MEMBRATEK (Pty) Ltd

Report to the

WATER RESEARCH COMMISSION

on

AN INVESTIGATION INTO THE APPLICATION OF THE ADUF PROCESS TO FRUIT PROCESSING EFFLUENT

by

N K H Strohwald

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EXECUTIVE SUMMARY

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PROJECT BACKGROUND

The disposal of fruit processing effluent has always been a cause of concern, both to industry and effluent management bodies, mainly due to its seasonal volumetric fluctuations and the high level of organic pollutants.

During the past four years one of the major fruit processors in Ceres has taken the initiative to treat factory effluent on site with UASB digesters. During the peak processing period, however, carry-over of sludge and digester overload are experienced due to the high volumetric throughput which needs to be maintained.

The ADUF process, employing ultrafiltration membranes to retain biomass, was seen as a possible solution to these problems. Since no previous operational experience with the ADUF process on fruit processing effluent was available, experimental work concerning the digestion of this effluent had to be performed.

PROJECT OBJECTIVES

The investigation into the application of the ADUF process to fruit processing effluent, on a laboratory scale, was carried out to determine the following:

i) biodegradability of the factory effluent by means of mesophilic anaerobic digestion;
ii) flux values for ultrafiltration at stabilised digester conditions;
iii) maximum digester load rate and limits of general operating parameters;
iv) quality of final treated effluent at stabilised digester conditions;
v) comparison of the ADUF process with that of the existing full scale UASB digesters in order to determine whether the addition of ultrafiltration units to these digesters would solve the operational problems experienced.

RESULTS AND CONCLUSIONS

COD reduction percentages of more than 95% could be obtained, with final treated effluent COD values as low as 50 mg/l, at a space load rate of not more than 1,5 $kgCOD.m^{-3}.d^{-1}$. Operation at higher space load rates resulted in the deterioration of the COD reduction potential with a sharp increase in COD levels of the ultrafiltration permeate and volatile acid/alkalinity ratio, both of which are indicative of imminent digester failure. Operation at space load rates of up to

3 $kgCOD.m^{-3}.d^{-1}$ was possible, albeit at lower COD reduction rates of 70-85%. It was therefore concluded that the effluent was readily biodegradable, although high load rates could not be obtained. The UASB digesters were also reported to be incapable of attaining higher load rates. The reasons for this were not clear, but nutrient and trace element deficiencies are not excluded.

The flux values of the ultrafiltration unit could be maintained at 20-25 $l.m^{-2}.h^{-1}$ and fouling was never serious enough to cause decreased throughput. Flux decline was experienced on two occasions and could be traced back to high MLSS concentration of the anaerobic sludge (due to microbe population growth) and low linear flow velocity across the membrane surface (because of worn-out UF pump components). Both factors are known for their detrimental effect on membrane flux.

As such the addition of an ultrafiltration unit to the UASB digesters would prevent the loss of biomass from these units by carry-over from the clarifier section.

PRESENT STATE OF THE ART

The project objectives were satisified in the sense that the biodegradability of the effluent by anaerobic digestion was established and that economical membrane flux could be maintained for the duration of the experiment without resorting to chemical cleaning. A negative aspect proved to be the low digester load rates which could be obtained. The experimental results presented in this project report should be seen as an initial phase in the optimisation of the ADUF process for this particular application. It is envisaged that a master plan be put into practice with regard to the co-ordination of all research work relating to further development of the ADUF process. The Water Research Commission is currently considering such a proposal.

RECOMMENDATIONS FOR FURTHER RESEARCH

With regard to the application of the ADUF process to fruit processing effluent in praticular, further work should be performed to investigate the need for mineral and trace elements additions to the digesters. This should enhance the anaerobic digestion rate and improve digester load rates to more economical levels.

AN INVESTIGATION INTO THE APPLICATION OF THE ADUF PROCESS TO FRUIT PROCESSING EFFLUENT

by

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CONTRACT REPORT TO THE

WATER RESEARCH COMMISSION

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ABSTRACT

The use of the ADUF (Anaerobic Digestion - Ultrafiltration) process was investigated for the treatment of fruit processing effluent. Performance data from a laboratory-scale digester and ultrafiltration unit was collected over a test period of 121 days of continuous operation. A mean space load rate of 1,46 $kgCOD.m^{-3}.d^{-1}$ could be obtained at COD reduction rates in excess of 96% and a mean hydraulic retention time of 2,3 days. Ultrafiltration flux could be maintained at an average value of 14,8 LMH without the need for chemical cleaning.

ACKNOWLEDGEMENTS

The research results presented in this report emanated from a project funded by the Water Research Commission, entitled:

An investigation into the application of the ADUF process to fruit processing effluent

The financing of the project by the Water Research Commission and the co-operation of Ceres Fruit Growers (Pty) Ltd is gratefulle acknowledged.

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CFG	Ceres Fruit Growers
CIP	Cleaning in place
COD	Chemical oxygen demand
HCl	Hydrochloric acid
HRT	Hydraulic retention time
MEMTUF	Trade name for low-cost UF system
MLSS	Mixed liqour suspended solids
MMCO	Molecular mass cut-off
NaOH	Caustic soda
SCFA	Short chain fatty acid
SLR	Space load rate
TA	Total alkalinity
UASB	Upflow anaerobic sludge bed
UF	Ultrafiltration
VFA	Volatile fatty acids

1. INTRODUCTION

The disposal of factory effluent from the fruit processing industry has always been a cause of some concern to both fruit processors and controlling bodies responsible for effluent management. Traditionally the factory effluent is collected in ponds, some of which are designed to provide anaerobic action for the decomposition of organics. This practice often causes pollution of nearby rivers, especially in winter when the evaporation rate is reduced and overflow from the ponds may occur due to rain. Direct disposal of the effluent to the local sewerage works is often undesirable. These works are often not designed to treat the high seasonal volumetric flows and organic loads of such effluents, resulting in overloading and improper purification.

Realising the undesirability of this situation, Ceres Fruit Growers (CFG) has, during the past four years, taken the initiative to treat factory effluent on site. The fact that the effluent contains mainly carbohydrates should make it an ideal candidate for biodegradation. As a result CFG has operated three UASB digesters, each of 175 m^3 capacity, in conjunction with a 30 000 m^3 balancing pond since 1988 *(Ross, 1989)*. Temperature and pH control were added at a later stage in oder to improve digester control and load rates. Since the factory effluent flow varies between about 430 m^3/d and 120 m^3/d, in accordance with the fruit processing season, carry-over of sludge in the clarifier section of the digesters has been problematic *(Broodryk, 1991)*. As a result digester overloads were experienced at times when high load rates were desired during the peak processing period when the average COD content of the effluent may reach 5 000 mg/l.

