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Upflow Anaerobic Sludge Blanket low cost sanitation research project in Bandung/Indonesia

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SUMMARY

This research report deals with investigations concerning the development of a low-cost on site treatment system for black water and combined black + grey water, using 0.86 m ^{3} modified anaerobic reactors of the UASB (Upflow Anaerobic Sludge Bed) principle.
From the results obtained so far in 0.86 m^3 reactors, it can be concluded that the modified UASB-septic system indeed could represent an effective on-site treatment system. This holds particularly for black water; up to 93 % of the COD-total and 97 % of the TSS can be removed from the waste water, while also a satisfactory sludge stabilization can be achieved. The process was found to be highly stable. Moreover a sludge of a fairly reasonable specific methanogenic activity develops on black water. The excess sludge production found amounts to 0.005 kg TSS/day.capita or 0.08 liter/day.capita. By installing a reactor of 1.2 m^3 for 8-10 people, the frequency of sludge-discharge is only once every 3.5 year. However, as the system, is not sufficiently effective in removing pathogens, it should be emphasized that the effluent is still quite hazardous. Therefore in many cases post-treatment will be required for eliminating pathogens, but also for removing other remaining pollutants.

The system performs also fairly satisfactory on combined black + grey water, i.e. at a HRT of appr. 36 hr and a COD load of appr. 1.0 kg COD/m^3.day, up to 75 % of COD-total and over 80 % of TSS is eliminated from the waste water. Although still a lot of information is lacking, tentatively it can be concluded that for practical application a reactor volume of 1.5 m^3 for 10 people will suffice. The excess sludge production amounts to 0.008 kg TSS/day.capitae or 0.08 liter/day.capita, which results in a filling up time of a 1.5 m^3 reactor of approximately 4 years for 10 persons. It was also found that the system even performs satisfactorily under conditions of relatively high sludge over-loading, i.e. when less than 15 % of the reactor volume is filled up with sludge.
Both for black and for combined black + grey water this modified UASB-septic tank looks quite attractive for on-site sanitation systems, and it also could represent a very promising proposition for Community on Site Sanitation Systems; from experiments with domestic sewage it is known that much bigger reactors than those used in the present study perform quite satisfactory. Like conventional on-site sanitation systems, community on site sanitation systems principally represent a far more very attractive solution for preventing environmental pollution from domestic origin than off-site sanitation systems. Low cost and effective systems for on-site treatment are available now.

PREFACE

This report contains the results of a research project which has been carried out in Indonesia to assess the feasibility of UASB technology for the on site treatment of domestic waste water.
On behalf of the National Institute for Public Health and Environmental Protection (RIVM) I take the opportunity to thank several parties who have made this research possible.
At first the Indonesian Ministry of Public works/Directorate General Cipta Karya/Directorate of Environmental Sanitation in co-operation with Puslitbang Pemukiman for acting as the counterpart and offering the hospitality to carry out the research.
Also the financial support of the research division of the Netherlands Directorate General for International Co-operation (DGIS/DPO-OT) is kindly appreciated.
A special word of thanks goes to Dr. J. Moeliono of the St. Borromeus Hospital in Bandung who has managed to keep the project on going in an original and unimitable way; also the inputs of the remainder staff of the Borromeus team and staff and students of the Institut Teknologi Bandung and Universitas Pajajaran are acknowledged. The Biofarma Institute is acknowledged for giving admission to conduct part of the research at her location.
The scientific soundness of the research is largely due to the efforts of Prof. Lettinga and Dr. Wiegant, both staffmembers of the Waste Water Division of the Agricultural University at Wageningen, the Netherlands. I would also greatly acknowledge the contribution of ir. v. Knippenberg, who participated as project engineer during part of the project.
Last but not least greatful mention is made of all the young and enthousiastic research assistents who, as doctoral students in anaerobic waste water treatment of the Agricultural University, have made valuable contributions to the research in Indonesia: Marja v.d. Kraats, Gemma Dijkstra, Ingrid Haas, Ruud Keller, Aart v.d. Horst, Karin v. Knippenberg, Ric Wichers, Bart Botzen, Rick Heijstee, Pam Minnigh, Kees Baas en Rolf Luyendijk.

Bert Jansen, project supervisor

1. INTRODUCTION

1.1. SECTOR DEVELOPMENT IN EUROPE

Hygienic living conditions are a prerequisite to reach and to maintain a reasonable level of public health. Full coverage with adequate water and sanitation facilities is indispensable in this respect. To arrive at sustainable systems however requires a number of conditions to be fulfilled. The development of the sector in Europe can serve as a reference in this respect:

At the beginning of the 19th century the living and working conditions of major parts of the population on this continent were extremely bad: cities were densily populated, housing conditions poor, adequate water and sanitation facilities lacking, unsufficient and unbalanced nutrition and unacceptable working conditions with no attention for occupational hygiene at all. Under these circumstances it was not surprising that large parts of the population were regularly victimized by epidemics of cholera and typhoid.

One of the factors which has contributed to a change of this situation was the increase in knowledge about the relation between environmental hygiene and public health. An important contribution in this respect has been made by John Snow who, on the basis of an extensive epidemiological research, has demonstrated the causal relation between faecally contaminated water supplies and the outbreak of cholera epidemics. Also the development of the medical microbiology in the second half of the 19th century has deepened the knowledge about environmental risk factors.

The national governments in those days were also motivated to improve the level of public health, while in the same time sufficient budget was available to translate policies into practice. For instance in the Netherlands this has resulted in the implementation of large scale water supply and sanitation programmes in the period 1850 - 1950 realising a population coverag of almost 100 %.

Another important circumstance was that the technical facilities could function in an institutional framework of organisations with sufficient and trained personnel at different administrative levels.

Those levels could sufficiently be supported by the results of scientific and applied research carried out by the government institutes, universities or private bodies.

Finally the water and sanitation sector could operate on a sound economic basis since consumers were able to pay a tariff which at least covered the cost of operation and maintenance and depreciation of assets.

1.2 SECTOR DEVELOPMENT IN INDONESIA

The development of the water supply and sanitation sector in Indonesia shows a great deal of similarity compared to the one described for Europe.

At policy level it is quite well understood that inadequate and unsufficient water- and sanitation facilities contribute to the high infant mortality rate of appr. 100/1000. There is also a strong political will to alter this situation. In a number of subsequent 5 year national plans, REPELITAS, therefore ambitious targets have been set to increase the population coverage with water- and sanitation facilities. The Indonesian government has succeeded to make substantial budgets available for this purpose in the past decade, supplemented by the financial commitments of bi- and multilateral donor agencies. The International Decade on Water Supply and Sanitation has without doubt accelerated this development.

The magnitude of the government task is obvious when realising that out of the total population of about 180 million approximately 16 mln people in (semi)urban areas receive safe water through piped systems (40 %; target 1990: 75 %) while 38 million of the rural population have safe drinking water available through mainly handpumps (32 %; targe 1990: 60 %).

As to sanitation 13 million of the (semi)urban population make use of septic tanks (32 %; target 1990: 60 % coverage-including sewerage) while in rural areas 37 million people make use of hygienic pit latrines (31 %; target 1990: 40 %).

As an important feature of the water- and sanitation program carried out in Indonesia substantial attention is being paid to institutional- and human resources development aspects, complementary to the construction of facilities. This results in the establishment of adequate organisations at local level which are capable to carry out required operation and maintenance tasks.

It is furthermore realised that the involvement of local governments and the communities during the planning and implementation proces is prerequisite to arrive at sustainable systems which are tailored to the local carrying capacity. For that reason the approach has shifted in the recent years from top down to bottom up planning.

Another recent development in Indonesia concerns the fact that water and sanitation projects are no longer planned on a sectoral basis but as part of integrated urban infrastructure programmes. The so-called integrated Urban Infrastructure Development Programme (IUIDP) serves as an example in this respect; in the framework of IUIDP local governments plan urban infrastructure investments on an annual, mid- and long term basis and submit these plans for complementary subsidy to the central government.

Finally the development of a water management system in Indonesia is relevant mentioning. Apart from the water and sanitation sector also other sectors, like irrigation and industry, put demands on scarce resources such as available land and surface- and groundwater; intitial steps have been taken to develop a system on the basis of which these conflicting sectoral interest can be managed and optimized.

It can the concluded that the water supply/sanitation sector in Indonesia is well balanced with due attention for hardware implementation, institutional and human resources development, consumer related aspects, bottum up planning and water-management. As such this process shows many similarities with the sector development in western countries. Different is however the magnitude of the government task and the relatively short period which has been planned for realizing the objective.

1.3. SANITATION

The sanitation sub sector in Indonesia includes:

- solid waste: collection, transport, disposal and/or treatment
- drainage: safeguarding the proper functioning of primary, secundary and tertiary drains through a.o. removal, transport and disposal of solid waste and sludge.
- human waste: collection, transport and treatment of human and industrial wastes through on-site sanitation facilities and sewerage.

The sub-sector is still relatively young which finds its expression in the fact that the Directorate of Environmental Sanitation as part of the Ministry of Public Works/Directorate General Cipta Karya, pays much attention to policy formulation. This process is supported by the results of research produced by government agencies (Puslitbang Pemukiman) or bi/multilateral donor assisted projects. Examples are the research on dual pit latrines, the development of guidelines for solid waste management, experiments with consultation cycles to assess priorities of local governments and communities for sanitation options and the establishment of credit schemes/revolving funds for the financing of on/site sanitation facilities by the local communities. The institutional framework of the sanitation sub-sector is still in development and shows a broader diversification compared to the water supply sub-sector. In the latter case central government agencies provide initial capital investments while regional water enterprises assume responsibility for extension of the systems and operation and maintenance. This more or less uniform pattern does not apply to the sanitation sub-sector. For instance solid waste management systems can be operated under responsibility of local government agencies or an enterprise. Also sewerage systems can be operated and maintained by either a water supply company or a seperate enterprise. Another feature in this respect is that the local communities are being held responsible for investments in on-site sanitation facilities and the financing of operation and maintenace; the role of the central government is limited to the construction of demonstration facilities, the establishment of credit schemes and the implementation of educational programmes.

The construction of sanitation facilities actually started on a full fledged basis at the beginning of Repelita III. In (semi)urban areas the construction program includes human waste, drainage and solid waste systems. For the smaller cities this integrated approach is realized through the so-called Kampung Improvement Program (KIP) which aims at the construction of micro-drainage, garbage disposal boxes and collection charts, the implementation of communal units for bathing, washing and toilet facilities (so-called MCK) and individual latrines. In addition, other ongoing and planned programmes are geared towards the implementation of sewerage in 10 large towns, the construction of human waste facilities in smaller towns as part of the KIP program and the realisation of solid waste management and drainage systems in 200 cities.

Rural areas are characterized by small size communities and a low population density; in general solid waste and drainage do not constitute a problem and the attention is mainly focussed on the promotion of simple latrine facilities.

1.4. THE UASB RESEARCH PROJECT

This report contains the results of a research project which has been carried out in the period May 1984 - April 1988 in Bandung to assess the feasibility of small scale UASB reactors for the on-site treatment of domestic waste water.
As such the research has contributed to broadening the range of available low cost sanitation options such as pit latrines and septic tanks.
Also the project has succeeded in starting the discussion i Indonesia about the application of the UASB technology for the off-site treatment of domestic and industrial waste waters.
From the above paragraphs it follows that although a sanitation technology like the UASB treatment is promising, it is important to realize that the successfull application is at the end very much dependent of its functioning in a sound institutional framework.
The research described in this report has been followed up in the meantime. Topics which receive attention during the follow up include a.o. the adaptation of experimental reactors into low cost UASB facilities suitable for mass application and the development of guidelines for appropriate operation and maintenance. Eventually post treatment can be considered to arrive at an effluent which is safe from a hygienic point of view.

2. WASTE WATER TREATMENT

2.1. CHARACTERISTICS OF HUMAN WASTE

Excreta and black water

The volume, composition and consistency of faeces depend on factors like diet, state of health of the population and its climate as well.
In tropical countries per capita average quantities faecal weights of 130 - 520 grams daily can be found; Europeans and North Americans produce between 100 and 200 grams daily. Vegetarians generally have higher faecal weights than other groups and faecal weights in rural areas are significantly higher than in urban and metropolitan areas.
Adults produce between 1.0 and 1.3 liters urine per day, which also depends on various factors.
When reliable data are lacking, it should be assumed that in developing countries adults produce about 350 grams of faeces and 1.2 liter urine per day in rural areas and 250 grams of faeces and 1.2 liter urine per day in urban areas.
The weight of dry faeces depends on the total faecal weight and varies between 25 % at a daily faecal weight of 100 - 150 grams and 10 % at a daily faecal weight of 500 grams (Feachem et al, 1980).

The composition of excreta, especially faeces, is very complex. In the U.S.A. , Laak (1974) has found that urine contains 8.6 grams BOD_5 per liter and faeces appr. 9.6 grams per 100 grams.
Some typical figures are presented in Table 2.1.

Table 2.1. Composition of human faeces and urine (Source: Gotaas, 1956 in Feachem et al, 1980)

Item	Faeces	Urine
Quantity (wet) per person daily	100-400 g	1.0-1.31 kg
Quantity (dry) per person daily	30-60 g	50-70 g
Moisture content (%)	70-85	93-96
Appr. composition (percent dry weight)		
Organic matter	88-97	65-85
Nitrogen	5.0-7.0	15-19
Phosphorus (as P_2O_5)	3.0-5.4	2.5-5.0
Potassium (as K_2O_5)	1.0-2.5	3.0-4.5
Carbon	44-55	11-17
Calcium (as CaO)	4.5	4.5-6.0

Volumes of domestic sewage depend strongly on the level of watersupply services and cultural habits, such as anal cleansing practices, which is common use on Java.
Households in Western countries,having available generally many water using devices and who commonly are connected to sewer, may have a water consumption up to 200 liter per capity per day and even more. The amount of black water

produced per capita in rural areas on West-Java is estimated at 6 liters daily, at least if no private water connection is available. De Kruyff (1985) estimates the production of black water in Indonesia (a figure used for the design of on site sanitation systems) on 10 liters per person daily.
Taking into account a BOD-load of 30-40 g BOD per person daily (Feachem et al, 1980), this results in a BOD value of 2700-5000 mg/L for black water.

In excreta several pathogenic organisms can be present:

- Viruses. The most important ones are Hepatitis A-virus and polio-viruses, but also diarrhea and influenza are often caused by viruses
- Protozoa.
- Bacteria. The faeces of a healthy person contains large numbers of many different species of commensal bacteries. Escherichia coli is the most wellknown, because of its use as indicator organism. Important pathogenic bacteria are Salmonella typhi and Vibrio Cholera.
- Helminths.

Pathogens will be only briefly described here, for more information the information provided by Feachem et al, 1980 should be consulted.

Sullage

Sullage, also known as grey water, is domestic water not containing excreta.
The volumes of sullage produced also depend strongly on the water consumption pattern. Where people use public taps, domestic water use may be as low as 10 liters per capita daily, whereas households with full plumbing water consume 200 liters or more.
In Western Java average water consumption in rural areas is estimated at 65-100 liters per capita daily (Burgers, 1985; Hofman 1982).
As far as the characteristics of sullage are concerned, only reliable information on households in industrialized countries is available in literature and this information is not representative for the situation in Indonesia, consequently not relevant for this study.

2.2. ON SITE TREATMENT

2.2.1. GENERAL

The provision of water-borne sewer systems combined with the installation of central treatment facilities, which unfortunately are considered by many as a symbol of social progress, is financially and practically not feasible in developing countries (Cairncross & Feachem, 1983).
According to de Kruyff (1983) a sewer system with central off site treatment systems in Indonesia is 5 to 10 times as expensive as on site systems (de Kruyff, 1983).
Small-scale and sewerless on site techniques for disposal and treatment of domestic wastewater therefore constitute a very attractive, consequently appropriate solution.
Considering the treatment of domestic wastewater, one has to distinguish:
- grey water, also known as sullage, which is the wastewater component that not contains excreta, i.e. water from bathing, washing etc.
- black water, which is wastewater from toilets, consequently containing excreta and flushwater.

As the blackwater imposes by far the greatest health risks, because of the presence of pathogenic organisms and also contains the bulk of organic pollution produced in households, it is obvious that particularly this component deserves all attention with respect to disposal and treatment.
In Indonesia the black and grey water stream generally are disposed separately. Grey water commonly is disposed in soakaways and open drains, despite the possible health risks (Feachem et al, 1980), whereas the black water stream in some situations iss disposed of and treated in on site sanitation systems.

2.2.2. TECHNICAL OPTIONS FOR ON SITE TREATMENT

The technical possibilities for on site treatment of domestic wastewater will be described in this section. Several, commonly applied systems in tropical countries will be described.
The first distinction to be made is between "wet" systems, that collect and treat excreta diluted by water, and "dry" systems, which are based on little if any water dilution of the excreta.
An overview of both systems is given in Figure 2.1.

Pit latrine (Fig. 2.1.A)

The socalled pit latrine represents the simplest and cheapest system for disposal of excreta. For this reason it is also the most commonly used system in tropical developing countries. The pit is a simple hole in the ground into which the excreta drop down, accumulate and slowly degrade. Usually the latrine is provided with a prefabricated floor in the form of a squatting slab or with a seat. After the pit has filled up to 2/3 a new one is digged.

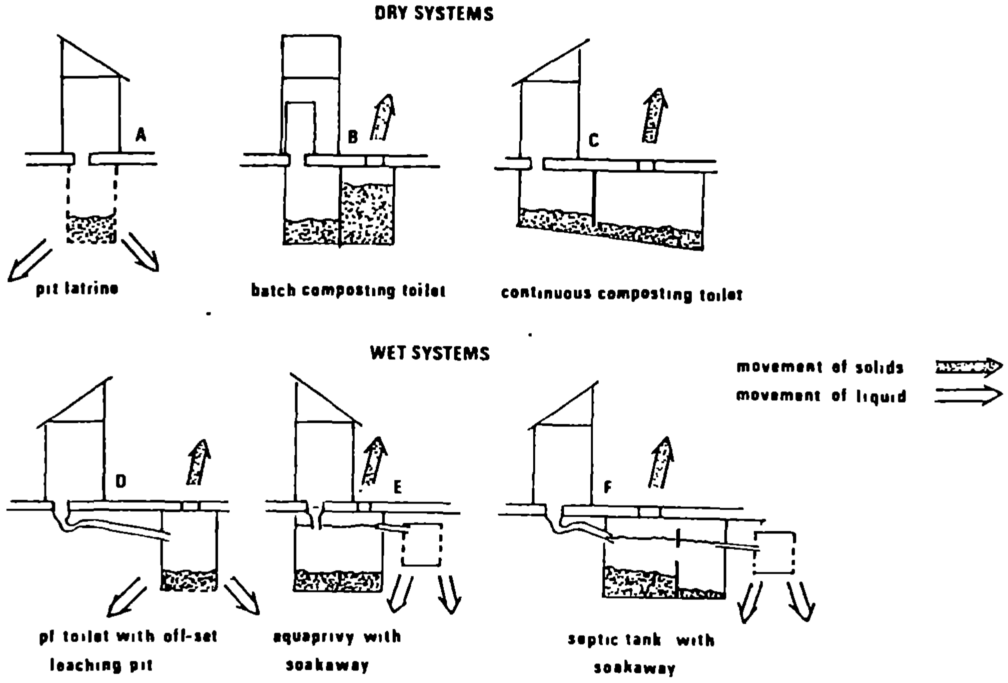


Figure 2.1. On site sanitation systems

The two principal disadvantages of the conventional pit latrine (the smell and "production" of flies) are reduced in the **Ventilated Improved Pit latrine**, which is provided with a vent pipe.
A drawback of the pit latrine system is the pollution of groundwater in areas with high watertables. Nearby water supplies will in that case be in danger of contamination.

Pour-flush toilets (Figure 2.1.D)

A further improvement of the pit latrine is obtained by using a waterseal, which is a U-pipe filled with water, below the squatting slab. This device prevents the passage of flies and odours completely. Appr. 1-3 liters water is needed to flush the excreta into the pit. The pit can be situated up to 8 meters from the toilet.
A pour-flush toilet can also be connected to a septic tank system.
Important advantages of the pour-flush toilet are:
- possible location inside the house
- complete odour and fly elimination
- low water requirements

Composting toilets (Fig. 2.1.B and C)

In developing countries as well as in industrialized countries, systems are used in which excreta and other organic materials are composted. It might create an extra stimulus

for householders to empty their latrine. The composting process may be aerobic or anaerobic and only takes place at a low moisture content (20 - 60 %). This makes the system less feasible when water is used for anal cleansing.
Two basic types of composting toilets can be distinguished: continuous and batch.
Continuous composting requires much attention from the user (removal of the humus, addition of refuse to obtain the correct C/N ratio etc.). Therefore this system is not recommendable for on site sanitation.
The most common type of batch composting toilet is the **Double Vault Compost (DVC)** toilet.
The system includes two adjacent vaults, of which one is used until it is filled up for 75 %. Then this vault is closed and the other one is used, now composting processes take place in the first one.
A similar system is the **Twin Leaching Pit (TLP)**. Instead of closed vaults, leaching pits are used. For both the DVC and the TLP system a minimum composting time of one year per pit/vault is required to obtain a pathogen free and safe use compost.

Aqua-privies and septic tanks (Fig. 2.1.F)

Both systems belong to the socalled "wet" systems, which means that the excreta are diluted with water. They consist of a watertight settling tank in which the solids settle and are anaerobically digested.

Aqua-privies are located directly underneath a squatting plate. The plate has a vertical droppipe, which is submerged into the liquid level of the tank, thus forming a simple waterseal. In practice, maintenance of the waterseal, necessary to prevent mosquito and odour nuisances, has proved difficult.

Septic tanks are situated at some distance from the toilets and are able to receive both black and grey water (Kalbermatten et al, 1980). This system is described seperately in the next section.

The Indonesian situation

In Indonesia it is common practice to use water for anal cleansing. In this situation P.F. toilets are considered most suitable. They can be constructed in an inexpensive way with direct discharge to a leaching pit, or slightly more expensive with an offset pit to allow location indoors. This system can be upgraded to include a septic tank. The usual system of excreta disposal in urban areas, where water is already available, is a leaching pit or a septic tank with soakaway or drainfield.
Because a sufficient supply of water, sufficient space and permeable soil are required for the application of a septic tank, it is particularly suited for low-density urban areas or rural areas.

A commonly observed excreta disposal facility is the "jumbleng": a system usually consisting of a small elevated bamboo squatting plate with a low privacy screen. The disposal is usual to open pits or water courses. In rural areas, jumblengs are often conbined with fish-ponds.
When no sanitation facilities are available, direct defaecation to cannals, drains and open waterways can be seen in every urban or rural area. In this situation communal facilities as MCK (Mandi-cuci-kakus = Bathing-washing-toilet) units are appropriate and have been provided through sanitation programs for many years now.

2.2.3. SEPTIC TANK SYSTEMS

The septic tank was patented in 1881 as "Mouras automatic scavenger". Since then it has become one of the most widely used sewage treatment/disposal facilities in the world. Nevertheless, and in fact surprisingly, it has also become one of the least understood sewage disposal technologies.

The function of a septic tank

A septic tank is a watertight settling tank designed and constructed to receive and treat domestic wastewater.
The septic tanks are constructed from reinforced concrete, brick, fiberglass or ferro-cement, mostly rectangular in shape and build according to Figure 2.2.

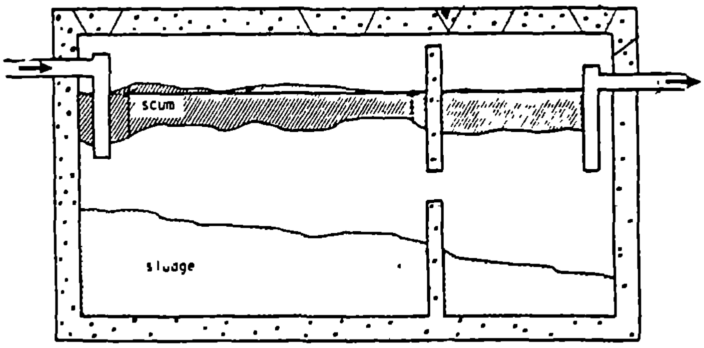


Figure 2.2. Schematic of conventional septic tank (Kalbermatten et al, 1980).

The main functions of a septic tank are the following:

- Sedimentation. The most important function is to remove solids. If sufficient liquid retention time is provided, settleable solids fall to the bottom and floatable solids rise to the top.

- Storage. The septic tank has to be designed in order that sludge and scum are stored for at least two years.

- Digestion. Anaerobic bacteria will digest sludge and scum in the tank.

A septic tank only is a pre-treatment system; the effluent remains to be disposed off (section 2.2.4.).

Design of a septic tank

Septic tanks in tropical countries normally are designed on criteria established in temperate climate countries. However septic tanks in tropical countries, designed on temperate climate criteria, will show an increased performance, because of the higher ambient temperatures.

De Kruyff (1985) suggests the following design mode for septic tanks in the Indonesian situation.
The required volume of the septic tank (effective volume), which relates to the volume below the influent and effluent pipe, consists of the volume required for sludge and scum storage and the volume necessary for maintaining a sufficient liquid retention time.

- The sludge and scum storage volume

$$A = P * N * S$$

A = required sludge and scum storage in liters
P = number of persons expected to contribute to the filling of the tank
N = number of years between desludging (min. 2 years)
S = yearly rate of sludge accumulation (liter/person)
25 liters for watercloset and pour-flush waste only
40 liters for watercloset and household sullage waste when bath and kitchen waste also drain into the tank

- The liquid volume

$$B = P * Q * T_h$$

B = required liquid volume in liters
Q = sewage flow in liter per person daily
120-160 lit/pers.day for house with full services and all waste disposed of in the septic tank
50-80 lit/pers.day for house with minimal connections (watertap in yard)
35 lit/pers.day for conventional cisternflush toilet only
10 lit/pers.day if the septic tank is connected to a handflushed pour-flush toilet only
T_h = minimum required liquid retention time in days

For tanks receiving W.C. waste only:
$T_h = 2.5 - 0.3 \log (P*Q)$, larger than 0.5
For tanks receiving W.C. waste and sullage:
$T_h = 1.5 - 0.3 \log (P*Q)$, larger than 0.2

Septic tanks are usually rectangular with a minimal liquid depth of 0.8 meter. The length-width ratio should be between 2:1 and 15:1.

Opinions differ upon the effect of vertical compartmentilazation. Usually the septic tank is divided into two compartments. The first compartment (2/3 of the total volume) contains the active sludge. If the second compartment contains sludge and scum in high concentrations, this is an indication that the tank is full and needs desludging.
In a meander tank, the principle of meander rivers is imitated by vertical partitions running the length of the tank, thus creating three compartments.
The first compartment comprises 2/3 of the total volume, the second 2/9 and the third 1/9. Research has shown that this different design provides better effluent qualities (Winneberger, 1984).

Imhoff tanks are divided into two levels. The lower level provides space for sludge storage, the upper one for sludge settling (de Kruyff, 1985).

Efficiency of a septic tank

In temperate climates generally merely combined black and grey water is treated in a septic tank system. The BOD and TSS removal are mainly achieved by plain sedimentation.
In tropical countries biodegradation also contributes to a considerable extent to the removal of organic pollutants. Depending on temperature and retention time, BOD and TSS removal efficiencies up to 70 % (Table 2.2.) are achieved. However, pathogen removal in a septic tank still remains very poor, consequently the effluent has to be subjected to further treatment for this purpose.

Table 2.2. Removal percentages in septic tanks

	Polprasert et al 1982	de Kruyff, 1985 temperate clim.	tropical clim.
BOD	27 %	25-45 %	up to 70 %
COD_{tot}	47 %		
COD_{fil}	-		
TSS	70 %	50-70 %	up to 70 %

2.2.4. POST TREATMENT

In connection with the description of the various on site sanitation systems, several health aspects, connected with the disposal of sludge and/or effluent were already mentioned.

When pour-flush toilets or pit latrines are used, the pit contents are, in most cases never dugged up and therefore will not represent any hazards.
If the tank contents is used, a minimum burial period of one year is considered sufficient to get hygienically safe material for reuse.

In areas of high groundwater tables however, these leaching systems can result in groundwater pollution.

Composting toilets can, as a result of prevailing relatively high temperature conditions, destroy most pathogens within three months, except for helminths. To destroy helminths as well, a period up to one year is considered to be necessary.

In Aqua privies and septic tanks pathogens can settle together with the solids. The settling rate of pathogens depends on the hydraulic retention time, the density of the pathogens and the ability of pathogens to adsorb on or to be absorbed by settling solids. However, not all the pathogens are settled out; the effluent of aqua-privy or septic tank is highly pathogenic.
Direct use of the acumulated sludge is hazardous, since it is inevitable that some of it will be relatively fresh. Further composting or digesting before reuse is recommended.

Frequently the effluent of a septic tank is disposed by means of a sub-soil drainage field. The soil will provide further treatment to the effluent. It is essential that this system is well designed and that the soil is able to absorb and purify the wastewater, so that groundwater pollution will not occur.
Other possible post treatment systems are sand/gravel filters or (fishing) ponds (very common on West-Java).

2.3. ANAEROBIC WASTE WATER TREATMENT

2.3.1. GENERAL

Anaerobic digestion and biogas production certainly are not new techniques or processes. Already in the 18th century, the relation between decaying vegetation and the production of inflamable gases was known. The application of biogas installations for energy generation from the digestion of domestic and animal wastes, are common practice in rural areas in Asia (India, Korea and China) for a long time now.
In Western countries anaerobic digestion has been considered feasible for already a long time for digesting concentrated wastes such as manure, and excess sludge from conventional aerobic treatment plants. More recent is the application of anaerobic digestion as a treatment method for less concentrated wastewaters. Since 1950 several treatment systems were developed; e.g. the Anaerobic Contact Process (Schroepfer et al, 1955) and the Anaerobic Filter (Young and McCarty, 1969). The energy crisis in the western world in the 70's stimulated the research in this field, which resulted in the development of more advanced methods such as various fixed film reactor types (Schwitzenbaum and Jewell, 1980; Heynen, 1983) and the Upflow Anaerobic Sludge Blanket (UASB) process (Lettinga et al, 1980).

Anaerobic digestion as waste water treatment method offers a number of significant benefits over conventional aerobic systems, viz.:

- a lower consumption of high grade energy (electricity), combined with the production of useful biogas from the organic pollutants.
- a lower production of excess sludge, which also is greatly stabilized and therefore easier to dispose. In many cases it can be used as a soil conditioner or fertilizer.
- anaerobic sludge can be preserved unfed during many months without serious deterioration.
- since nutrients as phosphorus (phosphate) and nitrogen (ammonium) are poorly removed from the wastewater by anaerobic treatment, the effluent could be used for irrigation purpose, thus leading to a saving on the expenses for fertilizers.

At the present state of knowledge the following limitations of the anaerobic process should be mentioned:

- Anaerobic methanogenic bacteria are highly sensitive for a number of chemical compounds, e.g. chlorinated hydrocarbons, cyanide and formaldehyde.
- Relatively long period of time needed for start-up of the process when sufficient seed sludge is not available, this is due to the slow growth rate of anaerobic bacteria.
- The poor removal efficiency with respect to minerals, which can be considered as drawback when the effluent can not be applied for irrigation but instead has to be discharged to surface and/or groundwater.
- Anaerobic treatment is not efficiently effective in eliminating pathogens.

- Anaerobic digestion essentially is a pre-treatment method, consequently frequently an adequate post-treatment (for instance a small aerobic treatment or fish-ponds) should be applied, depending on effluent discharge restrictions.

High temperatures and high concentrations of pollutants are favorable with respect to the rate of anaerobic digestion. Numerous succesful applications for the treatment of medium strength wastewaters (CODtot = 4000-5200 mg/L), at higher temperatures (30 - 35 °C) and liquid retention time of 6 to 8 hours are known for a long time. However, recently it has been shown that vary satisfactory results even can be obtained with domestic sewage (CODtot = 300 - 600 mg/L) at a temperature of 20 °C and a retention time of 8 hours (Lettinga, 1984).
Considering its simplicity and low capital costs, the lack for needs of supply of electricity and its feature to produce an usefull energy carrier from the organic pollutants, anaerobic treatment offers tremendous potentials, particularly for developing countries. An important drawback is of course the rather poor pathogen removal. However, cheap anaerobic treatment systems, combined with proper post-treatment can be an ideal solution for the severe environmental pollution problems in many third world countries.

2.3.2. MICROBIOLOGICAL ASPECTS OF ANAEROBIC TREATMENT

The anaerobic breakdown of organic, biodegradable wastes is a very complex process in which different groups of bacteria participate. This microbiological process takes place in every anaerobic system (e.g. anaerobic filter, UASB system or septic tank system). Those systems may be different in the ways the bacteria are kept in the system, or the way the waste is supplied to the system, but the processes of breakdown are virtually the same.
Generally, four sub-processes can be distinguished in the total process of methane digestion (figure 2.3.).

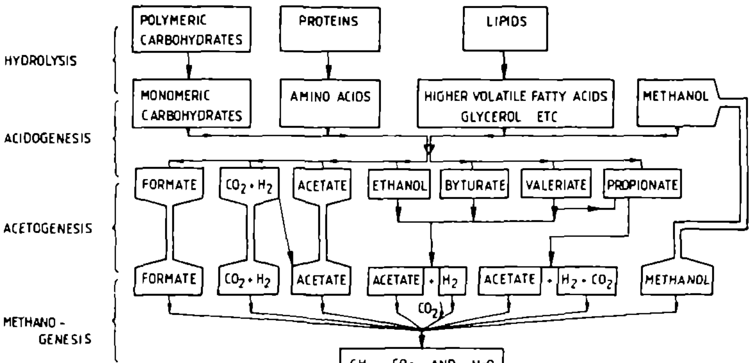


Figure 2.3.: Schematic survey of the four subprocesses involved in anaerobic treatment (Source: de Zeeuw, 1984)

The so-called fermenting bacteria perform the first two subprocesses.

1. Hydrolysis (or liquification)
Dissolved or undissolved polymers like proteins, fats and carbohydrates are hydrolysed, by exo-enzymes, to smaller components, which can enter the cells.
The hydrolysis step generally is rate limiting in the overall conversion of complex organic wastes such as household sewage.

2. Acidogenesis (or fermentation)
Those smaller components (monomeric carbohydrates, amino-acids, fatty acids) are transformed by intra-cellular oxidation-reduction processes, into carbondioxide, hydrogen and mainly volatile fatty acids (VFA).
Because of this VFA-production, the fermenting bacteria are usually called the "acidifying population".

3. Acetogenesis
The next step is performed by the acetogenic bacteria (named after their main product: acetate). In this subprocess, the products of the acidogenesis are converted into acetate, H_2 and, in the case of odd-numbered carbon compounds, CO_2.

4. Methanogenesis
The final step in the anaerobic digestion is accomplished by the methanogenic bacteria.
These bacteria can be divided into two major groups:
- acetate converting (acetotrophic) bacteria, which ocnvert acetate into methane
- hydrogen utilizing (hydrogenotrophic) bacteria, which convert H_2 and CO_2 into methane.

Of the formed methane 70 to 75 % is produced by the acetotrophic bacteria, the rest by the hydrogenotrophic bacteria (Zehnder et al, 1981).

