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TWO EXAMPLES OF ANAEROBIC PRE-TREATMENT OF WASTEWATER IN THE BEVERAGE INDUSTRY

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ABSTRACT

Two examples of full scale UASB-reactors in a fruit juice factory and a brewery are given. In both cases, the design was based on semi-technical tests. Although the wastewater concentrations are rather similar and move within a low range, the parts of the anaerobic treatment plants and their design are different. In both cases, the COD removal efficiency in the UASB-reactors is consistently above 80%. It becomes apparent that UASB-reactors are very suitable for industries with seasonal load variations. The co-fermentation of a kieselguhre-sludge-mixture was tested in lab-scale experiments. It became obvious that the pellet structure of the biomass gets lost. Furthermore, it is shown that the running expenses of anaerobic pre-treatment are very low, even when combined with an aerobic stage. © 1997 IAWQ. Published by Elsevier Science Ltd

KEYWORDS

Anaerobic digestion; UASB-reactor; anaerobic/aerobic treatment; beverage industry; fruit juice industry; industry with seasonal variations; brewery.

INTRODUCTION

The anaerobic pre-treatment of industrial wastewater is the cheapest way as far as the running expenses are concerned. In former times, it was reckoned that anaerobic pre-treatment was suitable for wastewater with a COD higher than 5000 mg/l. Meanwhile, it has become obvious that plants working with anaerobic digestion, in particular upflow anaerobic sludge blanket reactors (UASB-reactors) and fluidized bed reactors, are suitable for wastewater with a COD of 1000-2000 mg/l (Austermann-Haun, 1994). In this paper, experiences with two full scale UASB-reactors in the beverage industry are presented.

UASB-REACTOR IN THE FRUIT JUICE INDUSTRY

The fruit juice factory Lindavia Fruchtsaft AG indirectly discharges its wastewater into the municipal sewage treatment plant at Lindau, Germany. When it became necessary to reduce the load of the discharged wastewater in order to keep the location of the factory and to have a tool against increasing loads, it was decided to build an anaerobic pre-treatment plant for the industrial wastewater. Based on semi-technical experiences with a trickling filter, anaerobic fixed film reactors and an upflow anaerobic sludge blanket reactor (UASB-reactor), the operators decided to build a two-stage anaerobic treatment plant with a methane reactor constructed as a UASB-reactor.

The treatment plant consists of a sieve and a sand grip (both in the factory), two buffer tanks with pH-regulation and dosage of nutrient salts (N, P), a wastewater filtration unit (0.1 mm), an acidification tank (551 m^3), a USAB-reactor (591 m^3, 131.4 m^2), and an aeration tank (8.5 m^3). Moreover, the plant sports a wash-liquor tank, a pellet storage tank which can be changed to a UASB-reactor if necessary, a gasholder with flare, a burner to produce steam from biogas, and a biofilter for the exhaust vapours. Figure 1 shows the details of the volume of the tanks. The wastewater treatment plant was constructed very close to the factory in the middle of the built-up area; it was initiated in September 1990. Until now, the project has been accompanied by the ISAH (Institute of Sanitary Engineering and Waste Management); it is partly subsidised by the German Ministry for Education, Science, Research and Technology.

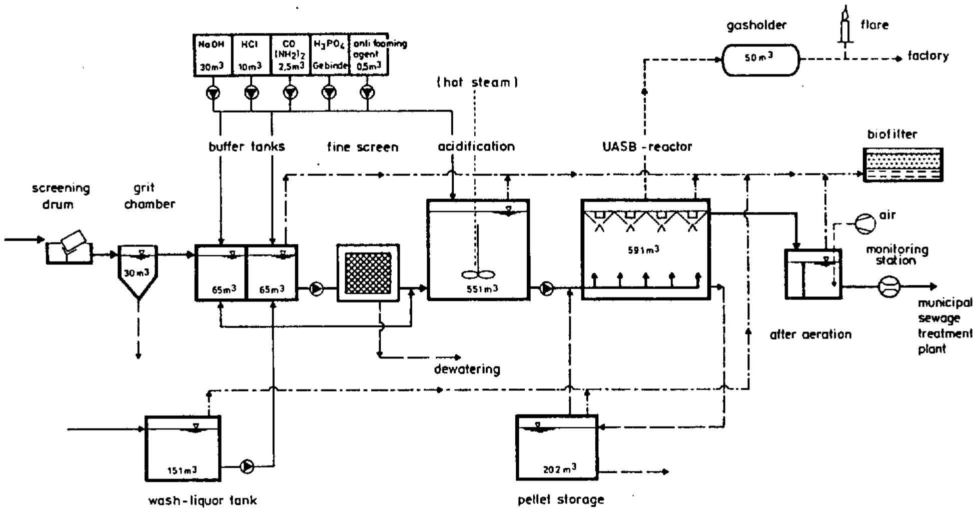

Figure 1. Flow diagram of the anaerobic wastewater treatment plant in the fruit juice factory.