The need for effective effluent treatment in the fruit and vegetable industry was highlighted in WRC project no. 96 *(Binnie & Partners, 1987)*. This report identified several treatment processes and methods, including membrane separation processes, for the treatment of effluent and the reuse of water. Unfortunately the way in which these processes should be applied, was not addressed.

Traditional treatment methods are mainly concerned with the disposal of effluent, with the elimination of pollutants being of secondary concern. The ADUF process was viewed as providing a possible solution for the treatment of fruit processing effluent. This process has been developed for the treatment of organic waste streams and found to be efficient for a variety of effluents, ranging from proteinaceous to carbohydrate substrates. Unfortunately no previous experience regarding the treatment of fruit processing effluent had been established.

The ADUF process employs ultrafiltration membranes as a means of phase separation for the reclamation of all biomass, which is recycled to the digester. The natural conclusion, therefore, was that the addition of an ultrafiltration unit to the existing UASB digesters would solve some of the operational problems that had been experienced in the past. This was to be investigated with the aid of a laboratory scale ADUF unit.

2. OBJECTIVES

The investigation into the application of the ADUF process to CFG factory effluent, on a laboratory scale, was carried out to determine the following:

i) biodegradability of the factory effluent by means of mesophilic anaerobic digestion;
ii) flux values for ultrafiltration at stabilised digester conditions;
iii) maximum digester load rate and limits of general operating parameters;
iv) quality of final treated effluent at stabilised digester conditions;
v) comparison of the ADUF process with that of the existing full scale UASB digesters in order to determine whether the addition of ultrafiltration units to these digesters would solve the operational problems experienced.

3. MATERIALS AND METHODS

Experimental work was mainly concerned with the gathering of operational data for process optimisation. Efforts were made to note the effect of nutrient addition in instances where there was thought to be a deficiency. Initially, effluent samples from the balancing pond, and subsequently, contrashear water (fresh factory effluent after screening) were collected twice weekly in 200-400 l batches. The effluent samples were settled and screened to 200 μm before use in the experimental digester.

3.1 EXPERIMENTAL APPARATUS

Anaerobic digestion was carried out in a polyethylene reactor of 100 l capacity, having an active sludge volume of 50 l. The initial MLSS concentration was approximately 23 g/l. Sludge circulation was achieved by means of a positive, screw-type pump which was fitted with appropriate pulley sets for the variation of delivery rate. A schematic diagram of the laboratory scale reactor system is given in Figure 3.1.

Biomass separation was effected with a MEMTUF ultrafiltration unit of 0,44 m^2 membrane area (2x20 tube configuration), fitted with polyethersulphone membranes of 40 000 MMCO. The ultrafiltration permeate was recycled to the digester in order to maintain a constant level inside the digester. A float operated return valve and gooseneck combination served to direct excess permeate to drain while maintaining a gas seal. Biogas was collected at the top of the reactor and the wet gas flowrate was totalised with the aid of a mechanical gas meter. The concentrated biomass was returned to the digester after passing through a heat exchanger. Temperature control was obtained with a digital temperature indicator/controller acting on the heating element inside the hot water tank which contained the sludge return heat exchanger. Fruit processing effluent was dosed into the sludge return line, from a 200 l polyethylene feed buffer tank, by means of an adjustable dosing pump.

3.2 SAMPLE ANALYSES

Collection of operating data and chemical sample analyses were performed daily, except on weekends. Conductivity and pH recordings were made by standard potentiometric measurements. COD was assayed photometrically after reaction with sulphuric potassium dichromate and silver sulphate (Dr. Lange Lasa Aqua, cuvette tests LCK 014, 114, 314). VFA were determined by titration against standardised NaOH to the phenolphtalein end-point, after steam distillation of the sample with magnesium sulphate and sodium tungstate, in accordance with Ross *(1990)*. Similarly, TA was determined titrimetrically against standardised HCl, using methyl orange as indicator. Membrane flux was recorded through volume-time measurements.

3.3 ANAEROBIC SLUDGE CONDITIONING

Anaerobic sludge for the experiment was obtained from the UASB digesters of CFG. The sludge was found to contain a considerable amount of undesirable solids and was screened thoroughly to remove grass, leaves and other cellulosic material which originated from the balancing pond. According to CFG the sludge was active, but was not substantiated by its physical appearance and odour which rather indicated symptoms of overloading. The sludge was therefore subjected to a one week rest period prior to feeding with fruit processing effluent.

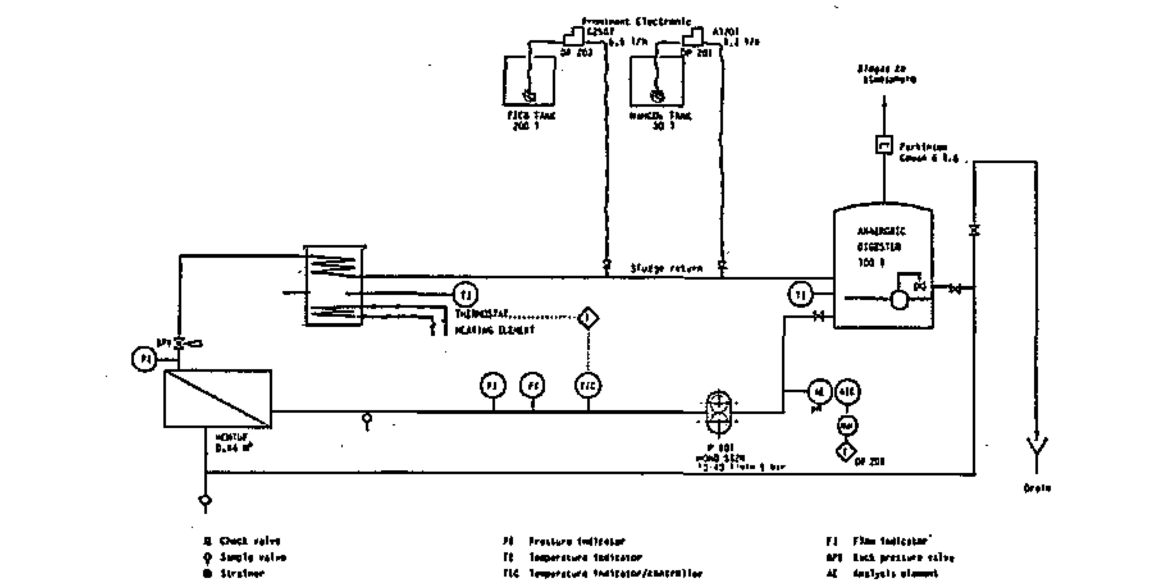

FIGURE 3.1: SCHEMATIC DIAGRAM OF EXPERIMENTAL APPARATUS

Since the sludge was supposedly conditioned for the treatment of fruit processing effluent, the initial space load rates that were used with the experimental reactor were relatively high, ranging from 0,47 to 1,19 $kgCOD.m^{-3}.d^{-1}$. At a MLSS concentration of 23 g/l these load rates proved to be too high since the sludge had been inactive for about four months, as revealed by later communications with CFG personnel *(Broodryk, 1991)*.