Of course, oxygen is a toxic compound for these obligate anaerobic methane bacteria. However, the biomass in an anaerobic reactor contains also a large number of facultative anaerobic bacteria, which can consume oxygen entering the system. The process of anaerobic digestion as a whole is therefore not too sensitive for oxygen.
The partial pressure of hydrogen in an anaerobic system is kept sufficiently low by the activity of the hydrogen utilizing methanogens and also by sulphate reducing bacteria. If, as a result of a non-equilibrium between acetogenesis and methanogenesis, hydrogen accumulates, this can lead to an inhibition of the VFA breakdown. This will result in a pH drop. Acid formation by the fermenting bacteria can take place till pH 4. The methanogenic bacteria, however, perform at an optimum pH of 6.8 - 7.4 (Zehnder et al, 1981). Thus, a pH drop will affect further H_2 consumption and can lead to a complete disturbance of the digestion process.
For the well functioning of the total digestion process it is of utmost importance that all the sub-processes are in balance. The presence of a sufficient amount of buffer is always necessary. Generally this is the case in the form of the H_2CO_3 / HCO_3^- buffer system, with an optimum buffercapacity at pH = 6.5.

2.3.3. HIGH RATE ANAEROBIC WASTE TREATMENT PROCESSES, THE UASB-CONCEPT AND ITS APPLICATION

Applicable loading rates of anaerobic treatment systems are primarily determined by the following two factors:

- the amount of active sludge which can be retained in the reactor and
- the contact that can be achieved between this retained sludge and the incoming waste.

The more sludge is retained in the reactor and the better is the contact between sludge and the waste water, the higher are the loading potentials of the reactor.

The retention of biomass can be accomplished in various ways: bacterial sludge entrapment in the interstices between an inert material present in the reactor (viz. Anaerobic Filter), bacterial immobilization by attachment mechanisms to fixed surfaces or to mobile particulate surfaces (e.g. sand, clay, viz. Fluidized Bed).

The Upflow Anaerobic Sludge Blanket (UASB) process, is characterized by a reactor containing no packing material or biomass support material, so no reactor space is lost here.
The waste has to be introduced over the bottom of the reactor, consequently is forced upward through the reactor vessel, where it contacts the biomass retained in here.
Together with the mixing force of rising gas bubbles sufficient contact is ensured.
After a start up period, the sludge generally will attain good settling properties: development of the so-called granular sludge with exceptionally good settling characteristics can be accomplished on mainly soluble wastes.

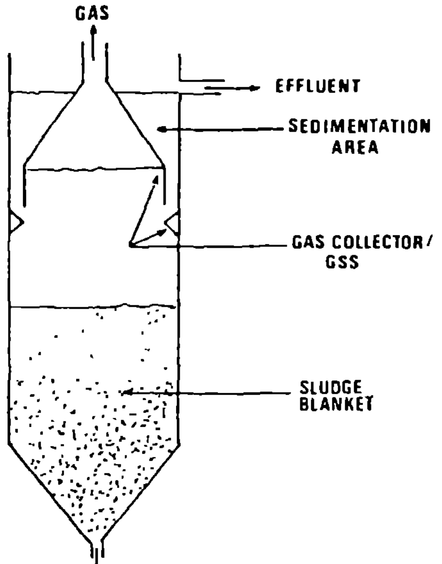


Figure 2.4. Diagram of the UASB-reactor.

An important feature of the UASB reactor design is the gas-solids separator (GSS) where the seperation of biogas, the liquid and the sludge is accomplished. This GSS device provides a quiescent zone at the top of the reactor where suspended solids will settle and return to the lower part of the reactor.
Figure 2.4. gives a schematic representation of an UASB-reactor.

Presently the UASB process is by far the most used anaerobic treatment system in practice. Full scale UASB plants, treating a variety of wastes have been installed all over the world. Sizes of these reactors range from 20 to 5500 m^3. Most of these UASB plants treat wastes from food-industries (e.g. sugar-industry, potato-industry, dairy industry, slaughterhouses, distilleries and breweries).

2.3.4. ANAEROBIC TREATMENT OF DOMESTIC WASTEWATER

Since 1974 research for the application of the UASB-process for the treatment of domestic wastewater has been conducted at the Department of Water Pollution Control of the Agricultural University Wageningen. The COD-values of the sewage varied here between 140 and 1100 mg/L and CODss-values between 6 and 800 mg/L. It was possible to achieve a COD-reduction of 50 - 80 % in a 6 m^3 reactor with flocculant sludge at temperatures of 20 °C and a retention time of 8 hours under dry weather conditions (Grin, 1985).
Rsearch was carried out in order to assess the feasibility of the UASB process for one-step treatment of raw domestic sewage under Dutch climatic conditions. The sewage contains appr. 450 mg/L suspended solids COD, 150 mg/L colloidal COD and 300 mg/L soluble COD. Small scale laboratory experiments indicate that these COD-fractions can be removed for respectively 90, 50, 70 % at temperatures of 10-20 °C (A.W.A. de Man et al, 1988).
Research performed in Cali, Colombia showed the possibility to treat even more diluted domestic wastewater at a temperature of 24-26 °C in a 64 m^3 UASB-reactor. The characteristics of the wastewater were: CODtot = 150 - 300 mg/L; CODss = 110 - 170 mg/L. The domestic sewag here was fairly septic of character. A COD-reduction of 75 - 82 % was achieved (BOD-reduction 78 - 85 %) at a retention time as low as 3 - 3.5 hours.
The sludge accumulation amounted to ca. 7.3 kg TSS/person/ year; the accumulated sludge was fairly well stabalized.
However, posttreatment of the effluent of the UASB-reactor was necessary to remove the remaining TSS, NH_4^+, PO_4^{3-} and pathogenic organisms (Haskoning, 1985).

Table 2.3 summarizes some relevant experiences with UASB-reactors treating some typical industrial wastewater and domestic wastewater as well.

Table 2.3. Some experiences with UASB-reactors

Wastewater	Volume Reactor (m^3)	COD infl. (mg/L)	Ret. time (hrs)	Temp. (°C)	Effic. *	Source
Industrial						
Brewery	1400	1200-1500	8-15	18-21	75-85	Swinkels '85
Slaughterhous	30	1500-2200	12-18	20	80-85	Sayed '84
Potato-starch	6	3300-5000	6-12	26	95	Lettinga '84
Sugarbeet	200	4000-5200	6- 8	30-34	85-90	Lettinga '80
Domestic						
Netherl.	0.12	400- 600	12	8-20	65-85	Lettinga '84
Netherl.	6	400- 600	8	9.5-19	55-80	Grin '85
Colombia	64	200- 350	3-3.5	24-26	75-82	Haskoning '85

Efficiency = (CODfiltered,effluent/CODtotal,influent)*100

3. OBJECTIVES OF THE PROJECT

The underlying project aims at the development and optimization of a modified Upflow Anaerobic Sludge Blanket (UASB) reactor as a low-cost compact, reliable and effective on-site treatment system for domestic sewage, the system also should provide a sufficiently long hold-up time of sludge and a satisfactory stabilisation of the sludge. The system should be a cost-effective alternative for conventional septic tank systems

Compared to aerobic treatment processes the advantages of the anaerobic upflow treatment technique include a lower production of excess (highly stabilized) sludge, energy production instead of energy consumption and the use of relatively simple and non-expensive installation. In comparison with the conventional septic tank treatment, it can be expected that the anaerobic upflow process will give a significantly better effluent, containing less biodegradable organic matter.
Moreover less space will be required for the installation of this system compared to conventional septic tank systems.

4. ORGANISATION OF THE UASB RESEARCH PROJECT

The research has been carried out in the period May 1984-May 1988 in Bandung West Java, on the basis of a budget allocation of Dfl 512.000,- provided by the research department of the Dutch Directorate General for International Co-operation (DGIS/DPO-OT).

The Indonesian counterpart in the project was the Ministry of Public Works, Directorate General of Human Settlements (Cipta Karya), Directorate of Environmental Sanitation, in co-operation with the Ministry of Public Works/Agency for Research and Development (Puslitbang Pemukiman).

The overall management of the project was with the National Institute for Public Health and Environmental Protection (RIVM) in the Netherlands.

The research division of the St. Borromeus Hospital at Bandung was responsible for field implementation; the Borromeus project staff consisted of a teamleader, finance/administrative personnel, analysts and operators of the UASB reactors. Their activities have included the establishment of regular contacts concerning the research with a.o. Directorate General Cipta Karya, Puslitbang Pemukiman and universities (ITB and Pajajaran University).

The Waste Water Division of the Agricultural University at Wageningen, the Netherlands are responsible for the technical and scientific execution of the project; this Division has coached research assistens, i.e. graduate students of the Agricultural University, who have participated in the project in Indonesia.

In the course of the project 5 progress reports and the present final report have been submitted to GON and GOI and other interested parties.

5. DESCRIPTION OF THE EXPERIMENTS

5.1. U.A.S.B. PILOT PLANT EXPERIMENTS

5.1.1. Description of the small scale U.A.S.B.-reactor

A schematic diagram of the small scale on site U.A.S.B. reactor which was designed according to the criteria given by the Department of Water Pollution Control of the Agricultural University of Wageningen is shown in Fig. 5.1.

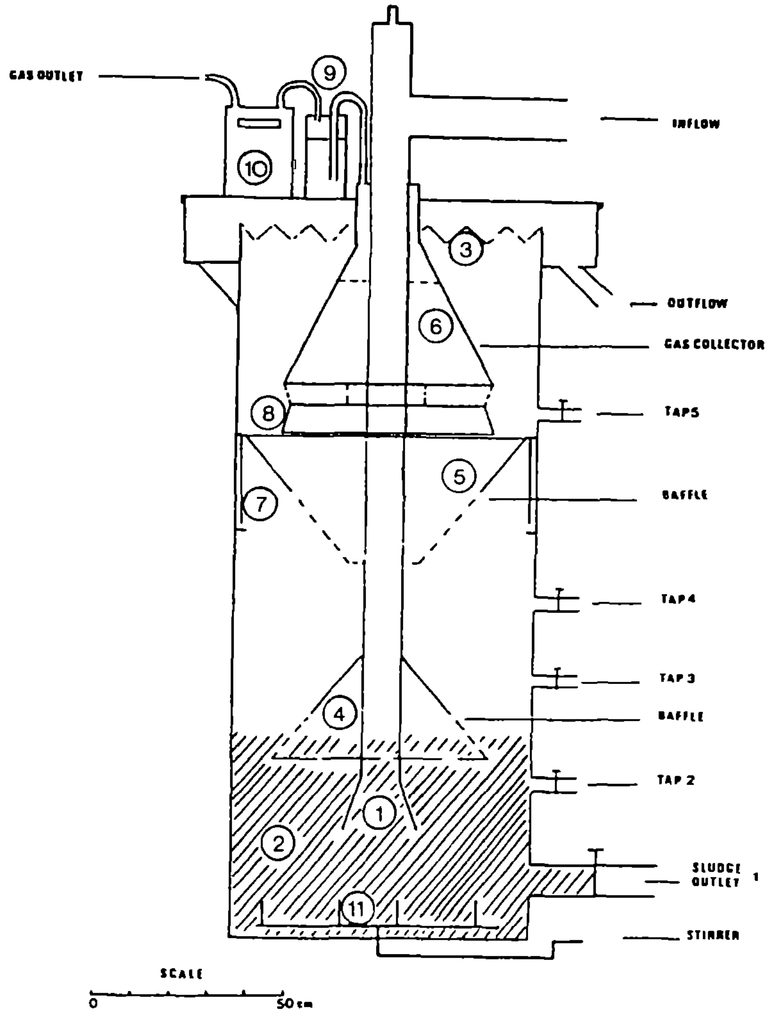


Fig. 5.1. The construction of the small scale U.A.S.B. reactor

Preliminary experiments were performed during a period of 14 weeks (in expectation of the construction of the larger reactor) in a 200 liter prototype U.A.S.B.-reactor with the same construction (Keller, 1986).
The design of the larger reactor, with a volume of 0.86 m^3, is based on an estimated filling up time of ca. 2 years. The reactor is placed in a pit below the discharge level of wastewater from the dwellings. In this way the wastewater flows into the reactor by gravity.

The influent is led via the central inlet pipe (1) to the bottom of the reactor, from where it streams upwards through the sludge blanket (2), as far as present here. The effluent leaves the reactor via the effluent gutter placed at the top of the reactor (3), and is collected in a collection drum.

The lower baffle (4), with holes at its outer side, serves to prevent fresh faeces from floating, and therefore forces the fresh faeces to desintegrate and to hydrolyze in the lower part of the reactor. The main function of the upper baffle (5), with holes near the centre, is to conduct the produced gas as completely as possible towards the gas collector (6). This baffle is gastight sealed to the reactor wall (7).

The gas collector is an essential part of a U.A.S.B.-reactor and is provided with a little ring (8) which improves gas collection.

The level of the gas/liquid interface is situated appr. 10 cm under the effluent outstream; because the gas inside the gas collector is under slight overpressure as established by a waterlock (9).

The produced amount of gas is measured with a dry gas meter (10) and is then discharged into the atmosphere.

The reactor contains five taps to collect sludge samples and/or wastewater samples. In order to facilitate the discharge of sludge the diameter of the lower tap is larger. On top of the reactor a control hole is situated for inspection of a scum layer, if present, and for collection of samples from the settler.

A stirrer (11) is installed at the bottom of the reactor. The effect of stirring in fact has not been investigated during the experiment so far.

5.1.2. Selection of the sites

The original objective of the project was to develop a low cost, compact, reliable and effective on site treatment system for merely black water.

In September 1985 the first 0.86 m^3 U.A.S.B.-reactor was installed at the Biofarma site. This reactor was operated on the black water from two housholds (in which ca. 9 persons are living).

Later, the objective of the project was extended to the treatment of total domestic wastewater, which involves the treatment of black and grey water.

For this purpose a second 0.86 m^3 U.A.S.B.-reactor was put into operation at the Cimindi low cost residential site of the Borromeus Hospital in December 1986, immediately after the dwellings received their inhabitants. The combined black and grey water of two households (viz. 10 persons) is treated by this reactor.

Compared to the Biofarma reactor the average influent concentration obviously is significantly lower, and therefore the hydraulic retention time accordingly shorter.

5.1.3. The research programme of the reactors

Influent sampling

In order to enable influent sampling, the reactors at both sites, could be disconnected from the discharge pipes of the houses, to connect them instead to sampling containers.
At the Biofarma site several influent samples were already taken prior to the start of the operation of the reactor. After almost one year of continuous operation the reactor was disconnected again during a number of days for the purpose of influent sampling. From then onwards, each month influent samples were taken at the Biofarma site.
Likewise, at the Cimindi site, several influent samples were taken prior to putting the reactor into operation. Hereafter, this reactor was disconnected every 1 or 2 months for sampling of the influent.

Effluent and gas production

During the operation of the reactor, every two or three days an effluent sample was taken from the reactors through the control hole on top of the reactor, while a second sample was taken from the collection drum. After sampling, the contents of the collection drum was pumped into a nearby septic tank.
The amount of produced gas was monitored by using the gas meter.

Sludge profiles

Every one or 2 months, during the monitoring period, water and/or sludge samples were taken from the five taps over the height of the reactor (see Fig. 5.1.) and from the control hole at the top of the reactor (from here on referred to as tap 6).

5.2. ANALYSES AND SPECIFIC MEASUREMENTS

5.2.1. Analyses

Influent

During two days, the wastewater produced by the two households was collected and was kept in the container for another two days under occasional stirring, in order to allow desintegration and hydrolysis of the fresh faeces. Here after, the total amount of wastewater was measured and samples were taken for conducting the required analyses in the laboratory. All influent samples were analyzed for total-COD, filtered COD, BOD, Volatile Fatty Acids, Alkalinity, pH, total phosphate, ortho-phosphate, Kjeldahl-nitrogen, ammonia-nitrogen, TSS and the ash content of the TSS.
All analyses were performed according to Dutch Standard Norm (N.E.N.), except for the VFA/Alkalinity and Kjeldahl-nitrogen analyses (more details are provided in Appendix 1).

Effluent and gas production

During the first period of the operation of the Biofarma reactor, effluent samples were taken merely from the collection drum (of course after mixing the content of the drum) and analyzed in the laboratory for total-COD, filtrated COD, BOD, VFA, Alkalinity, pH, total- and ortho-phosphate, Kjeldahl- and ammonia-nitrogen, TSS and the ash content of the TSS.
This sampling method implies that part of the effluent is present in the collection drum for up to 3 days at the ambient temperature of appr. 23 °C, before sampling is done. Biological degradation will start and procede inside the drum and will effect various of the parameters to be measured.
Therefore at the 14th of May 1986 (day no. 233 for the Biofarma reactor) a new more reliable sampling method was implemented. At the location Cimindi merely this improved method has been used.
Samples were taken from both the collection drum and the control hole on top of the reactor. Assuming that no further significant degradation of suspended solids will occur in the drum, but mainly degradation of the soluble substances (filtered COD), the total effluent COD of the reactor has been calculated as follows:

$$\text{total COD reactor} = (\text{total COD drum} - \text{filtrated COD drum}) + \text{filtrated COD reactor}$$

The filtered COD, pH, VFA-content and alkalinity are determined directly in the reactor sample, whereas total COD, filtered COD, BOD, total- and ortho-phosphate, Kjeldahl- and ammonia-nitrogen, TSS and ash content are determined in the sample from the collection drum.
The analytical methods used for the effluent samples are summarized in Appendix 1.

Occasionally a certain amount of gas was collected and analyzed (on a Riken Keiki Combustible Gas Detector Mocel NP-237) for the percentage of methane in the gas.

Sludge profiles

In the samples collected from the various taps over the height of the reactor immediately the pH and temperature were measured.

If the sample contained sludge, it was also analyzed for COD, TSS, Ash content and Sludge Volume Index (for a detailed description of the methods, see Appendix 3).

The samples consisting merely of liquid as well as the liquid part of a sludge/water sample were analyzed in the same way as the influent and effluent samples.

5.2.2. Specific measurements

Pathogens and Parasites

The performance of the U.A.S.B. reactor with respect to the removal of coliform bacteria (total and faecal) and worm eggs (Ascaris lumbricoides, Enterobius vermicularis, Trichuris trichuria) was followed for a number of successive months.

The Most Probable Number (M.P.N.) method (according to Standard Methods, description in Appendix 4) was used in analyzing the amount of total and faecal coliform bacteria.

In order to assess the amount of worm eggs in sludge/faeces and influent/effluent Stoll's method was used (Lewis et al, 1977), a short summary of this method is given in Appendix 4.

Balances of the digestibility experiments

After termination of the digestibility experiments, the contents of some of the serum flask assays were analyzed in more detail in order to make a COD-balance for that particular assay. For this purpose the serum flask was shaken firmly, whereafter the pH was measured. After deposition of the sludge at the bottom of the flask, liquid- and sludge-fraction were seperated; the quantities of both fractions were measured and then analyzed.

The sludge was analyzed for TSS, Ash content, COD and Sludge Volume Index (see Appendix 3).

The liquid fraction was analyzed for TSS, Ash content, COD, VFA and alkalinity, according to the methods described in Appendix 1.

Faeces experiments

Several test on the digestibility of faeces were performed. Each time the composition of the faeces was analyzed properly. The method used for this analysis is described in Appendix 3.

5.3. SUPPORTING LABORATORY INVESTIGATIONS

In addition to the pilot plant experiments several laboratory digestion experiments were performed to assess the gas production of sludge samples with or without the addition of a defined substrate(s).
An important factor in assessing the possibilities for the ultimate disposal and/or for any form of reuse of the sludge as well, concerns the extent to which the sludge is stabilized. Insufficiently stabilized sludge may give serious malodourous problems to the environment and may initiate insect nuisance. For this purpose "sludge stability digestion tests" were performed.
Standard tests with a feed of volatile fatty acids were conducted to asses the maximum specific activity of the sludge. Similar experiments but with faeces as substrate were conducted to assess the anaerobic biodegradability of faeces. The specific sludge activity provides information about the maximum rate of conversion of volatile fatty acids into methane. This test is used to get information about the development of the sludge activity.
Faeces digestion experiments were performed to gain information about the conversion of black water components into methane and the rate of the conversion process.

Method:

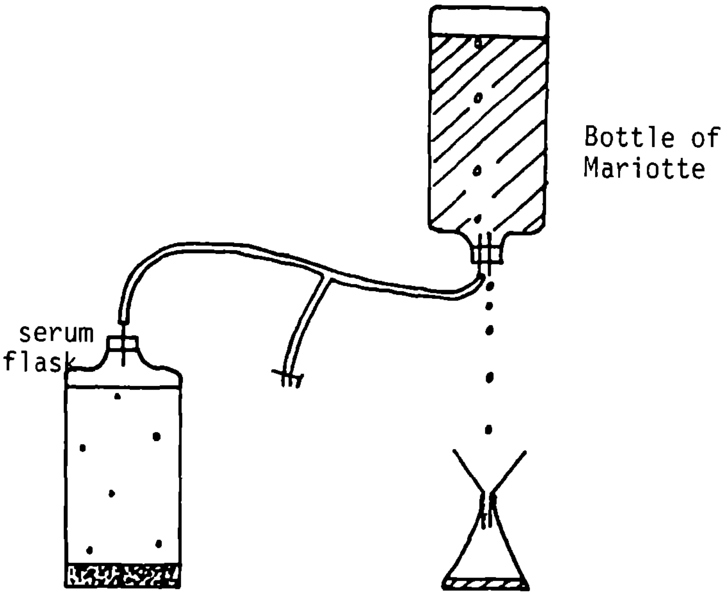


Fig. 5.2. Experimental set up for digestibility experiments

Figure 5.2 shows the experimental set up for these tests. The digestion process takes place in the serumflask. The gas produced in the digestion process passes through a teflon tube into a bottle of Mariotte. The CO_2 present in the biogas is removed here via absorption in the NaOH solution present as displacement liquid. The amount of displaced NaOH solution collected in the Erlenmeyer flask is a direct measure for the amount of produced methane in the serumflask.

All digestion experiments were carried out in the same way, only the content of the serumflask differed in the different types of experiments.

Conditions applied in the tests:

Sludge stability test:
- 10 grams of sludge-VSS
- no nutrients
- no trace-elements
- no pH correction

Specific activity test:
- 2.5 gram sludge-VSS
- 5 ml nutrient-solution*
- 1 ml trace-elements**
- a feed of volatile fatty acids (VFA), used as feed: in succession 200, 200, 400 and 600 mg C_2, C_3 and C_4 / liter
- pH correction at pH = 7.0

Faeces digestion test:
- 2.5 gram sludge-VSS
- 5 ml nutrient-solution
- 1 ml trace-elements
- a known amount of faeces-COD (the rough composition of the faeces is known)

After the various ingredients had been supplied to the flask, the mixture was always first flushed with N_2-gas before putting it in the set up for the experiment. These experiments were performed at ambient temperatures (24-28 ^{o}C). A blank test (filled with tap water) was run in order to enable the required corrections in the gasproduction. These corrections are necessary because liquid will be displaced from the Mariotte bottle due to temperature fluctutations.

* nutrients-solution: 13.6 mg $(NH_4)_2SO_4$/L
73.6 mg NH_4Cl
13.6 mg KH_2PO_4

** trace-elements according to Zehnder (1976).

Calculations:

Sludge stability

As an example the measured cumulative gasproduction relative to the digestion time as found in a sludge stabilisation experiment is shown in Figure 5.3. The results of the sludge stability tests are presented in terms of the fractional (in %) conversion of sludge-COD into CH_4-COD (after 100 days) relative to the total COD present in the flask at the the start of the experiment.
The calculation of the conversion factor of 2.343 for the COD-content of 1 L. CH_4-gas is explained in Appendix 2.

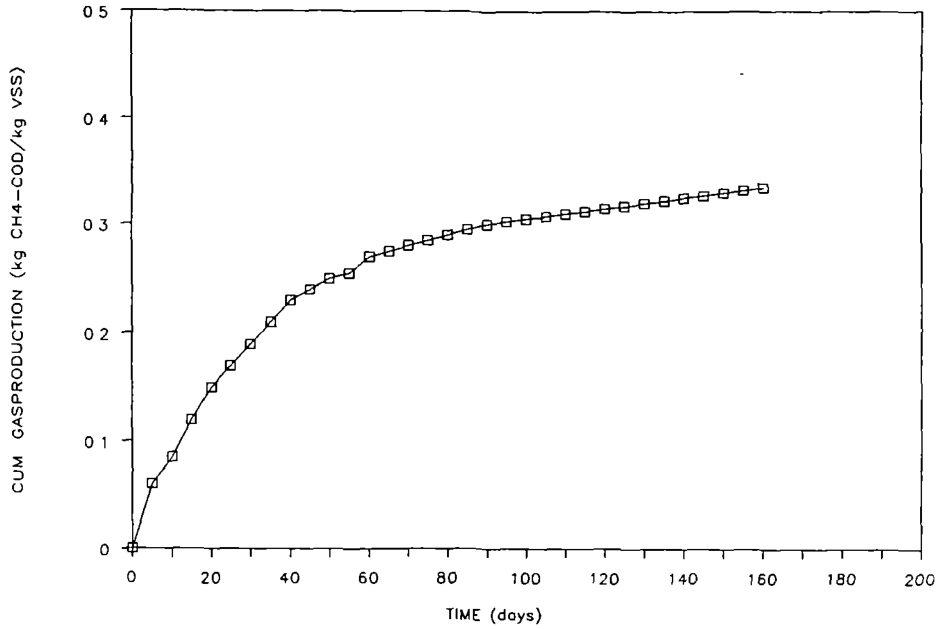


Fig. 5.3. Cumulative gasproduction as a function of time during a sludge stability experiment (10 g sludge-VSS from the 200 L prototype UASB reactor in a 1 L serum flask)

Specific sludge activity

The gas production measured in the specific activity assay obviously has to be corrected for the specific gas production measured in the stability experiments.

For the purpose of calculating the maximum specific methanogenic activity the corrected cumulative gas production for each feeding is plotted versus the digestion time (the duration of the experiment). The maximum rate of gas production is calculated from this plot (Figure 5.3) and expressed as kg CH_4-COD / kg VSS.day.

Faeces digestibility

Similarly as in the sludge activity assays, the maximum rate of gas production is calculated from the slope of the cumulative gasproduction curve and also expressed as kg CH_4-COD/ kg VSS.day.

In addition also the % COD removed from the flask as CH_4 (at the end of the experiment, when gas production almost has ceased) relative to the COD present in the flask at the start of the experiment is calculated.

6. RESULTS LABORATORY EXPERIMENTS

6.1. FAECES DIGESTION EXPERIMENTS

Faeces analyses

One of the factors affecting the performance of an U.A.S.B.-reactor treating black or combined black + grey water is the composition of excreta-products.
In general the compounds present in urine are easily biodegradable, while faeces generally contains a considerable fraction of vegetable components, which are non- or poorly biodegradable.
For that reason, several faeces samples have been analyzed in the laboratory for their TSS, ash, VSS and COD-values. Keller (1986) has carried out analyses on several faeces samples; the results are shown in Table 6.1.

Table 6.1. Faeces composition (Keller 1986).

Sample Date	TSS (%)	Ash (% ofTSS)	VSS (%)	Ash (%)	mg COD per g. wet	mg COD per g. TSS	mg COD per g. VSS
140185	30	10	27	3	402	1340	1489
160485	29	8	27	2	442	1525	1637
160585	17	10	15	2	209	1230	1393
140585	36	12	32	4	369	1025	1153
100885	29	8	27	2	429	1480	1589
130885	27	9	25	2	343	1270	1372
AVERAGE	28	10	26	3	366	1312	1439
STAND.DEV	5.66	1.38	5.16	0.76	77.70	165.95	159.48
% ST.DEV.	20.2	13.8	19.8	25.3	21.2	12.6	11.1

In addition analyses have been carried out on faeces samples originating from the Biofarma site (v.d. Horst et al, 1986). Table 6.2. summarizes the results of these tests.

Comparing the results in Table 6.1 and 6.2 reveals that the composition of "Keller's" and "v.d. Horst's" faeces is very similar, apart from the somewhat lower ash content of the latter. The results are also well comparable with data in the literature (Gotaas 1956, Chapter 2.1.).

Faeces consists for about 70 % of water and the dry matter mainly consists of organic matter (appr. 10 % ash content).
Table 6.2. shows that both COD- as Nitrogen-values per gram faeces-TSS are more constant than the values per gram wet faeces or faeces-VSS. Therefore, the amount of TSS present in the daily influent flow is the most appropiate to estimate the incoming faeces-COD and faeces-nitrogen.

Table 6.2. Composition of faeces originating from the Biofarma site.

Sample Date	Day No.	TSS (%)	Ash (% ofTSS)	VSS (%)	Ash (%)	mg COD per g. wet	g. TSS	g. VSS	mg N-total per g. wet	g. TSS	g. VSS
110985		30.55	6.76	28.48	2.07	317	1033	1113			
101085	17	30.32	9.03	27.58	2.74	402	1327	1458			
161085	23	38.57	8.08	35.45	3.12	469	1216	1323			
231085	30	30.00	5.38	28.38	1.62	390	1300	1374			
311085	38	27.65	8.73	25.24	2.41	323	1169	1281			
131185	51	20.19	9.91	18.19	2.00	219	1089	1209			
201185	58	33.19	8.27	30.45	2.74	414	1246	1358	2.34	7.06	7.70
271185	65	21.67	5.13	20.56	1.11	239	1101	1160			
41285	72	29.30	8.89	26.70	2.60	374	1278	1402			
111285	79	24.74	9.02	22.51	2.23	343	1388	1526			
181285	86	22.00	11.87	19.39	2.61	288	1308	1484			
271285	95	28.32	8.25	25.98	2.34	367	1297	1414			
311285	99	31.98	6.88	29.78	2.20	421	1316	1413	2.41	7.53	8.09
150186	114	31.69	9.38	28.72	2.97	437	1379	1522	2.09	6.61	7.29
230186	122	26.66	5.88	25.09	1.57	377	1414	1502	1.41	5.28	5.61
60386	164	28.25	9.62	25.53	2.72	351	1244	1377	1.59	5.62	6.22
90486	198	36.17	6.58	33.79	2.38	412	1140	1220	2.03	5.62	6.02
AVERAGE		28.90	8.10	26.58	2.32	361.35	1249.71	1360.94	1.98	6.29	6.82
STAND.DEVIATION		4.78	1.73	4.53	0.51	65.80	107.59	123.18	0.37	0.83	0.92
% ST.DEV.		16.5	21.4	17.0	22.1	18.2	8.6	9.1	18.5	13.2	13.5

Some of the faeces samples from the Biofarma site (Table 6.3.) have also been tested for the amount of pathogens, viz. the total coliforms and faecal coliforms.

As expected the amount of coliforms per gram wet faeces fluctuates considerably. As expected it is impossible to assess a clear relation between the amount of coliforms and the COD-, TSS-, VSS-and Ash-values.

Table 6.3. Amount of coliforms (in $\log_{10}$-units) in faeces samples originating from the Biofarma site

DATE ddmmyy	DAY No.	TSS (% wet)	ASH (% TSS)	COD (mg/gTSS)	COLIFORMS PER g wet	g TSS	g VSS	g Ash	g COD	FAECAL COLIFORMS PER g wet	g TSS	g VSS	g Ash	g COD
131185	51	20.19	9.91	1089	6.6	7.3	7.4	8.3	7.3		ALL FAECAL COLIFORMS			
201185	58	33.19	8.27	1246	7.6	8.0	8.1	9.1	7.9		ALL FAECAL COLIFORMS			
271185	65	21.67	5.13	1101	9.3	10.0	10.0	11.3	10.0		ALL FAECAL COLIFORMS			
41285	72	29.30	8.89	1278	8.0	8.6	8.6	9.6	8.5		ALL FAECAL COLIFORMS			
111285	79	24.74	9.02	1388	6.2	6.8	6.8	7.8	6.7		ALL FAECAL COLIFORMS			
181285	86	22 00	11.87	1308	8.5	9.2	9.3	10.1	9.1	8.2	8.9	9.0	9.8	8.8
271285	95	28.32	8 25	1297	8.4	8.9	8.9	10.0	8.8	7.4	7.9	8.0	9.0	7.8
311285	99	31.98	6.88	1316	7.8	8.3	8.4	9.5	8.2	6.8	7.3	7.4	8.5	7.2
150186	114	31 69	9.38	1379	8.0	8.5	8.6	9.5	8.4		ALL FAECAL COLIFORMS			
230186	122	26.66	5.88	1414	6.1	6.6	6.7	7.9	6.5		ALL FAECAL COLIFORMS			
60386	164	28.25	9.62	1244	6.7	7.2	7.3	8.3	7.2		ALL FAECAL COLIFORMS			
90486	198	36.17	6.58	1140	8.0	8.4	8.5	9.6	8.4		ALL FAECAL COLIFORMS			
AVERAGE		27.85	8.31	1267	7.6	8.2	8.2	9.3	8.1	7.5	8.0	8.1	9.1	7.9
STAND.DEV.		4.78	1.83	104	0.95	0.97	0.96	0.98	0.98	0.57	0.66	0.66	0.54	0.66
% ST. DEV.		17.9	23	8.2	12.5	11.8	11.7	10.5	12.1	7.6	8.3	8.2	5.9	8.4
MEAN					7.9	8.3	8.4	9.5	8.3	7.5	7.7	7.8	9.1	7.9

Faeces desintegration and hydrolysis (under conditions of unbalanced digestion)

In the laboratory, under conditions of ambient temperature, an experiment was performed in which the course of the gas production and composition of a faeces suspension were followed during a 40 days period.
This test was carried out in order to assess the possibility to start up a U.A.S.B.-reactor without using a separate inocculum and to follow the growth of various bacterial species. Besides, the rate of desintegration and hydrolysis of the faeces were the point of interest. The faeces suspension had the following composition (faeces 31-10-1985; see Table 6.2.)

- 9.97 gram faeces per liter
- 2.76 gram TSS per liter
- 2.52 gram VSS per liter
- 3.22 gram COD per liter

To prevent rapid acidification of the mixture, a buffer was added (3.6 g $NaHCO_3$/liter = 36.5 meq/liter = 14.5 meq $NaHCO_3$ /g faeces-VSS).

The course of the gas production from this mixture was assessed using the experimental set up as described in Chapter 5.3. Unfortunately, at day no. 40, due to the low gas production, NaOH entered the serum flask, and for that reason the assay had to be terminated.
At the start of the above experiment, several 500 ml flasks were filled with the same faeces-water mixture, locked and set aside under the same conditions. After different periods of time a flask was frozen in. All frozen flasks were analyzed for COD (total and filtered), pH, alkalinity, V.F.A., phosphate (total and ortho) and nitrogen (Kjeldahl and ammonia) at the end of the experiment.

The results of this experiment are listed in Table 6.4 and the Figures 6.1, 6.2 and 6.3 (v.d. Horst et al, 1986).