Design data. Influent flow 1,920-2,400 m^3/d; COD 2,500-5,000 mg/l; maximum 10 t COD/d; COD:BOD-ratio 1.5; pH 4-12; UASB-reactor space loading rate 10-17 kg COD/(m^3.d); COD removal efficiency 80-90%. *Boundary conditions for indirect discharging:* COD $\leq$ 600 mg/l, $BOD_5 \leq$ 300 mg/l, temperature $\leq$ 30°C, pH 6-9 and settleable solids $\leq$ 10 ml/l.

During the first campaign in 1990, only those parts of the wastewater from the fruit juice production which showed higher pollution were subjected to anaerobic pre-treatment. To reduce the fees ordained by the municipality, it was necessary to reduce the wastewater concentration to concentrations permissible for domestic sewage throughout the year. To achieve this prerequisite, the anaerobic treatment plant, which was designed to treat the highly polluted wastewater streams during the campaign, had to run the whole year. For the same reason, the water from the bottling machine was also led to the anaerobic treatment plant during the second year of operation. Because of good results in the third year of operation, all wastewater streams were conveyed to the industrial pre-treatment plant, including sanitary wastewater and water from the bottle washing units.

Wastewater situation and characterisation. There are considerable variations in the wastewater flow, especially during the campaign (September-November). The flow is smallest during the wintertime (December-April), when only the bottling machines are being run. In summer (May-August), when berries and stone fruit are being processed, the flow rises. The major flow and loads, however, occur during the harvest season when kernel fruit has to be handled during the campaign. Table 1 gives an overview of the changes in the wastewater flow.

Table 1. Daily Wastewater flow in the influent of the UASB-reactor in regard to seasonal and production differences [m^3/d] between 1990 and 1995

Season	**minimum**	**maximum**	**average**
Autumn - campaign	264-800	1280-1624	641*-1061
Winter and Spring (only bottling)	200-420	360-620	299-285
Summer (treatment of berries, stone fruit and bottling)	300-480	500-825	279-587

* first campaign without bottle washing, bottling and sanitary wastewater

The wastewater concentrations varied as well as the flow rate. Table 2 gives an idea of the situation regarding the COD as an example of the varying wastewater loads. Table 3 shows some major wastewater parameters in order to differentiate between different kinds of wastewater.

Table 2. COD in the influent of the UASB-reactor at different seasonal and production times [mg/l] between 1990 and 1995

Season	**minimum**	**maximum**	**average**
Autumn - campaign	740-1296 *	1721-3395	1520-2411
Winter and Spring (only bottling)	428-1147	1039-2258	820-1602
Summer (treatment of berries, stone fruit and bottling)	375-691	1670-2310	896-1418

* first campaign without bottle washing, bottling and sanitary wastewater

Table 3. Wastewater parameters measured in homogenised samples taken behind the fine screen during the campaign

Parameter	Dim.	process water 1990			process water and bottling machine 1991			mixture of all wastewater streams 1992		
		min.	max.	⌀	min.	max.	⌀	min.	max.	⌀
sedimentable solids	ml/l	0.1	6.5	1.5	0.0	10.0	3.3	0.0	5.0	1.6
filterable solids	g/l	0.02	0.73	0.2	0.04	1.82	0.35	n.d.	n.d.	n.d.
pH	--	4.3	8.7	6.3	n.d.	n.d.	n.d.	4.6	11.6	9.3
temperature	°C	17	45	27.5	17	45	27.5	21	35	26
COD	mg/l	939	3767	2356	839	4020	2524	491	3850	2109
BOD_5	mg/l	1000	1661	1241	839	4020	2524	n.d.	n.d.	n.d.
organic acids	mg/l	187	611	371	68	454	246	109	496	276
COD:N:P	--	800:2.3:2.6			n.d.			800:5.3:3.7		

During the campaign, the COD:N:P ratio was 800:2.3:2.6 in the process water; this means that it is necessary to add nitrogen to make sure that there is no limitation. When all the different wastewater streams of the fruit juice production are mixed together with the sanitary wastewater and are processed together, nitrogen and phosphorus are available in sufficient degrees. No additional dosage of trace elements as Co, Ni, Zn, Se, Mn, Fe, Wo, etc., was necessary.

