, the number of ultra-high rate systems increased dramatically in comparison to the conventional UASB systems (see Figure 2). Note that from 1981 to 1997, the ultra-high systems had only a market share of 19%. Nonetheless, from 1998 to 2004 their market share dramatically increased from under 20% to 53%. In fact 275 plants were constructed over 7 year period – with an annual average installation of 39 plants. Van Lier (2007) attributed to the vast growing experiences and the higher availability of the indispensable seeding granules as the basis for high rate uptake of ultra-high rate systems. Hence, it is not unreasonable to anticipate that such systems may become the most dominant AD technology with high market penetration in the future. Again, the UASB and EGSB/IC systems had the combined market share of 90% as other technologies almost disappeared from the market due to competition and high performance of the granular systems (UASB and EGSB/IC).

4.3 Vendor-based AD systems market Analysis

The annual market trends for the AD systems since 1976 – at the inception of the UASB technology – to 2007 is presented. The data were obtained from the vendors' website (Biothane Corporation, 2008) as well as published peer reviewed articles (Frankin, 2001; Kassam et al., 2003). Using statistical data (Frankin, 2001; Kassam et al., 2003; Biothane Corporation, 2008) the annual distribution of the AD systems for the three major suppliers are presented in Figures 3, 4, and 5) for Paques, ADI, and Biothane, respectively.

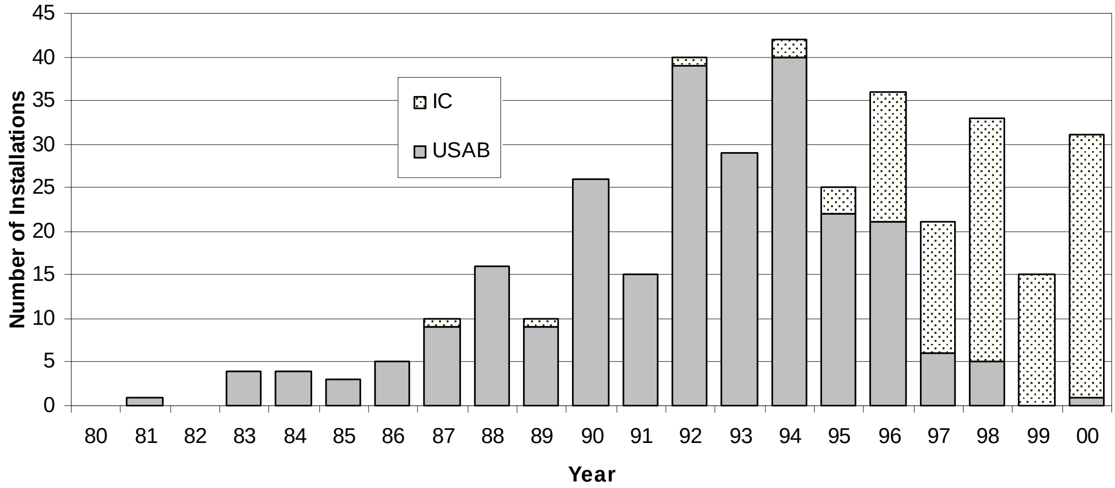

Figure 3: Anaerobic installations by the Paques Inc. from 1980 to 2000 (data source: Kassam et al., 2003).

In Figure 3, the number of the UASB installations by the Paques Inc dramatically increased from under five in 1983 to 40 plants in 1994. This shows a ten-fold increase on the total number of installations within a decade. Nonetheless, only five Paques BIOPAG® Internal Circulations (IC) reactors were installed over the same period. This scenario changed after 1994 where the number of UASB installations rapidly decreased annually to only two by 2000. Over the same period, the IC systems experienced high market dominance increasing from as low as two plants in 1994 to 30 installations by the turn of the millennium Notably, Paques Inc had no operational UASB or IC systems before 1981, however, the statistics in Figure 3 represents a total of 366 installations (USAB: 255; IC: 111) constructed over the 20 year period – which translates on average 12 UASB plants annually.

Figure 4 illustrates the market trends for the anaerobic systems supplied by the ADI Systems from 1979 to 2000 comprising of the ADI Bulk Volume Fermentor® (BVF), ADI Hybrid, and the lagoon technologies. Statistics show that the BVF systems were the most dominant technology supplied by the ADI systems. However, the market growth of this technology remained erratic as no steady trend can be deduced from since its inception into the market from 1980 to 1992. 1993 and 1994 had the highest constructed installations annually, however, thereafter the numbers decreased drastically into single digits reaching a minimum of two plants in 1999. Both the ADI hybrids and the lagoon treatment systems showed decimal market performance as in total there were only 10 installations over the entire period. Equally important, the ADI systems did not install a single UASB treatment system.

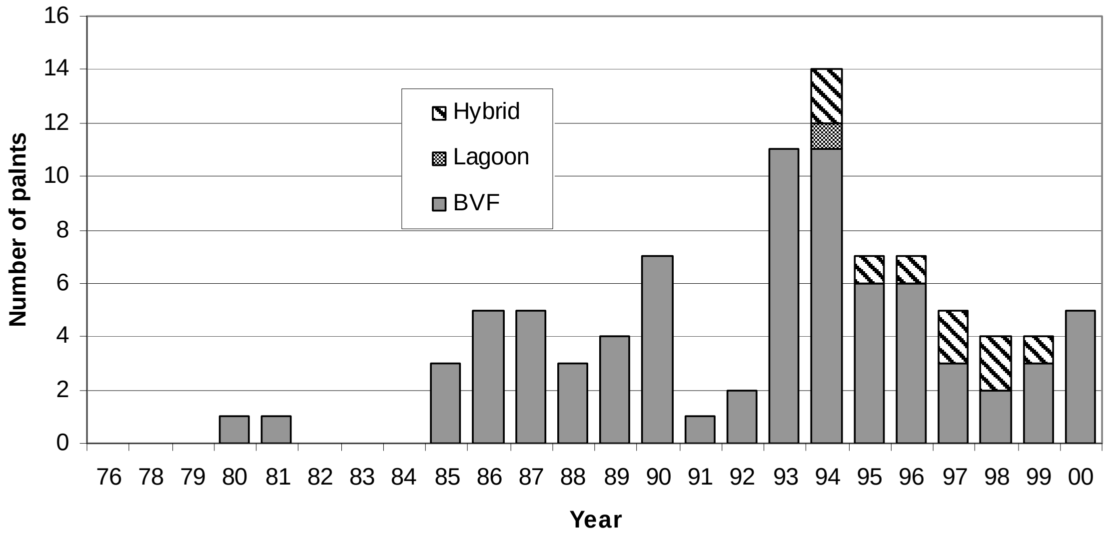

Figure 4: Anaerobic installations by the ADI Systems Inc. from 1980 to 2000 (data sourced: Kassam et al., 2003).