4. RESULTS AND DISCUSSION

4.1 DIGESTER LOADING AND CONTROL

The digester was monitored and controlled by observing the following parameters according to Ross and Louw *(1987)*:

i) Digester pH
ii) Digester temperature
iii) TA content of the UF permeate
iv) VFA content of the UF permeate
v) COD of the digester influent
vi) COD of the UF permeate
vii) Biogas production rate

The VFA and TA content of the UF permeate were taken as being representative of the digester content since the MMCO of the UF membranes, which were used in the experiment, was too high to result in any retention of low molecular weight organic acids or mineral salts.

The feed rate of fruit processing effluent to the digester was varied according to the specific COD content of the effluent so as to result in a steadily increasing load rate of total COD per day. The ratio between the VFA and TA, coupled with the COD of the UF permeate, were used as primary indicators of digester performance.

Detailed operating conditions and performance results are presented in the Appendix.

4.2 SPACE LOAD RATE AND HYDRAULIC RETENTION TIMES

It was attempted to gradually increase the space load rate, after the addition of brewery sludge on day 5, but this proved to be difficult due to the wide variation in specific COD content of the pond samples (refer to Figure 4.1 in conjunction with Table 4.1). Space load rates varied from 0,47 to 1,44 $kgCOD.m^{-3}.d^{-1}$, with spikes at day 13 (2,89 $kgCOD.m^{-3}.d^{-1}$) and day 19 (4,13 $kgCOD.m^{-3}.d^{-1}$). The HRT could be reduced from 3,8 to 0,5 days during this period. Unfortunately the COD of the pond samples had declined to below 1 000 mg/l by this time and it was decided to take future samples directly from the contrashear, rather than from the balancing pond.

These samples had a much higher COD content which made the operation at higher SLR possible, without decreasing the HRT unrealistically. During days 25 and 32 the digester was operated at SLR's of more than 2 $kgCOD.m^{-3}.d^{-1}$ which proved to be excessive, as was reflected in the increase of the VFA/TA ratio (Figure 4.2) and the corresponding drop in COD reduction (Figure 4.6). Feed to the digester was subsequently stopped from days 33 to 37 to prevent total metabolic overload. At this stage the UF membrane flux had deteriorated to very low levels and attempts were made to effect restoration (paragraph 4.5).

From day 38 to 65 (27 day period), another attempt was made to increase the SLR to higher values. The addition of nutrients, such as nitrogen (in the form of urea) and phosphate, as well as the trace element tungsten, which had been found to stimulate digester performance in another application *(Nel et al., 1985)*, seemed to have no noticeable effect on the ability of the digester to operate at higher load rates. As soon as higher SLR's were employed an immediate increase in the VFA/TA ratio and corresponding lowering in COD reduction was noticed.

Consequently a somewhat different approach was adopted. After consultation with Ross Consultancy *(Ross, 1992)*, alterations to the experimental procedure were made in an effort to obtain a clearer picture of the situation. These changes included the following:

i) installation of a different, more sensitive gas meter for more accurate biogas measurement;
ii) elimination of pH control and dosing of additives to achieve natural buffer action of digester contents and more representative VFA and TA values;
iii) nitrogen/phosphate analysis of feed and permeate samples to determine actual nutrient demand of biomass;
iv) determination of differences in filtered and unfiltered COD samples of the feed in order to ascertain representative sampling.

With these changes the SLR was maintained around 1 $kgCOD.m^{-3}.d^{-1}$ as from day 66 onwards, until mechanical problems with the UF circulation pump on day 103 were experienced, forcing a shut-down of the system. During this period any slight increase above a SLR of 1 $kgCOD.m^{-3}.d^{-1}$ immediately reflected in an increase of the VFA/TA ratio and permeate COD, which is indicative of metabolic stress of the biomass.