Table 6.4. The course of total and filtered COD in a faeces water mixture without using inocculation (average of two values)

Time (days)	1	3	6	11	18	27	42
CODtotal	3185	3031	3727	3919	3046	3573	2657
CODfilt.	1081	1155	1097	1120	1084	1301	1244

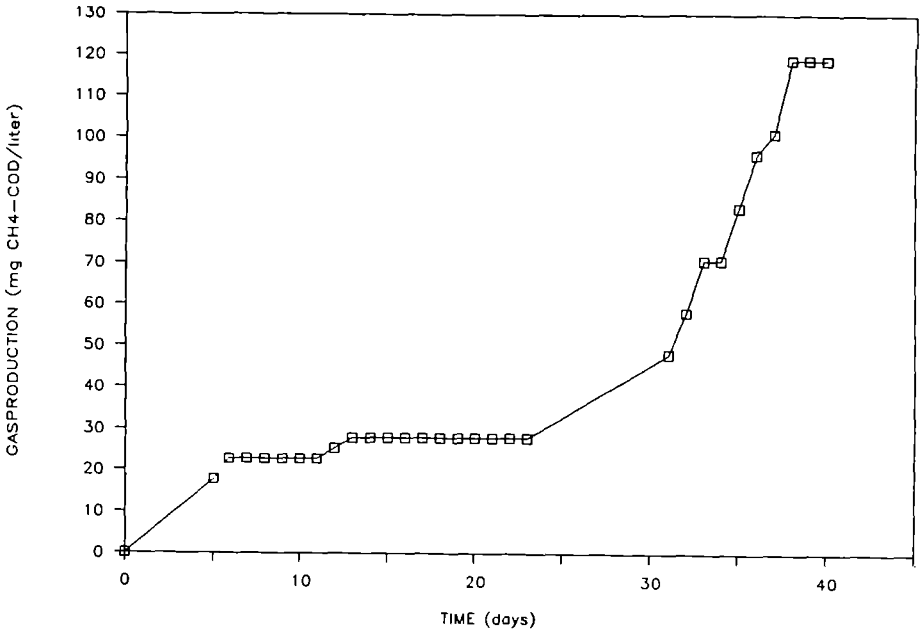


Fig. 6.1. Course of the gas production of a faeces suspension (unseeded, COD-value at the start of the experiment 3220 mg/L)

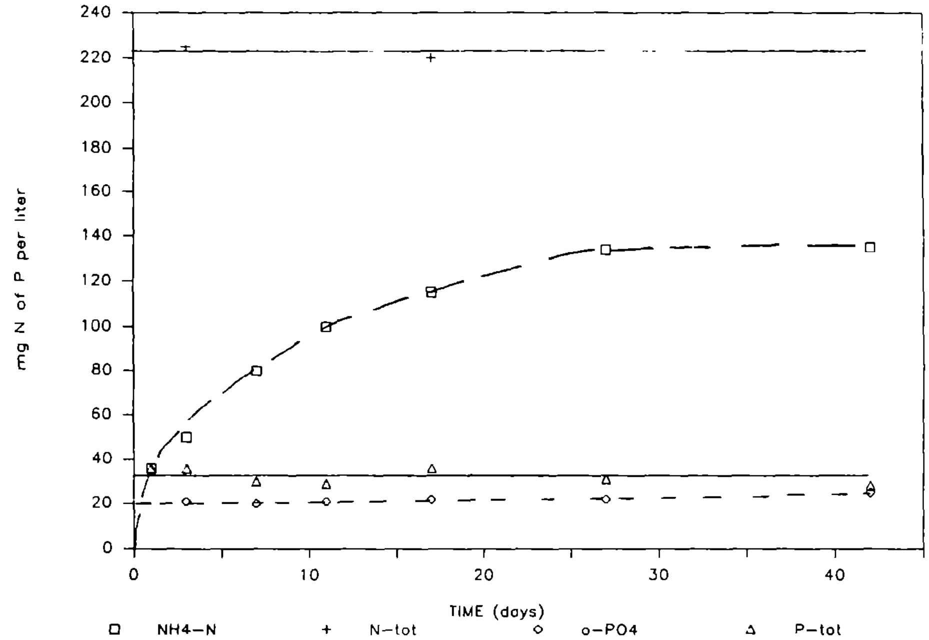


Fig. 6.2. Phosphate (total and ortho) and Nitrogen (total and ammonia) concentrations in a faeces solution in the course of time

The results in Fig. 6.1. and Table 6.4. show that only a small fraction of COD is converted into methane, in fact that small that it is not clearly reflected in a reduction of the COD in the faeces mixture. In considering these results, it should be taken into account that a relatively large error occurs in measuring the COD-concentrations in complex mixed liquors like those in the present experiments.

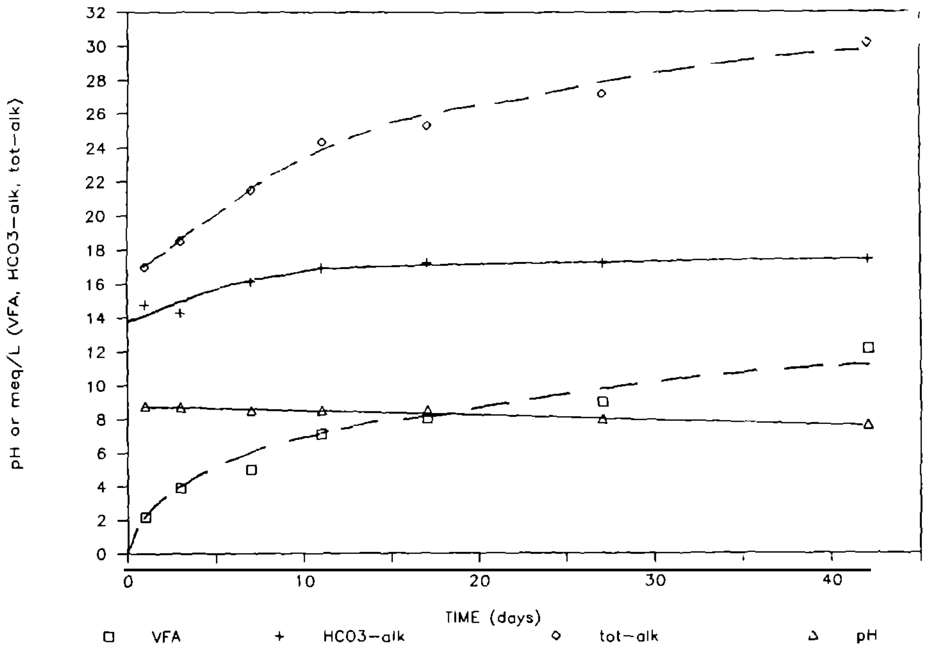


Fig. 6.3. The course of pH, alkalinity and V.F.A.-concentrations in a faeces suspension.

The rate of hydrolysis can be established by measuring the rate of ortho-phosphate and ammonia-nitrogen formation from the complex organic material, and the production rate of the soluble COD in the solution and CH_4-COD.
Fig. 6.2. shows that the formation of ortho-phosphate occurs rapidly; as was observed in previous experiments 50 % of the total available phosphate passes into solution within 2 days: appr. 30 % of the total available phosphate in faeces apparently consists of non- or very poorly hydrolizable matter.
The formation of ammonia-nitrogen occurs clearly at a much slower rate; only after 25 days the maximum amount of ammonia-nitrogen to be found, comprising appr. 65 % of the total available nitrogen, is reached. Apparantly 35 % of the total-N is non-or poorly biodegradable.

As a result of the formation of VFA and CO_2 and the slow breakdown of VFA by methanogenic bacteria, the pH in the mixed liquor drops slightly (Fig. 6.3.). A VFA-concentration of 12 meq/L roughly corresponds to a COD content of 1320 mg/L (Appendix 5), so almost all filtered COD in the faeces solution can be attributed to volatile fatty acid-COD. Apparently the rate of hydrolysis of non-soluble COD proceeds very slowly (see Table 6.4.).
Bicarbonate-alkalinity remains fairly constant; major part of it can be attributed to the $NaHCO_3$ which was added at the beginning and the formation of NH_4^+. The total alkalinity increases as a result of the formation of NH_4^+.
The amount of ammonia (in meq), formed from faeces (10 meq) is almost equal to the amount of VFA (12 meq); consequently the VFA will be neutralized. In addition some additional ammonia will be present in the reactor, i.e. as formed from urine.

Resuming the results, it can be concluded that during a start up of a U.A.S.B.-reactor without inocculation, processes take place at a rather low rate so that considerable time will be involved before an actively digesting sludge will have been produced. Methanogenesis starts after appr. 30 days. Particularly the rate of liquefaction proceeds very slowly. On the other hand the results show that little if any bicarbonate alkalinity has to be applied to maintain the pH at an optimal level.

Faeces digestion

In order to assess the digestibility of faeces, several experiments were performed using as seed material the sludge applied for the start up of the 0.86 m^3 reactor at location Biofarma. Several faeces-sludge ratios were investigated using the experimental set up described in Chapter 5.3.
Feed mixtures were made with faeces samples originating from location Biofarma, sampled at 11 september, 10, 16 and 23 oktober 1985 (the composition of these samples is described in Table 6.2.).

Results of the digestion experiments with faeces are presented in Fig. 6.4. and 6.5. The faeces-concentration at the beginning of the experiment is expressed as kg COD-total/kg sludge-VSS resp. kg faeces-VSS/kg sludge-VSS.
For reason for comparison, the results of the activity measurements with VFA-feedings are also shown in Fig. 6.4.

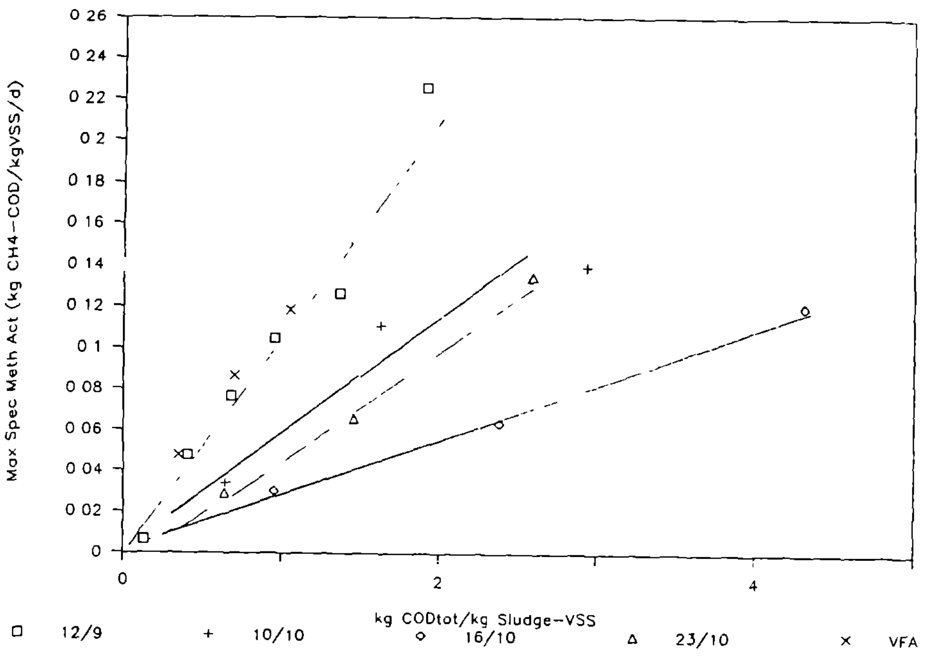


Fig. 6.4. The measured maximum specific methanogenic activity of sludge at different initial sludge loadings (2.5 g sludge-VSS/L, at ambient temperature).

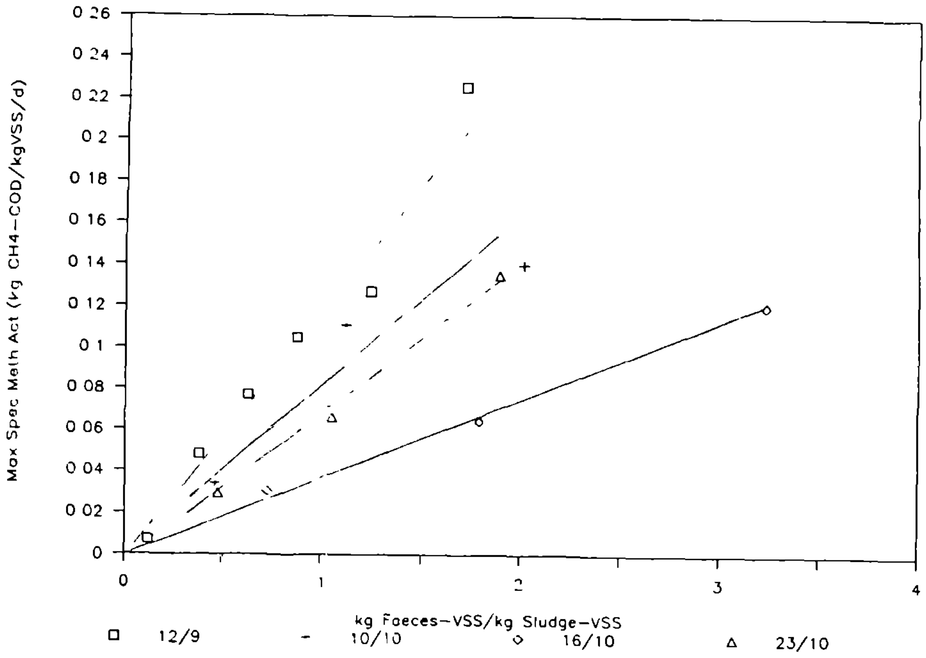


Fig. 6.5. The measured maximum specific methanogenic activity of sludge on different faeces-concentrations (2.5 g sludge-VSS/L, ambient temperature).

As can be seen from the results quite strong variations in activity occur. These fluctuations most likely can be attributed to large differences in the composition of the used faeces samples. Faeces 11-9 was very well digestible and accordingly the activity on this faeces sample is well comparable to the activity assessed on volatile fatty acids feedings. Activities on other faeces samples are distinctly lower and no clear relation is found between the activity and the faeces-COD/sludge-VSS resp. faeces-VSS/sludge-VSS ratios. Regarding the results obtained with one faeces mixture, the activity appears to increase linearly with increasing faeces-COD/sludge-VSS resp. faeces-VSS/sludge-VSS ratio.

As COD/sludge ratios to be applied in the U.A.S.B.-reactor will be in the range of 0.01-0.70 kg COD/kg sludge-VSS, depending on the amount of sludge present in the reactor, some of the experiments are less appropriate regarding the operation of the U.A.S.B.-reactor under practical conditions. The experimental results reveal that in fact a maximal tolerable faeces-concentration is not found and also that at least in these experiments the upper maximal sludge activity is not reached.
Besides the large differences found in activity on the faeces-mixtures, there also exist large variations in digestibility of the faeces samples, and in the duration of the digestion process as well.
Table 6.5. shows the results of all faeces digestion experiments.

Table 6.5. Results of the faeces digestion experiments

Date	Faeces mixture ml	CODtot mixture mg/L	Faeces-VSS Sludge-VSS ratio	Max.Spec. Meth.Act. kgCH$_4$-COD/ kgVSS	COD conversion %	Duration of exp. days
11-9-85	25	342	0.12	0.007	36	32
	75	1026	0.37	0.048	58	
	125	1710	0.62	0.077	68	
	175	2394	0.86	0.105	72	
	250	3420	1.23	0.127	79	
	350	4788	1.71	0.226	84	
10-10-85	50	1631	0.45	0.034	44	43
	125	4079	1.12	0.111	44	
	225	7342	2.01	0.140	49	
16-10-85	50	2386	0.72	0.030	44	107
	125	5964	1.80	0.064	45	
	225	10786	3.24	0.121	52	
23-10-85	40	1622	0.47	0.029	72	82
	90	3650	1.06	0.066	55	
	160	6489	1.89	0.135	52	
	160*	6489	1.89	0.125	61	

* PH in the beginning not corrected to 7.0

The faeces sample 11-9-85 was very well and easily digestible, whereas the other faeces samples, after a rapid initial degradation of easy digestible compounds, showed only a low gas production for a long time onwards, up to 107 days after the start of the experiment.

6.2 SLUDGE INHIBITION EXPERIMENT

A survey made on water consumption and water use at the Biofarma location, showed that toilets are regularly cleaned with detergents such as carbol, lysol etc (Dijkstra, 1984). Use of these detergents might have negative side effects on the viability of the active biomass in the reactor.

For this purpose some experiments have been performed with respect to possible inhibitory effects of the frequently used lysol (a phenolic compound). According to the prescript on the bottle (bought in a local shop) the investigated lysol should be applied for cleaning purposes in a concentration of 20 ml lysol per liter water.

The experiments were carried out using U.A.S.B.-sludge. Several sludge activity measurements were performed using 200 mg VFA/L as substrate and with different lysol concentrations. Table 6.6 presents the calculated activities and the calculated percentage of inhibition to the activity without additional lysol.

Table 6.6. Inhibitory effects of lysol on U.A.S.B. sludge

ml lysol added per liter	dilution factor*	specific activity	% inhibition
0	-	0.06	0
0.5	40	0.05	20
1.0	20	0.04	35
2.0	10	0.03	50
4.0	5	0.03	50
6.0	3.3	0.03	50
10.0	2	0.03	50

* Dilution factor with respect to the concentration to be used (20 ml/L)

At low concentrations of 0.5 ml/L, lysol already has an inhibitory effect on the methanogenesis. Inhibition increases when higher concentrations are used. However, 100 % inhibition was not found, the maximum inhibition was appr. 50 %.

The question obviously is: what are the maximum lysol concentrations that can occur in an on-site U.A.S.B.-reactor? Assuming the worst possible case: one bucket containing 200 ml lysol is flushed through the toilet and directly contacts the biomass in the lower part of the reactor (say 100 liter). This will result in a lysol concentrion of 2 ml/L and an inhibitory effect can be expected.

Whether or not the sludge will recover such an event has not been investigated yet.

7. BLACK WATER TREATMENT: THE BIOFARMA REACTOR

7.1. SITE DESCRIPTION

The 0.86 m^3 on site U.A.S.B. reactor treating black water was installed at the housing complex of Biofarma, the state Pharmaceutical Laboratories at Bandung. The reactor was connected to two households (in which 4 adults and 5 children are living) belonging to a unit of low-income housing types. Water is supplied by means of individual yard pumps. Each house has its pour-flush squatting toilet; the toilet waste is discharged into an oversized septic tank (5 m^3 volume, although 1 m^3 presumably should be sufficient).
An outline of this (former) situation is shown in Fig. 7.1.

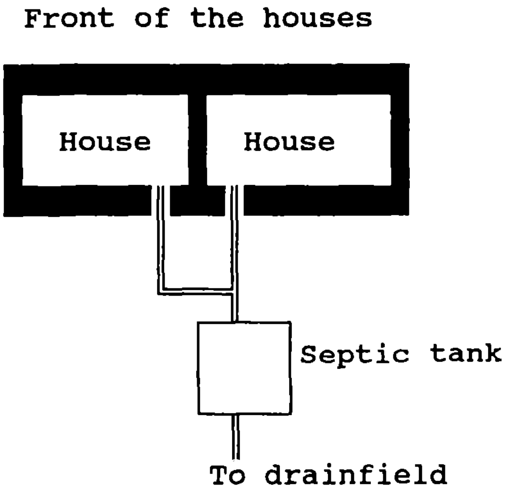


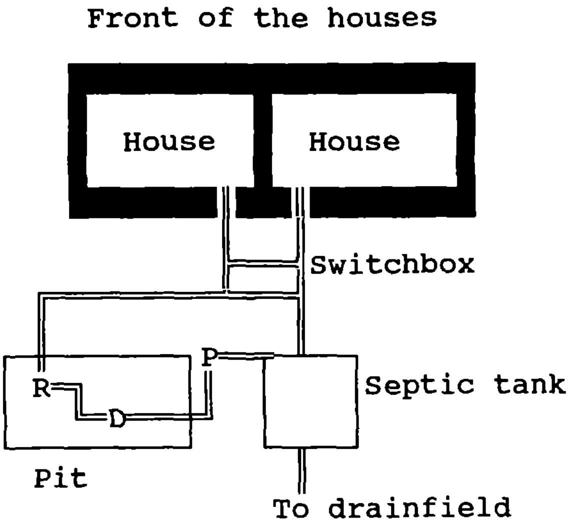
Fig. 7.1. Outline of the former situation at the Biofarma site

The black water entering the septic tank contains excreta-products and water only. In Indonesia water is used for anal cleansing. Sometimes sanitary towels and preventives are discharged into the toilet as well.

The effluent of the septic tank is discharged in a subsoil infiltration bed.
At the start of the experiments the septic tank already was for 7 years in operation and so far had never been desludged. Upon opening of the tank for inspection, it appeared to be empty; due to broken inlet pipes very little feed had been put in the tank during these 7 years. The tank contained only a small amount of sludge at the bottom.
Most occupants of the houses were not aware of the existence of the septic tanks as there was no attribution (in labour or money) for the maintenance of these tanks (the Biofarma institute takes care of the maintenance).

The grey water of the houses is not submitted to any treatment; it is directly discharged in an infiltration pit behind the houses into the soil.

The inlet pipes of the septic tank were repaired together with the preparations for the installation of the reactor, which resulted in the lay-out of the reactor site, as shown in Figure 7.2.



R = Reactor
D = Drum
P = Pump

Fig. 7.2. Site Biofarma after installation of the U.A.S.B.-reactor.

The housing pit for the reactor is situated next to the septic tank. The separate black water streams from the two households join in a switchbox. From here, the waste can be distributed either to the septic tank or to the reactor. The effluent of the reactor is collected in a drum (used for sampling). The contents of the collection drum are pumped into the septic tank for further discharge.

7.2. INFLUENT MEASUREMENTS

As mentioned in Chapter 5.1.3., the 0.86 m^3 U.A.S.B.-reactor was, after almost one year of continuous operation, regularly disconnected for a few days from the discharge pipes of the two households in order to enable the sampling of the influent.
In order to assess the conditions for the start-up of the reactor, several influent measurements had already been performed prior to the installation of the reactor.
All samples were analyzed according to the methods described in Chapter 5.2.
The results of these measurements are listed in Table 7.1. below.

Table 7.1. Influent measurements at location Biofarma

Parameter	Unit	Average	Standard Deviation
CODtotal	mg/L	5542	2224
CODfiltered	mg/L	1507	722
CODss	mg/L	4034	2036
BODtot	mg/L	1586	714
pH	-	7.1	0.4
Total Alkalinity	meq/L	15.5	6.7
VFA	meq/L	8.9	4.5
N-total	mg/L	383	114
NH_4^+-N	mg/L	205	102
P-total	mg/L	55	17
PO_4-P	mg/L	40	12
TSS	mg/L	1803	1175
VSS	mg/L	1529	833
ASH	% of TSS	9.7	2.7

The influent can be characterized as a medium strength complex type of waste. The main part of the organic pollutants is present as insoluble suspended matter (73 % of the total COD). The COD/BOD ratio can be put at ca. 3.91, which is very high. The pH is neutral and the buffering capacity is sufficient.
Considering the total VFA-values, we can conclude that about 57 % of the soluble COD (CODf) is already acidified (taking 1 meq total VFA is appr. 110 mg COD, Appendix 5).
Of the total available phosphate, about 73 % is present as ortho-phosphate. This is comparable with the faeces experiments (chapter 6.1.).
Ammonia-nitrogen represents about 54 % of the total available nitrogen. Comparing this with the results from the faeces digestion experiment, we can conclude that after 2-4 days (of hydrolyzation) not all the hydrolyzable nitrogen in the influent (65%) is measured.
The ashcontent of the influent is comparable with the amounts found in faeces samples.

On four successive days (2-6 February 1988) the amount of influent was measured frequently over the day in order to obtain the distribution of the black water-flow over the day. Figure 7.3. shows the distribution of the black water-flow over the day for Friday (a day of prayer for the muslim society) and a normal working day.

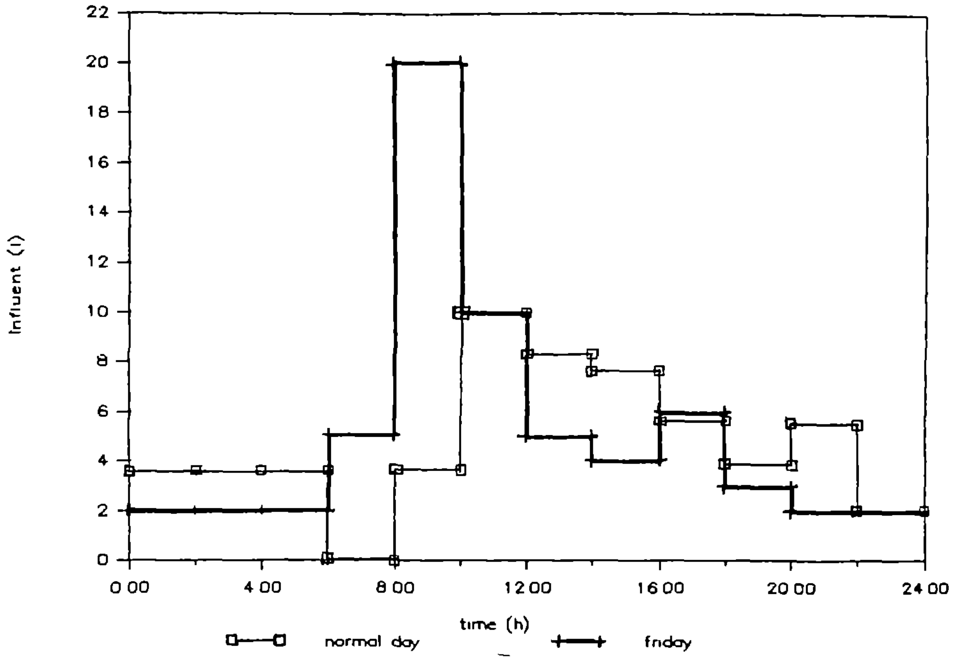


Fig. 7.3. Distribution of the black water-flow over a normal day (averages of three days) and on a Friday.

The mean peak flow occurs between 10 and 12 o'clock a.m. and amounts up to 10 liters/2 hours. Figure 7.3. shows that there does not exist much difference between Friday and a normal day, except for the peak flow between 8 and 10 o'clock a.m.. This is not according to our expectations, because a peak was expected between 10 and 12 o'clock a.m. just before the most important prayer hour.

The influent flow rates during the experimental period are shown in Fig. 7.4.

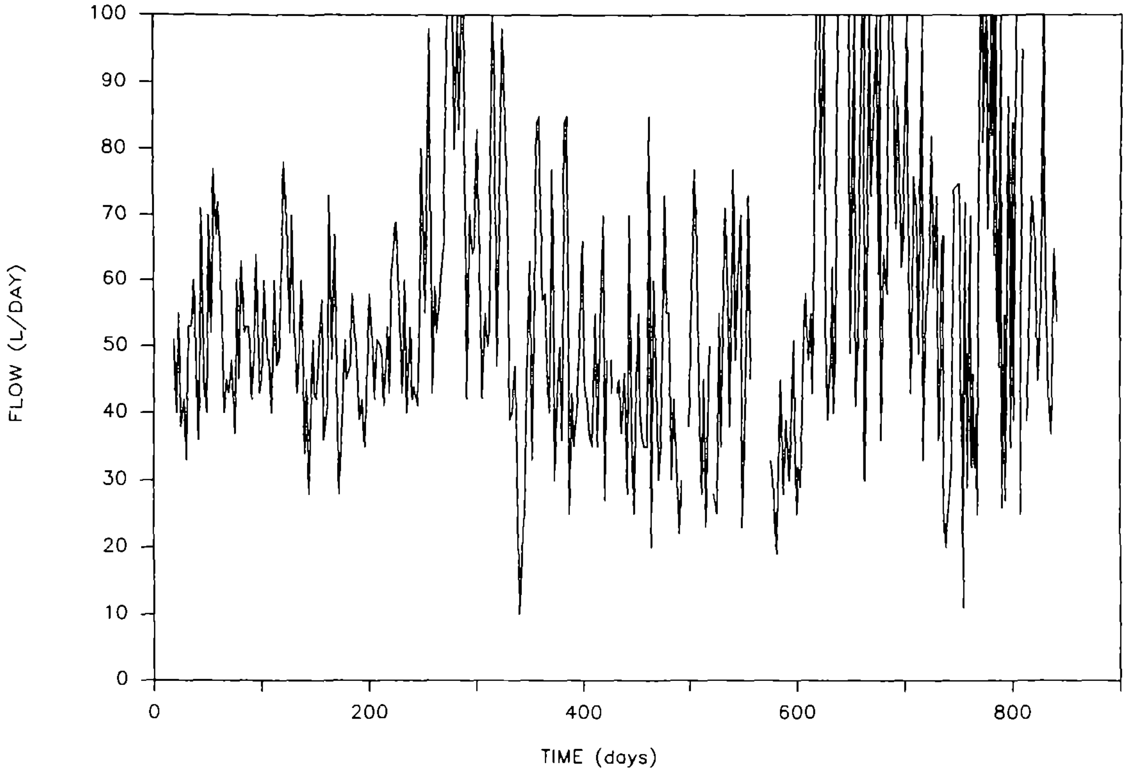


Fig. 7.4. The course of the influent flow rate during the operation of the 860 L. U.A.S.B. reactor at the Biofarma location

7.3. RESULTS OF THE BIOFARMA REACTOR TREATING BLACK WATER

7.3.1. Performance of the reactor

Preliminary research

Prior to the start up of the 860 liter reactor, Keller (1986) performed some experiments using a scaled down 0.2 m^3 U.A.S.B.-reactor. This prototype reactor was monitored during a period of 14 weeks. Initially this reactor (inocculated with 110 liter seed sludge from a septic tank) performed well: i.e. CODtot and TSS reduction amounted up to resp. 83 and 79 %. The seed sludge improved in its methanogenic activity (from 0.026 to 0.061 kg CH_4-COD/kg VSS.d with the 2nd feed of 200 mg VFA/L) and with respect to its settleability. However, after 10 weeks of continuous operation, a significant solids wash out started, due to sludge growth and the insufficient buffering volume of this small reactor. During the last weeks the performace of the reactor was therefore poor, i.e. it dropped down to a CODtot- and TSS-removal efficiency of resp. 68 and 36 %. The biogas production could not be measured in this reactor.

Start up conditions of the 860 L UASB reactor

At the 25th of September 1985 (corresponding to day 0 of the monito-ring program) the 0.86 m^3 U.A.S.B.-reactor at location Biofarma was seeded with 166 liter seed sludge and connected to the influent flow.
The sludge used for inocculation partly originated from the small prototype (200 liters) U.A.S.B.-reactor, previously operated by Keller (1986), and partly from a nearby septic tank.
The characteristics of the seed sludge are summarized in Table 7.2.

Table 7.2. Characteristics of the seed sludge of the Biofarma reactor

TSS	gram/liter	21.4
VSS	gram/liter	13.5
ASH	% of TSS	37.1
SVI	ml/gram TSS	20.8
COD	mg/gram TSS	740

Assuming a daily black water inflow of 51 liter/day (the average influent flow during the first 3 months of operation) with a COD content of 5313 mg/L (because no influent measurements were carried out at the time the U.A.S.B. reactor was started up, the influent quality is supposed to have the average value of the measurements in June/July 1985 and May 1986), the prevailing start up conditions are as shown in Table 7.3.

Table. 7.3. Start up conditions for the 0.86 m^3 U.A.S.B.-reactor at Biofarma (assuming a net reactor volume of 800 liter)

Parameter	Unit	Biofarma
Hydraulic retention time	day	15.7
Sludge concentration	kg VSS/m^3	2.8
Organic sludge loading	kg COD/kg VSS.d	0.121
Organic space loading	kg COD/m^3.d	0.339
Surface loading	m/hour	0.005
Upward velocity	m/hour	0.010

After 16 days of operation the reactor had filled up completely with water and the first effluent could be collected. Unfortunately, due to a leak in the upper baffle main part of the gas escaped from the gas collector, so that no reliable gasproduction data are available over the first period. At day no. 37 the gas collector and baffles were removed from the reactor in order to repair the leak. From day no. 73 onwards gas production could be measured in a reliable way.

Gasproduction

The measured daily biogas production rate is shown in Fig. 7.5.

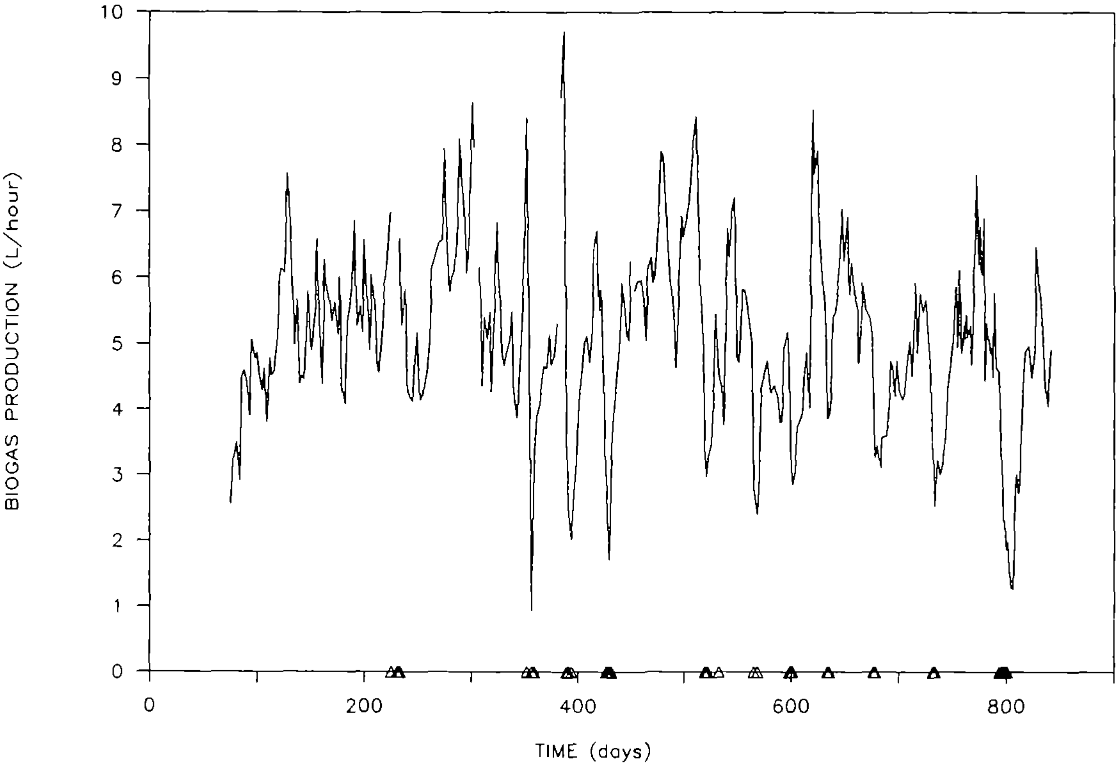


Fig. 7.5. The course of the biogas production during the operation of the 860 L. U.A.S.B. reactor at the Biofarma location over the whole experimental period (△ = influent measurement).

Gas production increases during the first two months, after which it stabilizes at appr. 5-6 L/hour. Fluctuations occur as a result of the variations in the influent flow and strength and, beyond day 300, also due to feedless periods because of influent sampling.

The composition of the biogas was found to be 65 volume % methane gas.

Effluent characteristics

COD and BOD

The COD and BOD values measured in the effluent of the 860 L Biofarma reactor during the experimental period are shown in Figure 7.6.

Both the filtered and the unfiltered COD clearly fall off during the first 100 days, after they showed quite high initial levels. Thereafter they reach a fairly stable level. After each period of influent sampling the values increase for a short period of time, but then they level off to their former values.

The same holds for the effluent BOD values.