Biothane Corporation was the first company to install UASB reactors in the late 1970s (see Figure 5). Between 1976 and 1990 the market growth for the UASB installations fluctuated significantly, and therefore, no clear growth trend can be deduced. After 1990, the UASB plants increased dramatically to 10 and above per year, however, this growth plummeted to zero by 2000. On the other hand, there were only seven EGSB plants in total by 1993 but the number increased to 13 installations by 1997. The EGSB installations appear to be most dominant after 1997. Though Biothane also supplied CSTR AD systems, company website (Biothane Corporation, 2008) indicates that only six installations were completed between 1992 and 2000, and consequently, they are considered insignificant in this analysis.

Using the latest data on AD plant installations by the Biothane Corporation (2008), the market trend analysis for the UASB and EGSB technologies were re-examined for 32 years from 1976 to 2007. The findings are presented in Figure 6. Over this period, the Biothane installed 413 plants globally with EGSB and UASB technologies being 196 and 243 installations, respectively. From Figure 6, 211 UASB plants were installed between 1976 and 2000 with the last nine years accounting for 64% of these plants. Conversely, from 2001 to 2007 there was a sharp decline in the

UASB installations from double figures annually to single digits – with only one plant completed in 2007. In addition, in the past eight years of the period under investigation, the UASB technology only contributed to 21% of the total plants constructed by the Biothane Corporation globally.

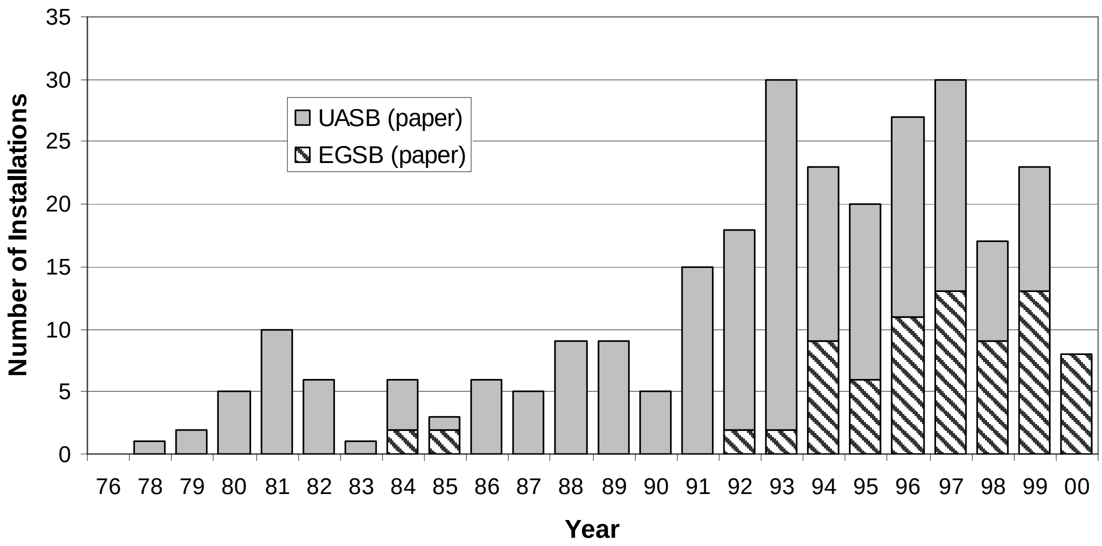

Figure 5: Anaerobic installations by the Biothane Corporation from 1980 to 2000 (data sourced: Kassam et al., 2003).

On the other hand, EGSB experienced slow and erratic market growth in the years preceding 2000 – where it accounted for about 36% of the AD systems supplied by the Biothane Corporation. After 2000, the EGSB installations in the wastewater industry stabilized and exerted a dominant presence where a total of 118 plants were constructed between 2001 and 2007 – accounting for 79% plants installed by Biothane Corporation over the same period.

Through combining the statistics for the AD installations constructed by the three major vendors – the market trend analysis findings are summarized in Figure 7. Notably the Paques Inc and the Biothane Corporation are the major vendor suppliers accounting for 50% and 38% of the AD systems constructed globally between 1978 and 2000, respectively.

The statistics presented in the foregoing discussions depicts the market trends for the most dominant technologies – UASB and EGSB – as a function of time. Primarily they point to the phasing out of high-rate systems such as the UASB owing to market competition occasioned by efficient performance of ultra-high rate systems, in this case, the EGSB and IC reactors. This is true for the installations supplied by the Paques Inc and Biothane Corporation globally where the EGSB and IC systems experienced the highest

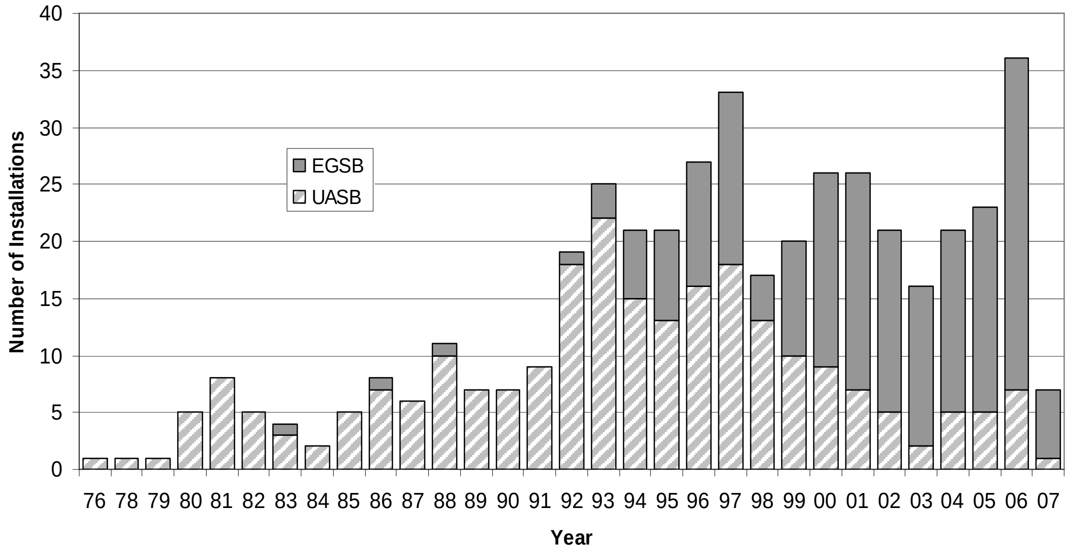

Figure 6: Distributions of annual EGSB and UASB installations for Biothane Corporation from 1976 to 2007[7].