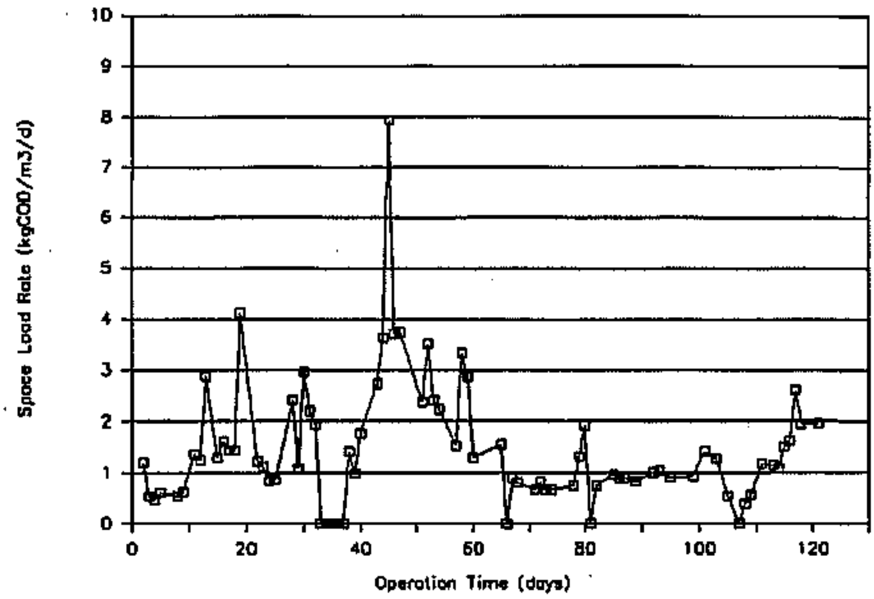

FIGURE 4.1: PLOT OF SPACE LOAD RATE AGAINST OPERATING TIME

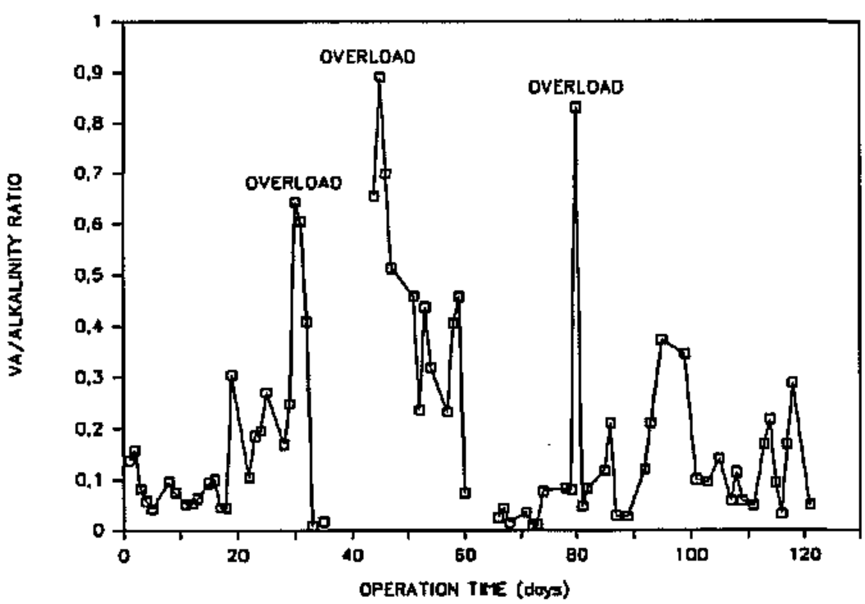

FIGURE 4.2: VARIATION OF VFA/TA RATIO WITH TIME

4.3 *ADDITIONAL NUTRIENTS AND pH CONTROL*

Nutrient additions and pH control were used on occasions to try and induce better digester performance. The addition of nitrogen in the form of urea served to increase digester pH by about 0,2 units, but did little to improve operation at higher SLR's. Similarly, phosphate and tungsten (as sodium tungstate) addition at elevated levels seemed to have no noticeable effect on performance efficiency of the digester, as mentioned previously.

Confusing results were obtained when the feed and permeate streams were analysed for TKN and TP (refer Table 4.1), even after the digester had been operating continuously for more than 72 days. This implies that the rates of growth and decay of the different microbe populations had not stabilised even after this extended acclimatisation period.

TABLE 4.1 NITROGEN (TKN) AND PHOSPHATE (TP) LEVELS OF FEED AND PERMEATE STREAMS AT VARIOUS OCCASIONS

DAY	FEED		PERMEATE	
	TKN (mg/l)	TP (mg/l)	TKN (mg/l)	TP (mg/l)
73	55,4	0,62	52,4	6,8
79	12,6	4,8	36,4	1,8

The pH of the digester could be maintained at between 6,8 and 7,2 without the addition of alkali, provided that the load rates were low enough to prevent metabolic overload. The alkalinity/influent COD ratio of the effluent was below the minimum of 1,2 mg($CaCO_3$)/mg influent COD which is desired to prevent a pH decline of the bed below 6,6 in UASB digesters. System failure can result below this pH value. However, for most waste waters in completely mixed anaerobic systems, little or no alkalinity supplementation of the digester influent is deemed necessary to maintain the pH above 6,6 *(Sam-Soon et al., 1991a)*. Since the ADUF system employs an essentially mixed reactor, membranes being used for phase separation, the deficiency in alkalinity of the influent is not considered to be the cause for poor digester performance at load rates above 1 kgCOD.m^{-3}.d^{-1}.

4.4 BIOGAS PRODUCTION RATE

It is apparent from the data presented in Table 4.1 and Figure 4.3 that the rate of biogas production was generally low and not in balance with the total mass of COD fed to the digester. Furthermore, the degree COD conversion to biogas was poor and below 15%, except for occasional spikes of 36 to 56% (days 67, 73, 82, 108, 109 and 114). The degree of conversion advocated for proper digestion is 65-75% *(Ross and Louw, 1988)*.

Replacement of the gas meter with a more sensitive instrument on day 66 resulted in more accurate biogas production rate measurement, but the observed conversion rates were still below the expected theoretical values. The difference in measured COD from filtered and unfiltered influent samples (1,5% on average) was not considered to be significant enough to account for the vast difference in observed and theoretical biogas production rates.

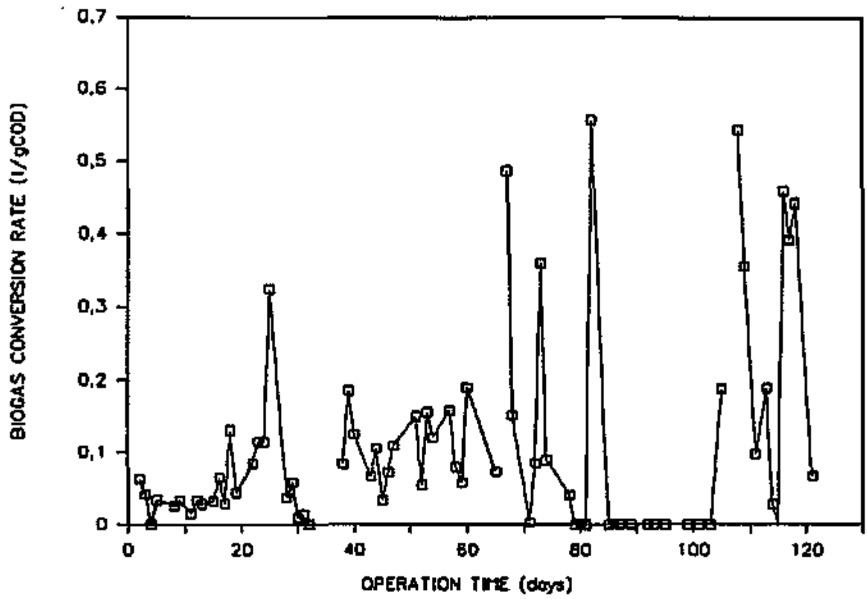

FIGURE 4.3: PLOT OF BIOGAS CONVERSION RATES AGAINST OPERATING TIME

It was noticed, however, that the observed gas production ceased after 2 to 3 days of continuous feeding of fruit processing effluent to the digester. Nevertheless the digester seemed active since the reintroduction of feed to the digester, after stopping the feed overnight, immediately resulted in gas formation. A corresponding change in gas production with change in feed rate is considered to be the prime indicator of an active anaerobic system *(Ross and Louw, 1987)*. It may, therefore, be deducted that the system was indeed active, but that it was incapable of producing appreciable amounts of methane indicative of complete biological degradation of the feed. Another possibility which cannot be excluded, is that the mechanical gas meter did not register the gas production correctly. Unfortunately most mechanical meters are sensitive to flowrate and often show serious error at reduced rates.

The microbial population of an anaerobic system, involved in the fermentation of soluble carbohydrates, is reported to comprise four categories *(Sam-Soon et al., 1991b)*, viz. Acidogens, acetogens, acetoclastic methanogens and H_2-utilising methanogens. The acidogens convert soluble carbohydrates to SCFA (acetic, propionic and butyric acids), carbon dioxide and hydrogen. The SCFA generated, depends on the hydrogen partial pressure, but butyric acid has not been observed when apple juice was the substrate *(Sam-Soon et al., 1990)*. Acetogens convert propionic acid to acetic acid, hydrogen and carbon dioxide. Propionate conversion is a function of the hydrogen concentration. Acetoclastic methanogens convert acetic acid to methane and carbon dioxide, the conversion being independent of the partial hydrogen concentration. Hydrogenotrophic (H_2-utilising) methanogens utilise hydrogen as sole energy source and CO_2 as carbon source, to produce methane.