The black area in Figure 7.6. represents the difference between the COD of non-filtered and filtered samples, it represents the COD of the suspended solds (COD$_{SS}$).

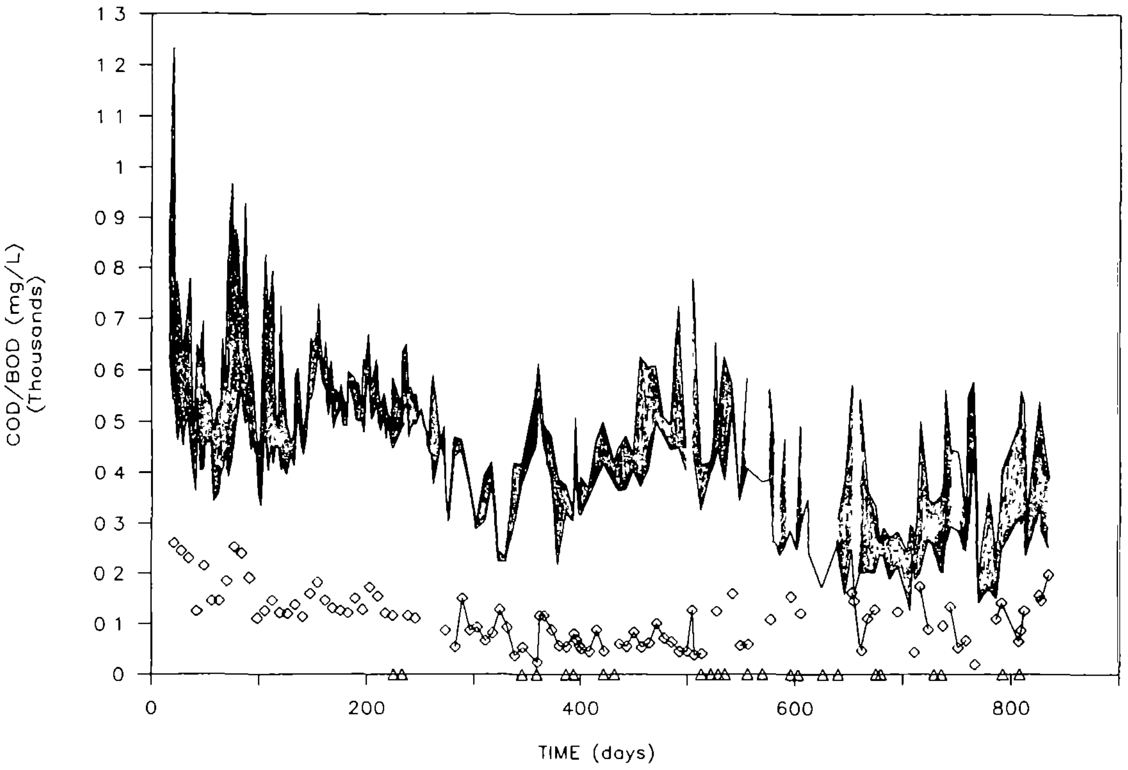


Fig. 7.6. The course of the effluent COD concentrations of non-filtered samples (upper edge of solid black area), filtered samples (lower edge of solid black area) and of the total BOD (◇), during the operation of the 860 L U.A.S.B. reactor at location Biofarma (△ = influent measurement).

Similarly as for the COD, in the beginning quite high values for COD_{SS} occur, but later on they also drop down to fairly low levels. After 350 days of operation the COD_{SS} increases slightly, but remains during the rest of the monitoring period at a fairly low level. This is also reflected in the amount of suspended solids found in the effluent of the reactor, shown in Figure 7.7.

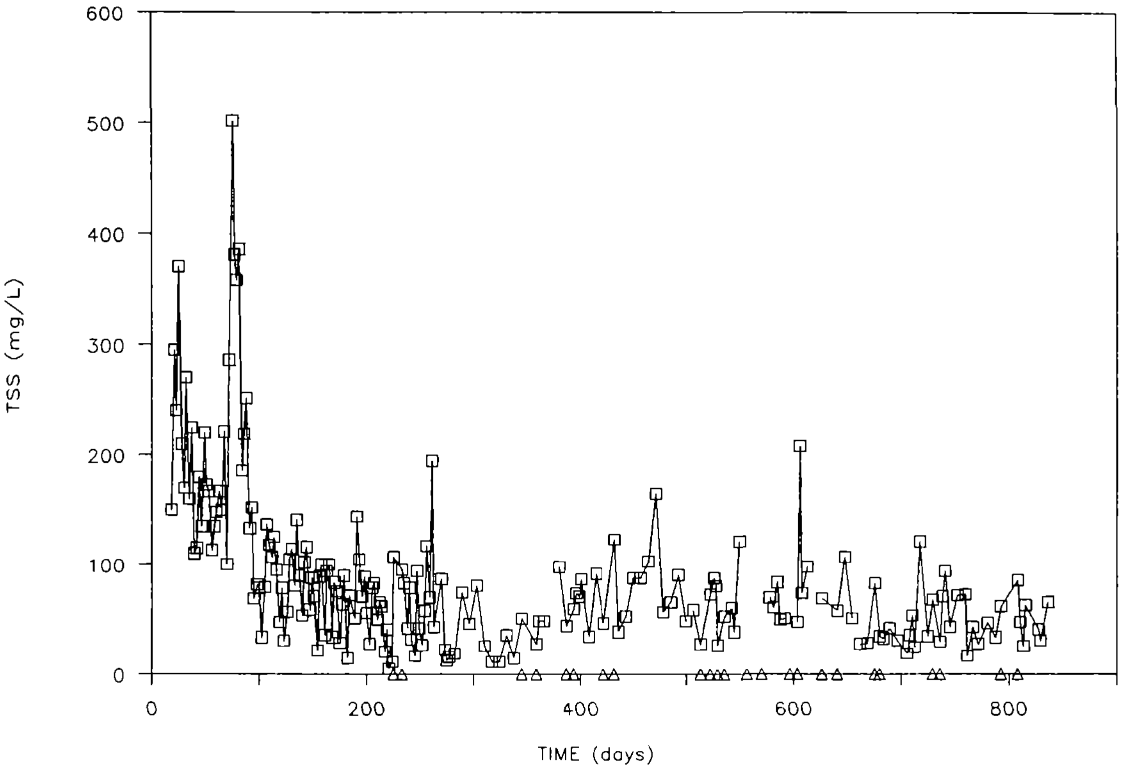


Fig. 7.7. The course of the effluent total suspended solids (TSS) during the operation of the 860 L UASB-reactor at location Biofarma

Total alkalinity, VFA and pH values of the effluent are presented in Figure 7.8.

The alkalinity of the effluent is rather high, indicating a good buffer capacity. Accordingly the pH is fairly constant. The concentrations of volatile fatty acids remain very low and in fact are not well assessable via the titration method.

Nutrients

Phosphate concentrations remain very constant during the first 300 days of operation (total phosphate averages 44.1 ± 9.4 mg/L and ortho-phosphate averages 28.8 ± 7.8 mg/L). From day no 300 up to day no 400 these measurements could not be carried out due to the fact that the spectrofotometer was not available. From day no. 400 onwards analyses could be resumed and again about the same values were measured (total phosphate averages 45.6 ± 12.7 mg/L and ortho-phosphate averages 34.3 ± 11.5 mg/L). All determined phosphate values over the course of the experiment are plotted in Figure 7.9.

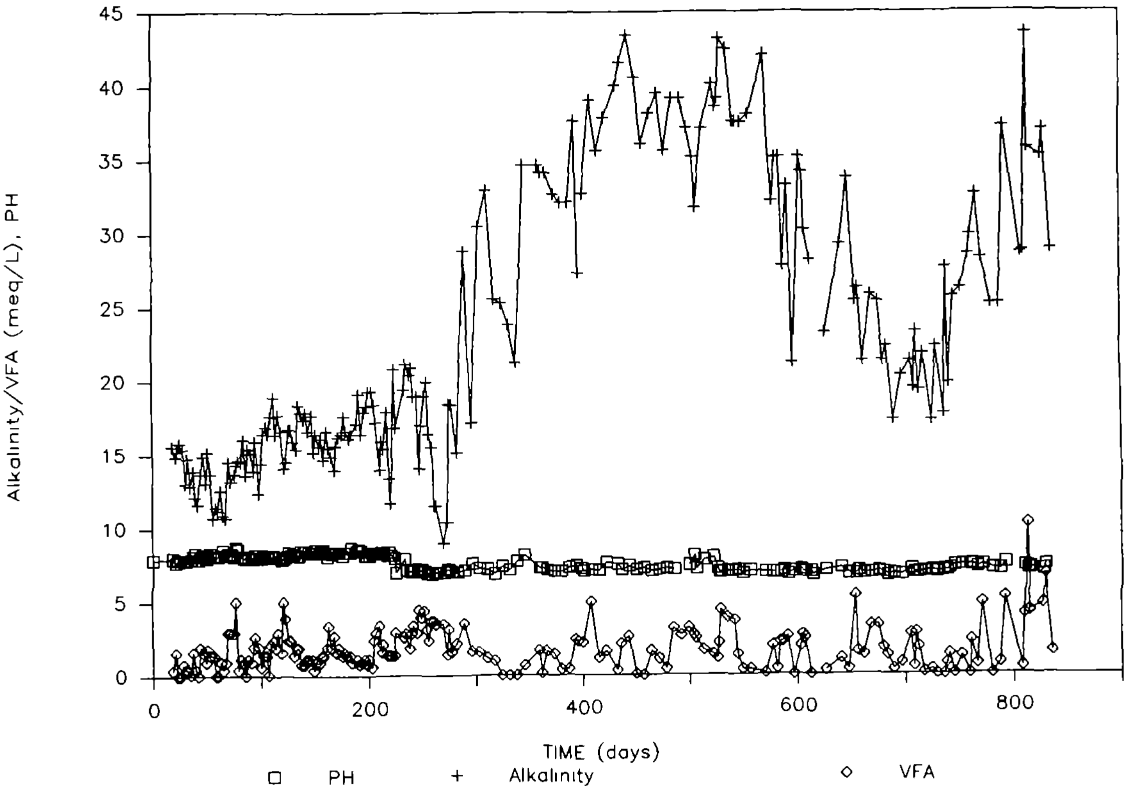


Fig. 7.8. The course of the effluent concentration of volatile fatty acids and bicarbonate alkalinity as determined by titration, and the pH during the operation of the 860 L U.A.S.B.-reactor at location Biofarma

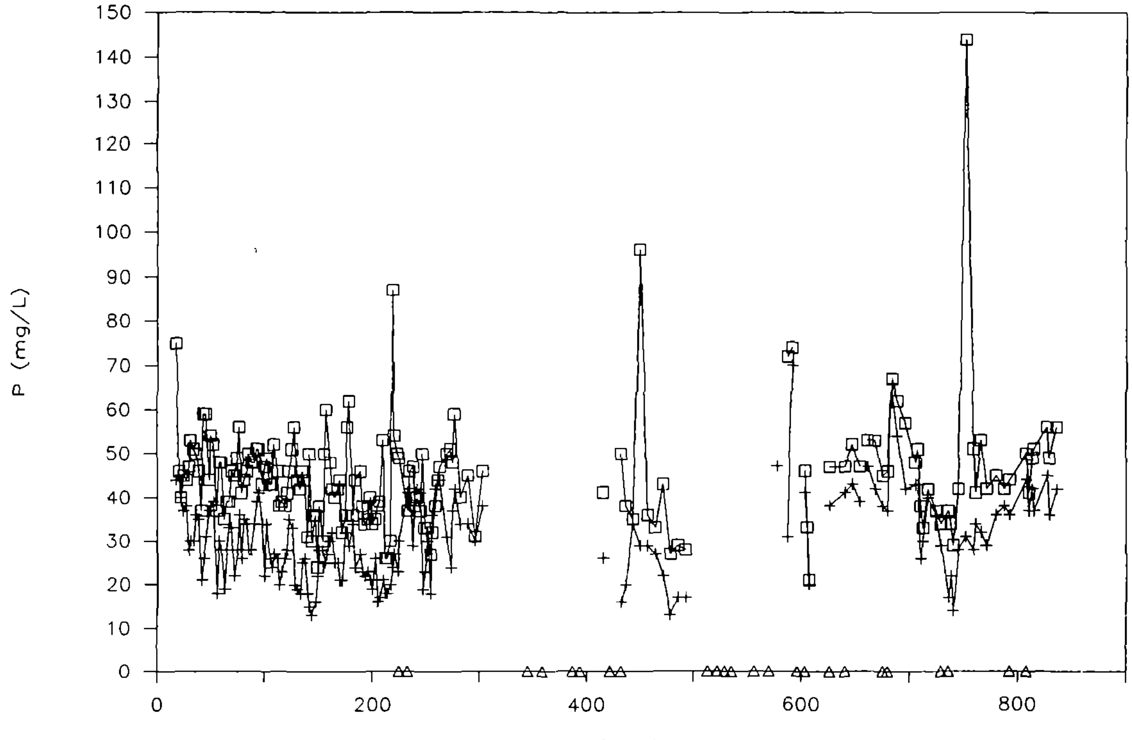


Fig. 7.9. The course of the concentrations total (□) and ortho (+) phosphate during the operation of the 860 L U.A.S.B.-reactor at location Biofarma

Both Kjeldahl and ammonia nitrogen increased slightly during the first 200 days of operation (Figure 7.10) but then suddenly decreased around day no. 250. The reason for this sharp drop is unknown.
From day 300 onwards both these nitrogen parameters show rather strong variations, while also the N-Kjeldahl values may significantly exceed NH_4^+-N, contrary to the values masured up to day 300.
The course of the nitrogen concentrations does not correspond with that of the phosphate concentrations.

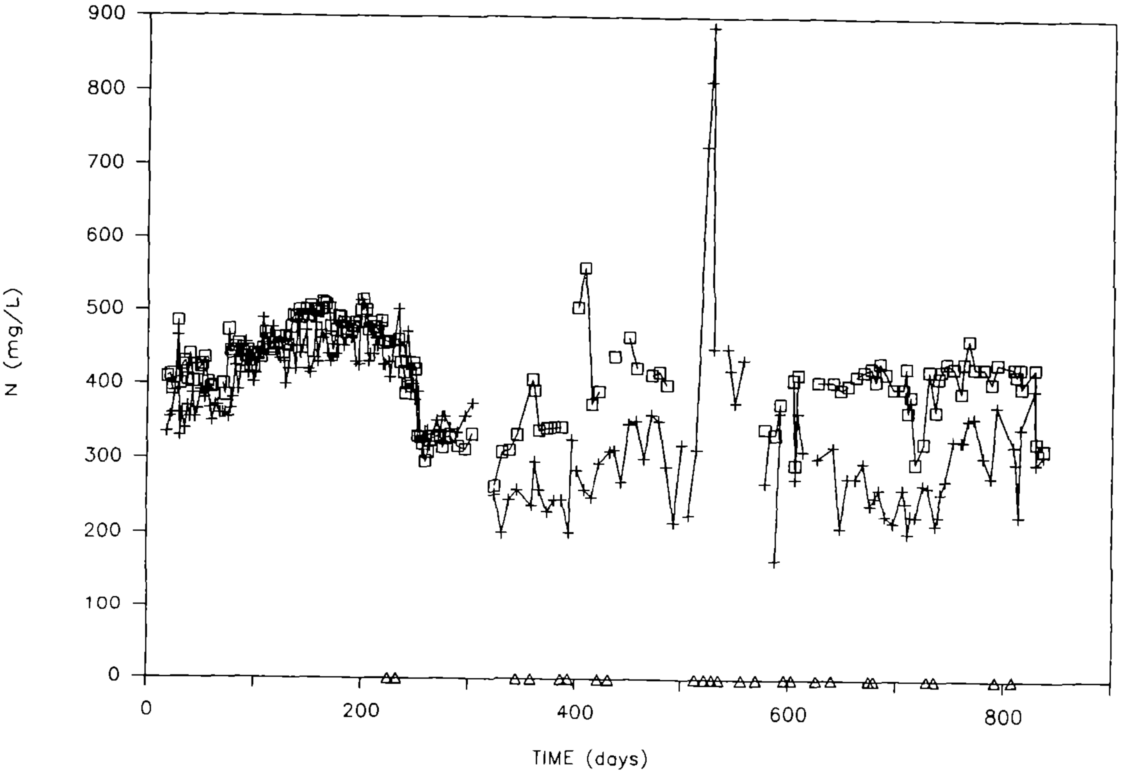


Fig. 7.10. The course of the concentrations Kjeldahl (□) and ammonia (+) nitrogen during the operation of the 860 L U.A.S.B.-reactor at location Biofarma

Sludge profiles

The results of the monthly performed sludge profiles measurements (described in Chapter 5.1.3.) are summarized in Appendix 6.

The soluble parameters (CODf, VFA, alkalinity, nitrogen and phosphate) show no clear (increasing or decreasing) pattern over the height of the reactor. The values of these parameters at different heights are fairly constant.
Temperature fluctuates from 22.4 - 24 °C at the bottom of the reactor up to 22.9 - 24.6 °C in the reactor effluent.
The pH of the reactor content remains fairly constant at different heights and never any accumulation of fatty acids occured.

Pathogens and parasites

As mentioned in before faecal contamination is one of the major problems in dealing with wastewater treatment in the tropics. In order to examine the removal of pathogens in the U.A.S.B.-reactor, tests were performed using indicator organisms.

In this research the coliform bacteria were chosen as indicator organisms for pathogen removal, because they are easy to detect with the equipment available in Indonesia.
The coliform bacteria are present in large quantities in the faeces and their number is related to the amount of faeces. A drawback of using coliform bacteria as an indicator is the fact that a number of coliform bacteria is not related to the intestine (better said to faecal material) and therefore not indicative for faecal contamination.
The method used for counting the amount of coliforms is described in Chapter 5.2.2.

The amount of pathogens in fresh faeces samples has already been described in Chapter 6.1.
In order to determine the efficiency of the reactor for pathogen removal, samples from tap 1, 3 and 5 (15, 65 and 133 cm height) were analyzed for coliform organisms.

In Figure 7.11 an overview of the results of the determinations of the number of (faecal) coliforms over the height of the reactor is given.

The counting of the number of coliforms reveals a rather poor removal: in the effluent still 10^7 - 10^8 coliforms/100 ml are present.

Besides the reduction of pathogenic bacteria, the survival of Helminth eggs in the reactor was investigated. The amount of Ascaris lumbricoides, Trichuris trichuria and Enterobius vermicularis eggs is counted according to Lewis et al (1977).

Table 7.4., 7.5. and 7.6. show the results of the ova counting.

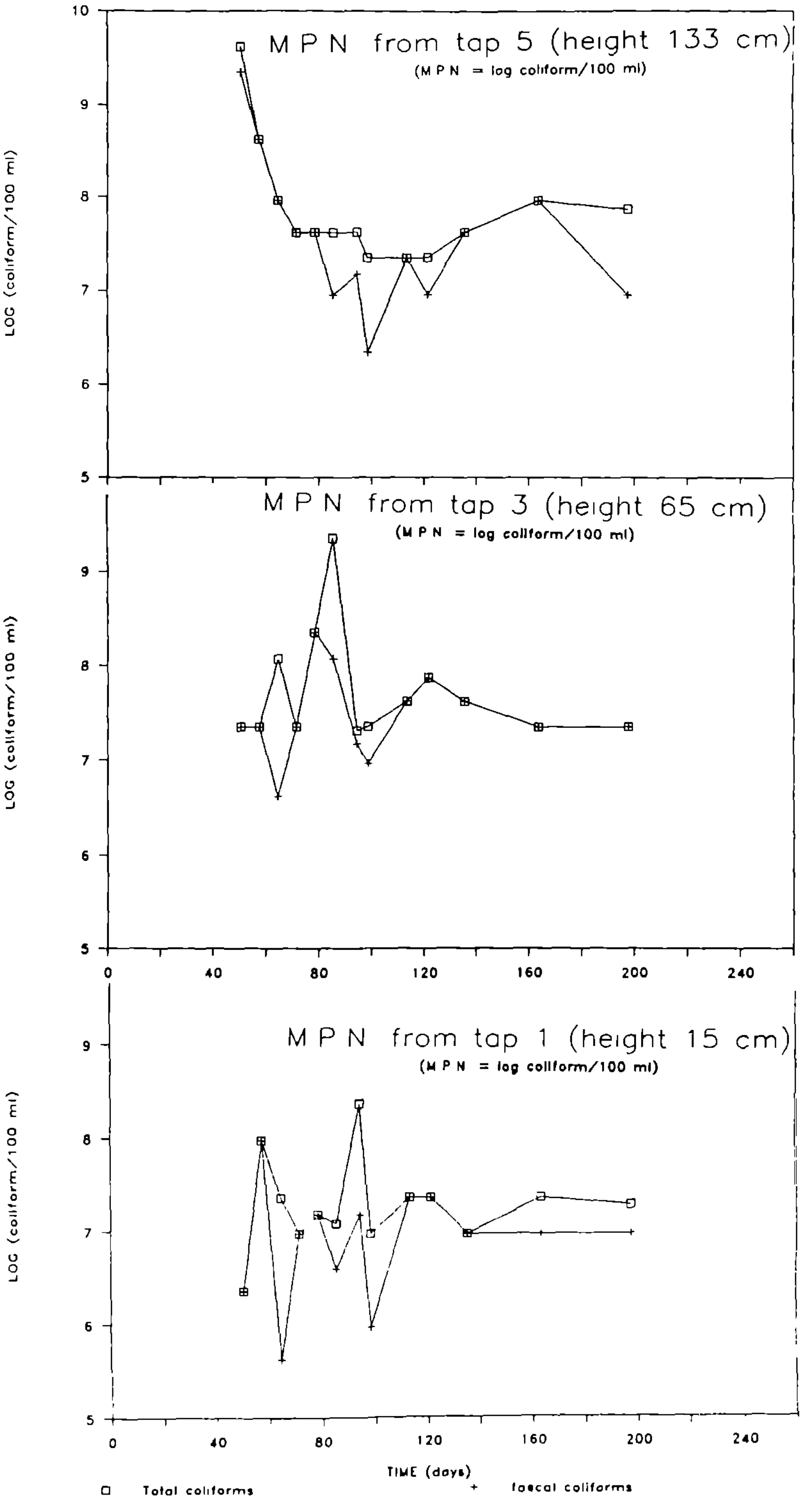


Fig. 7.11. The concentrations of indicator organisms at various heights in the reactor at location Biofarma. (□) total coliforms, (+) faecal coliforms; A, 15 cm height; B, 65 cm height; C, 133 cm height.

Table 7.4. Results of Ascaris lumbricoides ova counting at the reactor at location Biofarma

ASCARIS lumbricoides (roundworm) Average number of ova per ml

DATE	INFLUENT	TAP 1	TAP 2	TAP 3	TAP 4	TAP 5	TAP 6	EFFLUENT
10986		1640	1200	1450	228	35	67	
90986	15							
110986	64							
130986	16							4
170986								3
190986								0
290986		1740	870	570	432	18	75	
11086								0
81086								2
151086								0
191086	48							
211086	30							
221086								2
231086	51							
241086								2
101186		1350	1530	990	60	21	75	
251186	64							
271186	20							
291186	56							
11286								0
31286								2
101286								2
71086								
291086								

Table 7.5. Results of Enterobius vermicularis ova counting at the reactor at location Biofarma

DATE	INFLUENT	TAP 1	TAP 2	TAP 3	TAP 4	TAP 5	TAP 6	EFFLUENT
10986		400	180	160	5	0	3	
90986	13							
110986	4							
130986	0							0
170986								0
190986								0
290986		510	210	180	60	9	9	
11086								2
81086								0
151086								0
191086	27							
211086	24							
221086								2
231086	30							
241086								0
101186		210	210	210	10	11	15	
251186	3							
271186	19							
291186	0							
11286								0
31286								0
101286								0

Table 7.6. Results of Trichuris trichuria ova counting at the reactor at location Biofarma

Trichuris trichuria (whipworm) Average number of ova per ml

DATE	INFLUENT	TAP 1	TAP 2	TAP 3	TAP 4	TAP 5	TAP 6	EFFLUENT
10986		240	180	180	3	0	10	
90986	0							
110986	32							
130986	0							0
170986								0
190986								0
290986		240	270	120	72	3	6	
11086								0
81086								0
151086								0
191086	18							
211086	9							
221086								0
231086	3							
241086								0
101186		30	0	30	0	1	5	
251186	0							
271186	0							
291186	0							
11286								0
31286								0
101286								0

It is evident that helminth eggs precipitate in the reactor.

Sludge accumulation

The data obtained in the sludge profiles measurements (Appendix 6) were used to determine the rate of accumulation of solids in the reactor. The sludge hold-up of the reactor is an essential parameter with respect to the ultimate design of the reactor. The outcome of these measurements is shown in Figure 7.12.

Sludge stability

Long term digestion experiments were performed to determine the stability of the sludge, because this is another important parameter.
Stability can be expressed as the percentage COD removed from the flask (used for the experiment: see Chapter 5.3.) as CH_4 relative to the total COD present in the flask at the start of the experiment.
The results of all the stability assays conducted over the experimental period are summarized in Table 7.7.

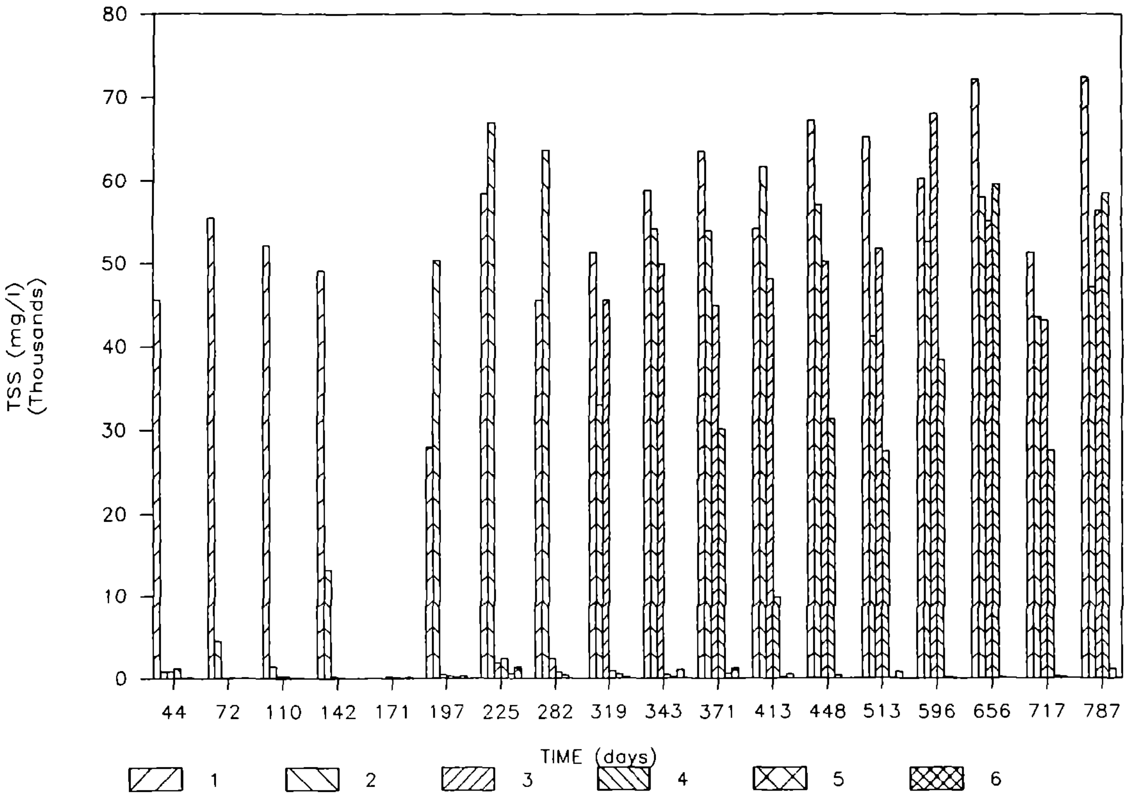


Fig. 7.12. The amount of total suspended solids at different heights of the reactor as a function of time during the operation of the Biofarma reactor. The centre of each profile is situated at the time of sampling. The height of the sampling points were (from left to right in each sludge profile): 15, 39, 65, 85, 133 and 176 cm respectively.

Table 7.7. Results of the sludge stability assessment assays with sludge removed from the lowest tap of the Biofarma reactor

Sludge obtained at day no.	days (a)	% COD 100 d. (b)	% COD total (c)
0	228	8	17
44	262	20	30
72	139	12	13
110	108	17	17
142	130	13	14
197	167	16	23
225	138	11	16
319	308	16	34
371	324	17	35
448	263	10	17
513	268	9	17

a = duration of the experiment (days)
b = % of COD removed from the flask as CH_4 (after 100 days) relative to the total COD present in the flask at the start of the experiment
c = % of COD removed from the flask as CH_4 (at the end of the experiment) relative to the total COD present in the flask at the start of the experiment

After a slight decrease in the stability during the first 40 days, the sludge stability remains fairly constant over the whole period of operation of the Biofarma reactor.

Sludge stability can also be assessed by evaluating the development of the ash content of the accumulated solids in the reactor. Figure 7.13 shows the course of the ash content of the sludge in the reactor i.e. tap 1 together with the ash content of the effluent solids.

Compared to the results of the stability test a similar trend can be observed, viz. a decreasing sludge stability from the start of the operation, after which the ash content remains fairly stable. The ash content of the solids in the effluent is clearly higher as compared to the ash content of the retained sludge (see Figure 7.13 and Table 7.8).

The sludge from each profile measurement sampling was tested for its activity using volatile fatty acids. The results of these activity assessment assays (the method is described in Chapter 5.3.) are shown in the Figures 7.14 up to 7.17. Each figure shows the course of the activity of the sludge at a specific height in the reactor.

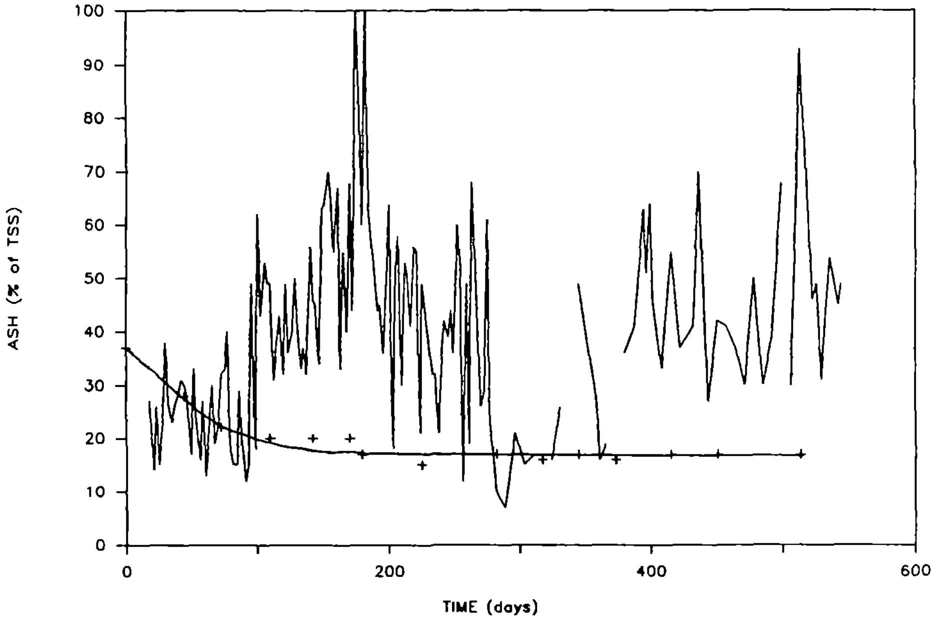


Fig. 7.13. The course of the ashcontent of the sludge (+) and of the solids in the effluent (—) during the operation of the 860 L reactor at location Biofarma

Table 7.8. Ash content (% of TSS) of the sludge in the reactor (the data printed in bold type respresent samples from the sludge blanket in the reactor)

Day	Tap 1	Tap 2	Tap 3	Tap 4	Tap 5	Tap 6
0	**37.1**					
44	**27.6**	21.2	21.0	22.0	14.4	16.1
72	**22.2**	**24.5**	10.0	26.5	30.0	19.9
110	**20.2**	18.8	17.7	15.2		20.6
142	**20.2**	**17.5**	13.0	40.0	32.0	40.0
171			11.0	13.0	3.0	7.0
197	**17.0**	**15.0**	12.0	15.0	11.0	11.0
225	**15.3**	**15.3**	12.0	13.0	7.0	11.0
282	**17.0**	**16.0**	14.0	16.0	16.0	12.0
319	**15.6**	**15.5**	**15.7**	16.0	16.0	17.0
343	**17.0**	**16.0**	**16.0**	37.0	61.0	20.0
371	**16.0**	**16.0**	**17.0**	**17.0**	10.0	12.0
413	**17.0**	**17.0**	**17.0**	18.0	22.0	13.0
448	**17.0**	**16.0**	**17.0**	**16.0**	16.0	
513	**16.9**	**16.0**	**16.0**	**16.0**	40.0	14.0
596	**12.8**	**14.6**	**14.7**	**14.9**	3.9	4.3
656	**15.0**	**15.0**	**13.0**	**14.0**	6.0	
717	**16.0**	**15.0**	**15.0**	**13.0**	4.0	7.0
787	**17.1**	**14.5**	**14.8**	**15.0**	9.7	9.7

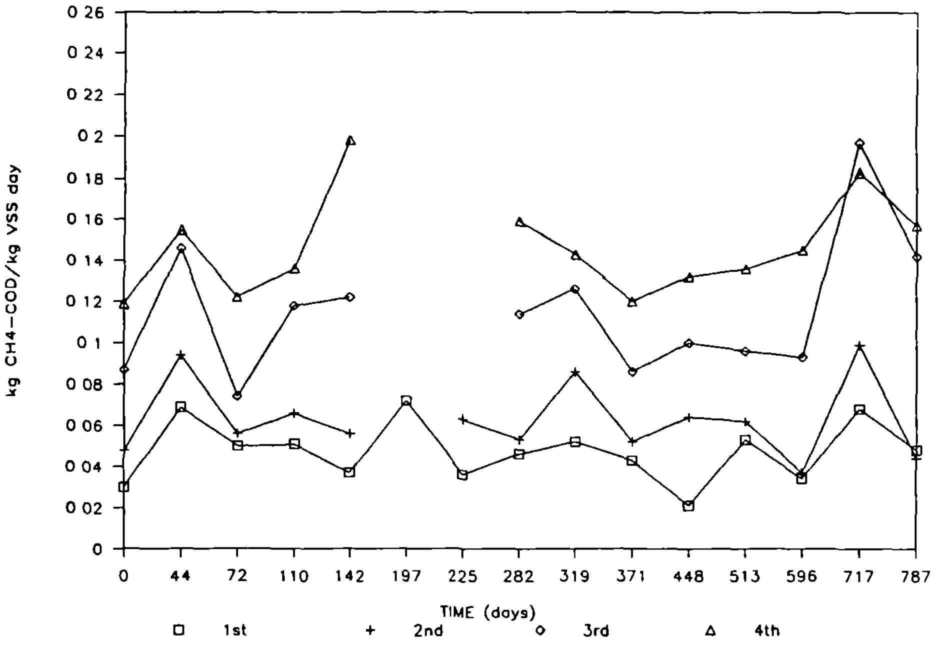


Fig. 7.14 The course of the methanogenic activity of the sludge from tap 1 (height 15 cm) during the operation of the 860 L reactor at location Biofarma