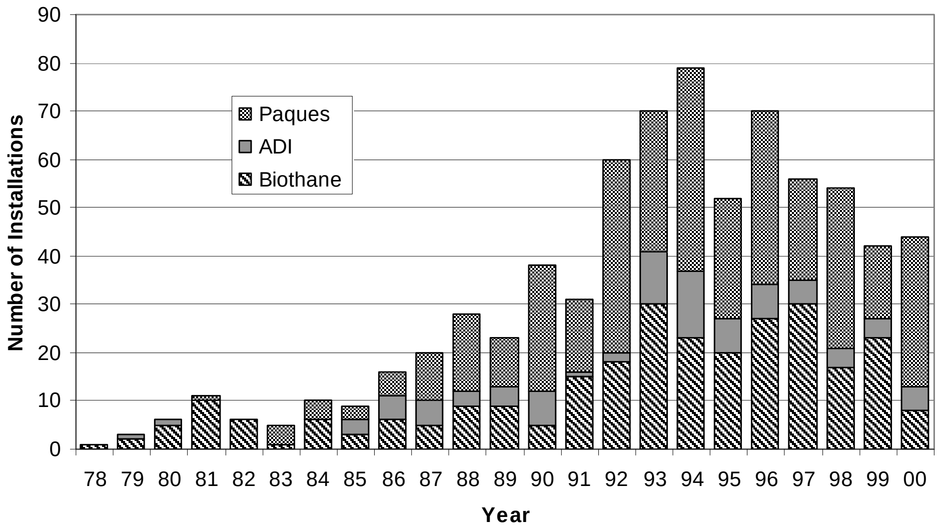

Figure 7: Global installations of AD systems by the three major vendors from 1978 to 2000.

market growth since the turn of the millennium. The high market growth for the ultra-high rate systems can be attributed to various factors including: their inherent small footprint, high loading capacity, ability to handle effluent of wide COD concentration ranges as well as very low HRT. On the basis of these findings it is unlikely for the seeding granules demand required in the traditional UASB reactors to increase in the foreseeable future as the number

[7] Data was sourced from the Biothane company website in March, 6, 2008.

plants under construction has continued to decline rapidly globally over the recent years.

4.4 Geographical distribution of AD systems

Findings of Frankin (2001) illustrated that most of the AD systems were mainly in the organization of economic corporation and development (OECD) countries – with 12 countries accounting for 70% of all the plants built between 1980 and 2000. Figure 8 depicts the AD systems in three continents, namely North America, Asia and Europe. From Figure 8, it appears that the market for the AD systems has stabilized in Europe since 1996 with 20 to 30 installations yearly.

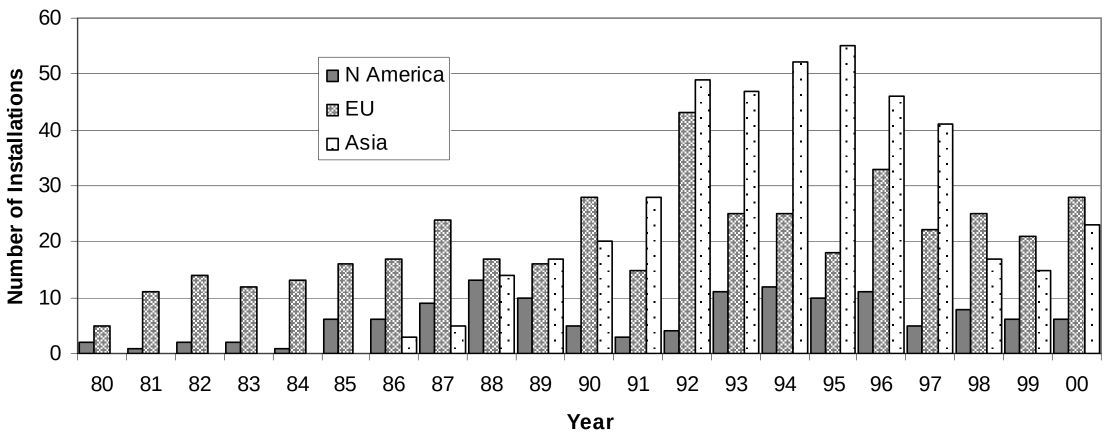

Figure 8: Annual AD systems installations in North America, Asia and Europe

Owing to strong economic growth in Asia especially in the early to middle of 1990s led to high market demand for AD systems – where 40 to 50 plants were installed annually till 1997. Thereafter, the figures plummeted owing to the Asia financial economic crisis of the late 1990s. It should be noted the AD systems entered into the Asian market after 1985 almost over 10 years after the first UASB was contrasted in Europe. Secondly, owing to very low or none existence of AD systems in the African and Australasian continents, their statistics are not featured in this analysis. This shows high market potential for the AD technologies in these two continents that remained untapped.

The American market trend for the AD systems exhibits high volatility, where the installations were less than 10 per year. It is unclear what the underlying causes for such trends are, yet, North

America continent has high diversity and density of industries that generates large quantities of effluent with high organic content.

Frankin (2001) reported that the UASB accounted for 62% of all the plants installed by 1997. Nonetheless, this market performance decreased to 56% as the number of EGSB plants globally increased accounting for about 50% of all the plants installed by 2000. In summary, from 1997 to 2000 – the UASB and EGSB accounted for 84 % of all the global installations as compared to 76% over the period 1990 to 1996. Therefore, it is evident that granular sludge systems experienced dramatic growth in the 1990s; however, this growth favored EGSB systems (see Figures 3, 5, and 6) – which has hedged out the UASB systems from the wastewater treatment industry owing to its effectiveness.

4.5 Industrial applications of AD systems

In this section, the industrial distribution of the AD systems with particular emphasis on the UASB and EGSB technologies is presented. Data from Biothane Corporation (2008) indicates that the company installed 474 plants globally from 1976 to 2007[8]. The technologies are distributed as shown in Table 6. Because the EGSB and USAB are the most dominant technologies with a combined market share of about 93% - their market trend growth before and after 2000 will be further examined.

Table 6: Technology installed in various industries.