Acidification. Table 3 shows that, depending on the wastewater composition, 10 to 16% of the COD is based on organic acids (mostly acetic acid) contained in the fruit and on the fact that this wastewater is easily degradable. In the influent of the acidification tank, the concentration of acetic acids is about 200 mg/l, with a slight increase in the acidification stage. In the acidification tank, the most prominent acid produced is propionic acid; it amounts to up to 254 mg/l. Semi-technical tests have shown that a decrease of the hydraulic retention time to 10, 8 or 6 hours will also decrease the acidification degree; the ratio between acetic acid and propionic acid, however, will remain almost constant, regardless of the hydraulic retention time (HRT). For these reasons, the water level in the acidification tank is held as high as possible. This led to

HRTs between 12 and 29 hours. At a HRT of about 13 hours, 20 to 27% of the COD was based on organic acids, which means that the design was suitable for this particular kind of easily degradable wastewater.

UASB-reactor - start-up. The UASB-reactor was inoculated with 130 m^3 pellet sludge from a UASB-reactor used in the paper industry. One metre of the reactor height was filled with sludge, amounting to 21 kg SS/m^3, calculated to the entire reactor volume. During the first three weeks of operation, at least 3200 kg TS, a quarter of the total sludge, were wasted due to the problems of the adaptation phase; but within one further week the first instances of sludge enrichment occurred. This shows the importance of a large amount of inoculum which shortens the start-up. This corresponds with the experiences of Lettinga and Hulshoff Pol (1991) who recommend an amount of inoculum between 10-20 kg VSS/m^3.

UASB-reactor - efficiency. The UASB-reactor was running well throughout. In the seasons beyond the campaign, the reactor was fed 6 to 9 hours a day. During the rest of the day, there was no input and no recirculation of the effluent. The COD elimination ranged from 82 to 88% during the campaign, and from 87 to 90% at other times. The reason for these results was the low sludge load rate, which ranged from 0.1 to 0.2 kg COD/(kg SS.d) during the campaign, and from about 0.02 to 0.05 kg COD/(kg SS.d) the rest of the year. In spite of these low loads, the pH-value measured in the effluent of the methane reactor ranged from 6.8 to 6.9. As a consequence, recycling from the effluent to the influent should be done while the reactor is being fed.

No problems occurred with any restarting of the UASB-reactor when there had been a standstill over a period of several days or even weeks. In contrast, problems did occur with the pH-value and the COD removal efficiency at any sudden start of the campaign. In those cases when the wastewater flow rose within a week to an amount which was four times as high as the normal flow (maximal load 8.5 kg COD/(m^3.d)), the COD removal efficiency was about 70% during the first three weeks. After that the COD removal efficiency rose to over 90%. Any slow increase of the loads did not create any problems.

High sludge contents of up to 40 kg SS/m^3 led to low average sludge load rates of 0.16 kg COD/(kg SS.d) during the campaign and 0.03 kg COD/(kg SS.d) outside the campaign. Because of these very low loads, there was a loss of sludge activity outside the campaign. This is shown in Table 4. Thus, the ISAH recommended to remove one to two thirds of the pellet sludge at the end of the campaign and to store it in sludge storage tanks, for the sludge to be refilled only before the start of the next campaign. This method has several advantages: a) higher sludge activity does not coincide with the busy time at the end of the campaign b) a higher amount of biomass is available at the beginning of the campaign; c) the sludge load is kept at a consistent level throughout the year.

Table 4. Development of sludge activity [kg COD/(kg vssd)]

Date	UASB-reactor	sludge storage
13.08.1992	0.11	
15.10.1992 campaign	0.36	
02.11.1992 campaign	0.57	
15.04.1993	0.05	0.31
14.06.1993	0.17	
16.08.1993	0.13	0.44

From 1990 to 1995, the mixing efficiency was tested twice by a tracer test with lithium chloride. It became apparent that there were no dead zones or short circuit streams - the reactor was nearly ideally mixed. During these tests, the upflow velocity of the fluid was between 0.29 and 0.39 m/h, of the gas 0.17 to 0.28 m/h.

Running expenses. Running expenses (without capital costs) were 2.52 DM/m^3 during the first year of operation, and 0.99 DM/m^3 during the later routine operation.

Other aspects of research and emerging problems

The co-fermentation of the kieselguhre-sludge-mixture in the UASB-reactor was tested in lab-scale experiments. 10 litre UASB-reactors were used, which were being run with a space loading rate of 3 kg COD/(m^3.d), 10-60% of the load resulting from the sludge-kieselguhre-mixture. Based on these lab-scale experiments, co-fermentation cannot be recommended because the biomass lost its pellet structure. In contrast, composting with a structure material is possible and practised in the full-scale plant.