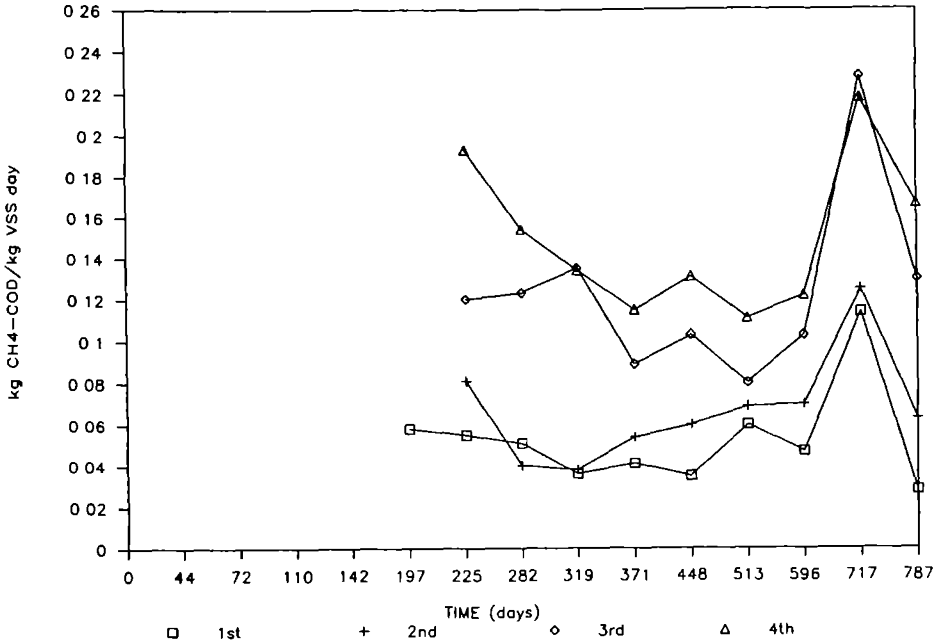


Fig. 7.15 The course of the methanogenic activity of the sludge from tap 2 (height 39 cm) during the operation of the 860 L reactor at location Biofarma

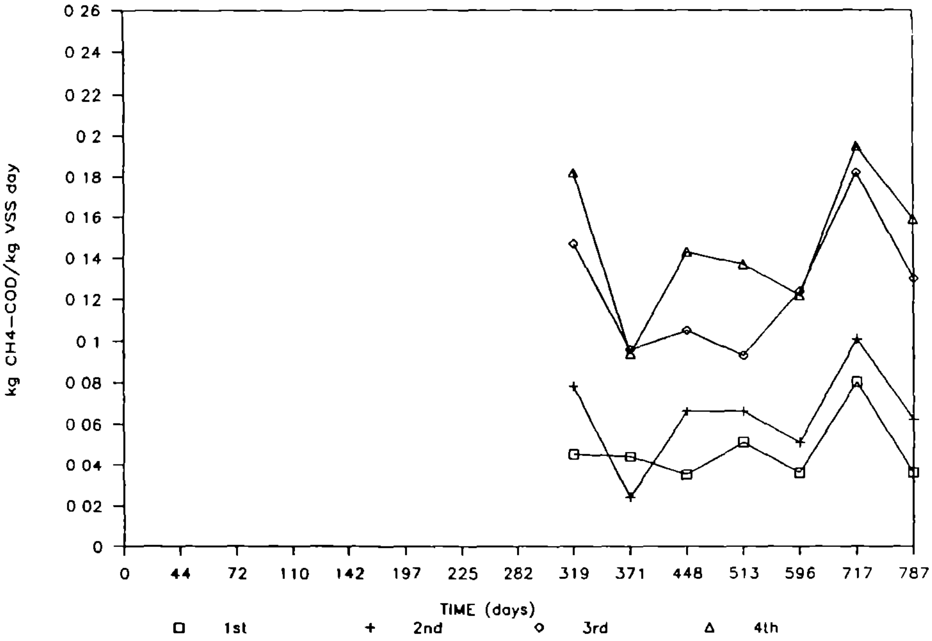


Fig. 7.16 The course of the methanogenic activity of the sludge from tap 3 (height 65 cm) during the operation of the 860 L reactor at location Biofarma

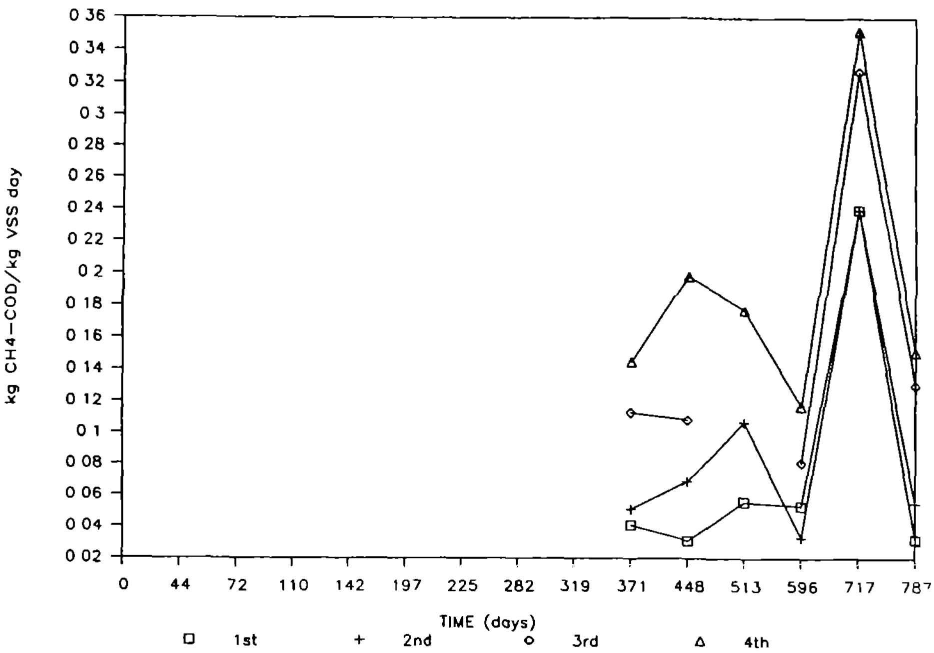


Fig. 7.17 The course of the methanogenic activity of the sludge from tap 4 (height 85 cm) during the operation of the 860 L reactor at location Biofarma

Mixing behaviour of the 860 L UASB reactor

In order to determine the mixing characteristics of the reactor at the Biofarma location, and the distribution of the retention time (RTD), a tracer experiment (using Li^+) was carried out at day no 753. The following calculations were made:

The theoretical hydraulic retention time = HRT_{th} = V/Q
V = the volume accessible for the fluid, not corrected for the sludge volume (m^3)
Q = the volumetric flowrate (m^3/h)
The mean residence time = HRT_m = $t * E(\theta)*d\theta$
$\approx (\Sigma t * C(t) *\Delta t)/(\Sigma C(t) *\Delta t)$
t = time (hours)
θ = normalized time (t/HRT_{th})
E = normalized effluent concentration (C_t/C_0)
C = concentration of tracer (g/L)
The spread in the residence time = $\sigma_\theta^2 = (t-HRT_m)*E(t)*dt$
$\approx \{\Sigma(t^2*C(t)*\Delta t/(HRT_m)^2*\Sigma C(t)*\Delta t\} - 1$
The number of ideal mixers, as calculated from the E curve equals $j = 1/\sigma_\theta^2$
The number of ideal mixers, as calculated from the time on which the mean signal (θ_{max}) occurs, equals $n = 1/(1-\theta^{m}_{ax})$
The percentage of dead space = %DS = $(1-HRT_m)/HRT_{th} *100$ %
The % recovery equals $Q * \Sigma C(t)*dt$/used amount Li_+

The graph of $E(\theta)$ versus θ of this experiment is shown in Figure 7.18. The peak, at $\theta = 0.66$, which is a result of a short circuit or an error in measuring the Li^+ concentration, is disturbing the E curve. In order to make calculations a corrected graph was drawn, which is shown in Figure 7.19.

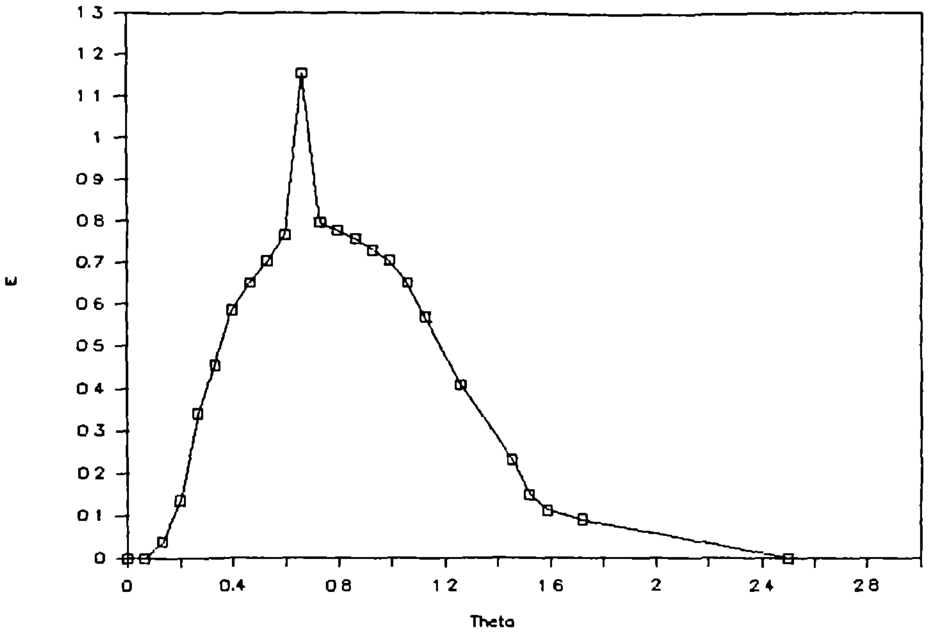


Fig. 7.18 The E(θ) graph of a tracer experiment performed at location Biofarma

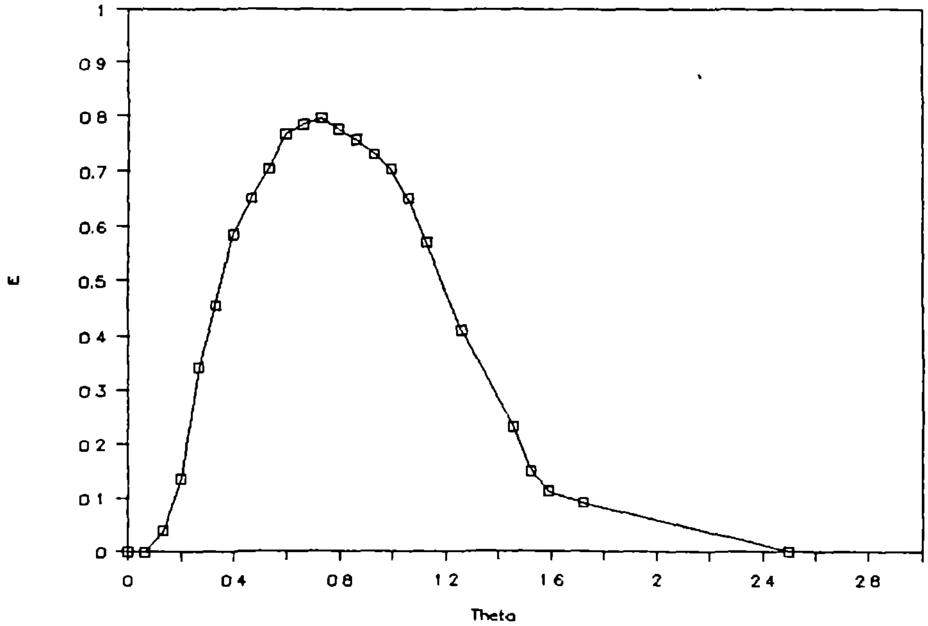


Fig. 7.19 The corrected E(θ) graph for the Biofarma reactor

The conditions and results of the tracer experiment are shown in Table 7.9.

Table 7.9. The conditions and results of the tracer experiment at the Biofarma location

	VALUE
Conditions:	
mean flow (L/hr)	2.21
HRT_{th} (hr)	362
dosage of Li^+ (mg)	3000
accessible volume (L)	800
Results:	
HRT_m (hr)	301
C_0 (mg/L)	3.75
max. E value	0.80
variance $\sigma_\theta{}^2$	0.18
number of ideal mixers j	5.46
θ_{max}	0.81
number of ideal mixers n	5.26
% DS	16.89
% Recovery (t = 1.7 HRT)	75.49

7.3.2. Discussion

Influent characterization

Comparing the results of the influent measurements during the first year, with those found later during the operation of the reactor, the values of COD and BOD found after the first year vary significantly stronger. The reasons for these larger variations are unclear, but (if consistent) these fluctuations obviously have an impact on the effluent concentrations and also on the biogas production.

On the basis of influent measurements an attempt has been made to establish a relation between the incoming organic pollution (COD and BOD) and the amount of nutrients (N and P). As, in a good functioning UASB reactor nutrients are hardly removed, the nutrient concentration in the effluent could be a measure for the incoming organic pollution, provided there exists a clear correlation between these parameters.
In this connection it should of course be taken into account, that additional ammounts of ammonia and ortho-phosphate will be released slowly from the accumulated solids (see also Chapter 6.1. faeces desintegration and hydrolysis).
Using the influent measurements during the first half year of reactor operation, v.d. Horst and v. Knippenberg (1986) found the following relationships:

tot.COD (mg/L) = -6714 + 193 tot.PO_4-P (mg/L) $r^2=0.96$ n=8
fil.COD (mg/L) = 458 + 7.37 NH_4^+-N (mg/L) $r^2=0.90$ n=9
CODsus. (mg/L) = -6148 + 152 tot.PO_4-P (mg/L) $r^2=0.94$ n=8
tot.BOD (mg/L) = -145 + 42 tot.PO_4-P (mg/L) $r^2=0.88$ n=5

These data were obtained after carefull sampling, homogenization and analyses. There appears to consist a linear relationship between total phosphate and total COD, COD_{ss} and total BOD and between filtrated COD and NH_4^+-N as well.
However, taking all 47 influent data collected during later periods of operation, the above correlations between any nutrient and organic pollutants hardly could be reestablished It is not yet clear what is the reason of the strongly increased variability of the data. As we know afterwards that during the later periods of operation less attention was paid to correct sampling and/or correct sampling preparation, tentatively the above found correlations can be presumed to be reliable. In the near future it will be attempted to collect additional reliable data both by conducting measurements and by consulting the literature.

Start-up

Although only a relatively small amount of seed sludge (166 liter) was applied, resulting in quite high organic sludge loading rates (viz. 0.121 kg COD/kg VSS.d; see Table 7.3.) at the start of the operation, relative to the max. spec. methanogenic activity of the seed sludge (0.034 kg CH_4-COD/ kg VSS.d), the system performs fairly satisfactorily from the very beginning, although (as expected) the treatment efficiency in terms of CODtotal and CODfiltered, BODtotal and TSS shows a slight improvement over the first 100-200 days of operation. It therefore can be concluded that the system in fact could be started using approximately 150 L of sludge. Presumably even with a significantly smaller amount of seed sludge the performance of the system will be fairly satisfactory. It will be attempted to get more information about such a situation in the near future.

Gasproduction

Theoretically, the biogas production should show a slight steady increase, as a result of the contribution of the background gas production from the accumulating solids in the reactor. However this expected slight increase (if existing at all) is masked effectively by variations in the influent strength and flow.
As can be foreseen, the gasproduction data show a sharp drop during feedless periods (see Fig. 7.4.). Apparently the easily digestible substrate ingredients daily supplied to the system indeed are converted fairly rapidly. Immediately after resuming the feeding the gas production always recovers rapidly. Both phenomena will be investigated in more detail in the near future.

Treatment efficiency of the process (see Fig. 7.6 up to 7.10)

Up to the moment that the 860 L reactor becomes completely filled up with solids, it performs very well. The effluent values of the various parameters reflect to some extent the fluctuations in the influent. As mentioned above this particularly is true for the daily gasproduction rates.
Although the reactor becomes filled up gradually with solids, COD, BOD and TSS values stay fairly low during the whole operation time.

The main performance data for the Biofarma reactor as obtained over the 1st and 2nd half of 1986 (period 1 and 2) and the 1st and 2nd half of 1987 (period 3 and 4) are presented in Table 7.10., together with the mean influent and effluent values of COD, BOD and TSS.

Table 7.10. Treatment efficiency of the 860 L UASB reactor at the location Biofarma

	INFLUENT (values in mg/L) PERIOD				EFFLUENT (values in mg/L) PERIOD				% REDUCTION PERIOD			
	1	2	3	4	1	2	3	4	1	2	3	4
CODtot	5310	4230	6589	5631	512	458	499	371	90	89	92	93
CODfil	2616	1219	1492	1208	506	373	378	228	81	69	75	81
BOD	2328	491	1368	1426	114	68	99	110	95	86	92	92
TSS	1230	1020	2423	1830	49	69	73	46	96	93	96	97

This Table clearly demonstrates the excellent performance of the reactor over the whole monitoring period.

Phosphate effluent concentrations remain, with a few exceptions, fairly constant over the whole monitoring period, indicating little (if any) change in influent phosphate concentrations. The value for o-PO_4/tot-PO_4 in the effluent averages 0.70 ± 0.19 , which corresponds well with the values found in the faeces desintegration experiment, i.e. showing a 30 % non-biodegradable P-fraction.
The effluent nitrogen (both Kjeldahl but particularly ammonia) concentrations show a less constant picture in the time. During the first 300 days of operation the NH_4^+N/ N-Kjeldahl values in the effluent average 0.96 ± 0.09, which is considerably higher than found in the faeces desintegration experiment (65 % of total nitrogen is biodegradable). This was expexted because the faeces desintegration experiment also showed the slow hydrolysis of ammonia from the accumulated solids. Because of the long sludge retention time in the reactor, the contribution of ammonia-nitrogen from the accumulated solids in the reactor to the effluent value should increase in the course of time. However during the last period of operation, i.e. from day 300 onwards NH_4^+N/ N-Kjeldahl values in the effluent are considerably lower, viz. 0.72 ± 0.13. The reason for this phenomena is still unknown.

Pathogens and parasites

Removal of coliforms in the UASB reactor is poor, similarly as found in other anaerobic waste water treatment systems. The effluent (equal to the sample of tap no 5, Figure 7.11) still contains 10^7 - 10^8 coliform per 100 ml. Therefore posttreatment of the effluent is necessary. Apparently the sludge blanket does not act as a filter system with regard to coliform organisms.
Because of the continuous supply of fresh material (faeces) and the unsignificant kill of these organisms, the sludge in the reactor still contains a lot of coliforms. In case of reuse of the sludge, a further digestion of (according to literature) at least a year or composting will be required.

With respect to the removal of helminth eggs, the situation is definitely better. The sludge acts as a filtering medium and/or helminth eggs are trapped in the reactor by a filtration mechanism. However, although only a small amount of eggs could be counted in the effluent of the reactor, it even in this respect should be considered as hygienically unsafe and consequently it has to be subjected to posttreatment. As the helminth eggs are very resistent, the sludge, which contains large amounts of these parasites, should be handled with care, when emptying the reactor.

Sludge accumulation

After 787 days of monitoring (i.e. 731 days of operation) the top of the sludge bed extended up to the fifth tap, i.e. up to a height of 133 cm (i.e. 76 % of the reactorheight)

The reactor then still is not completely "filled up" with sludge, because space is left for more sludge. At that time the average sludge content has risen to 70 kg TSS/m^3 at tap 1 and to 50 - 60 kg TSS/m^3 at the other taps.
From the results of the sludge profile measurements, the amount of sludge-TSS in the reactor can be calculated. The amount of suspended solids present in the reactor at various instants of the experiment has been plotted versus the time in Figure 7.20.

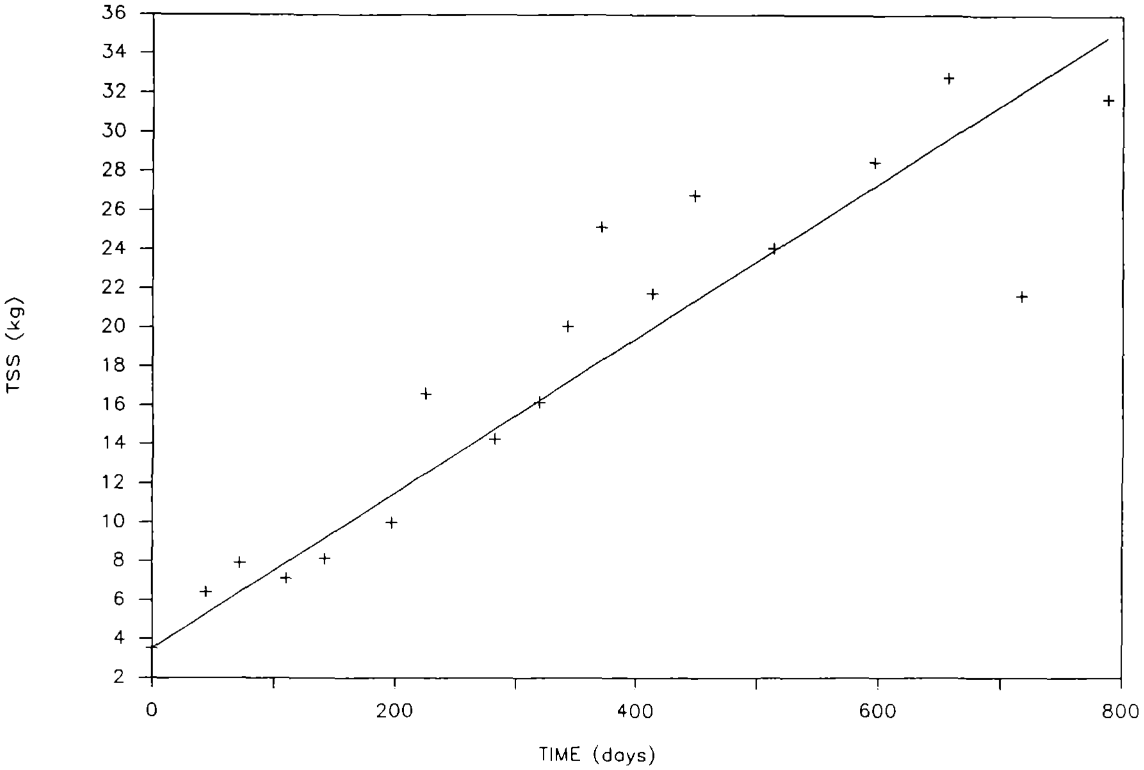


Figure 7.20 The estimated amount of solids, calculated from the sludge profile data in the Biofarma reactor

The linear relationship shown is found by linear regression analysis of the data. It corresponds to the algebraic equation: Y = 3.552 + 0.0397*t, where Y is the amount of accumulated solids (in kg) in the reactor, and t is the time in days. The amount of seed sludge was equal to 3.552 kg TSS.

On the basis of these results and considering that the reactor is "full" when it contains 600 liters of sludge with an average TSS content of 60 g/L (this corresponds to 36 kg TSS over the total reactor volume) the "filling up time" will be 2.2 year.
This is a small overestimation of the actual time required to fill the reactor, viz. 787 days.

The daily amount of accumulating "stabilized" solids under operational conditions amounts to: (787 monitoring days/ 731 operation days) * 0.0397 = 0.0427 kg TSS
As the reactor can be started using appr. 3.5 kg TSS and

sludge should be discharged once it contains appr. 42 kg TSS, the filling up time of the system corresponds to:
(42 - 3.5)/ 0.0427 = 902 days.

Sludge stability

An important factor concerning the applicability of the system certainly is the extent to which the accumulating solids will become stabilized. As the biodegradable substrate is introduced at the bottom of the reactor and the solid flow in the reactor relative to the total sludge residence time certainly does not respond to a plug flow, non- and poorly biodegraded substrate ingredients will be present all over the sludge bed. Particularly upon discharging, the sludge will be mixed up and freshly introduced substrate ingredients will be present throughout the sludge.
The extent of stabilization of the sludge (expressed as % CH_4-COD produced after 100 days of digestion relative to the total sludge-COD content at the beginning), compared to the seed sludge, rapidly decreases in the intitial phases of the operation of the reactor, i.e. from 8 % to 20 % and later it stabilizes at appr. 15 %.
The course of the ash content of the sludge shows a similar trend. During the intitial phases the ash content of the sludge drops from 37 % within 150 days to 17 % and from then onwards it remains at this level, also the ash content of the sludge in the sludge bed remains almost constant over the reactor (see Table 7.8).

The results in Fig. 7.12 reveal that over the whole period the ashcontent of the solids leaving the reactor with the effluent is significantly higher than of the sludge retained in the reactor. Occasionally even extremely high values for the ash content of the effluent solids are found. On the other hand the amount of TSS in the effluent is very low (compare Fig. 7.5. and 7.6.). Apparantly there occurs a selective wash out of inorganic matter.
Considering the data in Table 7.8. there seems to be a trend of a lower ash content of the solids present in the upper part of the reactor, particularly beyond day 513.

Sludge activity

The specific methanogenic activity of the sludge in the reactor remains, after a clear intial increase fairly constant. However, the assay applied in the activity assessment yields a fairly wide scatter in the results (e.g. due to the fact that it is highly sensitive and therefore depends on the way in which it is performed), and therefore any conclusions concerning possible existing differences over the height of the reactor cannot be drawn. On the other hand the results clearly indicate that the sludge can be considered of reasonable quality in terms of activity, i.e. it is comparable with digested sewage sludge.

COD-balances

The calculated COD balance over the Biofarma reactor, during its 25 month of operation is shown in Figure 7.19 and all detailed data used in the calculation are presented in Appendix 7.

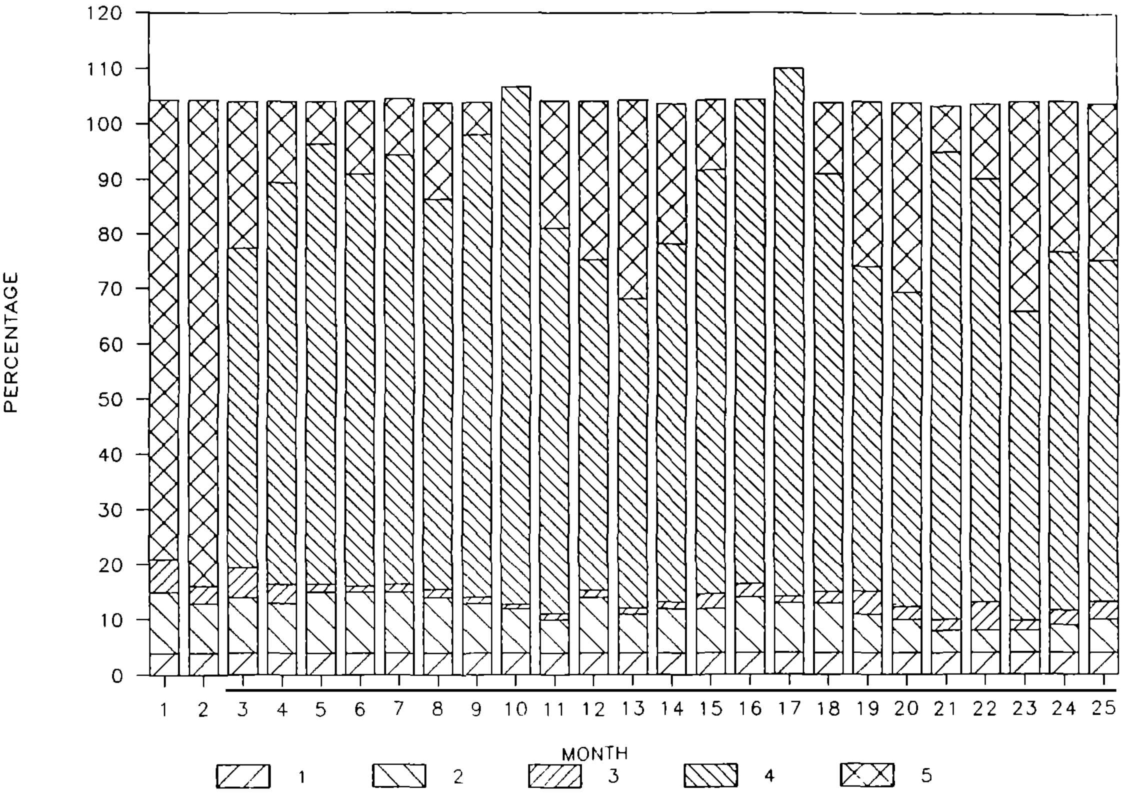


Fig. 7.19 The COD balance of the Biofarma reactor over 25 months of operation (see text below for explanation of numbers)

The COD balance calculations were made using the following equation (the numbers refer to Fig. 7.19):

COD-influent = COD-effluent,filtrated (2) +
COD-effluent,ss (3) + COD-gasproduction (4)
+COD-sludge accumulation (5)
+ COD-sludge profile (1)

where:
COD-influent = (average g CODinfl/day) * number of days
COD-effluent = CODfil,eff * 53 lit/day * number of days +
CODss,eff * 53 lit/day * number of days
COD-gasprod. = 2.343 * 0.65 * liters gas produced
COD-sludge profile measurement = per month 300 g COD = 4 % of CODinfl.

The factor 0.65 refers to a 65 % methane content of the biogas, whereas the factor 2.343 refers to the COD-content of 1 liter gas (Appendix 2).

The sludge accumulation factor Y can be calculated from these data using the expression:

Y =(gram COD-sludge accumulation/g COD-influent) * 1/1.45
(1 gram sludge VSS = 1.45 gram COD)

The total COD-balance over the period January 1986 to Oktober 1987 is shown in Table 7.10.

Table 7.10. The COD-balance of the Biofarma reactor during the period January 1986 - Oktober 1987

gram COD-influent,total	170595	100 %
gram COD-effluent,filtrated	13280	8 %
gram COD-effluent,ss	3463	2 %
gram COD-gas	124158	73 %
gram COD-sludge profile	6600	4 %
gram COD-sludge accumulation	23166	14 %

These figures give an excess sludge accumulation rate of 35.1 gram COD per day and (using the measured equation: 1 g sludge TSS = 1.19 g COD) 29.5 gram TSS/day. According to these data the reactor will fill up within 1100 days (600 liters with TSS = 60 g/L, using 3.552 kg TSS seed sludge), which is a large overestimation.
Obviously when estimating the filling up time on the basis of the COD-balance, the large "uncertainty" in the average COD-influent has to be taken into account, as only very few influent measurements were performed during the whole period.

The estimated sludge accumulation factor calculated for each month (Appendix 7) ranges from 0.05 to 0.28 g sludge-VSS/ g COD-influent, which is anyhow in the range of values presented in the literature for complex wastewater.

Similar to the balance over the reactor, balances over the faeces digestion experiments in the laboratory (section 6.1) have been made. For this purpose, after termination of digestion experiment, the contents of the serumflasks were analyzed. The following equations apply:

COD-sludge,start + COD-feed = COD-sludge,end + COD-gas + COD-solution

or,

The difference in COD-sludge = COD-feed - COD-gas - COD-solution

The results of the COD balance calculations are summarized in Table 7.11 together with the calculated sludge accumulation factors.

Table 7.11 COD-balances and sludge accumulation factors for the faeces digestion experiments.

Date	CODin	CODsol		CODgas		CODsludge		Y
	mg	mg	%	mg	%	mg	%	g sludgeVSS/ g CODinfl
11/9	342	88	26	117	34	137	40	0.29
	1026	139	13	561	55	326	32	0.23
	1710	142	8	1091	64	477	28	0.20
	2394	184	8	1620	68	590	24	0.18
	3420	306	9	2527	74	587	17	0.12
	4784	331	7	3793	79	660	14	0.10
10/10	1631	186	11	681	42	764	47	0.34
	4079	187	5	1692	41	2200	54	0.39
	7342	306	4	3403	46	3633	50	0.36
23/10	1622	153	9	1102	68	367	23	0.16
	3650	161	4	1913	53	1576	43	0.31
	6489	254	4	3222	50	3013	46	0.33
	6489	204	3	3783	58	2502	39	0.28
16/10	2386	169	7	1008	42	1209	51	0.36
	5964	231	4	2573	43	3160	53	0.38
	10736	277	3	5296	49	5163	48	0.35

Table 7.11 once again shows the high digestability of the faeces dated 11/9/85. However other faeces samples are considerably less biodegradable, consequently result in a higher calculated sludge yield factor. These calculated sludge accumulation factors calculated are comparable with these obtained from the COD balance over the reactor. A part of the faeces-COD is difficult or non digestible and accumulates in the sludge. At the end of these experiments 200-300 mg COD was still present in the 1 Liter serum flasks.

Mixing behaviour of the reactor

Fig. 7.18 shows that channeling occurs in the 860 liter reactor, because E is larger than 1.0. The corrected graph in Figure 7.19 is characteristic for a system with an arbitrary flow; partly complete mixing and partly plug flow.
The mean hydraulic retention time is 12.5 days, which is lower than the theoretical HRT (16 days), but this was expected as the volume of the sludge bed has to be taken into account.
The number of mixers, calculated by two different methods yields a number of 5.5. Relating this to the design of the 860 L reactor, one could distinguish four "compartments" between which free exchange of fluid is more or less hindered:- the zone beneath the lowest baffle

- the zone between the two baffles

- the zone between the upper baffle and the gas-solids separator
- the zone where suspended solids can settle down: between the overflow rim and the gas-solids separator

The percentage Li^+-recovery is calculated up to t = 1.7 HRT, which was the moment the last sample was taken. Extrapolation to 2.5 HRT yields a somewhat better recovery, viz. 78.34 %. Of course a certain amount of Li^+ can get adsorbed to sand, present in the sludge. At the time the tracer experiment was carried out, the reactor was filled with nearly 600 liters sludge.

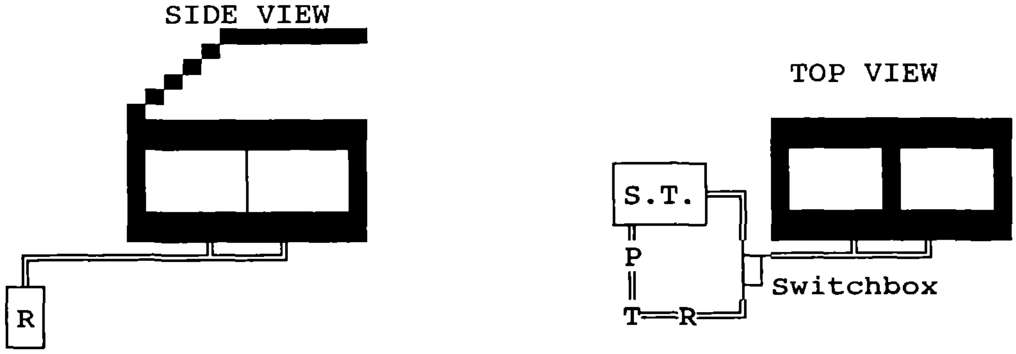
8. BLACK AND GREY WATER TREATMENT: THE CIMINDI REACTOR

8.1. SITE DESCRIPTION

The experiments with the U.A.S.B.-reactor treating combined black + grey water, were conducted at the low cost housing complex of the Borromeus hospital at Cimindi.
Similar to the Biofarma site, each house here has its own pour-flush squatting toilet. A backyard hand pump for water-supply is shared by two households.