Technology	Number of Plants	%
UASB	243	51.3
EGSB	196	41.4
Biopuric	21	4.4
Lagoon	2	0.4
CSTR	12	2.5
Total	**474**	**100**

Table 7 presents the distribution of the UASB and EGSB plants in seven major industrial sectors. The food and beverage industry accounted for the highest number of installations for UASB and EGSB totaling to 154 with each technology accounting for 67% and 33%, respectively. Note that these technologies have near zero application in sewage-related waste streams because of their

[8] From the Biothane Corporation only four UASB plants were installed in Africa between 1976 and 2007 – one in Angola and three in South Africa. No EGSB plant has been installed in Africa yet according to this database.

Table 7: The distribution of the EGSB and UASB plants for the Biothane Corporation from 1976 to 2007

Industry	**UASB**		**Total UASB**	**EGSB**		**Total EGSB**	**Total**	**%**	**UASB %**	**EGSB %**
	≤1999	≥2000		≤1999	≥2000					
Breweries	45	10	55	22	19	41	96	21.9	57.3	42.7
Pulp and Paper	19	0	19	2	21	23	42	9.6	45.2	54.8
Bioethanol	9	3	12	0	17	17	29	6.6	41.4	58.6
Chemical & Pharmaceutical	30	5	35	18	33	51	86	19.6	40.7	59.3
Fermentation	15	2	17	6	7	13	30	6.8	56.7	43.3
Food & Beverages	84	19	103	12	39	51	154	35.1	66.9	33.1
Sewage	0	2	2	0	0	0	2	0.5	100	0.0
Totals	203	41	**243**	60	136	**196**	**439**	**100**		

relatively very low COD concentrations. An analysis on the EGSB and UASB plants installed before and after 2000 yields the following findings. Of the total 243 UASB plants constructed over this period – 83 % were constructed in the period 1976 to 1999. Only about 17% of the UASB plants were constructed between 2000 and 2007. Again, this demonstrates the dramatic reduction of the conventional UASB plants demand in the wastewater treatment industry. Therefore, this indicates declining demand for the seeding granules presently and in future in the international markets.

The EGSB market growth before 2000 was slow mainly in the breweries, chemical and pharmaceuticals as well as food and beverages industries. However, the technology exhibited strong growth in the pulp and paper as well as bioethanol industries after 2000. Factually, the EGSB market grew by 200% between 2000 and 2007 in comparison to pre-2000. In addition, the EGSB (136) technology grew by more than three times the UASB (41) in post-2000. These findings show that the EGSB technology is the most preferred technology for treating high strength effluent in diverse industries. These results are in agreement with those presented by Frankin (2001), and Driessen and Vereijken (2003).

4.6 Questionnaire survey results

In Chapter 2, use questionnaires were used to conduct a written survey to solicit data and information essential for this study in understanding present and future market demand trends of UASB seeding granules. In this section, survey results from questionnaires targeting industries using, or suspected of using UASB, and the experts in the field of wastewater treatment in South Africa, are summarized hereafter. For the purpose of clarity, findings under each questionnaire category will be presented separately.

4.6.1 Type-I questionnaire survey findings

As mentioned earlier, Type-I questionnaire were sent to 13 industrial plants using, or suspected of using UASB technology in South Africa. Only two (n=2) responses were received back, representing a mere 15.3% response rate. Only a single plant returned the questionnaire with the correct information, and the second response indicated that earlier attempts to use UASB technology were unsuccessful in effluent streams generated from chemical and petrochemical processes. This is because of high toxicity which inhibited the growth of the organic granules. Also, the plant that provided the most proficient data accepted an interview to authenticate the results and offered further clarity. It is therefore in the opinion of the researchers that the data it provided was of high integrity and can be relied on. However, because the data and information are only from a single plant, they cannot be used here to draw generic aspects of UASB technology application in South Africa.

The rest of the industrial plants including municipalities did not respond to the questionnaires – even after follow up calls to the relevant personnel. Others did not provide information due to the technical problems of the plants which had rendered them out of service for sometime to problems unrelated to seeding granules. The reasons for non-response from the companies contacted to the questionnaire survey include:

- The commercial agreements between the UASB technology suppliers and the wastewater plant owners. Because of these existing commercial agreements – the industrial owners had no liberty to provide the requested information to the third parties. Similarly, the technology suppliers declined to offer the information after they were contacted citing same reasons.

- Sensitivity of environmental aspects in the present business climate. Many industries operating UASB plants were of the view that – providing the necessary data and information about their operations were equivalent to publicly declaring their level of care to the environment. Consequently, this led them to decline responding to the survey questionnaire;

- Non-willingness of the industrial personnel to grant interview so as to fill up the questionnaire. The exception was in one plant that granted us an interview, and also, filled the questionnaire as comprehensively as possible. Notably, the data provided from this plant was found to be highly reliable and the UASB plant was efficiently run with COD removal performance exceeding 90%;

- Most of the UASB plants were run by the technology suppliers, and therefore, they were custodian of the data and information on the UASB plants. In fact, the data from the plant was periodically sent to the technology suppliers for analysis. Under such circumstances – the plant owners referred us to the technology suppliers – but who declined to respond owing to confidential business agreements with their industrial clients.

- On contacting some of the companies, they indicated that they no longer operated UASB plants, or they never had such a plant. However, no reasons were provided as to why certain UASB plants were no longer in operations.

Owing to the poor responses from the industry – it became unfeasible to meet the second objective in terms of establishing a comprehensive database of UASB plants in South Africa to aid in predicting the future market growth.

4.6.2 Type-II questionnaire survey findings

Data and information on the UASB technology application was solicited from 18 experts in South Africa through a questionnaire and interviews. Most important, South Africa has very few experts in the field of UASB technology or generally in the wastewater treatment industrial sector, and explains why very small population sample of experts was used in this study. The responses constituted 50% (n=9). Of the total respondents, 44.4% (n=4) indicated they had no knowledge on the market dynamics of the UASB technology nationally and internationally. In addition, they had limited knowledge of UASB technology application though initial contacts rated them as experts in this field. Unfortunately, despite the attempts of contacting the experts who did not respond to our questionnaires and a request for an interview did not yield much.

The respondents who provided the most useful information responded both in writing and accepting the request for an oral interview. These were mainly experts directly involved in supplying the UASB and other AD technologies to various industrial clients in South Africa, and elsewhere in the African continent. Alternatively, they were representatives of major global suppliers of UASB technology such as Biothane Corporation and Pagues Inc in South Africa. The experts provided information underlying the market dynamics of the UASB technology application in South Africa, and globally mainly in qualitative terms. Finally, they expressed diverse opinions on what they considered to be the major challenges facing UASB technology growth in South Africa, and Africa in general. In the following sections, the survey findings from the experts are summarized.