Since excellent COD reduction was obtained with the digester at a SLR of below 1 kgCOD.m^{-3}.d^{-1} it would seem that methanogenesis was inhibited by some unknown cause. The low biogas production rates are attributed to a lack of H_2-utilising methanogens since the generated biogas seemed to contain an excess of carbon dioxide. Unfortunately no analysis of the biogas composition was performed due to the difficulty of obtaining a pressurised sample from the digester. Nevertheless, attempts to burn the generated biogas resulted in poor flame sustenance and a yellowish colour, indicative of high percentages of carbon dioxide.

4.5 ULTRAFILTRATION MEMBRANE FLUX

The flux of the ultrafiltration unit declined steadily for the first 34 days of operation, as illustrated in Figure 4.4. Fouling of the membranes by undigested carbohydrates or tannin was suspected, because the digester had shown imminent overload symptoms (high VFA/TA ratios and low COD reduction percentages). CIP experiments were carried out in an attempt to restore membrane flux and to obtain information with regard to the nature of the foulant.

The UF module was subjected to consecutive CIP cycles (refer Figure 4.5), starting with Pectinex in order to establish whether tannin fouling had taken place. Since practically no fresh water flux improvement was obtained with the pectinase solution, the module was washed with a chlorine-caustic soda combination which has been proven to be effective for the removal of foulants in UF systems treating apple juice. A significant fresh water flux increase resulted from this CIP solution and the removal of foulant was obvious from the typical brown discolouration of the permeate and concentrate streams. A subsequent acid rinse further improved the fresh water flux, which suggests that some inorganic fouling had occurred. Paradoxically no flux improvement resulted once the module had been hooked up to the anaerobic digester. The conclusion was made that the condition which was responsible for the operational flux decline was masking the effect that membrane fouling had on the observed flux values. Theoretically the membranes in an ADUF system should not show a flux decline since anaerobic digestion and ultrafiltration are complementary. The high molecular weight organic membrane foulants should be broken down by the anaerobic microbes, provided that the digester is operating effectively.

A reduction in MLSS concentration of the digester contents from 38 g/l to 20 g/l resulted in the desired flux restoration as can be seen from Figure 4.4. It is known from past experience that the MLSS concentration of the sludge has a drastic influence on membrane flux. Experiments performed with wine distillery waste showed a severe flux decline above a MLSS concentration of 40 g/l *(Ross et al., 1989)*. A similar relationship between membrane flux and MLSS concentration was obtained with brewery effluent, but a distinct flux decline was already noticed at MLSS concentrations above 20 g/l *(Strohwald, 1991)*. Once the MLSS had been reduced from 38 to 20 g/l an immediate flux improvement of approximately 50% was experienced. During the following 67 day period (day 38 to 105) the flux again declined gradually to a minimum of about 10 LMH. Investigation revealed that the UF circulation pump's rotating parts had worn substantially. The pump was subsequently fitted with a new rotor/stator combination and seals which resulted in improved discharge rates. Consequently the linear flow velocity across the membrane surface increased. The effect of linear flow velocity on membrane flux in ADUF systems is well known from previous investigations *(Strohwald, 1991)* and a flux increase of 20-30 LMH can be expected for every unit (m/s) of velocity increase, with intermediate MLSS concentrations of 22-38 g/l. It is obvious from Figure 4.4 that membrane flux increased by a factor of roughly 1,5 after the pump overhaul to a value of 25 LMH, similar to that at the beginning of the experiment. It can therefore be concluded that membrane fouling was not problematic and that flux was controlled by operating conditions, the most important of which are MLSS concentration of the sludge and linear flow velocity across the membrane surface.

The relationship between membrane flux and feed temperature has been found to be linear, with a slope of 2% per 1°C temperature increase (Ross et al., 1989). Since a mesophilic anaerobic system must be operated at 37-39°C, to obtain optimum load rates and prevent system failure, feed temperature is not a parameter that can be manipulated to increase flux. Similarly operating pressure was found to have virtually no effect on membrane flux *(Strohwald, 1991)*.