Each house is provided with a 1 m^3 septic tank treating the black water discharged from the toilet; the effluent of the septic tank is discharged in a subsoil infiltration bed.

The grey water is, as in most cases, remains untreated and is discharged behind the house into a little gutter which leads to surface water.
Figure 8.1. gives a lay out of the present situation at location Cimindi.



R = Reactor
S.T = Septic Tank
T = Tank for effluent storage
P = Pump

Fig. 8.1. Lay out of the Cimindi site.

Because of the geographic situation at the Cimindi site it was not necessary to dig a pit for the reactor. The two households which are discharging their black and grey water into the reactor are situated at a higher level than the reactor, so no pump is required in this situation.
Black and grey water flows from the two households in a switch-box, and can be conveyed to either a septic tank or the U.A.S.B.-reactor.
The effluent of the reactor is collected in a tank and from there it can be pumped (after sampling) into the septic tank.

8.2. INFLUENT MEASUREMENTS

Similar to the procedure at location Biofarma, several influent samples were analyzed before the reactor was connected to the discharge pipe from the two households. After the reactor had been put in operation, every one or two months it was disconnected in order to enable sampling of the influent. The method of sampling and analyses are described in Chapter 5.1.3. and 5.2.
Table 8.1. gives the results of the influent measurements at Cimindi.

Table. 8.1. Influent measurements at location Cimindi

Parameter	Unit	Average	Standard Deviation
CODtotal	mg/L	1359	671
CODfiltered	mg/L	393	110
CODss	mg/L	967	654
BODtot	mg/L	387	250
pH	-	7.6	0.4
Total Alkalinity	meq/L	7.4	3.5
VFA	meq/L	2.1	3.0
N-total	mg/L	176	78
NH_4^+-N	mg/L	73	37
P-total	mg/L	31	6
PO_4-P	mg/L	25	6
TSS	mg/L	274	147
VSS	mg/L	219	133
ASH	% of TSS	22.4	10.7

The Cimindi influent is of a medium to low strength type; 71 % of the COD is present as suspended solids.
The calculated COD/BOD ratio averages 3.14, which can be considered as high.
The pH is in neutral range and very stable; although the alkalinity is considerably lower as compared to the influent at the Biofarma site, it can be considered as sufficient.
About 58 % of the soluble COD (CODf) is already acidified (2.1 meq VFA equals 231 mg COD). This is similar as compared to the amount found in black water.
Of the total available nitrogen about 42 % (54 % in the black water influent at Biofarma) is present as ammonia-nitrogen.
The ortho-phosphate presents up to 81 % (72 % in black water) of the total phosphate concentration.
The ashcontent of the TSS present in the influent averages 22.4 %, which is significantly higher than found for the black water.

A striking difference is found between both the total COD and TSS values of the samples from June/September 1986 and those measured later, which are, with a few exceptions, much higher.

The course of the daily use of water at Cimindi, and thus of the influent flow to the reactor, is shown in Figure 8.2.

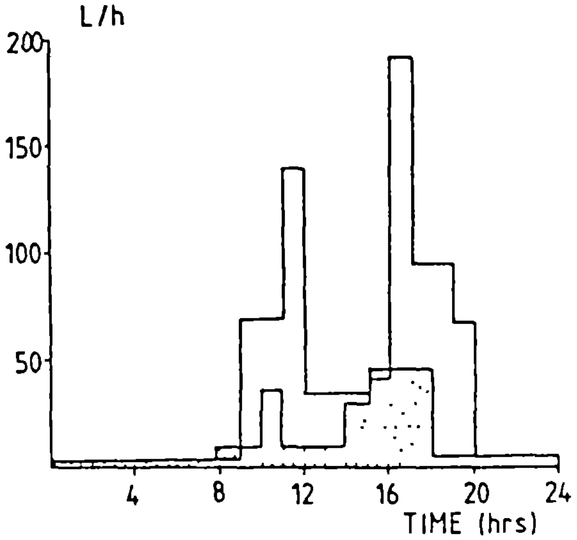


Figure 8.2. The influent flow during a normal working day (▨) and a Friday (□).

It is clear that during Fridays, there is an enormous peak in the influent flow rate, which can be attributed to religious reasons, i.e. viz. bathing. These high flow rates during the two peaks at Friday. which last three to four hours each, result in a flow rate which temporarily exceeds the design value of 0.1 m/hour.

Figure 8.3. shows the total daily influent flow rate during the whole monitoring period of the Cimindi reactor.
The data obtained over the period 0 - 82 are less reliable than those obtained later. From day no. 83 onwards these measurements were performed using new equipment which resulted in a significantly lower mean influent flowrate.

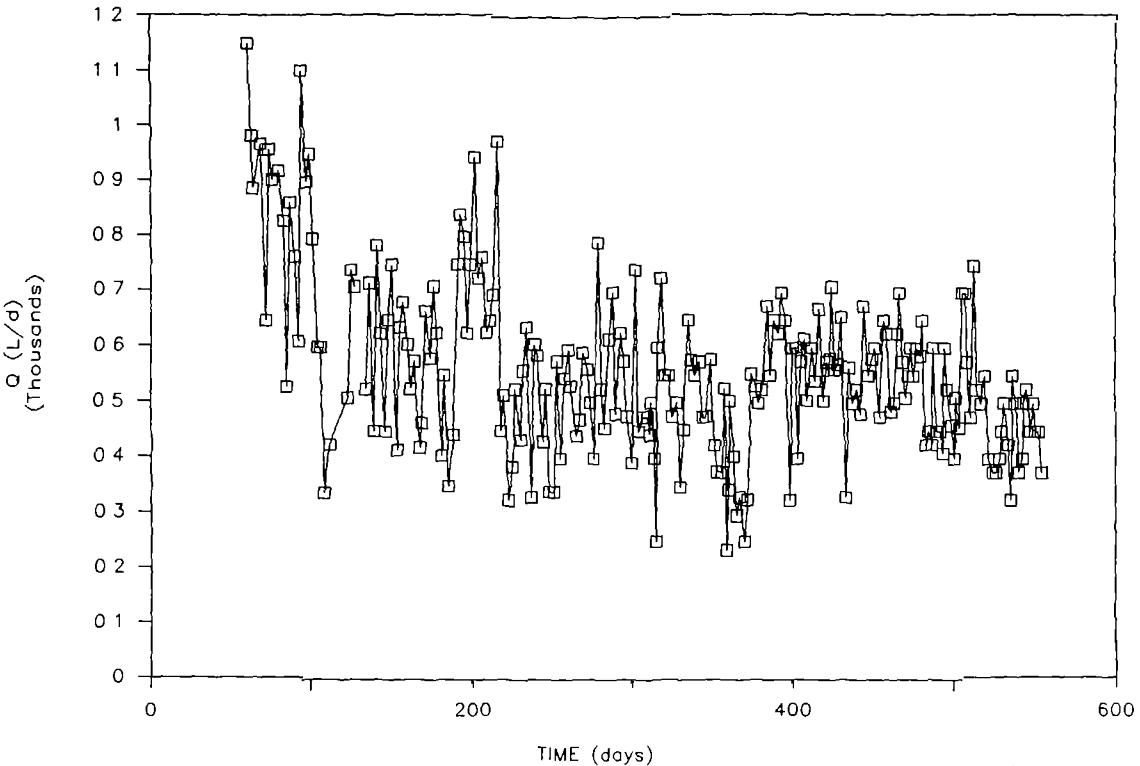


Fig. 8.3. The course of the influent flowrate during the operation of the 860 L U.A.S.B. reactor at location Cimindi.

8.3. RESULTS OF THE REACTOR TREATING BLACK AND GREY WATER

8.3.1. Performance of the reactor

Start up conditions

At the end of October 1986 the Cimindi reactor was inoculated with 120 L sludge from an old cesspool; this sludge was very low in VSS content (3.9 g/L). The feeding of the reactor was interrupted when after 37 days it still didn't show any clear (methanogenic) activity. At the fifth of December 1986 (day no. 46) the reactor was re-inoculated using 150 liter sludge from a septic tank.
Table 8.1. shows the characteristics of the seed sludge.

Table 8.1. Composition of the seed sludge of the 860 L reactor at location Cimindi

TSS	(g/L)	47.9
VSS	(g/L)	17.2
Ash	(% of TSS)	64
COD	(mg/g TSS)	996

Assuming a daily influent flow of 860 liters and an average influent COD of 578 mg/L (the average values of June/September 1986) the prevailing start up conditions are as shown in Table 8.2.

Table 8.2. The starting conditions of the 860 L reactor at location Cimindi (the effective reactor volume is assumed 0.8 m^3)

Parameter	Unit	
Hydraulic retention time	day	0.9
Sludge concentration	kg VSS/m^3	3.2
Organic sludge loading	kg COD/kg VSS.d	0.193
Organic space loading	kg COD/m^3.d	0.622
Surface loading	m/hour	0.084
Upward velocity	m/hour	0.169

Gasproduction

The course of the daily gasproduction is shown in Figure 8.4.

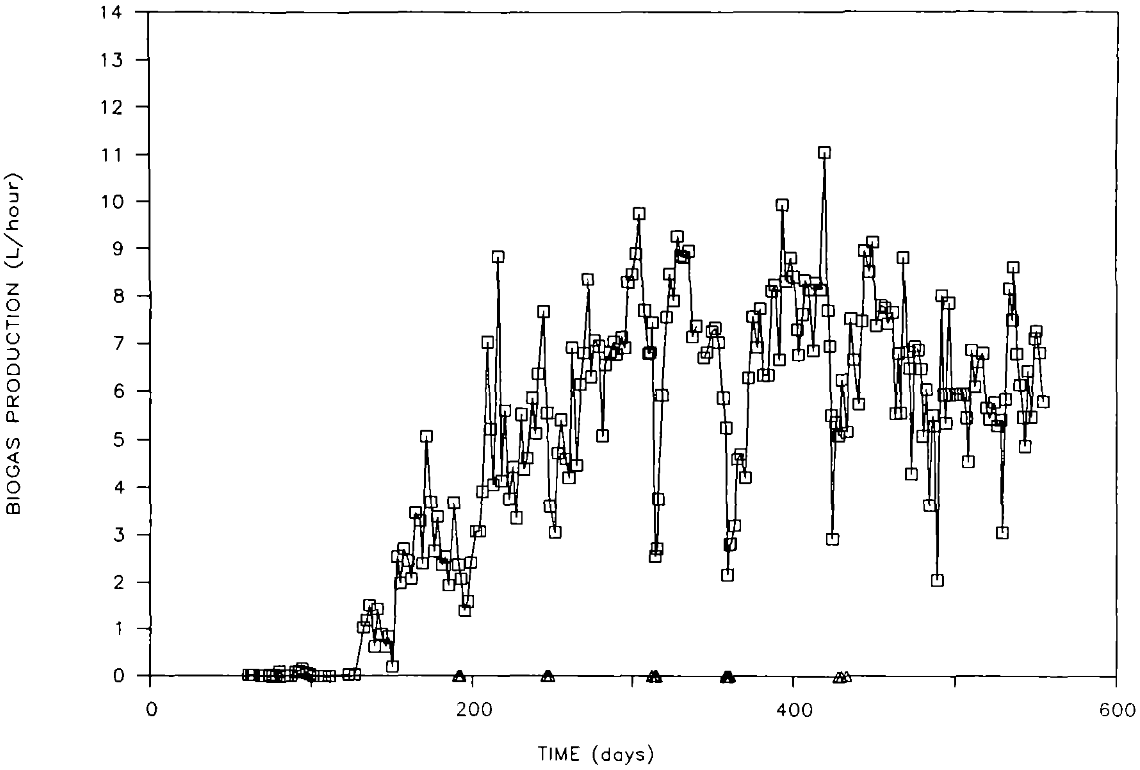


Fig. 8.4. The course of the biogasproduction during the operation of the 860 L U.A.S.B. reactor at location Cimindi (▲ = influent measurement).

During the first 120 days after the reinocculation little if any gas was measured, which presumably should be attributed to a gas leak, because after 100 days of operation two leaks in the upper baffle were detected. Reparations were made at day no. 132, and from day 132 onwards reliable measurements of gas were made.
Starting from day 130 the gas production increased rapidly to 6-7 L/hour beyond day 200. The effect of the feedless periods for influent sampling are clearly reflected by the sharp drops in the gas production.
The biogas was found to contain 78 volume % methane gas.

Effluent characteristics

COD/BOD
Figure 8.5. shows the measured COD and BOD effluent values during the monitoring period of the Cimindi reactor.
These measurements started at day 47, after the second inocculation of the reactor.

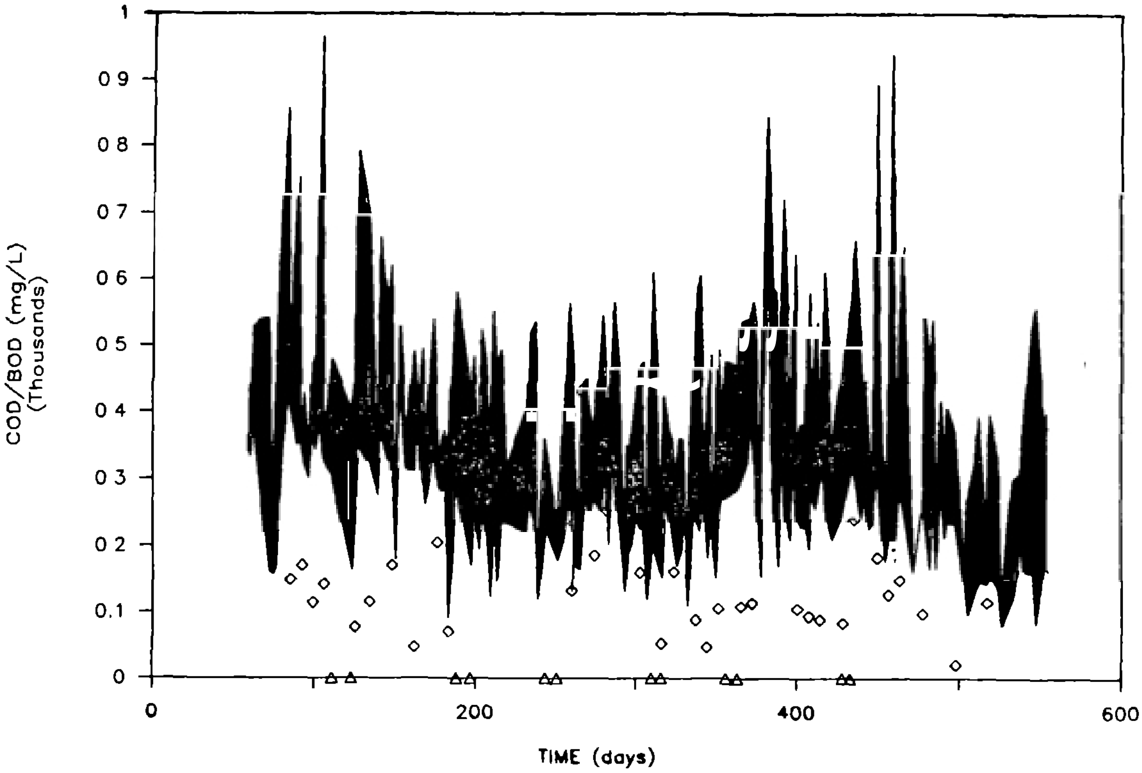


Fig. 8.5. The course of the effluent COD concentrations of non-filtered samples (upper edge of the solid black area), filtered samples (lower edge of the solid black area) and BODtotal (◇) during the operation of the 860 L U.A.S.B.-reactor at location Cimindi (△ = influent measurements).

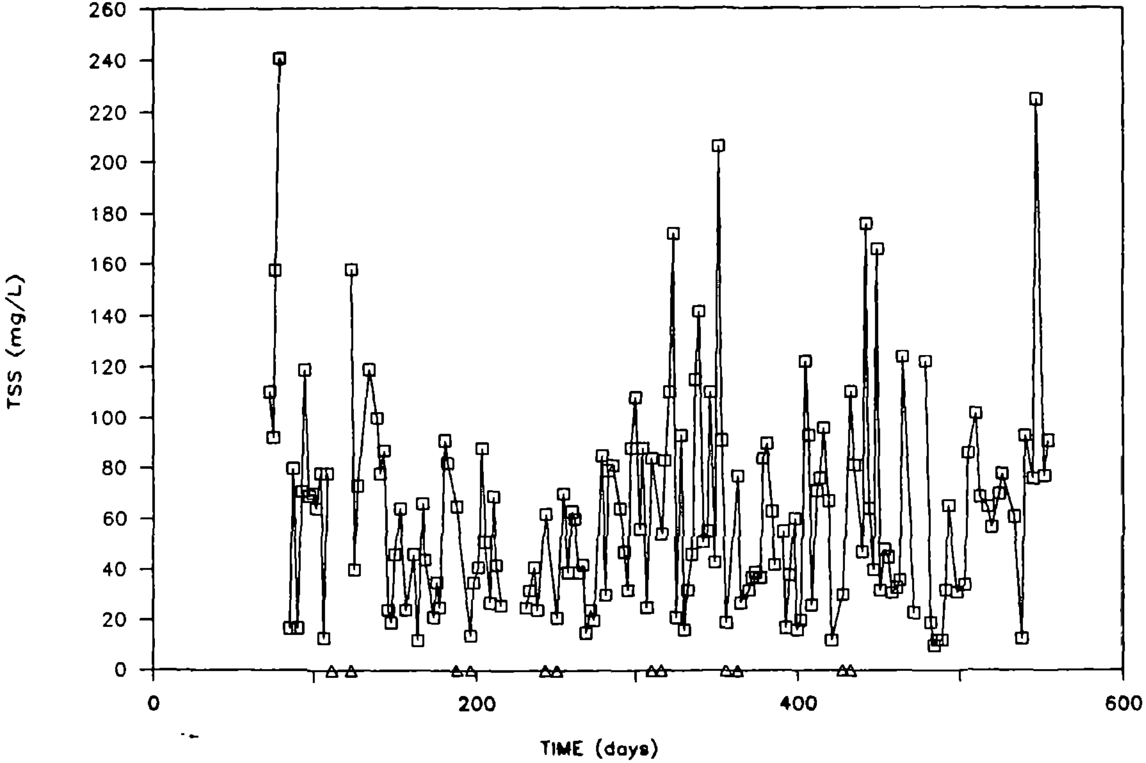


Fig. 8.6. The course of the effluent total suspended solids (TSS) during the operation of the 860 L U.A.S.B.-reactor at location Cimindi (△ = influent measurement).

Both the COD and BOD values of the effluent show a more varying pattern than found for the Biofarma reactor, treating merely black water. This must be due to the varying influent flow and the lower mean detention time.
Feed interruptions for the purpose of influent sampling cause a temporary increase in the COD of the suspended solids immediately after resuming the feeding of the reactor.

The amount of suspended solids in the effluent of the reactor is shown in Figure 8.6.
During the course of operation of the reactor effluent-TSS values fluctuate between 10 mg/L and occasionaly up to appr. 220 mg/L.

The results of the analyses of the total alkalinity, the VFA in the effluent and the pH measurements are presented in Figure 8.7.

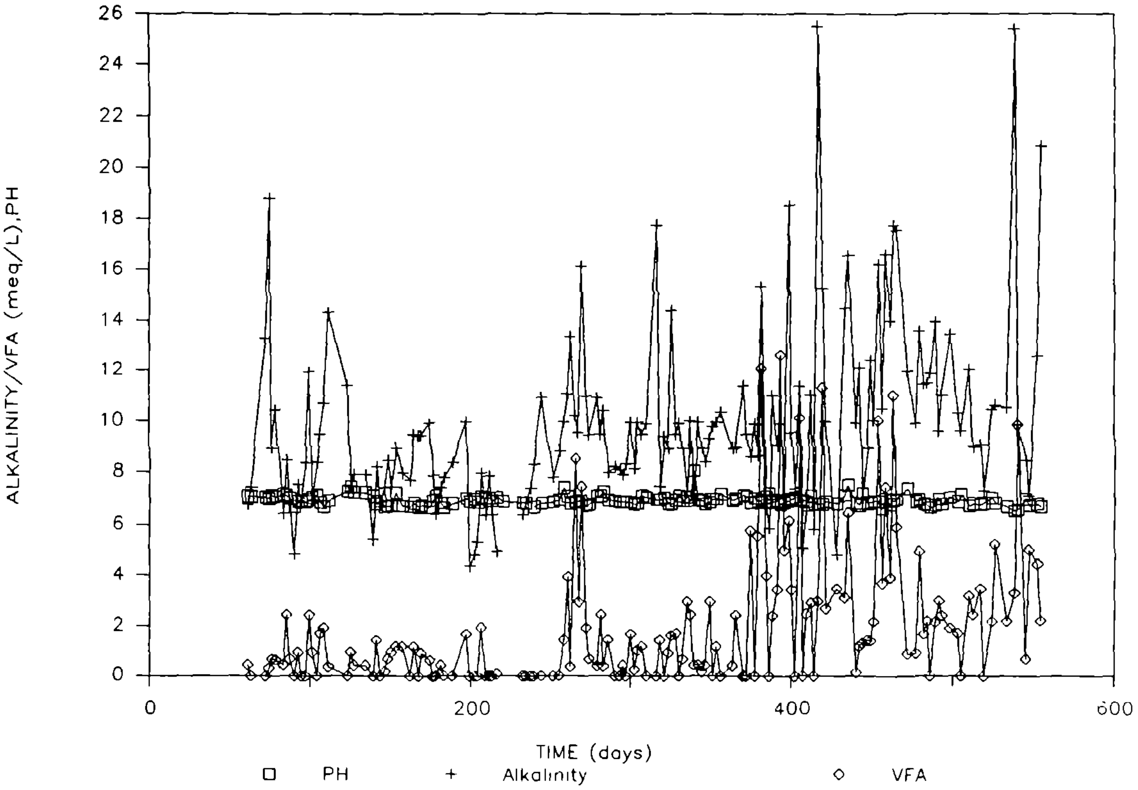


Fig. 8.7. The course of the effluent concentration of volatile fatty acids and bicarbonate alkalinity and pH during the operation of the 860 L U.A.S.B. reactor at location Cimindi

The pH values remain quite constant (around 6.5 - 7) during the operation. The alkalinity shows some fluctuations due to fluctuating influent pollution but there clearly is always sufficient buffercapacity.
During the first 300 days of operation volatile fatty acids concentrations remain very low, but from day 300 onwards occasionally some higher peaks occur which give no further problems.

Nutrients

The effluent phosphate concentrations (ortho and total) remain fairly constant during the monitoring period of the Cimindi reactor. Total phosphate averages 28.6 ± 5.4 mg/L and ortho-phosphate 20.7 ± 4.9 mg/L.
The results of all phosphate measurements are shown in Figure 8.8., while those of NH_4^+-N and N-Kjeldahl are shown in Fig. 8.9.

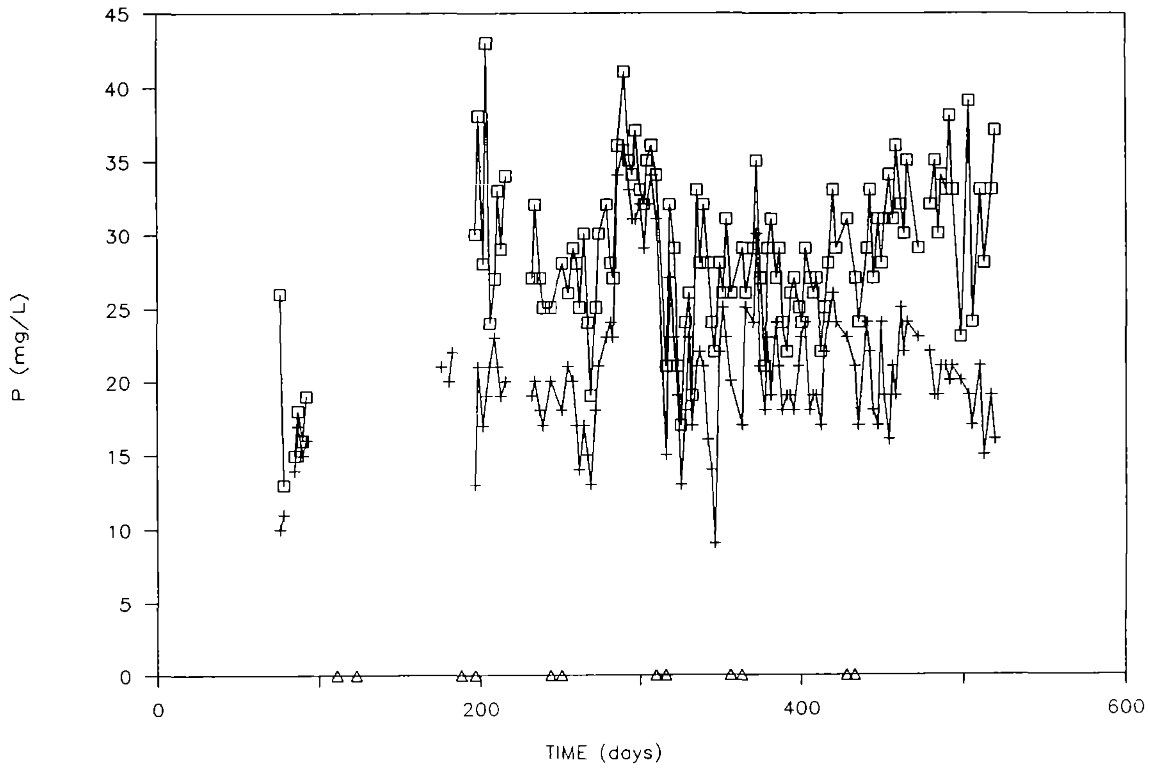


Figure 8.8. The course of the concentrations total (□) and ortho (+) phosphate during the operation of the 860 L U.A.S.B.-reactor at location Cimindi

Right from the start of the operation both Kjeldahl and ammonia nitrogen show a steady increase. From day no. 400 onwards there seems to be a stabilisation or even a slight decease in both values.
This totally different pattern as compared to the phosphate concentrations is also registred at the Biofarma reactor.

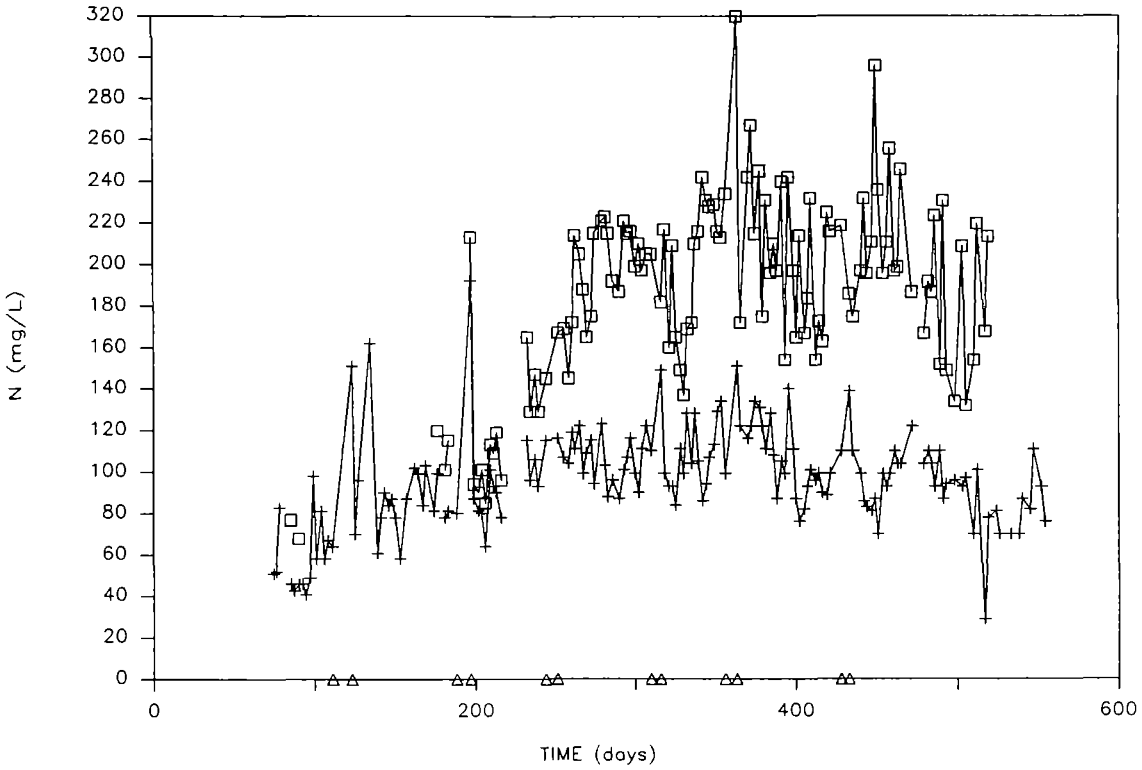


Fig. 8.9. The course of the concentrations Kjeldahl (□) and ammonia (+) nitrogen during the operation of the 860 L U.A.S.B.-reactor at location Cimindi (Δ = influent measurement).

Sludge profiles

Regularly sludge profiles were measured in the Cimindi reactor. Appendix 8 summarizes the results of these measurements.
Over the reactor height all parameters (CODf, VFA, alkalinity, nitrogen and phosphate) remain fairly stable.
The good buffercapacity as indicated by the bicarbonate alkalinity and the low volatile fatty acids concentration demonstrate the high stability of the process for acidic pH conditions.

Sludge accumulation

Figure 8.10. presents the calculated accumulated amount of solids in the reactor. These data are derived from the results of the profiles summarized in Appendix 8.

After 518 days of operation the sludge bed has extended just up to a height of 85 cm (tap 4).

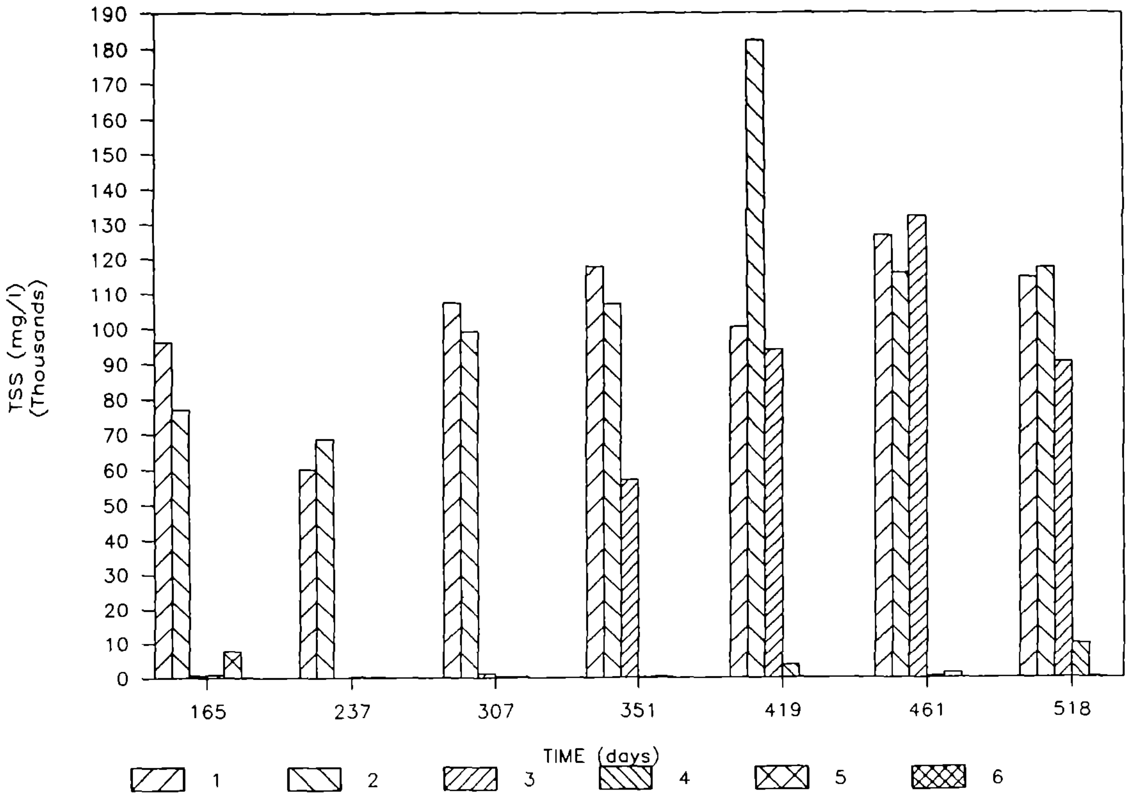


Fig. 8.10. The amount of Total Suspended Solids at different heights of the reactor as a function of time during the operation of the Cimindi reactor. The centre of each profile is situated at the time of sampling. The height of the sampling points were (from left to right in each sludge profile): 15, 39, 65, 85, 133 and 176 cm respectively.

The importance of monitoring the stability of the sludge has been explained before. Results of the sludge stability tests with sludge samples from the Cimindi reactor are summarized in Table 8.3.

Table 8.3. Results of the sludge stability assessment tests with sludge from the Cimindi reactor.

	days	% COD 100 d.	% COD total
	(a)	(b)	(c)
Sludge obtained at day no.			
0	179		
165	155	17	19
237	103	9	9

The course of the ash content of the sludge in the reactor, which represents another index for sludge stability, together with the ash content of the effluent solids are presented in Figure 8.11.

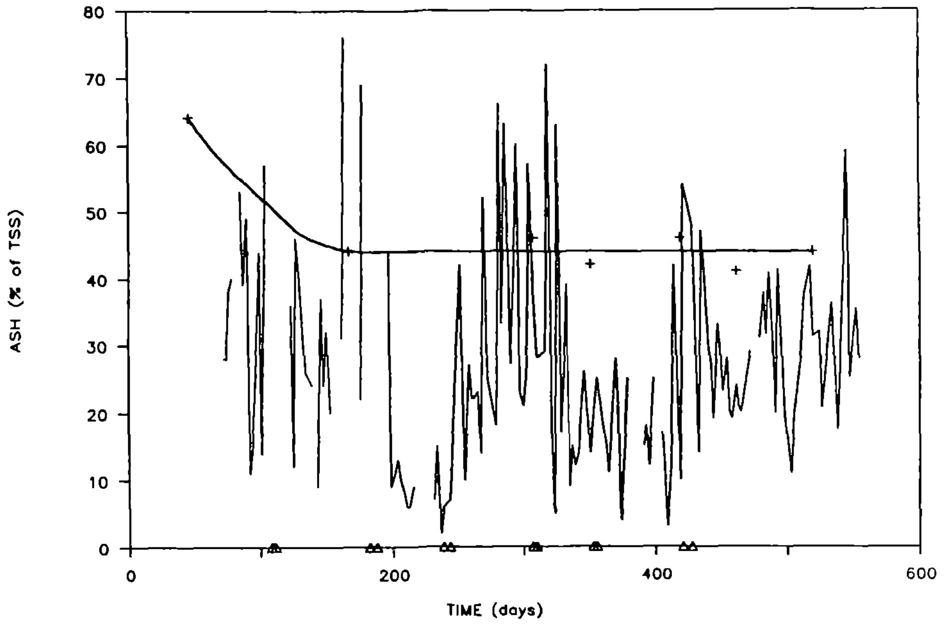


Fig. 8.11 The course of the ashcontent of the reactor sludge, i.e. tap 1 ( ) and of the solids in the effluent during the operation of the 860 L U.A.S.B.-reactor at location Cimindi.