4.6.2.1 UASB granules demand in South Africa and globally

Of the nine experts' responses, only two expressed an opinion that there exists real demand for the seeding granules in the wastewater treatment industry in South Africa. This was viewed in the context of the current monopoly enjoyed by a single supplier for the granules in the country. However, certain experts indicated that 20–30 tonnes of sludge are generated in South Africa daily apparently with excessive production of granules. For instance, according to estimates of Driessen and Vereijken (2003), the anaerobic granular sludge production is approximately 1.53 kgCOD/hlx80% x 0.02 kgTS/kgCOD = 0.02 kgTS/hl.

Because the granules are only required by new plants – and since South Africa there is very low demand for treating high COD – as only 1 to 2 plants are installed annually, therefore, the sludge is currently used for compositing, or stored in tanks before it is disposed off. This shows presently there are numerous quantities of granules that are not fully utilized in terms of starting up new UASB installations. Currently, according to experts estimates South Africa has approximately 20 UASB plants and it is highly unlikely to justify the construction of a plant with single purpose of producing seeding granules.

The granules market demand in the international market especially in continents with large number of UASB plants e.g. Europe and Asia is currently saturated. However, there is high demand for the granules in the Eastern Europe countries as many UASB plants are constructed annually. This is to address poor environmental performance of industries in this region owing to weak or no environmental concerns during the industrialization process under cold war era. However, such rapidly emerging markets for the seeding granules have easy access to readily available supplies from the neighbouring Western European countries.

4.6.2.2 Challenges of UASB technology growth in South Africa

The UASB technology is faced with several challenges that hamper its wide spread application for treating high strength effluent in South Africa. These comprise of:

- Relatively low demand for the UASB technology in SA as evidenced by very few plants, or companies using it for treating effluent. This can be attributed to poor enforcement of environmental law as well as none existence of incentives for the companies to treat the high strength organic waste streams adequately. Unlike in the developed countries where the environmental laws are stringently enforced – in the case of South Africa is characterized by laxity.

  Also as a consequence of the low demand for the UASB technology, leads to low or no demand for the seeding granules – and makes it unjustifiable to motivate for a full-scale plant for generating the granules. In SA, there is low demand in terms of treating high COD effluent using the UASB technology. Consequently, this renders the demand for the granules to be very low to justify full-scale pledged plant for manufacturing them. On the other hand, the granules demand can increase dramatically if industries that generate high strength effluent adopt UASB technology. However, currently in South Africa the industries which are potential users of UASB technology such as the food and beverages (e.g. wineries, distilleries, etc), pharmaceuticals, fruit industry, and confectionary (nuts, chocolates, sweets, etc) are yet to adopt this technology citing high investment capital for constructing new plants. The challenge lies in promoting the acceptance of UASB technology in SA by offering locally designed plants whose initial cost is reasonable. That way, the demand for the granules can increase exponentially.

- Owing to single focus of using the UASB for effluent treatment, makes it highly unattractive technology. This is because the cost per unit of treated water is high. Therefore, it will be most appropriate to introduce a new outlook on the application of UASB technology where besides the traditional application for effluent treatment – also, they are designed as a source of renewable energy through biogas production. Almost all the AD systems currently in use in South Africa, including the UASBs, have no biogas recovery as a fuel or for co-generation of electricity. The recovery of energy has the merit of reducing treatment costs, and also, the quantities of greenhouse gasses released into the atmosphere.

- Highly prohibitive costs of building UASB plants owing to the importation of the technology. This can be addressed through research to aid in designing a unique low cost UASB plants, but, with high performance particularly in the context of developing countries. For instance, the possibility of increasing the COD loading per day from around 10 to 20 kg COD m^3/day needs to be addressed. Currently, South African-based companies are obliged to pay high loyalties to European companies to build and operate UASB plants – as the later holds patent rights. Notably, such approach has been proven successful in Mexico where 76% of the anaerobic market, including UASBs, are designed, constructed, and operated by national companies (Monroy et al., 2000). According to expert estimates the cost of the seeding granules for a UASB plant only constitutes approximately 0.5% to 1% of the total plant. In addition, in view of increasing availability of the granules in many operational UASB plants, the seeding sludge is offered to clients free of charge as part of the commercial agreements.

On the other hand, there are challenges at operational level with respect to gas, liquid, and solid separation. Consequently, this accounts for low recovery rate of the biogas from most UASB systems in South Africa. This implies that energy recovery has not been achieved, and needs to be addressed through the optimization of plants – and this shortcoming is not a function of the quality, or activity of the granules used. And finally, for the UASB technology to be widely used in the developing countries – including South Africa – the cost of the plant has to be reduced by 25-30% in comparison to that of aerobic technology.

- Another need identified by the experts is the high transportation and storage costs of sludge from source to the new UASB plants. One option of addressing this challenge is through the development of special equipment to transport the seeding granules – particularly when sludge is highly concentrated. However, this option is likely to increase the cost of the granules. The second option is by increasing the activity of the sludge through the dewatering process. Normally the sludge accessible from the plants is of very low concentration such that large quantities are required for start-up processes. Also, there should emerge a brokerage business for the sludge – to make its supply to new customers more efficient as opposed to the current situation.

4.6.2.3 Alternative technologies to UASB in South Africa

According to current trends in the South Africa wastewater treatment industry – two technologies are increasingly becoming more dominant in place of the UASB technology. These comprise of the aerobic filters (AFs) and membrane bed reactors (MBR). The aerobic filter systems are being preferred in diverse industries as they do not require long retention times for the sludge, and secondly, owing to their ability to treat effluent containing toxic fatty acids adequately.

The MBR is edging out the UASB technology in South Africa due to several reasons. First, the MBR system does not require sludge separation unlike in the case of the UASB technology. Secondly, no seeding granules are required, and therefore, the treatment process commences instantly as opposed to sometimes long start-up periods experienced in the UASB plants. And finally, the MBR system is highly compact with few moving parts.

4.7 Possibilities of Valorization

For the UASB technology to be a preferred option to potential industrial clients for treating high strength effluent especially in South Africa, additional attractive bonuses in terms of finding economic value to the end byproducts is highly desirable. This is because such additional benefits will give it an edge over other technological competitors in terms of overall lower costs per unit of treated effluent. Presently majority of UASB and other AD systems in South Africa do not utilize the biogas for energy recovery. Nonetheless, most of it is released directly into the atmosphere – resulting to an increase in greenhouse effect as it contains carbon dioxide, methane and nitrous oxide.