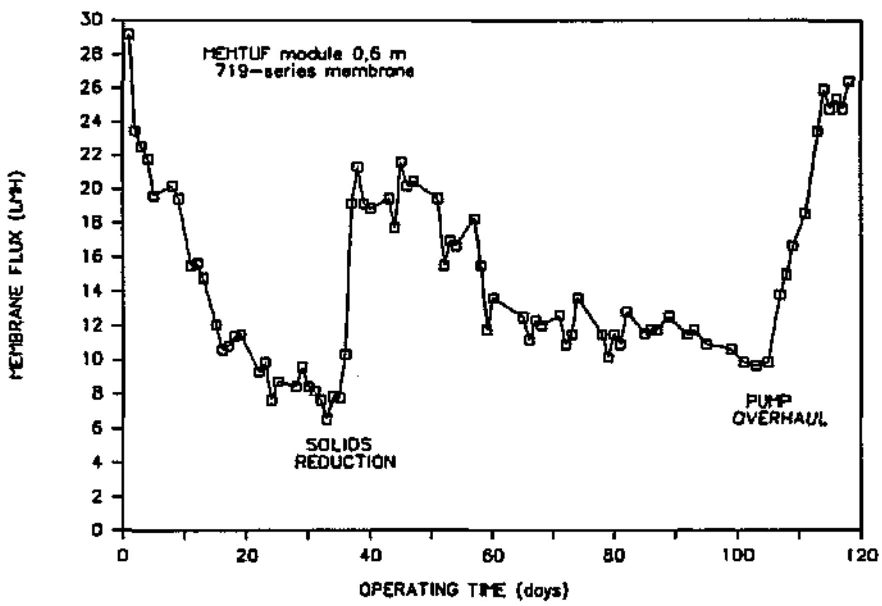

FIGURE 4.4: VARIATION OF UF FLUX WITH TIME

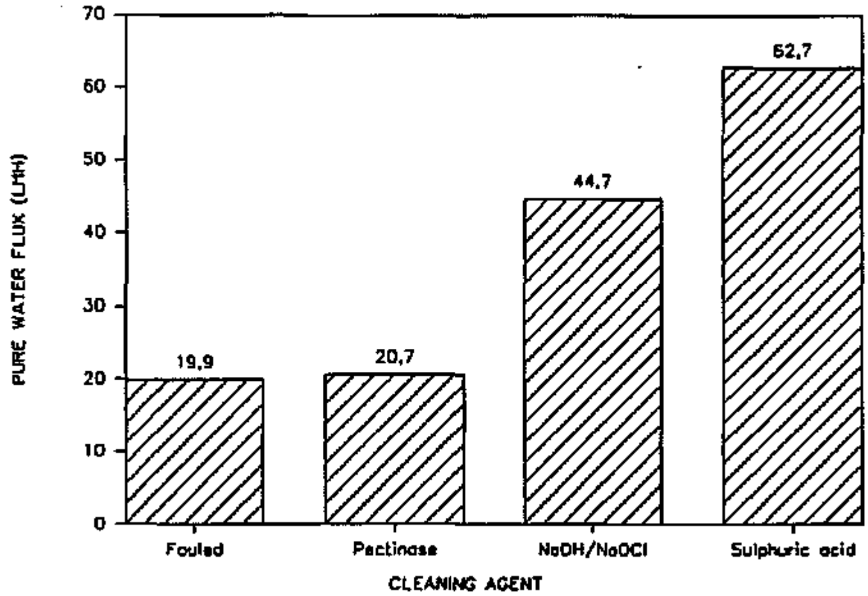

FIGURE 4.5: EFFECT OF MEMBRANE CLEANING AGENTS ON WATER FLUX

4.6 *QUALITY OF FINAL TREATED EFFLUENT*

Treatment of the factory effluent with the ADUF process resulted in excellent COD reduction, provided that the anaerobic digester performed properly and a good balance of sludge pH, VFA and TA was maintained. The effect of digester overload on COD reduction is illustrated vividly in Figure 4.6. Generally the COD reduction values were maintained above 95%, except when the chemical balance of the digester was disturbed by excessive feed rates or temperature drops.

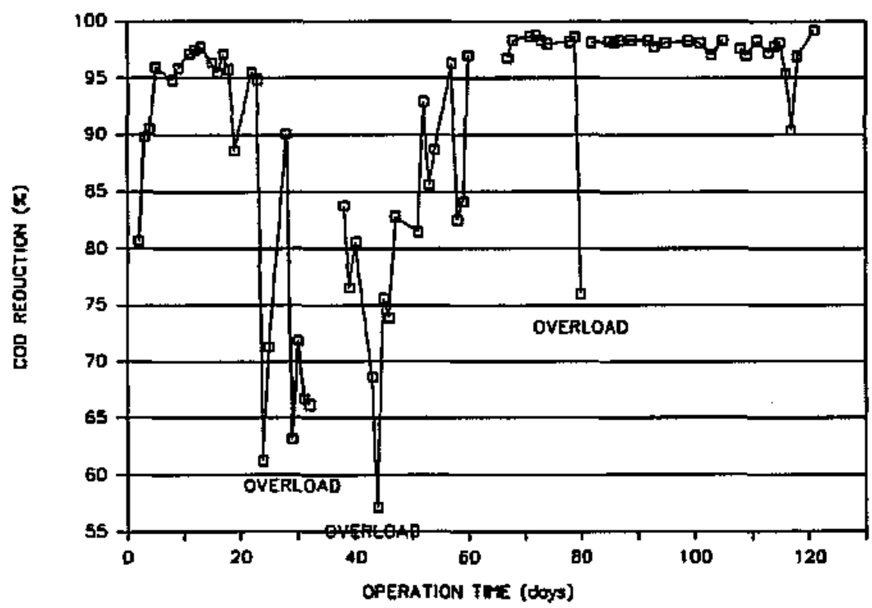

FIGURE 4.6: PLOT OF PERCENTAGE COD REDUCTION AGAINST OPERATING TIME

The COD value of the final treated effluent (UF permeate) could be reduced to below 50 mg/l when the digester operated effectively and the SLR was maintained below 1,5 kgCOD.m^{-3}.d^{-1}. The average influent COD value for the 120 day operating period was 2 812 mg/l. The possibility that the UF membrane was responsible for a substantial reduction in COD was investigated. Filtration tests that were performed with raw factory effluent showed that the UF permeate typically had a COD content of about 1 000 mg/l and it is therefore obvious that the UF membrane could not have been responsible for the high COD reduction percentages which were obtained with the ADUF unit.

5. CONCLUSIONS

The laboratory ADUF system was operated continuously for a period of 121 days with fruit processing effluent as substrate. The mixture of sludge *ex.* CFG digesters and sludge which had been used to treat brewery effluent in a previous experiment, was given adequate time to acclimatise.

COD reduction percentages of more than 95% could be obtained, with final treated effluent COD values of less than 50 mg/l, at a SLR of not more than 1,5 kgCOD.m^{-3}.d^{-1}. Operation at higher SLR resulted in the deterioration of COD reduction potential with a simultaneous sharp increase in COD content of the UF permeate and VFA/TA ratio which was indicative of imminent digester failure. It would seem that the system could be operated at a maximum SLR of 2-3 kgCOD.m^{-3}.d^{-1} with substantially lower COD reduction, provided that tight temperature and pH control can be maintained and shock loads are eliminated. The conclusion can thus be made that the effluent is readily biodegradable and amenable to anaerobic digestion.

Unfortunately it would seem that high SLR's are not readily attainable. The reasons for this are not clear. Nevertheless it would seem that there is an inhibition in the anaerobic reaction, as reflected in the poor biogas conversion rates which were recorded. The logical conclusion is that a deficiency in the number of hydrogenotrophic methanogens (responsible for converting hydrogen and CO_2 to methane) exists. No improvement in digester efficiency was noticed with the addition of nitrogen- and phosphate-containing compounds. However, a deficiency in minerals and trace elements, which are required for optimum anaerobic action, is not ruled out. Unfortunately this could not be determined due to time and logistical constraints. The alkalinity deficiency of the influent, as advocated by Sam-Soon *et al. (1991a)* for UASB systems, is considered to be not applicable in the ADUF system since the digester is essentially a mixed reactor. This fact could, however, explain some of the operational problems that are experienced with the UASB digesters of CFG. Possible improvement in performance of the UASB digesters could be obtained by introducing a recycle of the overflow, according to the guidelines given in the literature *(Sam-Soon et al., 1991a)*.

The UF unit performed well throughout the entire test period. Flux values could be maintained at high levels (20-25 LMH) and fouling was never serious enough to cause decreased throughput. Flux decline was experienced on two occasions and could be traced back to high MLSS concentration of the anaerobic sludge (due to microbe population growth) and low linear flow velocity across the membrane surface (because of worn-out UF pump components). Both factors are known for their detrimental effect on membrane flux.

In retrospect, it can be stated that the ADUF system performed well, despite the unfortunate low SLR's that were obtained, and succeeded in producing a final effluent of very low COD content.

6. RECOMMENDATIONS

In order to improve the performance efficiency of the existing UASB digesters at CFG, it is recommended that the addition of a UF unit be considered.

Since a major problem with these digesters is the loss of biomass in the overflow at high volumetric throughputs, *i.e.* low hydraulic retention times, proper phase separation is the first priority. Once all biomass can be retained in the system, operation at increased load rates may be attempted with proper temperature and pH control. The existing balancing pond would serve to prevent shock loads on the system.