The ashcontent drops quickly from 64 % at the start of the experiment to ca. 40 % and remains at that level during the rest of the operation. Table 8.4. shows the ashcontent of the sludge at several heights in the reactor in the course of time.

Table 8.4. Ash content (% of TSS) of the sludge in the reactor (the data printed in bold type respresent samples from the sludge blanket in the reactor)

Day	Tap 1	Tap 2	Tap 3	Tap 4	Tap 5	Tap 6
0	**64**					
165	**44**	**52**	56	40	47	37
307	**46**	**48**	39	40	38	38
351	**42**	**45**	**44**	42	38	38
419	**46**	**35**	**40**	41	37	16
461	**41**	**42**	**37**	41	36	32
518	**44**	**44**	**36**	**42**	34	32

All sludge samples were also tested for their spec. methanogenic activity using the standardized spec. act. assay. The results of these assays are presented in Table 8.5.

Table 8.5. Results of the activity asays with sludge from the Cimindi reactor (maximum specific methanogenic activity at ambient temperatures).

Date (ddmmyy)	Day no.	200 (mg/L)	200 (mg/L)	400 (mg/L)	600 (mg/L)	200 (mg/L)	200 (mg/L)	400 (mg/L)	600 (mg/L)	200 (mg/L)	200 (mg/L)	400 (mg/L)	600 (mg/L)
	0	0.021	0.023	0.041	0.044								
40487	165	-	0.015	-	0.147	0.025	0.026	-	-				
150687	237	0.036	0.026	0.036	0.025	0.035	0.025	0.04	0.034				
240887	307	-	-	0.037	0.083	0.039	0.029	0.034	-				
171087	351	0.028	0.036	0.046	0.04	0.025	0.026	0.039	0.035	0.045	0.03	0.034	0.035
141287	419												
250188	461												
220388	518												
			tap 1				tap 2				tap 3		

8.3.2. Discussion

Influent characterization

In comparing the characteristics of the influent (Table 8.1.) with those of black water (Table 7.1.) it has to be kept in mind that combinated grey and black water is not simply a diluted black water. The influent of the Cimindi reactor contains for instance domestic garbage and a considerable amount of ash, which is used to scour the pans. The higher ashcontent of the TSS in the wastewater is also of importance with respect to the characteristics of the sludge accumulating in the reactor during its operation.

Similarly as in the case with the black water (section 7.3.2.) it was attempted to estabish the existence of a reliable correlation between incoming organic pollutants and any nutrient-compound in the Cimindi influent. However so far no such relations could really be established, which perhaps partially can be attributed to the fact that not always sufficient attention has been paid to correct sampling and sample preparation. Therefore additional measurements will be conducted in the future in order to collect more reliable data.

Gasproduction

The course of the biogasproduction of the Cimindi reactor shows a very similar pattern as found for the reactor treating only black water at the Biofarma location.
Moreover the measured average daily gas production in both reactors is very similar, viz. 5-6 L/hour in the Biofarma plant treating the black water of 9 people and 7-8 L/hour for the Cimindi reactor which treats the combined black and grey water of 11 people. As in the case of the Biofarma reactor the feed interruptions are very well reflected in the pattern by steep drops in the measured daily gas production. Apparantly the easily digestible substrate ingredients introduced daily in the reactor are rapidly converted in biogas.

Treatment efficiency of the process (see Fig. 8.5. up to 8.9)

Table 8.6. summarizes the treatment efficiency of the Cimindi reactor over the first 1.5 year of operation. It is clear that the system is fairly effective in removing COD and BOD and TSS as well from black + grey water.

The relatively low treatment efficiency found during the first half year can at least partly be attributed to the low measured influent values.
Regarding the relative constant quality of the effluent over the whole experimental period, it can be stated that the system is operating fairly satisfactorily, despite the big differences in the amount of sludge in the reactor.

Table 8.6. Treatment efficiency (as % reduction) of the 860 L UASB reactor at the location Cimindi.

	1st half year	2nd half year	3rd half year
CODtot	67	73	75
CODfil	22	43	47
BOD	57	46	82
TSS	74	81	80

Comparing the results of the Biofarma and Cimindi reactors it is clear that the Cimindi reactor is less efficient in removing TSS. This is not surprising, considering the fact that the Cimindi reactor is operating at H.R.T. of ca. 1 day whereas this is 16 days in the Biofarma reactor. Moreover, as shown in Fig. 8.2. the wastewater flow is concentrated in two distinct peak hours during the day, which means that the system is temporarily being exposed to relatively high hydraulic (and organic) shock loads. Considering the relatively low TSS concentrations in the effluent, it can be concluded that the system indeed is well feasible to accomodate the shock loading rates that prevail in on site situations where combined black and grey water has to be treated. This finding obviously is of big importance in considering the applicability of the system for such and similar situations. The limits of the system in terms of max. acceptable hydraulic peak loading rates so far have not been established.

The high process stability of the system is also reflected in the constant pH and relatively high alkalinity and the low VFA content of the effluent.
The o-PO_4/tot-PO_4 value in the effluent, viz. 0.73 ± 0.14, are similar to those found in the Biofarma effluent and in faeces desintegration experiments. The reason for the apparantly higher biodegradability of P-compounds during period 280-450 is obscure.
Values for the NH_4^+-N/N-Kjeldahl ratio in the effluent, i.e. 0.57 ± 0.15, are somewhat lower than expected, because in the faeces desintegration experiments a value of 0.65 NH_4^+-N/N-Kjeldahl was found. As the increasing amount of solids in the reactor in fact should increasingly contribute to the formation of NH_4^+-N in the effluent the found values for NH_4^+-N/N-Kjeldahl are surprisingly low. The reason for this could be a poorer biodegradability of N-compounds present in the waste water at Cimindi relative to that present in the faeces digestion experiments.

Sludge accumulation

The sludge accumulation rate is an important factor with respect to the ultimate design of the treatment system.
After 518 days of monitoring (i.e. 487 days of operation) the

sludge bed in the Cimindi reactor amounted just up to a height of 85 cm, i.e. 48 % of the reactor height.
As in the Biofarma experiments the sludge profile measurements were used to calculate the accumulated amount of sludge-TSS in the reactor. Together with the TSS concentrations in the sludge bed the sludge "filling up" time of the reactor can be estimated.
Figure 8.12 shows the amount of accumulated solids in the reactor versus the time.

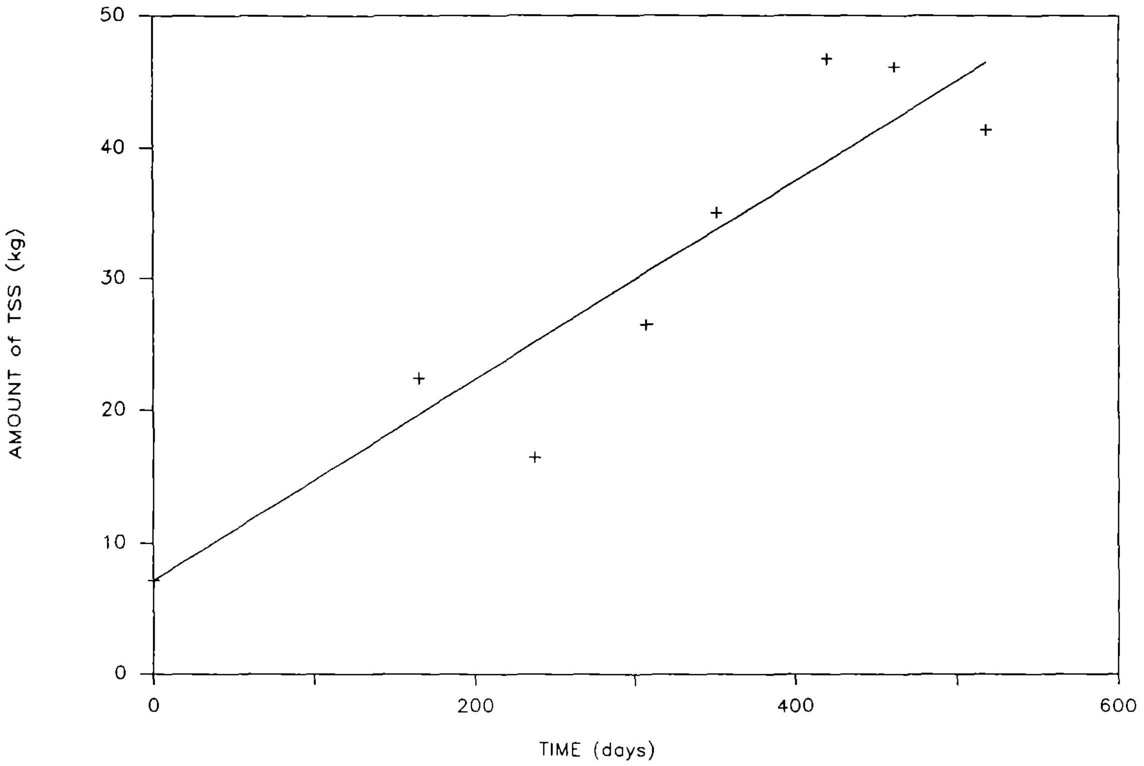


Fig. 8.12 The estimated amounts of solids, calculated from the sludge profile data in the Cimindi reactor

The equation from a linear regression analysis of the data is: $Y = 7.185 + 0.0758 * t$, where Y is the total amount of accumulated solids (in kg) in the reactor and t is the time in days, where 7.185 kg TSS equals the amount of seed sludge supplied to the reactor.
Compared to the accumulation rate found for the Biofarma reactor, viz. 0.0369 kg TSS/day, in the Cimindi reactor an almost twice as high sludge accumulation rate is found.

The "filling up" time now can be estimated using an average TSS content of the sludge of 100 g/L and an available reactor volume of 600 liter. This corresponds with 60 kg TSS over the total reactor volume and a filling up time of 697 days (assuming that 7.185 kg seed slduge is required), i.e. almost 2 years.

The daily amount of accumulating solids under operational conditions amounts to: (518 monitoring days/487 operation days) * 0.0758 = 0.0806 kg TSS

Sludge stability

Up till this moment only very few consistent data are available concerning the sludge stability (Table 8.3). Therefore any definite conclusions can not yet be drawn. The ash content of the retained sludge stabilizes on 44 %, after an initial decrease (from 64 to 44 %). This figure applies for all the sludge present in the reactor. The higher ash content in the Cimindi reactor as compared to the values found in the Biofarma reactor can be attributed to the higher ashcontent of the influent at the Cimindi location.

Sludge activity

The max. specific methanogenic activity (Table 8.4) of the sludge in the reactor is fairly constant over the height of the reactor, but compared to the values assessed with the sludge from the Biofarma reactor, the sludge is distinctly less active.

Despite the lower activity, the results obtained in the reactor don't reveal any indication of overloading. The daily biogas production even exceeds that in the Biofarma reactor. Based on this biogas production and the estimated amount of sludge present in the reactor, the retained methanogenic activity has been calculated. The results are summarized in Table 7.7.

There exist another striking difference between the sludge of the two reactors. Contrary to the results obtained with the slduge from the Biofarma reactor, the spec. activity doesn't increase upon feeding with a higher VFA-dose, moreover not all the VFA substrate was removed in the assays. The reason for latter discrepancies is unknown and will be point of further investigation.

Table 7.7. Retained methanogenic activity of the Cimindi sludge (assuming 78 % methane in the biogas; using the above mentioned equation to calculate the amount of TSS and assuming an ashcontent of 44 %)

Day no.	Biogasprod. (L/hour)	gCH_4-COD/d	g TSS	Activity gCH_4-COD/ gVSS.d
165	3	132	19692	0.0120
237	5.5	241	25150	0.0171
307	7.5	329	30456	0.0193
351	7.5	329	33791	0.0174

In considering these results it should be recognized that the biogas very likely is also produced in peaks (a point of further investigation), which in fact means that the specific activity of the slduge even may significantly exceed the values given in Table 7.7., the more because the VFA substrate level in the reactor is by far lower than that used in the assays.

COD balance

Fig. 8.13 shows the COD balance over the Cimindi reactor during the first 17 months of operation. Appendix 9 shows all detailed data used in the calculation.

The COD balance calculations were made using the following equation (the figures refer to Fig. 7.13):

COD-influent = COD-effluent,filtrated (2) +
COD-effluent,ss (3) + COD-gasproduction (4)
+COD-sludge accumulation (5)
+ COD-sludge profile measurement (1)

where:

COD-influent = (average g CODinfl/day) * number of days
COD-effluent = CODfil,eff * 53 lit/day * number of days +
CODss,eff * 53 lit/day * number of days
COD-gasprod. = 2.343 * 0.78 * liters gas produced
COD-sludge profile measurement = per month 1% of CODinfl.

The factor 0.78 refers to a 78 % methane content of the biogas, whereas the factor 2.343 refers to the COD-content of 1 liter gas (Appendix 2).

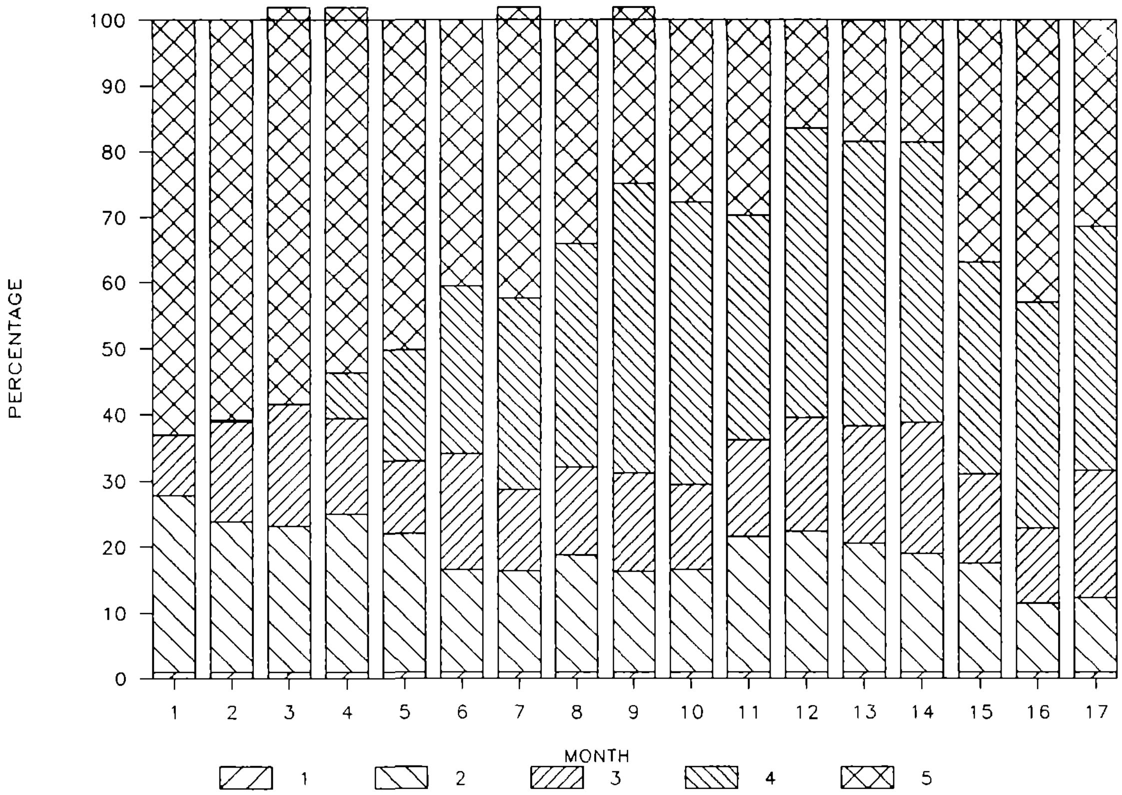


Fig. 8.13 The COD balance of the Cimindi reactor over 17 months of operation (for explanation of 1 up to 5, see above mentioned equation)

The sludge accumulation factor Y can be calculated from these data using the expression:

Y =(gram COD-sludge accumulation/g COD-influent) * 1/1.40
(1 gram sludge VSS = 1.40 gram COD)

The total COD-balance over month 6 up to 17 (a period of 360 days of stable performance) is shown in Table 8.8.

Table 8.8. The COD-balance of the Cimindi reactor during its monitoring period.

gram COD-influent,total	283515	100 %
gram COD-effluent,filtrated	46692	17 %
gram COD-effluent,ss	43444	15 %
gram COD-gas	104551	37 %
gram COD-sludge profile	2835	1 %
gram COD-sludge accumulation	85993	30 %

These figures give an excess sludge accumulation rate of 245 gram COD per day and (using the measured equation: 1 g sludge TSS = 0.84 g COD) 292 gram TSS/day. According to these data the reactor would fill up within 180 days (600 liters with TSS = 100 g/L, starting with 7.185 kg TSS seed sludge).
Once again the difficulty to calculate a COD balance with only very few influent data available is shown.

The estimated sludge accumulation factor calculated over each month (Appendix 9) ranges from 0.14 to 0.46 g sludge-VSS/ g COD-influent.

9. FINAL DISCUSSION, CONCLUSIONS and RECOMMENDATIONS

Environmental Protection and Resource Conservation and Recovery constitute the basis of human survival; they can not and should not be considered separately. The living environment must be kept healthy in a way which leads to maximum of recycling, a minimum of consumptive use and consequently with a minimum of production of wastes, both in terms of absolute amounts of organic and inorganic pollutants as well as in terms of volumes of diluted wastes. In the light of that and considering particularly the wastes originating from domestic areas, it is clear that sanitary schemes which focus on preventing heavy dilution of originally concentrated organic wastes (e.g. human excreta), principally are preferable over systems where excreta are removed from the residential site(s) by using large amounts of clean water - generally even 'expensive' potable water- as is common practice in the more prosperous countries and/or areas. A number of principle objections can be brought up against these so-called sophisticated sanition schemes . Not only a lot of clean water is spoiled, but also huge amounts of polluted water have to be treated in order to prevent serious damage to the environment, and -last but not least- expensive sewer and collector systems have to be installed to remove the diluted wastes from the residential sites and to convey them to the central treatment facilities, or if these are not (yet) available - to the central outfall. In latter case large amounts of polluted water are discharged in receiving waters, which frequently have far too little capacity to accommodate the relatively large amounts of pollution. Generally developing countries financially are not in the position to implement these 'sophisticated' sanition systems, despite the fact that presumably they frequently are advised from various sides to proceed in this direction. However despite this pressure, authorities and specialists in developing countries in many cases may choose for a very different - but more appropriate - approach for solving the severe environmental pollution problems in their countries, and certainly not merely because of the lack of financial means.
In a country like Indonesia it seems to be well recognized that **on site sanitation/treatment systems** are not merely low cost, but in fact also could offer very significant principle advantages over the off-site sanitation/treatment approach, provided of course a sufficient treatment can be achieved.

The **main objective of the project** was to develop, to optimize and - as far as possible - to demonstrate a compact low cost on site treatment system for domestic waste water, which combines a high treatment efficiency in terms of COD, BOD and TSS with a high stabilization of the sludge and with a sufficiently long sludge hold-up, viz. 2 - 3 years before discharge is required. The system investigated concerns a modified anaerobic reactor (or septic tank) based on the UASB-principle. Originally it was intended to focus the research on merely black water treatment, but later on - based on the very satisfactory results obtained in the plant treating the black water and the excellent results obtained with UASB-pilot plant reactors treating domestic sewage in some tropical countries - it was decided to use the second reactor for combined black and grey water at the low cost residential site of Borromeus Hospital at Cimindi . A third reactor was made available to DPMB for similar experiments. This report deals merely with the results obtained with the Biofarma reactor, treating black water (Chapter 7) and the Cimindi reactor, treating combined black and grey water(Chapter 8), together with results of complementary supporting laboratory investigations (Chapter 6).

In evaluating the results obtained with the two pilot plants it has to be taken in mind that for investigations dealing with on-site treatment systems representative - consequently reliable - sampling of the influent and the effluent is extremely difficult, and also a very unpleasant and quite hazardous job. It has been attempted to get consistent data throughout the investigations, and to extract from these data a representative correlation between various parameters, i.e. particularly between the COD of the influent and the concentration of nitrogen (Total and ammonia-N) and of phosphorous (total and ortho). On the basis of such a relation the influent COD-pollution (and perhaps BOD) could be estimated from N- and P- values in the effluent. In the case of black water there indeed seems to exist a linear correlation between total-P and total-COD, COD_{SS} and total-BOD, and between filtered -COD and ammonia-N, but additional information has to be obtained in the near future before a definite conclusion can be drawn. This applies particularly also for the combined black + grey water.

Regarding the **pollution strength of the waste waters**, the black water can be considered as medium strength - complex type - of waste water, i.e. having an average COD of 5500 mg/l of which roughly 75 % is present in insoluble form (Chapter 7.2). The total-COD/total-BOD ratio found (viz. approximately 3.5) is high, in fact considerably higher than at first sight one might expect from the results of the faeces-digestion experiments (Chapter 6.1, see Table 6.5), which show that generally far over 50 % of the faeces-COD is converted in CH_4-COD, provided a sufficient long period of time (over 50 days) is reserved for the digestion process to complete. In practice the average sludge residence time in a septic tank will exceed 400 days, consequently even a higher fraction of the organic pollutants will end up in methane. The BOD-assay refers to a 5-day period, and considering the complexicity of the faeces ingredients, this is far too short for aerobic organisms to convert these compounds. The ash content of suspended matter is low, which is completely in accordance with the analyses of faeces samples in the laboratory (Chapter 6.1), viz. approximately 10 %. The combined black + grey water belongs to the category low strength complex waste water, i.e. average COD 1350 mg/l (roughly 70 % insoluble), but it still is far more concentrate than generally found for domestic sewage. The ash-content of the suspended solids is significantly higher

than found for black water, which can be due to the use of ash for cleaning pans etc.
As far as the temperature concerned the situation is fairly satisfactory for anaerobic digestion to proceed rapidly, viz. it ranges from 23 to 27 ^{o}C.

Although not yet sufficient data have become available for the Cimindi reactor (black + grey water), it already can be concluded that the **performance** of the system in terms of **COD, BOD- and TSS- treatment efficiency** is fairly satisfactory, both for black water and for combined black + grey water treatment. This applies particularly for **black water treatment,** because on COD-total basis the efficiency exceeds 90 %, while the COD-filtered , BOD-total and TSS-efficiencies range from 70 - 80 %, 85 - 95 % and 93 - 97 % respectively. This obviously in many cases still is far from sufficient, but considering the fact that relatively small amounts of waste water are involved per capita, viz. 4 - 5 liter per capita (compared to sometimes over 200 liter/capita when all domestic waste water would be involved !!), and particularly also that a considerable fraction of the daily released amount of organic pollutants from dwellings are present in the black water fraction, the efforts required to achieve 'complete' treatment are relatively very small. On the basis of the COD-pollution data presented in Table 7.1 and 8.1 for black and black + grey water respectively, and the data of the measured daily flows at both sites (respectively 9 and 10 people) shown in Figures 7.4. and 8.3, it can be estimated that roughly 40 % of the COD-pollution is present in the black water fraction, which in terms of volume constitutes less than 10 % of the daily total waste water flow (sum of black + grey water).
The system was found to be rather efficient in eliminating helminth eggs, but not in removing coliforms. As **pathogenic organisms** generally will occur mainly in the black water, it would be attractive if this fraction of the total domestic waste water flow could be treated separately, i.e. first in an anaerobic reactor system, next in a post- treatment step, which particularly is effective in the elimination of pathogens. The big advantage of such an approach obviously would be that only small amounts of very hazardous water are involved.
The performance of the **black + grey water reactor** at Cimindi so far is quite reasonable, viz. on basis of COD-tot, COD-fil and TSS, 70 - 75 %, 43 - 47 % and over 80 % treatment efficiency respectively was achieved. These figures correspond fairly well to those obtained in the 64 m^3 UASB-reactor treating domestic sewage in Cali, Colombia. The COD-load applied in both these reactors is of the same order of magnitude, viz. ranging from 0.8 - 1.5 kg COD/m^3.day. However as the COD-pollution of the combined black + grey water exceeds that of the Cali sewage with a factor 5 - 9, considerably higher hydraulic loads are imposed to the system in Cali, i.e. minimum (peak) hydraulic detention times of 2.5 hrs were applied there, while this is 4.5 hrs in the Cimindi reactor and then only for 1-2 hours once a week and in a reactor which is only half as high as the Cali-reactor.

Apart of that, considerable differences exist in reactor size and design, as well as in the (e.g. the septic) character of the waste water and flow distribution pattern between both experimental situations. However, considering the more extreme conditions applied in the Cali-situation and considering the good results obtained in that reactor, it is reasonable to expect that for combined black water + grey water more severe conditions could accommodate by such a system without serious deterioration in the performance in terms of treatment efficiency. We'll come back to this matter below when discussing the specific activity of the sludge.
The results obtained clearly show that the **pH-stability** of the process is high; this particularly is true forblack water treatment (compare Fig. 7.8), but also for black + grey water treatment; generally the bicarbonate alkalinity suffices for neutralizing the maximum possible amount of VFA that (in absence of methanogenesis) could be formed (viz. 1 meq per 100 mg of COD). From the faeces-digestion experiments described in Chapter 6, it is clear that in fact less than 30 % of the total-COD will be converted rapidly into VFA-COD.

The results in Chapter 7 and 8 show that the systems performs quite satisfactorily with respect **to sludge stabilisation**; for the sludge from the Biofarma reactor it was found that only approximately 15 % of the sludge-COD will be converted in methane upon extending the digestion time with 100 days; the sludge in the Cimindi reactor even looks better stabilized. The ash-content of the Biofarma-reactor sludge stabilizes at appr. 17 %, this is about twice as high that of the influent-TSS. For the Cimindi-reactor sludge the situation is very similar, except that the ash-content here doubles from 22.4 to appr. 44 %. These figures mean that roughly 50 % of the original organic matter present in the waste water is being converted into methane. Regarding the data obtained in the faeces digestion experiments (Table 6.5.) in fact a somewhat higher conversion factor was expected. On the other hand it was observed that in the Biofarma reactor there occurs a slight - but distinct (compare results in Figure 7.13) - selective wash-out of solids having a relatively higher ash-content as compared to the retained sludge. This was not the case in the Cimindi reactor (Compare Figure 8.11), in fact even the contrary occurred here.
In addition to the sludge stability, another crucial factor with respect to the practical feasibility of the system are the **sludge thickening characteristics**, because particularly these characteristics control the sludge-TSS (-VSS) concentration in the sludge-bed, which is important for:

1. the total amount sludge that can be retained, consequently the sludge discharge frequency, but also the extent of sludge stabilization to be accomplished
2. the maximum amount of methanogenic activity that can be exerted by the system.

The results obtained are very satisfactory, both for treating black water and combined black + grey water as well. In latter case - despite the significantly higher hydraulic loading conditions imposed to the system - sludge concentrations in the sludge bed even exceed 100 g TSS/liter. In the Biofarma reactor the sludge-TSS concentration amounts to appr. 60 g/l, which still is satisfactory. The reason for the higher values found in the Cimindi reactor are not clear yet, but presumably are related to the higher ash-content of the combined black + grey water

With respect to the **filling up time** for the Biofarma reactor (black water merely) in Chapter 7 a operational period of 900 days was calculated, based on an daily sludge accumulation rate of 0.0427 kg TSS, using 3.5 kg sludge-TSS as seed material and considering the reactor as completely filled up when it contains 42 kg TSS (corresponding to 700 liter sludge at a sludge-TSS concentration of 60 g TSS/l). As the reactor under these conditions in fact still is not completely full, presumably even a filling up time up to 1000 days might apply, assuming that 10 % reactor space should be left free from sludge. For the practical application of this reactor system a bigger total reactor volume would be attractive, e.g. approximately 1200 liter in stead of 860 liter for approximately 10 persons. The filling up time in that case (at 90 % filling) will extend to 1230 days.
Application of a bigger reactor will also provide:

1. a higher treatment efficiency, because more actvity (sludge) will be present in the reactor,
2. a higher extent of stabilization of the sludge,
3. a further thickening of the sludge.

For the reactor treating combined black + grey water we would recommend an even slightly bigger reactor, because the daily sludge production is significantly higher in that case, 0.0806 kg TSS in stead of 0.0427 for the black water reactor (see Chapter 8), while also the imposed hydraulic and organic loading rates are distinctly higher. A total reactor volume of 1500 liter looks reasonable in that case. Taking 10 % of the reactor volume for seed sludge and operating the sytem at 90 % maximum filling, the filling up time at an average sludge bed TSS concentration of 0.1 kg/l will amount up to 1200 . 0.1 / 0.0806 = 1490 days.

Another important sludge characteristic comprises the **specific methanogenic activity** of the sludge. The quality of the sludge in terms of specific methanogenic activity is reasonable in the case of the Biofarma reactor, approximately 0.06 kg COD/kg VSS.day as assessed in the second 200 mg C-2/L feed (Fig. 7.14, 7.15 and 7.16). Surprisingly the sludge in the Cimindi reactor (Table 8.5.) exerts a significantly lower specific methanogenic activity, viz. only 0.03 kg COD/kg VSS.day as was assessed in the second C-2 feed. The reason for this discrepancy is not clear yet and deserves further investigation, because in addition to the amount of sludge retained in the reactor, the specific activity of the sludge is another major factor controlling the loading potentials of the system. As the imposed hydraulic loading rates in the Cimindi reactor are considerably higher than in the Biofarma reactor, there might occur a higher selective wash-out of methanogenic organisms from the Cimindi reactor. However, such a phenomenon would

have manifested even more seriously in the Cali-reactor treating domestic sewage, and this has not been found here. The specific activity of the sludge present in the 64 m^3 Cali-reactor was very similar or even higher than that of the Biofarma reactor. As significantly higher hydraulic loads were imposed to the Cali-reactor compared to the Cimindi reactor, the explanation given above does not look very likely. Therefore more attention should be paid to this matter in the on-going project extension.
A closer examination of the available specific activity data together with other performance data, provides some further relevant information about **the loading potentials** of the system. Assuming a specific activity of the Biofarma-sludge of 0.05 kg COD/kg VSS.day under the conditions prevailing in the system (i.e.where the acetate concentrations are significantly lower than under the assay conditions), the maximum daily CH_4-production (Q_d -CH_4 in m^3/day) can be estimated using a simple formula:

$$Q_d\text{-}CH_4 = 0.05 \cdot Q_{VSS} \cdot 0.426$$

where

Q_{VSS} = amount of sludge-VSS present in the reactor,

the factor 0.426 represents the CH_4-gas equivalent in m^3 for 1 kg COD under the prevailing conditions (see appendix 2)

From the formulae derived for the sludge accumulation rate, presented in Paragraphs 7.3.2 and 7.3.2 (or the results presented in Figure 7.20 and 8.12), combined with the data for the ash-content (see also paragraphs 7.3.2 and 8.3.2), then easily the potential CH_4-production rates can be estimated. So, when 5 kg of sludge-VSS is present in the reactors, already 106 liter/day (= 4.4 liter/hour) of CH_4-gas potentially can be produced. In the Biofarma reactor such an amount of sludge (occupying approximately 100 liter reactor space) is present within 100 days of operation. From the biogas (65 % methane) production measurements presented in Figure 7.5 it is clear that the estimated gas-production corresponds fairly well to the actual values. It will be also clear that the maximum CH_4-production potentials of the system after 50 % of the reactor volume (0.43 m^3) has filled up with sludge (at a sludge concentration of 60 kg TSS/m^3), i.e. when 0,43 . 60 = 25.8 kg TSS (= 21.5 kg VSS) is present in the reactor, is far bigger (viz. 456 liter/day), than the maximum amount of 216 liter biogas/day (= 140 liter CH_4-gas/day) actually measured. Therefore, the potential loading capacity of the reactor when half filled up with sludge amounts to appr. 1.0 kg COD/day, which is distinctly higher than the imposed COD-load of about 0.28 kg COD/day!

The same picture can be composed for the Cimindi reactor.
From Figure 8.4. it can be seen that, starting from day 210 the system can produce up to 7-8 l/hr or 168-192 l/day of biogas, which corresponds to 131-150 CH_4/day (CH_4-content of the biogas 76 %). Assuming an actual specific methanogenic actvivity of 0.02 kg COD/kg VSS.day in the case

of the Cimindi sludge, this means that the quantity of sludge-VSS should amount to approximately 10 kg VSS around day 210, or appr. 18.5 kg sludge TSS. Compared to the data shown in Fig. 8.12 this figure corresponds reasonably well. Due to the rather low specific activity of the sludge present in the Cimindi reactor, the loading potentials of the system around day 210, when approximately 185 liter of the reactor space has filled up with sludge (at an average sludge-TSS concentration of 100 kg $/m^3$), is only about 0.23 kg COD/m^3.day. In fact this is far too low, because the imposed average daily load is 0.55 . 1.36 = 0.75 kg COD/day (or 0.87 kg COD/m^3.day). It is obvious that the situation is even definetely worse in the preceeding period. This is also very well reflected in the results of the gas production measurements (compare Fig. 8.4). However, considering the effluent COD data (Fig. 8.5) over the whole experimental period, it can be seen that the system - despite the absence of sufficient activity - performs fairly satisfactory during the period 100 - 200; as a matter of fact there don't exist very significant differences with later periods. This certainly is an important observation, because it means that the system performs well under conditions of relatively low sludge hold-up, and consequently can be also applied under such conditions. This satisfactory performance apparantly must be attributed to a considerable extent to

1. the efficient removal of insoluble matter,
2. the fact that the major fraction of pollutants is present in insoluble form,
3. the rate of liquefaction (and/or hydrolysis) of the insoluble matter is slow (compare the results in Chapter 6 !)

From the above discussions it can concluded that the minimum amount of (seed) sludge required for a proper operation (e.g. secondary start-up) of the system only amounts to approximately 8 - 10 % of the reactor volume, both for black water and combined black + grey water treatment.

As mentioned before it is extremely difficult to get reliable and consistent information about the influent characteristics for on site treatment systems. Despite this rather big uncertainity in the reliability of the influent-COD measurements, COD-balances have been made for both reactors over a considerable part of the experimental periods (See paragraphs 7.3.2 and 8.3.2). From these balances the total excess sludge production factor (i.e. including all the sludge TSS in the balance) can be calculated. Using the data in Table 7.10 for the Biofarma reactor, an excess sludge production factor of 0.198 kg sludge-COD/ kg COD-removed or 0.17 kg sludge TSS/ kg COD-removed is obtained. Compared to the sludge accumulation factor calculated from the faeces digestion experiments (Table 7.11), where they were expressed in g sludge-VSS/ g COD-influent (which corresponds to approximately 1.25 g sludge-TSS/ g COD-removed), about half as high sludge accumulation factors are found. However, considering the fact that a 10 % higher influent value would result in a 50 % increase of the sludge accumulation factor, we can conclude that the values found for the influent-COD,

although presumably 10 - 15 % too low, indeed are fairly reliable.
In the same way the sludge accumulation factor can be calculated from the COD-balance made for the Cimindi reactor, viz. the data in Table 8.8. The value found amounts to 0.55 kg sludge-COD/ kg COD-removed, which corresponds to 0.70 kg TSS/kg COD-removed. These values are clearly much too high, which presumably mainly should be attributed to too high influent-COD values, but also to the fact that dissolved CH_4-COD was not accounted for in the balance. It will be attempted to get more reliable information in the near future.