Secondly, the final treated effluent should potentially be of re-usable standard. This option is highly attractive taking into account that South Africa is a water stressed country, and the cost of water both for domestic and industrial purposes continues to escalate. Such a scenario provides strong drivers to encourage recycling of the treated water. In addition, owing to the effectiveness of UASB technology in removing high organic concentrations (e.g. COD) will offer the companies economic benefit in terms of savings, or considerably reducing their effluent discharge tariffs.

Notably, previously it was feasible to recoup some economic benefits through the re-sale of excess biomass for re-seeding or start-up purposes of new UASB plants. However, this option has become less attractive in terms of low demand for the UASB technology in South Africa besides most companies providing the UASB technology offers the seeding sludge inoculum at no cost.

On the other hand, this option is currently unattractive due to high transportation costs per unit ton of sludge as discussed in section 4.6.2.2. For example, the transportation cost per tonne is almost equivalent to the cost of the granular sludge per ton, or even higher as a function of the distance between the supplying plant and the new start-up plant. This, in the South Africa context, has rendered the re-sale of granular sludge a highly unattractive option. Two alternatives are proposed for research consideration as a way of addressing this challenge. The first option entails developing a special equipment to transport seeding granules from the source plant to the new UASB facility – especially for highly concentrated sludge. Nonetheless, this option has a demerit of considerably increasing the cost of the granules.

The second option is based on the following premise. Because the activity of the sludge is very low – leads to a demand of large quantities of sludge for start-up purposes. For example, based on heuristics, if a certain plant generates 20 tonnes of COD/day, the equivalent volatile component is only about 5% and the 95% constitutes mostly water. Therefore, if a new UASB reactor requires 50 tonnes of volatile suspended solids (VSS), then approximately 1 000 tonnes of sludge needs to be shipped for start-up purposes[9]. This problem can be addressed by developing a novel technology of dewatering the sludge, and increasing its activity. Consequently, the sludge quantity required for the seeding purposes is considerably small hence reducing the transportation as well as the storage costs. Yet, both options remain unexplored in South Africa, and necessitate attention through research.

And finally, while the aerobic sludge requires dewatering resulting to high handling and disposal costs, the excess sludge from the anaerobic plants especially those generated from UASB plants – requires little or no further handling, and can be used for commercial purposes such as composting and making fertilizers.

4.8 UASB technology: the political context

At the onset of this project in May 2007 – the energy crisis in South had not reached the current unprecedented levels. Therefore, to a certain degree, the question of seeding granules demand, and the use of UASB technology in South Africa generally were relevant in the political context in terms of reducing the greenhouse effect through direct release of biogas into the atmosphere. Such political context was driven by the international legislative framework – particularly the Kyoto Protocol which South Africa is a signatory, and has shown commitment in meeting her obligations. For example, the Europe's commitment to reducing greenhouse gases emissions in accordance to the Kyoto Protocol principles and environmental protection partly explains the large disparity on the number of UASB and EGSB installations in European Union countries and the North America. Yet, the latter has a large number of industrial facilities and an economy equal, if not greater than the former.

Yet, owing to current severe energy crisis in South Africa – occasioned by high demand outstripping the supply from Eskom – formally poorly resourced renewable energy alternatives are beginning to attract considerable attention in terms of demand, and research funding from private and public sources. In this context, both the political and economic prevailing drivers are providing a

[9] Estimates provided through personal communication with experts in the UASB technology applications in South Africa.

widow of opportunity for the researchers in the field of anaerobic wastewater systems to source the necessary research funding to address some of the outstanding challenges hampering wide spread use of UASB technology in South Africa, and other anaerobic systems in general.

As a way of example, energy crisis increased the demand for the use of biogas in counties like the Netherlands (Raven and Verbong, 2004) and USA (Kassam, et al., 2003). Apparently the current energy crisis in South Africa can offer positive spin-offs in terms of providing an enabling environment essential for addressing the challenges discussed in the preceding sections. Furthermore, wide application of the UASB technology has a merit of reducing the pollution loads in the water courses like rivers and dams in South Africa as opposed to the current status.

Another means of creating economic motivation for the wide application of the UASB technology can be via legislative instruments. This is achievable through creation of tax incentives, which consequently promotes the use of UASB technology and other anaerobic treatment technologies – owing to their dual functionality of effluent treatment and energy recovery. Such mechanisms will have the effects of increasing the demand for the seeding granules, and hence, provide plausible justification for their large production at full plant-scale.

Owing to the effectiveness and efficiency of the UASB technology as previously proven globally, and if, the constitutional imperatives as stipulated in the South African Constitution regarding the provision of safe environment for every citizen are taken into account – the UASB technology appears to have a key role as part of the integrated solution. Therefore, the low demand for the UASB technology can be reversed if the constitutional provisions are used as political levers of safeguarding the environment from current increasing high levels of pollution.

Furthermore, in the absence of national policy on the use of anaerobic technologies often limits the extent to which these technologies are applied in treating waste streams containing high organic components. Such a perspective accounts for why countries like South Africa, Canada and USA despite their large industrial base, the penetration of the UASB technology is very low in comparison to other countries like Mexico, Sweden, the Netherlands and India. For instance, by 2000 Mexico had installed three times more digesters than Canada and over 90% of the digesters operating in the USA (Monroy et al., 2000). In summary, the political push-factors in the context of technology development needs to be investigated further and exploited to promote UASB technology in South Africa as it happened in the Netherlands in the 1970s.

5 Conclusions and Recommendations

5.1 Conclusions

In this study, a market trend analysis for the UASB granules demand – both nationally and internationally are presented. However, because it is improbable to assess the market demand data for the UASB seeding granules, the problem was addressed from the perspective of the UASB plants growth in South Africa and internationally – since the inception of the UASB technology in the 1970s. The direct relationship for the seeding granules demand and the UASB plants growth was based on the premise that, for each plant to commence effluent treatment, seeding inoculum was necessary for the start-up purposes.

From this study, it shows that the UASB technology is widely applied in diverse industries both in the developed and developing countries but with high intensity in the former states. Through the comparative studies presented in Chapter 4 it was illustrated that globally the UASB technology is currently being edged out of the market by the EGSB systems since the beginning of the 21st century. This points to technology "phase-out" -"phase-in" phenomenon – which shows unlikelihood of high future growth for the UASB technology. Likewise, in view of these findings, the demand for the seeding granules is expected to be very low or none existent as the current stocks are under utilized with respect to start-up processes of new UASB plants.