Operation of the UASB digesters with a recycle, as suggested by Sam-Soon *et al. (1991)* in an effort to improve influent alkalinity requirements, is not recommended in this case since the higher volumetric throughput would aggravate the loss of biomass in the overflow.

Further work should be performed to investigate the need for mineral and trace elements additions to the digesters in order to enhance the anaerobic digestion rate and improve digester load rates to more economical levels.

LITERATURE

Binnie & Partners (1987). "Guide to water and waste-water management in the fruit and vegetable processing industry". WRC report TT 30/87, Pretoria.

Broodryk, J (1991). Personal communication. Ceres Fruit Growers, Bon Chretin St., Ceres.

Nel, LH; Britz, TJ and Lategan, PM (1985). "The effect of trace elements on the performance efficiency of an anaerobic fixed film reactor treating a petrochemical effluent". Water SA, vol.11 no.3, 107-110.

Ross, WR and Louw, JM (1987). "Monitoring and control of anaerobic digestion". Water SA, vol.13 no.4, 193-196.

Ross, WR; Barnard, JP; le Roux, J and deVilliers, H (1989). "Application of ultrafiltration membranes for solids-liquid separation in anaerobic digestion systems : the ADUF process". Paper presented at 1st biennial WISA conference, Cape Town, 27-31 March.

Ross, WR (1989). "Anaerobic treatment of industrial effluents in South Africa". Water SA, vol.15 no.4, 231-246.

Ross, WR (1990). Personal communication. Ross Consultancy, PO Box 3483, Tygerpark 7536.

Ross, WR (1992). Personal communication. Ross Consultancy, PO Box 3483, Tygerpark 7536.

Sam-Soon, PALNS; Loewenthal, RE; Wentzel, MC; Moosbrugger, RE and Marais, GvR (1990). "Growth of biopellets on glucose in upflow anaerobic sludge bed (UASB) systems". Water SA, vol.16 no.3, 165-170.

Sam-Soon, PALNS; Loewenthal, RE; Wentzel, MC; Moosbrugger, RE and Marais, GvR (1991a). "Effect of a recycle in upflow anaerobic sludge bed (UASB) systems". Water SA, vol.17 no.1, 37-46.

Sam-Soon, PALNS; Loewenthal, RE; Wentzel, MC; Moosbrugger, RE and Marais, GvR (1991b). "Mathematical modelling of upflow anaerobic sludge bed (UASB) systems treating carbohydrate waste waters". Water SA, vol.17 no.2, 91-106.

Strohwald, NKH (1991). "The application of the Anaerobic Digestion - Ultrafiltration (ADUF) process to brewery effluent". Contract report to the Water Research Commission by Membratek (Pty) Ltd, WRC report no. 338.

APPENDIX

OPERATIONAL DATA FOR LABORATORY-SCALE ADUF UNIT : FRUIT PROCESSING EFFLUENT

Oper Time days	Feed vol l/d	Feed COD mg/l	Perm COD mg/l	COD Rej %	UF flux LMH	Temp °C	Gas Rte l/d	Gas Con l/g	COD Inf g/d	COD Eff g/d	pH Dig	VA Perm mg/l	Alk Perm mg/l	VA/Alk Ratio	HRT days	SLR days
1		1805	392		29.2	35.0					7.43	264	1910	0.14		
2	33	1805	348	80.7	23.5	35.2	3	0.06	60	11	7.48	204	1290	0.16	1.5	1.19
3	15	1805	183	89.9	22.5	35.2	1	0.04	27	3	7.42	102	1250	0.08	3.3	0.54
4	13	1805	170	90.6	21.8	35.3	0	0.00	23	2	7.40	72	1250	0.06	3.8	0.47
5	17	1450	73	96.0	19.6	33.6	1	0.03	31	1	7.31	54	1290	0.04	2.9	0.61
8	19	1740	75	94.8	20.2	32.8	1	0.03	28	1	7.24	90	940	0.10	2.6	0.55
9	18	1950	72	95.9	19.4	32.0	1	0.03	31	1	7.25	60	800	0.08	2.8	0.63
11	35	1950	55	97.2	15.5	33.0	1	0.02	68	2	7.28	36	700	0.05	1.4	1.37
12	32	2220	49	97.5	15.6	33.5	2	0.03	62	2	7.33	40	760	0.05	1.6	1.25
13	65	1500	50	97.7	14.8	33.0	4	0.03	144	3	8.16	50	800	0.06	0.8	2.89
15	43	1440	55	96.3	12.0	31.2	2	0.03	65	2	7.74	78	830	0.09	1.2	1.29
16	56	1200	66	95.4	10.6	32.3	5	0.06	81	4	7.46	65	650	0.10	0.9	1.61
17	60	1200	35	97.1	10.8	32.2	2	0.03	72	2	7.45	30	670	0.04	0.8	1.44
18	60	1930	51	95.8	11.4	35.2	9	0.13	72	3	7.60	32	720	0.04	0.8	1.44
19	107	1760	220	88.6	11.5	35.8	8	0.04	207	24	7.35	180	590	0.31	0.5	4.13
22	35	1200	79	95.5	9.3	35.4	5	0.08	62	3	7.26	70	670	0.10	1.4	1.23
23	46	749	62	94.8	9.8	36.6	6	0.11	55	3	7.45	120	650	0.18	1.1	1.10
24	57	960	290	61.3	7.7	33.8	3	0.11	43	17	7.15	170	870	0.20	0.9	0.85
25	45	3650	276	71.3	8.7	28.0	10	0.32	43	12	7.36	162	600	0.27	1.1	0.86
28	33	1200	363	90.1	8.4	36.6	4	0.04	120	12	8.11	161	950	0.17	1.5	2.41
29	45	2700	442	63.2	9.6	37.0	2	0.06	54	20	8.26	240	970	0.25	1.1	1.08
30	55	2200	760	71.9	8.4	36.9	1	0.01	149	42	7.37	534	830	0.64	0.9	2.97
31	50	1930	732	66.7	8.1	37.5	1	0.01	110	37	7.42	502	830	0.60	1.0	2.20
32	50		653	66.2	7.7	36.0	0	0.00	97	33	7.55	388	950	0.41	1.0	1.93
33	0		78		6.5	35.2	3		0	0	7.24	10	1210	0.01		0.00
34	0				7.9	27.0	1		0	0	7.09					0.00
35	0				7.8	32.0	2		0	0	7.20	20	1240	0.02		0.00
36	0				10.3	31.0	0		0	0	7.37					0.00
37	0	3520	40		19.1	34.7	0		0	0	7.17		500			0.00
38	20	2450	572	83.8	21.3	34.5	5	0.08	70	11	6.95		970		2.5	1.41
39	20	2940	574	76.6	19.1	35.0	7	0.19	49	11	6.94		970		2.5	0.98
40	30	2740	570	80.6	18.8	33.1	9	0.13	88	17	6.94		940		1.7	1.76
43	50	2800	860	68.6	19.4	34.8	6	0.07	137	43	6.93		980		1.0	2.74
44	65	7220	1200	57.1	17.7	34.0	11	0.11	182	78	6.93	852	1300	0.66	0.8	3.64
45	55	4640	1760	75.6	21.6	35.0	10	0.03	397	97	6.93	1212	1360	0.89	0.9	7.94
46	40	5350	1210	73.9	20.2	35.0	10	0.07	186	48	6.94	980	1400	0.70	1.3	3.71
47	35	4230	919	82.8	20.5	34.5	17	0.11	187	32	6.95	684	1330	0.51	1.4	3.75
51	28	5850	784	81.5	19.4	35.0	15	0.15	118	22	6.94	550	1200	0.46	1.8	2.37
52	30	3440	413	92.9	15.5	34.4	9	0.06	176	12	6.99	250	1060	0.24	1.7	3.51
53	35	3190	496	85.6	17.0	34.8	16	0.16	120	17	6.94	376	860	0.44	1.4	2.41
54	35	2550	360	88.7	16.7	36.0	12	0.12	112	13	7.22	312	980	0.32	1.4	2.23
57	30	4170	95	96.3	18.3	37.0	12	0.16	77	3	7.26	200	860	0.23	1.7	1.53
58	40	4110	728	82.5	15.5	34.6	11	0.08	167	29	7.22	576	1420	0.41	1.3	3.34
59	35	3610	653	84.1	11.7	30.0	7	0.06	144	23	7.23	640	1400	0.46	1.4	2.88
60	18	3860	109	97.0	13.6	32.0	12	0.19	65	2	7.23	96	1300	0.07	2.8	1.30
65	20				12.5	34.0	6	0.07	77	0	7.21				2.5	1.54