Although a considerable amount of very useful information has been obtained from these investigations, it is clear that in certain aspects additional research is required in order to come to more optimal design and construction criteria for the system. Particularly in the case of the treatment of combined black + grey water concerned too little information is available yet.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Considering the results obtained in these investigations so far, it can be concluded that:

1. A modified UASB-septic system represents an quite effective on-site treatment system for black water, because:

   - 89 - 93 % of COD-total, 69 -81 % of COD-filtered and up to 97 % of the TSS can be removed from the waste water.
   - a satisfactory sludge stabilization can be achieved.
   - the excess sludge production for 9 people amounts to 0.043 kg TSS/day or 0.7 liter/day.
   - by installing a reactor of 1.2 m^3 for 10 people, using 10 % of the reactor space for seed sludge and allowing the system to fill up with sludge to 90 % of the reactor volume, only once every 3.5 year sludge needs to be discharged from the system.
   - the process is quite stable, i.e. the risks for acidification of the reactor contents are extremely small, first of all because of the relatively high natural buffer capacity of the waste water, secondly because of the slow arte of hydrolysis of the complex organic pollutants. Moreover sufficient over-capacity in terms of methanogenic activity will be avaible in the system once more than aproximately 20 % of the reactor volume has filled up with sludge.

On the other hand it should be emphasized that the effluent from the reactor is still quite hazardous, particularly because the pathogen removal is poor.

2. The modified UASB-septic tank system performs also fairly satisfactory on combined black + grey water, i.e. under the conditions applied (HRT : appr. 36 hr, COD load: appr. 1.0 kg COD/m^3.day) up to 70-75 % of COD-total, 43-47 % of COD-filtered and over 80 % of TSS is eliminated from the waste water. Although the experiments are still in progress, tentatively it can be concluded that for practice a reactor volume of 1.5 m^3 for 10 people will suffice. The excess sludge production on combined black + grey water in terms of TSS is roughly twice as high (viz. 0.081 kg TSS/day for 10 people) as compared to black water. However, as the sludge is more concentrated in former case (viz. over 100 kg TSS/m^3 !), the filling up time will be still approximately 4 years. Important is also the observation, that the system performs fairly satisfactorily in terms of treatment eficiency and process-stability under conditions of relatively high sludge over-loading, i.e. when less than 15 % of the reactor volume is filled up with sludge.

3. Relatively reliable data have been obtained concerning the COD-pollution of black water, viz.

COD-total	5.5 g/l
COD-filtered	1.5 g/l
COD-SS	4,0 g/l

With respect to most of the other parameters additional information should be obtained. This particularly is also the case for combined black + grey water . The COD-values found for combined black + grey water (appr. 1550 mg/l) presumably are 15 - 20 % too high.

4. Laboratory digestion experiments with faeces samples show that over 50 % of the faeces-COD will be converted into methane-COD, when sufficiently long digestion periods are maintained. This is confirmed by the results obtained in the reactors treating black and combined black + grey water.

5. In terms of specific activity, but particularly also in terms of thickening characteristics, a sludge of satisfactory quality develops on black water. As far as the thickening characteristics concerned this is also the case for the sludge developing on combined black + grey water. However the specific activity of the sludge from combined black + grey water is relatively low.

Recommendations

Regarding the very significant advantages, which on-site sanitation systems in many circumstances will offer over off-site sanitation systems, and considering the promising results obtained sofar in these investigations with the modified UASB-septic tank system, it is essential to acquire additional information in order to come to a proper design, implementation and operation of low cost and technically simple reactor systems for black and/or for black + grey water treatment. The reactor system can and therefore should be technically simplified (e.g. removing baffles if not essential). On the other hand recent investigations performed at the Agricultural University clearly indicate that the performance of the system in terms of treatment efficiency can be improved significantly by relatively simple means. In this connection it looks interesting to investigate a two compartment reactor design, the first compartment consisting of a UASB-type of module, and the second (polishing) of either a UASB or an upflow or downflow anaerobic filter.

These systems particularly could represent a very promising proposition for Community on Site Sanitation Systems. As from experiments with domestic sewage conducted elsewhere, it is already known, that reactors much bigger than those used in the present study perform quite satisfactorily, it looks highly recommendable to start investigations in the near future in Indonesia in the field of Community On-Site Sanitation, aiming to investigate and demonstrate the feasibility of these reactors in combination with adequate low cost on-site sewer systems. For the same reasons as the conventional on-site sanitation systems, **community on site sanitation systems** in many cases may represent a far more attractive solution for protecting the environment from pollution with domestic wastes than off-site sanitation systems.

As in many cases post-treatment will be required for eliminating remaining pollutants, particularly pathogens, it is also highly recommendable to initiate investigations concerning the development of proper low cost post treatment systems, e.g. like plain sedimentation, lagooning, gravel filtration and fish ponds.

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APPENDIX 1

ANALYSES FOR INFLUENT AND EFFLUENT SAMPLES

TOTAL COD; FILTRATED COD: according to N.E.N.
BOD: according to N.E.N.
TOTAL- AND ORTHO-PHOSPHATE: according to N.E.N.
AMMONIA-NITROGEN: according to N.E.N.
TSS AND ASH CONTENT: according to N.E.N.
VOLATILE FATTY ACIDS AND ALKALINITY: according to method v.d. Laan and Hobma (1978)
KJELDAHL-NITROGEN: according to method v.d. Putte (Lembaga Ekologi)

Method: V ml sample in a destruction-receiver; add 300 mg Na_2SO_4, 2 ml sat. H_2SO_4 and 6 ml $CuSO_4$ (10%).
Destruate for 20 - 24 hours until a clear or grey solution, otherwise add a few drops of H_2O_2 (10%).
Let the content of the receivers cool down and afterwards transfer it for destillation (adding 10 ml NaOH, 10N)
The destillate is received in an erlenmeyer flask which contains already a ml Na-boraat and 2 ml indicator.
After the indicator turns blue, destillation must go on for another 10 minutes. Titrate back with 0.1 N HCl until the blue colour has disappeared again.

Calculation:
$$Ntot = \frac{(A-B)*N*14*1000}{V} \quad (mg/L)$$

A = ml HCl used for sample
B = ml HCl used for blanco
N = normality HCl = ca. 0.1
V = volume sample

APPENDIX 2

CONVERSION FROM AMOUNT OF GAS TO COD-CONTENT

-Oxidation of methane:

$CH_4 + 2\ O_2 \longrightarrow CO_2 + 2\ H_2O$
16 grams CH_4 + 64 grams O_2 $\longrightarrow$ 1 gram CH_4 = 4 grams COD

According to Gaslaw 1 mole of gas under standard conditions equals 22.4 liters of gas (273 ^oK; 1 Atm.).
Therefore 1 liter CH_4 = 16/22.4 gram CH_4
= 64/22.4 gram CH_4-COD
= 2.857 gram CH_4-COD (T=273 ^oK;1 atm.)

This factor has to be corrected for:

-temperature: $T_{stand.}(^oK)\ /\ T_{stand.}(^oK) = 273/295 = \mathbf{0.916}$

-water-vapour: $\dfrac{760 - P(H_2O)_{exp.}}{760} \dfrac{(mm\ Hg)}{(mm\ Hg)} = \dfrac{760 - 23.75}{760} =$

0.968

-height: $\dfrac{P}{P_o} = e^{-gMh/RT} = e^{-9.81*26.3*10^3*750/8.314*298}$

$= e^{-0.0781}$
$= \mathbf{0.925}$

This yields:
1 liter CH_4 = 2.857 * 0.916 * 0.968 * 0.925
= 2.343 gram CH_4-COD

APPENDIX 3

ANALYSIS OF SLUDGE AND FAECES

TSS: A known amount of sludge (ca. 40 ml) or faeces (5-10 g) is dried at 95 °C for 48 hours; cooled down in an exsiccator and weighed. The TSS content can then be calculated.

The dried sludge or faeces is then ground in a mortar; dried at 95 °C and used for further analysis.

Ash content: A known amount (ca. 0.5 gr.) of dried and ground sludge or faeces is put above a fire for 2 to 3 hours until the product has a lightgrey colour.
After cooling down in an exsiccator and weighing the product, the ash content and VSS content can be calculated.

COD: A known amount of dried and ground sludge or faeces (ca. 10-13 mg) is put into a COD-receiver and analyzed according to N.E.N.-standards.

N-Kjeldahl: A known amount of dried and ground sludge or faeces is analyzed according to v.d. Putte (Appendix 1).

An extra parameter for sludge only:

Sludge Volume Index: The sludge sample is diluted with tapwater up to a concentration of ca. 10 g TSS/liter. 1 liter of this mixture is poured into a cylinder; after 30 minutes the volume of the sludge is measured.

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APPENDIX 4

MOST PROBABLE NUMBER TEST AND STOLL'S METHOD

Most Probable Number (M.P.N.)-test (According to Standard Methods).

A series of dilutions was made from the original sample (1 ml sample is diluted with 9 ml demi water, 1 ml of this dilution is again diluted with 9 ml etc. etc.)
This series is examined in three steps:
the presumptive test: Each dilution (in threefold) is incubated for 48 hours on lactose at 35 °C. Gas production and cloudy medium ar interpretated as a positive test. No gas production indicates no coliform organisms present.
confirmed test: The positive tubes of the presumptive test are incubated for 48 hours at 35 °C on brilliant green lactose bile broth. Gas production is a positive sign and confirms the result of the presumptive test: coliform organisms are present.
completed test: This part is only necessary if drinking water is concerned and was omitted in this experiment.

To asses the amount of faecal coliforms, the positive tubes of the presumptive test are incubated for 24 hours at 44.5 °C on an E.C.-media. Gas production is a positive indication.

Stolls's Method (According to Lewis et al, 1977).

Influent: Take 30 ml sample and put it in a stoppered bottle. Add 15 ml NaOH, to ensure that all eggs are free from covering organic material. From this mixture 0.15 ml sample is examined under a microscope. The whole 0.15 ml is examined on the slide at a magnitution of 100x.

Effluent: The effluent samples were not treated; 1 ml sample was examined under the microscope.

Sludge: Take 3 ml sample; 21 ml aqua dest. and add 21 ml NaOH (10 N). From this mixture 0.15 ml is examined as influent.

Faeces: Take 3 g faeces and shake it with 42 ml NaOH (10 N). Onwards the same procedure as influent.

APPENDIX 5

CONVERSION FAKTOR FOR COD OF VOLATILE FATTY ACIDS

- Acetate: $CH_3COOH + 2\ O_2 \longrightarrow 2\ CO_2 + 2\ H_2O$

  64 gr. O_2 / mole HAc = 1.066 g COD / gr HAc

- Propionate: $CH_3CH_2COOH + 3\frac{1}{2}\ O_2 \longrightarrow 3\ CO_2 + 3\ H_2O$

  112 gr. O_2 / mole HProp. = 1.5135 gr COD / HProp.

- Butyrate: $CH_3CH_2CH_2COOH + 5\ O_2 \longrightarrow 4\ CO_2 + 4\ H_2O$

  160 gr. O_2 / mole HBut. = 1.8181 gr COD / HBut.

For a VFA-mixture containing equivalent weight-amounts of C_2, C_3 and C_4 can be calculated:
4.3982 gr COD / gr VFA mixture
(1 gram VFA mixture = 1 gram C_2 + 1 gram C_3 + 1 gram C_4)

For 1 meq total VFA, as mentioned in the VFA-titration method, a COD content of appr. 110 mg VFA-COD can be calculated.

APPENDIX 6: SLUDGE PROFILES AT LOCATION BIOFARMA

	TAP no	CODt (mg/L)	CODf (mg/L)	CODss (mg/L)	BOD (mg/L)	PH	ALKALI (meq/L)	VFA (meq/L)	Ntot (mg/L)	NH4 (mg/L)	Ptot (mg/L)	o-P (mg/L)	T (oC)	TSS (mg/L)	ASH (%TSS)	SVI (ml/g)	COD (mg/ gTSS)
	1					7.29								45554	27.6	20.76	853
date	2	1559	547	1012	356	7.24	14.6	1.3	449	392	62	51		846	21.1		
61185	3					7.33								833	21.0		
day 44	4	2286	542	1744	447	7.26	15.6	0.9	405	413	64	53		1214	22.0		
	5	593	538	55	199	7.54	15.9	0.9	513	413	58	52		59	14.4		
	6					7.24								73	16.1		
	1					7.13							23.7	55492	22.2	19.25	1242
date	2		492			7.22	16.7	2.6		424		50	23.9	4502	24.5		1076
41285	3	517	509	8	197	7.20	16.7	2.4		397	56	50	24.2	109	10.0		
day 72	4	629	483	146	200	7.17	17	2.6		392	57	49	24.2	102	26.5		
	5	577	451	126	181	7.11	18.2	2.9		498	54	49	24.4	57	30.0		
	6	485	324	161		7.01	16.9	2.4		413	62	49	24.6	80	19.9		
	1					7.05							22.2	52122	20.2	20.00	979
date	2	3282	562	2720		7.15	17.2	3.1		466	74	56	22.1	1406	18.8		
110186	3	967	519	448	295	7.15	20.3	5.1		477	64	60	23.1	207	17.7		
day 110	4	858	530	328		7.12	18.4	3.4		455	68	58	23.2	240	15.2		
	5	662	485	177	216	7.08	24.2	4.8		498	64	57	23.4	88			
	6	557	478	79		7.12	23.9	4.9		477	66	56	24.3	81	20.6		
	1					7.37							22.7	49191	20.2	20.83	1220
date	2					7.37							22.7	13245	17.5	21.95	1386
120286	3	870	448	422	292	7.40	20.1	1.3		628	52	26	22.8	217	13.0		
day 142	4	779	649	130		7.36	19.9	1.3		587	52	25	22.9	97	40.0		
	5	708	614	94	231	7.36	19.1	1.3		555	45	23	23.0	51	32.0		
	6	701	614	87		7.33	19.4	1.3		545	42	21	23.1	56	40.0		
	1					7.21							23.4				1092
date	2					7.20							23.4				946
130386	3	960	605	355	199	7.16	16.9	1.9	532	400	62	50	23.4	207	11.0		
day 171	4	927	609	318		7.17	15.9	2.8	534	472	60	52	23.4	168	13.0		
	5	742	601	141	153	7.15	14	2.4	514	477	60	54	23.4	63	3.0		
	6	867	518	349		7.16	16.5	2.9	550	483	62	54	23.4	193	7.0		
	1					7.23							22.6	28003	17.0	31.50	1263
date	2					7.23							22.5	50327	15.0		1210
80486	3	1220	483	737	303	7.37	22.8	2.1	567	514	73	36	23.1	447	12.0		
day 197	4	1035	595	440		7.35	20.4	2.6	553	519	45	33	23.4	305	15.0		
	5	865	584	281	210	7.25	23.2	3.1	541	597	47	32	23.5	183	11.0		
	6	1072	577	495		7.14	21.4	1.8	552	555	46	37	24.1	313	11.0		
	1					7.22							23.5	58367	15.3	20.80	1231
date	2					7.18							23.5	66892	15.3	19.00	1244
60586	3	2809	517	2292	471	7.32	17.6	0.8	586	454	71	52	23.7	1858	12.0		
day 225	4	3966	417	3549		7.31	16.4	1.9	562	439	69	45	23.8	2373	13.0		
	5	1532	556	976	344	7.26	13.9	1.1	482	457	67	44	23.9	565	7.0		
	6	2869	490	2379		7.14	15.7	1.6	510	431	73	60	23.9	1431	11.0		
	1					6.87							22.6	45600	17.0	17.50	902
date	2					6.97							22.7	63700	16.0	15.70	1078
20786	3	3246	369	2877	455	6.89	17.9	2.6	647	330	46	41	22.5	2350	14.0		
day 282	4	1604	358	1246		6.89	18.4	2.1	370	281	43	41	22.3	726	16.0		
	5	1044	366	678	203	6.86	19.2	2.4		363	43	43	22.4	372	16.0		
	6	515	390	125		6.86	18.9	2.9		341	43	43	23.3	140	12.0		

APPENDIX 6: SLUDGE PROFILES AT LOCATION BIOFARMA

	TAP no	CODt (mg/L)	CODf (mg/L)	CODss (mg/L)	BOD (mg/L)	PH	ALKALI (meq/L)	VFA (meq/L)	Ntot (mg/L)	NH4 (mg/L)	Ptot (mg/L)	o-P (mg/L)	T (oC)	TSS (mg/L)	ASH (%TSS)	SVI (ml/g)	COD (mg/gTSS)
	1					6.79							22.2	51327	15.6		1369
date	2					6.81							22.5	32974	15.5		1379
80886	3					6.80							22.5	45558	15.7		1365
day 319	4	2142	429	1713	382	6.88	26.5	0	356	231			22.5	896	16.0		
	5	895	352	543	204	6.81	25.3	0.3	330	239			22.5	482	16.0		
	6	550	348	202	206	6.81	25.7	0	321	231			22.9	154	17.0		
	1					6.75							23.1	58821	17.0		1148
date	2					7.10							23.2	54146	16.0		1218
10986	3					6.90							23.2	49948	16.0		1132
day 343	4	1147	498	649	219	6.92	33.2	0.4	494	333			23.1	434	37.0		
	5	913	328	585	195	6.90	33.6	0	423	319			23.0	155	61.0		
	6	1275	343	932	333	6.83	32.2	0	401	362			23.5	1046	20.0		
	1					7.18							23.6	63545	16.0		1290
date	2					7.12							24.0	53957	16.0		1187
290986	3					7.13							24.2	45056	17.0		1175
day 371	4					7.13	30.7	1.7		246			24.0	30209	17.0		1294
	5	1378	466	912	389	7.13	33.7	0.9	413	282			24.0	612	10.0		
	6	917	485	432		7.02	32.7	1.2	357	282			24.5	1323	12.0		
	1					7.04							23.0	54210	17.0		1351
date	2					6.93							23.2	61660	17.0		1311
101186	3					7.02							23.0	48230	17.0		1311
day 413	4	1085	450	635		7.41	35.7	1.7	889	290			23.0	9919	18.0		
	5	612	364	448		7.00	35.2	0.2	496	275			23.1	144	22.0		
	6	6201	422	5779	463	7.00	35.2	1.2	510	246			24.0	540	13.0		
	1					6.97							23.0	67229	17.0		1849
date	2					6.99							23.0	57136	16.0		1193
151286	3					7.09							24.0	50326	17.0		1384
day 448	4					7.18	43.6	0.1		435	53		23.5	31461	16.0		1342
	5	947	435	512	236	6.99	44.1	1.6	550	428	102	82	24.0	354	16.0		
	6								516	377	89	59					
	1					6.93							24.0	65257	16.9		1522
date	2					7.03							23.0	41365	16.0		1680
180287	3					6.94							23.5	51928	16.0	21.00	1545
day 513	4					6.91							23.5	27536	16.0	43 00	1128
	5				61	6.93	36.2	1.2		401			23.5	84	40.0		
	6	2400	328	2072		6.92	37.2	1.7		296			23.0	803	14.0		
	1					7.10								60413	12 8	18.87	1180
date	2					6.92								52832	14.6	23.80	1246
110587	3					6.95								68176	14.7	24.57	1216
day 596	4					6.95								38500	14.9	27 53	1070
	5	984	296	688	166	7.11	18.8	0		443				175	3.9		
	6	656	288	368	154	6.83	21.2	0		421				76	4.3		
	1					7.03								72332	15.0		
date	2					6.83								58181	15.0		
100787	3					6.86								55313	13.0		
day 656	4					6.87								59754	14.0		
	5	619	159	460	78	7.02	27.8	2						134	6.0		
	6	524	163	361	146	6.80	26.3	1.5									

APPENDIX 6: SLUDGE PROFILES AT LOCATION BIOFARMA

	TAP no	CODt (mg/L)	CODf (mg/L)	CODss (mg/L)	BOD (mg/L)	PH	ALKALI (meq/L)	VFA (meq/L)	Ntot (mg/L)	NH4 (mg/L)	Ptot (mg/L)	o-P (mg/L)	T (oC)	TSS (mg/L)	ASH (%TSS)	SVI (ml/g)	COD (mg/gTSS)
	1					7.03								72332	15.0		
date	2					6.83								58181	15.0		
100787	3					6.86								55313	13.0		
day 656	4					6.87								59754	14.0		
	5	619	159	460	78	7.02	27.8	2						134	6.0		
	6	524	163	361	146	6.80	26.3	1.5									
	1					6.85								51560	16.0		
date	2					6.70								43770	15.0		
90987	3					6.79								73300	15.0		
day 717	4					6.86								27630	13.0		
	5	1079	187	892	186	7.01	22.3	1.3	423	285	44	36		275	4.0		
	6	503	190	313	175	6.93	21.8	0.2	297	226	42	40		121	7.0		
	1					6.94								72530	17.1	17.37	1021
date	2					6.82								47482	14.5	21.98	1100
181187	3					6.96								56616	14.8	21.19	1285
day 787	4					6.91								58714	15	18.39	1071
	5	1005			316	7.23	25.5	1.3	469	309	42	38		1192	14.3		
	6	466	185	281	79	7.11	24.8	0.8	472	314	49	36		77	9.7		
	1					6.91								62740	16.6		1280
date	2					6.99								38400	19.4		
010288	3					6.97								36400	16.5		
day 862	4					6.87								59900	17.9		1388
	5	1216	423	793	210	7.49	39.9	17.7	425	390	64	49		176	18.2		
	6	414	323	91	17	7.75	37	10.1	456	367	71	52		25	12.1		

APPENDIX 7: COD BALANCE OVER THE BIOFARMA REACTOR

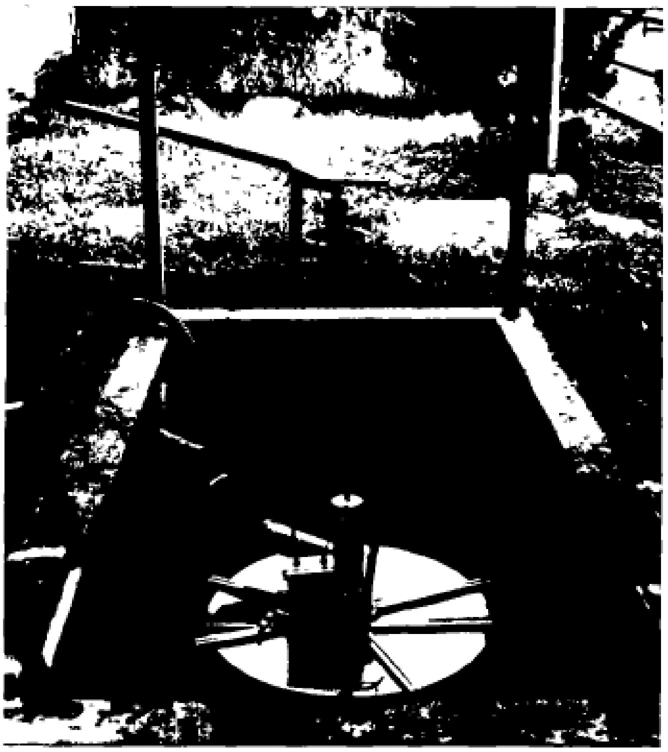
MONTH	YEAR	no	gram COD Influent (a)	gram CODf Effluent (b)	gram COD Removed (1)	gram COD Gasproduction	gram COD Production (2)	gram COD Sludge-wash out (3)	gram COD Sludge-accumulation(4)	gr.sludge-VSS/ gr.COD-infl.
October	1985	1	7905	841(11%)	7064	-	7064(*)	470	6594	-
November	1985	2	7650	660(9%)	6990	-	6690(*)	241	6749	-
December	1985	3	7905	782(10%)	7123	4583(58%)	2540(36%)	434	2106	0.22
January	1986	4	7905	693(9%)	7212	5777(73%)	1435(20%)	270	1165	0.13
February	1986	5	7140	779(11%)	6361	5714(80%)	647(10%)	100	547	0.06
March	1986	6	7905	872(11%)	7033	5915(75%)	1118(16%)	83	1035	0.1
April	1986	7	7650	816(11%)	6834	5946(78%)	888(13%)	110	778	0.08
May	1986	8	7905	810(10%)	7095	5605(71%)	1490(21%)	114	1376	0.13
June	1986	9	7650	684(9%)	6966	6435(84%)	531(8%)	80	451	0.05
July	1986	10	7905	606(8%)	7299	7434(94%)	-135(-2%)	61	-196	-
August	1986	11	7905	462(6%)	7443	5536(70%)	1907(26%)	83	1824	0.17
September	1986	12	7650	733(10%)	6917	4610(60%)	2307(33%)	99	2208	0.21
October	1986	13	7905	554(7%)	7351	4395(56%)	2956(40%)	87	1869	0.26
November	1986	14	7650	612(8%)	7038	4994(65%)	2044(29%)	87	1957	0.18
December	1986	15	7905	647(8%)	7258	6051(77%)	1207(17%)	206	1001	0.11
January	1987	16	7905	722(10%)	7133	6991(88%)	142(2%)	192	-50	0.01
February	1987	17	7140	624(9%)	6516	6837(96%)	-321(-5%)	76	-397	-
March	1987	18	7905	710(9%)	7195	6005(76%)	1190(17%)	159	1031	0.1
April	1987	19	7650	542(7%)	7108	4491(59%)	2617(37%)	312	2305	0.24
May	1987	20	7905	455(6%)	7450	4523(57%)	2927(39%)	187	2740	0.26
June	1987	21	7650	340(4%)	7310	6517(85%)	793(11%)	156	637	0.07
July	1987	22	7905	324(4%)	7581	6103(77%)	1478(20%)	403	1075	0.13
August	1987	23	7905	317(4%)	7588	4412(56%)	3176(42%)	138	3038	0.28
September	1987	24	7650	353(5%)	7297	4983(65%)	2314(32%)	207	2107	0.21
October	1987	25	7905	503(6%)	7402	4884(62%)	2518(34%)	253	2265	0.22

APPENDIX 8: SLUDGE PROFILES AT LOCATION CIMINDI

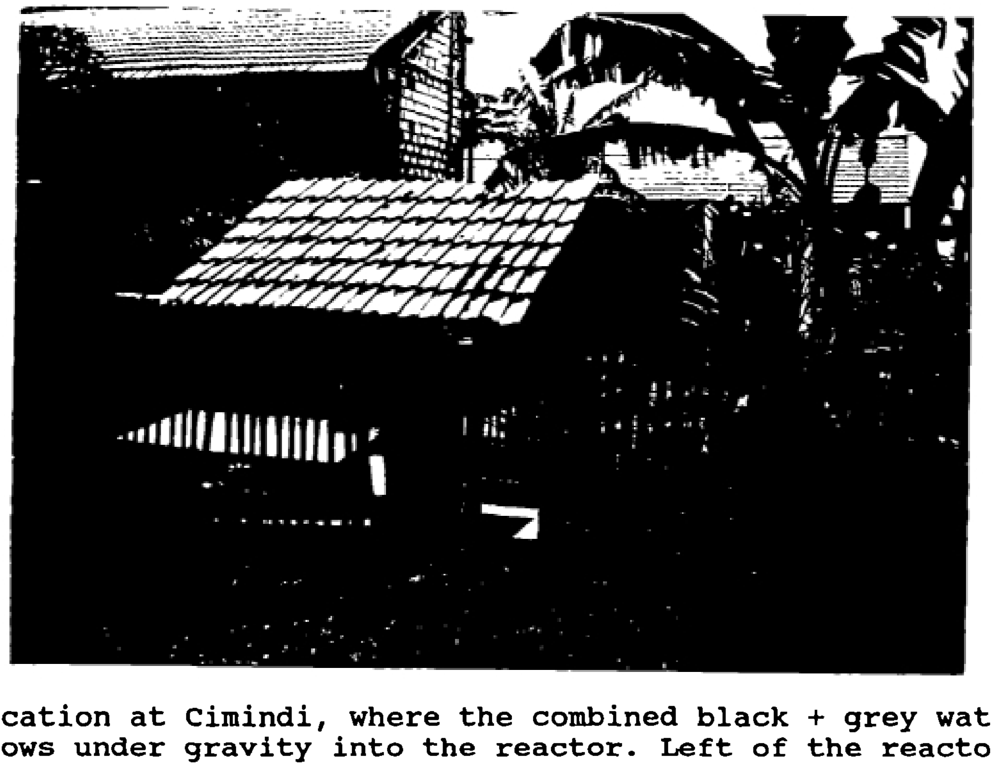
	TAP no	CODt (mg/L)	CODf (mg/L)	CODss (mg/L)	BOD (mg/L)	PH	ALKALI (meq/L)	VFA (meq/L)	Ntot (mg/L)	NH4 (mg/L)	Ptot (mg/L)	o-P (mg/L)	TSS (mg/L)	VSS (mg/L)	ASH (%TSS)	SVI (ml/g)	COD (mg/gTSS)
	1					6.64							96143	53840	44	13.9	637
date	2					6.71							77088	37002	52	13.0	606
040487	3	950	374	576		7.05	7.66	0.00		90			769	338	56		
day 165	4	781	382	399		6.85	7.92	0.68		99			980	588	40		
	5	4334	418	3916		6.81	10.18	0.91		110			7836	4153	47		
	6	603	386	217		6.95	8.96	1.18		90			225	142	37		
	1					6.73							60063	48050	20	19.3	1028
date	2					6.76							68712	54969	20	14.0	1197
150687	3	592	192	400		6.87	8.38	0.00	219	108	26	16	120	112	7		
day 237	4	432	160	272		6.94	8.85	0.00	178	110	28	22	307	197	36		
	5	976	272	704		6.84	9.83	0.00	225	107	33	26	373				
	6	536	244	292		6.83	7.40	0.00	147	106	27	18	41				
	1					6.90							107200	57888	46	12.5	820
date	2					6.92							98930	51443	48	12.5	814
240887	3	4515	202	4313	560	7.25	9.47	1.94	290	134	36	29	1182	721	39		
day 307	4	428	257	171	237	7.11	8.87	0.00	311	140	32	26	286	172	40		
	5	428	334	94	299	7.09	10.05	3.46	268	119	27	24	275	171	38		
	6	190	120	70	245	7.11	9.87	1.18	205	122	36	34	25	16	38		
	1					6.73							117530	68167	42	12.6	805
date	2					6.71							106900	58795	45	11.3	827
71087	3					6.81							57020	31931	44	10.6	943
day 351	4	1511	256	1255	111	7.05	9.79	0.00	242	151	29	25	225	131	42		
	5	1559	256	1303	113	6.98	10.00	1.34	225	139	31	24	302	187	38		
	6	512	256	256	87	7.02	10.33	0.00	235	160	31	26	93	58	38		
	1					6.7							100400	54718	45.5		861
date	2					6.7							182300	118313	35.1		619
141287	3					6.68							93900	56716	39.6		548
day 419	4	4031				7.07	15.13	6.97	287	100	36	31	3646	2144	41.2		
	5	948	277	671	139	7.18	17.67	8.48	282	99	34	29	266	419	36.5		
	6	593	288	305	148	6.97	19.1	6.67	284	99	35	29	77	65	15.5		
	1					6.75							126600	74694	41		914
date	2					6.68							115900	67222	42		844
250188	3					6.77							132200	835504	36.8		1112
day 461	4	947	115	832	140	7.04	16.04	5.69	267	110	41	27	572	199	41		947
	5	2293	150	2143	230	7.09	17.64	7.2	259	116	39	31	1515	967	36.2		
	6	477	192	285	81	7.14	16.61	6.96	265	104	39	28	120	82	31.8		
	1					6.67							114800	63829	44.4		917
date	2					6.66							117600	66326	43.6		768
220388	3					6.68							90570	57784	36.2		652
day 518	4					6.87							9920	5793	41.6		847
	5	716	126	590	104	6.85	17.83	1.18	322	117	33	16	312	206	34		
	6	420	143	277	116	6.74	8.92	0	298	122	32	17	23	16	31.5		

APPENDIX 9: COD BALANCE OVER THE CIMINDI REACTOR

MONTH	CODinfl	CODf(gr.)	%fil	J-F	CH4(g)	%gas	CODprod.	%CODprod.	CODss(g)	%CODss	Sl.acc.	Sl.VSS	g sl.VSS/ gCODinf
1	24013.53	6431.88	26.8	17581.65	27.19	0.1	17554.45	73.1	2173.41	9.1	15381.04	10970.78	0.46
2	24013.53	5465.47	22.8	18548.06	54.39	0.2	18493.67	77.0	3645.46	15.2	14848.21	10590.74	0.44
3	21689.64	4808.52	22.2	16881.12	12.28	0.1	16868.83	77.8	3996.84	18.4	12871.99	9181.168	0.42
4	24013.53	5754.53	24.0	18259	1672.42	7.0	16586.58	69.1	3465.28	14.4	13121.29	9358.985	0.39
5	23238.9	4883.76	21.0	18355.14	3898.80	16.8	14456.33	62.2	2563.29	11.0	11893.04	8482.916	0.37
6	24013.53	3747.81	15.6	20265.72	6099.57	25.4	14166.15	59.0	4194.86	17.5	9971.296	7112.194	0.30
7	23238.9	3588.15	15.4	19650.75	6737.04	29.0	12913.70	55.6	2827.20	12.2	10086.50	7194.369	0.31
8	24013.53	4277.61	17.8	19735.91	8134.34	33.9	11601.57	48.3	3180.60	13.2	8420.973	6006.400	0.25
9	24013.53	3687.73	15.4	20325.80	10547.11	43.9	9778.687	40.7	3555.20	14.8	6223.483	4439.003	0.18
10	23238.9	3630.46	15.6	19608.43	9961.92	42.9	9646.517	41.5	2972.77	12.8	6673.748	4760.163	0.20
11	24013.53	4944.07	20.6	19069.46	8192.13	34.1	10877.33	45.3	3488.06	14.5	7389.275	5270.524	0.22
12	23238.9	4965.58	21.4	18273.32	10212.86	43.9	8060.467	34.7	4007.98	17.2	4052.490	2890.506	0.12
13	24013.53	4694.92	19.6	19318.61	10393.47	43.3	8925.142	37.2	4254.94	17.7	4670.206	3331.103	0.14
14	24013.53	4332.10	18.0	19681.43	10239.60	42.6	9441.838	39.3	4744.40	19.8	4697.443	3350.529	0.14
15	22464.27	3708.23	16.5	18756.04	7224.78	32.2	11531.26	51.3	3016.73	13.4	8514.537	6073.136	0.27
16	24013.53	2501.29	10.4	21512.24	8215.55	34.2	13296.69	55.4	2721.18	11.3	10575.51	7543.163	0.31
17	23238.9	2613.86	11.2	20625.04	8592.36	37.0	12032.68	51.8	4480.20	19.3	7552.480	5386.933	0.23
Totals	400483.7	74035.94	18.5	326447.7	110215.8	27.5	216231.9	54.0	59288.38	14.8	156943.5	111942.6	0.28



- Location at the Bioforma-site. The reactor is placed in a pit beneath the shed.



- Location at Cimindi, where the combined black + grey water flows under gravity into the reactor. Left of the reactor the effluent collection tank.

- The 0.86 m^3 UASB-reactor.

- Central feed inlet pipe with attached baffles and gas-collector, which is placed in the reactor vessel.