In addition, experts in the wastewater industry in South Africa have indicated the membrane bed reactors and aerobic filters are the preferred options over the UASB. Therefore, it is unlikely to anticipate a high demand for the seeding granules particularly in the developed countries because of the prohibitive capital costs for a new UASB plant. Besides, presently there are increasingly large quantities of granular sludge innocula necessary for the start-up purposes of a UASB being readily and commercially available globally.

From this study, it is evident that the push-factors that may have necessitated a given research may drastically change over a short period of time. For instance, the question of understanding granules formation and the development of engineered seeding granules was relevant in the late 1990s and early 2000s in South Africa. However, this need has been addressed by market forces and new needs have begun to emerge. Thus, there is necessity for periodical review of market imperatives on how they impact a given technology evolution. In addition, this will aid in identifying the most salient needs that merits research attention.

And finally, owing to the need of protecting the environment – especially in the context of developing countries, the anaerobic digestion technologies holds great promise as part of the integrated solution for the wastewater treatment. This, viewed in the context of looming energy crisis may also prove to be a valuable source of clean energy to large populations in the developing world. On the other hand, it can help large industries such as pulp and paper, breweries, food processing, etc to reduce their energy dependence from national grids via co-generation processes of wastewater treatment and electricity generation.

5.2 Recommendations

In view of the findings from this study, it appears that the research needs for the UASB technology in South Africa necessitates a re-alignment. Such a strategic decision will ensure appropriate response to the present and anticipated future market imperatives. Consequently, we recommend the following activities to constitute part of the future research focus in this field, including:

- Development of suitable retrofitting options to promote optimal recovery of the biogas for energy production from existing UASB plants, and other anaerobic technologies currently in use in South Africa. Present focus on wastewater treatment only renders the UASB technology less attractive particularly in the context of the developing countries. For example, by 2003 Europe had a total capacity of 1 500 MW from anaerobic-related technologies which is estimated to increase to 5 300–6 300 MW by 2010 (de Mes et al., 2003).

- Research on the development of high-rate and high capacity UASB designs needs to be considered. This option is highly feasible owing to long experience in terms of UASB applications in South Africa and globally. A good example is the case of locally adopted plants in Mexico. While the EGSB technology is on the edge of replacing the UASB technology, this may not be the best option to focus on in South Africa due to high costs and mostly suitable where land is of very premium.

- Other areas of research focus should include finding efficient and cost effective technologies which are cost effective in terms of transporting granules from the source plants to the new UASB plants. Currently, this area is yet to receive attention and is costing industry colossal sums of dollars.

- For the Water Research Commission to re-focus more profoundly to the needs of wastewater treatment industry in South Africa, and in the developing countries in general – a comprehensive market study on all anaerobic and aerobic technologies is highly critical. This is because such study will provide further insights into current trends in the area of environmental biotechnology. Consequently, the findings will aid in defining the future research directions that may be of great benefit to South Africa. This is because any research in this field that fails to respond to the twin problem of environmental pressures in terms of improving environmental management, and meeting the exponentially growing demand for sustainable energy supply inform of renewable energy may find limited application in the current wastewater market trends emerging globally.

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APPENDIX A

Questionnaire to companies operating UASB plants in South Africa.

Dear Sir/Madam,

For several years now, the Water Research Commission (WRC) has been funding research on the fabrication of high quality seeding granules essential for effective wastewater treatment using the upflow anaerobic sludge bracket (UASB) technology. Presently, promising findings of this ongoing research have reached a stage where the Commission intends to upgrade the laboratory-scaled production of granules into a pilot-plant scale operation. However, currently there is no empirical data and information on the market size and demand for the UASB seeding granules in South Africa and other international markets. To facilitate informed decision making, WRC has commissioned the Department of Process Engineering at the University of Stellenbosch to undertake a market analysis for UASB seeding granules both in South Africa and international markets (WRC Project No. K8/739). In line with the WRC mandate, this questionnaire intends to solicit data and information on various aspects of seeding granules currently being used in South Africa in order to determine market size as well as their extent of demand. The data and information to be obtained from the questionnaire responses will then be analyzed for the purposes of, but not limited to:

- Determining the market size as well as the demand for the seeding granules in UASB wastewater treatment plants in South Africa both in terms of current and foreseeable future trends;
- Establishing a national database for UASB seeding granules suppliers in South Africa;
- Establishing the levels of activity/performance of seeding granules currently being used in the UASB granules in South Africa; and
- Any other aspects that may relate to the improvement of UASB process operations in South Africa as well as in identifying future priority research areas that may bring about the intended changes

Please you are hereby invited to fill out the attached questionnaire, and return it as soon as possible to the address given below. Please feel free to point any issues that may have been omitted in the questionnaire, or make comments that may be relevant. All this information will be used in formulating future UASB research thematics for the benefit of wastewater treatment industry in South Africa.

Should you require more information, please feel free to contact any of the following individuals:

Name	Telephone Number	Fax Number	Email Address
Dr N. Musee	021 808 4062	021 808 2059	nmusee@sun.ac.za
Prof. L. Lorenzen	021 808 4496	021 808 2059	Ll1@sun.ac.za

Mailing Address:

Department of Process Engineering, University of Stellenbosch, Private Bag X1, Matieland, 7602.

PLEASE NOTE THAT ALL THE INFORMATION SUPPLIED WILL BE TREATED AS STRICTLY CONFIDENTIAL

Industry details:

Name of company/Organization: ____

Private or publicly owned: -____

Company address: ____

____

____

____

____

____

Name of contact person: ________-____

Tel:________________________ Fax: ______________________________

Email: ____

A: UASB GRANULES SUPPLIERS

1. Who are current/former suppliers of UASB granules to your company? (Please fill the name and address of the company or companies in Table 1).

Table 1: List of granules supplier company(ies) to your effluent treatment pant and their addresses.

Company name & address (Tel/fax/email)	Location of the company	
	South Africa	Overseas

2. Are the suppliers identified in question 1 having their granules production plants in SA or elsewhere (overseas)? (Please tick in Table 1 whether they are located in South Africa or overseas).

3. If in question 2 the suppliers are located outside South Africa, who are their representative subsidiaries in South Africa? Please provide the names of the subsidiaries (fill the details in Table 2).

Table 2: List of the subsidiary companies supplying granules and their contact details.

Subsidiary name	**Postal address**	**Tel**	**Fax**

4. Please provide an estimate on the quantities of granules supplied by the suppliers to your UASB effluent treatment plant monthly/annually over the last six years (please fill up the details in Table 3)?