Oper Time days	Feed vol l/d	Feed COD mg/l	Perm COD mg/l	COD Rej %	UF flux LMH	Temp °C	Gas Rte l/d	Gas Con l/g	COD Inf g/d	COD Eff g/d	pH Dig	VA Perm mg/l	Alk Perm mg/l	VA/Alk Ratio	HRT days	SLR days
66	0	3185	50		11.2	33.0					7.28	42	1710	0.02		0.00
67	14	3350	103	96.8	12.3	33.7	21	0.49	45	1	6.98	56	1270	0.04	3.6	0.89
68	12	3330	56	98.3	12.0	34.0	6	0.15	40	1	6.91	16	1100	0.01	4.2	0.80
71	10	4040	45	98.6	12.6	35.1	0	0.00	33	0	6.94	32	920	0.03	5.0	0.67
72	10	3265	50	98.8	10.9	35.5	3	0.09	40	1	6.96	10	1000	0.01	5.0	0.81
73	10	3300	55	98.3	11.5	36.0	12	0.36	33	1	6.95	11	1050	0.01	5.0	0.65
74	10	3120	65	98.0	13.6	35.0	3	0.09	33	1	7.02	80	1040	0.08	5.0	0.66
78	12	3275	56	98.2	11.5	34.5	2	0.04	37	1	6.99	80	970	0.08	4.2	0.75
79	20	3005	45	98.6	10.1	36.0	0	0.00	66	1	7.03	80	1000	0.08	2.5	1.31
80	32	3110	720	76.0	11.5	37.0	0	0.00	96	23	6.48	624	750	0.83	1.6	1.92
81	0	3110	40		10.9	34.6	0	0.00	0	0	6.84	40	850	0.05		0.00
82	12	3000	58	98.1	12.8	35.3	20	0.56	37	1	6.77	64	770	0.08	4.2	0.75
85	16	2965	53	98.2	11.6	35.5	0	0.00	48	1	6.77	88	750	0.12	3.1	0.96
86	15	2970	55	98.1	11.7	36.0	0	0.00	44	1	6.77	160	760	0.21	3.3	0.89
87	15	2960	50	98.3	11.7	35.2	0	0.00	45	1	6.85	24	820	0.03	3.3	0.89
89	14	3120	48	98.4	12.5	36.5	0	0.00	41	1	6.94	24	870	0.03	3.6	0.83
92	16	3050	53	98.3	11.5	35.5	0	0.00	50	1	6.82	80	660	0.12	3.1	1.00
93	17	2820	67	97.8	11.7	36.0	0	0.00	52	1	6.79	150	710	0.21	2.9	1.04
95	16	3100	53	98.1	10.9	36.4	0	0.00	45	1	6.83	280	750	0.37	3.1	0.90
99	15	3205	54	98.3	10.6	37.8	0	0.00	47	1	6.89	256	740	0.35	3.3	0.93
101	22	2280	61	98.1	9.8	37.1	0	0.00	71	1	7.01	80	800	0.10	2.3	1.41
103	28	2445	67	97.1	9.7	37.1	0	0.00	64	2	6.79	60	630	0.10	1.8	1.28
105	11	2400	40	98.4	9.8	37.0	5	0.19	27	0	6.86	99	700	0.14	4.5	0.54
107	0	1940	49		13.8	35.0	0		0	0	6.72	45	760	0.06		0.00
108	10	2155	46	97.6	15.0	35.5	10	0.54	19	0	6.84	80	700	0.11	5.0	0.39
109	13	2100	65	97.0	16.7	36.0	10	0.36	28	1	6.82	38	650	0.06	3.8	0.56
111	28	2050	36	98.3	18.6	36.5	6	0.10	59	1	7.02	38	770	0.05	1.8	1.18
113	28	2010	57	97.2	23.5	35.2	11	0.19	57	2	6.73	83	490	0.17	1.8	1.15
114	27	1990	44	97.8	25.9	36.8	2	0.03	54	1	6.84	120	550	0.22	1.9	1.09
115	38	1850	37	98.1	24.8	36.8	0	0.00	76	1	7.01	60	640	0.09	1.3	1.51
116	44	2615	85	95.4	25.4	36.5	36	0.46	81	4	6.99	20	620	0.03	1.1	1.63
117	50	4865	250	90.4	24.8	36.5	46	0.39	131	13	6.93	120	710	0.17	1.0	2.62
118	20	4650	150	96.9	26.4	36.2	42	0.44	97	3	6.48	130	450	0.29	2.5	1.95
121	21	4630	38	99.2	18.8	25.0	7	0.07	98	1	6.76	30	600	0.05	2.4	1.95
Mean		2812	260	90.1	14.8	34.7					7.12				2.3	1.46
Sdev		1168	339	11.1	5.4	2.3					0.33				1.3	1.22
Min		749	35	57.1	6.5	25.0					6.48				0.5	0.00
Max		7220	1760	99.2	29.2	37.8					8.26				5.0	7.94