5. What is unit cost of granules (cost of granules per kg or tons, etc). Please insert the values in Table 3 for each year the granules were supplied?

6. For your company/organization, how many UASB plants do you own and operate in South Africa? ______. Please fill in the capacity of each plant in Table 4.

Table 3: Quantities of granules obtained from the suppliers and average cost (per month or annually) per day.

Year	Quantities of granules (kg or tonnes)*	Unit cost of granules (R/kg) or (R/ton)
e.g. 1999	20 762 kg or 20.76 tonnes	(Please specify your unit of cost)

* Just fill one set of units (i.e. if you provide weight in kg there is no need for the conversion to tons and the same applies when giving values for cost of the granules).

Table 4: Name of the UASB plant, design capacity and current operating capacity per day.

Plant name	Design maximum capacity	Current operating capacity	Province (in South Africa)

7. What volumes of the effluent are being treated using UASB technology per month (please provide the volumes for the last 12 months in Table 5).

Table5: Average monthly effluent treated over a period of 12 months .

Month (please indicate the year)	Volume (m^3)

B: GRANULES PERFORMANCE

8. What is the performance of the granules currently being or have been previously used in your wastewater treatment plant? (Please provide your response as a percentage in Table 6 below).

____
____

9. Please provide the unit cost of effluent treatment using UASB technology in your plant (dollars per unit volume or rands per unit volume e.g. R2/m^3 in Table 6).

   ____
   ____

10. Has the application of UASB technology been terminated for use in effluent treatment in any of your effluent treatment plant(s)? (yes/no) ____

11. If the response in question 10 is yes, please provide reasons why the UASB technology has been abandoned as a preferred effluent treatment technology?

    ____
    ____

____

____

____

____

____

____

12. Please state the effluent treatment technology(ies) that have been applied in your effluent treatment plants as a replacement (alternative) in the place of the UASB technology (please fill your responses in Table 6)?

13. What are the specific merits of the technology(ies) which have been applied to replace the UASB effluent treatment technology in your plant/organization (please fill your responses in Table 6)?

Table 6: List of alternative effluent treatment technologies to UASB, their merits as well as the loading rates.

Effluent treatment Technology	Merits of treatment technology over UASB	Organic loading rate (kg COD/m^3 day)	Technology efficiency/ performance (%)	Cost per unit volume (e.g. R2/m^3)
e.g. Aerobic digester				

14. What is performance efficiency of the alternative technologies used in treating the effluent in your company (please fill the values in Table 6)?

15. What is the unit cost of effluent treatment of each alternative technology(ies) stated in question 11 (dollars per unit volume or rands per unit volume e.g. R2/m^3. Please provide the values in Table 6).

16. Please provide all other relevant information as indicated in various headings in Table 6 for each of the alternative technologies currently in use in your treatment plants in place of UASB technology.

17. Please provide reasons or challenges that may have led to the replacement of the UASB technology in your effluent treatment plant(s)? ____

____

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18. In particular, what are the most challenging problems arising from the current form and functionality of the UASB granules currently being available in the South African market? ____

____

____

____

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____

19. Please provide some of the options in your considered opinion can address some of the challenges you have stated in question 18. ____

____

____

____

____

____

____

20. What sort of improvements on the UASB granules technology would you like to see in order to make it more effective in meeting the needs of your effluent treatment plant? ___________________

21. In your opinion, do you think that in South Africa, the UASB granules are readily available (yes/no)?

(a) If yes, please provide a reason(s) in support of your response

(b) If no, please provide a reason(s) in support of your response

22. For the case of new effluent plant(s) where UASB technology has not been used as the preferred effluent treatment technology, please provide reasons that may have motivated for use of alternative effluent treatment technology(ies) though UASB could have been a better option?

23. What are the sources of the wastewater being treated using the UASB technology (type of processes generating the effluent) in your production plant?

Please feel free to make comments that may improve an understanding the market dynamics of UASB granules market in South Africa.

<u>Thank you very much for your valuable time and insights you have provided through your participation in filling our questionnaire</u>

APPENDIX B

INTERVIEW QUESTIONS TO EXPERTS/SUPPLIERS OF UASB TECHNOLOGY IN SOUTH AFRICA

Expert/manager name: Code:

Company/organization: Interview date:

INTRODUCTION:

- Provide problem background (overview)
- State the objectives of the study
    - Determination of UASB seeding granules market size (SA and globally)
    - Establishment of a national database for UASB seeding granules suppliers in South Africa
    - Establishing performance of seeding granules currently being used in South Africa; and
    - Any other aspects for the improvement of UASB technology operations in South Africa
- Request/expectations from them
- Would you like to be acknowledged in the report as an expert who contributed in this study (Yes) or (No)?

QUESTIONS

Q1: In your opinion, do you think that in South Africa, the UASB granules are readily available (yes/no)?

(a) If yes, please provide a reason(s) in support of your response

(b) If no, please provide a reason(s) in support of your response

Q2: Who are the current suppliers/producers of UASB seeding granules in South Africa and or internationally?

Company name & address (Tel/fax/email)	Quantity/year	Company

(indicate supplier (S) or producer (P))	(kg or tonnes)	Location	
		SA	Overseas

Q3: What is the size of the UASB seeding granules market/demand in South Africa and internationally? Provide reasons why so. (Very low, low, moderate, high, very high)

(a) South Africa:

(b) Internationally:

Q4: List of companies using UASB technologies in South Africa currently and their sources of seeding granules

	Plant/organization name & address (Tel/fax/email)	UASB granules source(s)
1.		
2.		
3.		
4.		
5.		
6.		
7.		

8.		
9.		
10.		
11.		
12.		
13.		
14.		
15.		
16.		

Q5: What are the specific merits of the technology(ies) which have been applied to replace the UASB effluent treatment technology in plants/organizations (list of alternative effluent treatment technologies to UASB, their merits as well as the loading rates).

Effluent treatment Technology	Merits of treatment technology (you can compare it will UASB)	Organic loading rate (kg COD/m^3 day)	Technology efficiency/ performance (%)	Cost per unit volume (e.g. R2/m^3)
UASB				
e.g. Aerobic digester				

Q6: What are the greatest challenges facing UASB effluent treating plants in South Africa/internationally?

Q7: In your opinion, what should be the core focus on UASB technology to make it more effective?

Q8: In your opinion, do you think traditionally the long period of fabricating the granules can be a contributing factor in decline of UASB technology demand both in South Africa and internationally.

Thank you for your time and valuable insights