From time to time, there occurred problems with stenches emerging from the treatment plant, which is located in a residential area with the nearest neighbours being only a few metres away. The main reason for stenches are organic acids and the sulphur contained in the wastewater. For instance, the air in the aeration tank beyond the UASB-reactor was contaminated with 84-113 mg H_2S/m^3 and 2 to 3 mg mercaptan/m^3, that is 68,880 odour equivalents (olfactometric measurement). Semi-technical tests with biofilters have shown that it is necessary to keep the load ≤ 20 m^3 air/(m^3.h).

Because not only the air but the wastewater itself is loaded with H_2S which degasses on the way to the municipal wastewater treatment plant, there were problems with stenches emerging in the sewerage system. The aeration of the effluent and the installation of compost filters in the sewerage system could not solve this problem. Thus, semi-technical tests were done on the opportunities to treat anaerobically pre-treated wastewater in an aerobic stage with the odours from the reactors, using methods based on the Thiopaques (Paques, Netherlands) and Kaldness (Purac, Germany) processes. The aim was to oxidise the reduced sulphur. HRTs of 0.86, 1.08 and 1.43 h were tested. Only at an HRT of 1.43 hours was all H_2S oxidised and none was found in the exhaust vapours.

There was one occurrence of a wash-out of granulated sludge outside the campaign. Based on degassing problems caused by low sludge loading rates, thousands of pellets stuck together in large clusters with a size of up to 8 cm; these balls could not be kept in the system by the three-phase-separator in the top part of the reactor. Apart from the very low sludge loading rate, the main reason of this problem was found in the overdosing of coagulation aids in the fine screen. The solution was to reduce the dosage of coagulation aids to 10 g/m^3 SEDIPUR (BASF, Ludwigshafen, Germany) and dosage of 19 ml/m^3 of the antifoaming agent SEDIPOL (also by BASF).

ANAEROBIC/AEROBIC WASTEWATER TREATMENT PLANT AT A GERMAN BREWERY (LICHER PRIVATBRAUEREI)

Until November 1994, the wastewater produced at this brewery was aerobically pre-treated in an equalising tank which operated without any sludge support. The COD removal ratio was about 60-80%.

The first step of the municipal treatment plant of Lich is a flotation unit where the sludge is separated from the pre-treated brewery wastewater. In both plants, there occurred problems with bulking sludge. Because of the requirements for higher COD and BOD elimination as well as nitrogen and phosphorus elimination, the municipal treatment plant should be modernised. The costs were calculated to be 47 to 50 million DM (Birkenstock and Bößendörfer, 1996b); the manpower necessary to operate the plant was regarded as 6-10 persons. Based on economic considerations, the brewery decided to build its own wastewater treatment plant. Therefore, a UASB-reactor and two fixed film reactors were tested in parallel semi-technical experiments. The results of these tests yielded the following design criteria: - considerable pH-variations in the wastewater necessitated pH-regulation in the equalising tank and in the acidification tank, - a sieve was necessary to catch suspended solids, - aluminium precipitation (resulting from the bottle washing) required a settling tank, - some disinfectants and sliver lubricants had to be changed to boost the biodegradation performance of the wastewater.

The best results were obtained with the UASB-reactor. Space loading rates of 8-10 kg COD/(m^3.d) with a COD removal efficiency of ≤ 80% were reached. In 1990, the pilot scale tests were finished. It took more than 3 years to get the permission to build the plant, but only 13 months before the finished anaerobic/aerobic treatment plant was started in November 1994.

The wastewater treatment plant consists of an equalising tank, an acidification tank, a sieve (1 mm), a settling tank, two UASB-reactors, an aerobic stage working with biological nitrogen and phosphorus elimination, and a sand filtration unit. The surplus sludge from the UASB-reactors is collected in a pellet storage tank with a volume of 300 m^3. The surplus sludge from the aerobic stage is pumped into a thickener (154 m^3) and dewatered in a centrifuge. Figure 2 shows the reactor volume of the different stages of the wastewater treatment plant. The equalising tank has sufficient capacity to store the rainwater of the entire area around the factory. The UASB-reactors run with a continuous flow, which is achieved by recycling the reactor effluent to the second acidification tank. The activated sludge system consists of two activated sludge tanks with circulating flow and two final clarifiers which are run in parallel. Because of the low BOD:N-ratio of approximately 30%, the activated sludge tank is aerated and 70% of the volume is used for denitrification. The filtration unit consists of 5 continuously running flow sand filters (see Table 5 for design criteria of the plant).

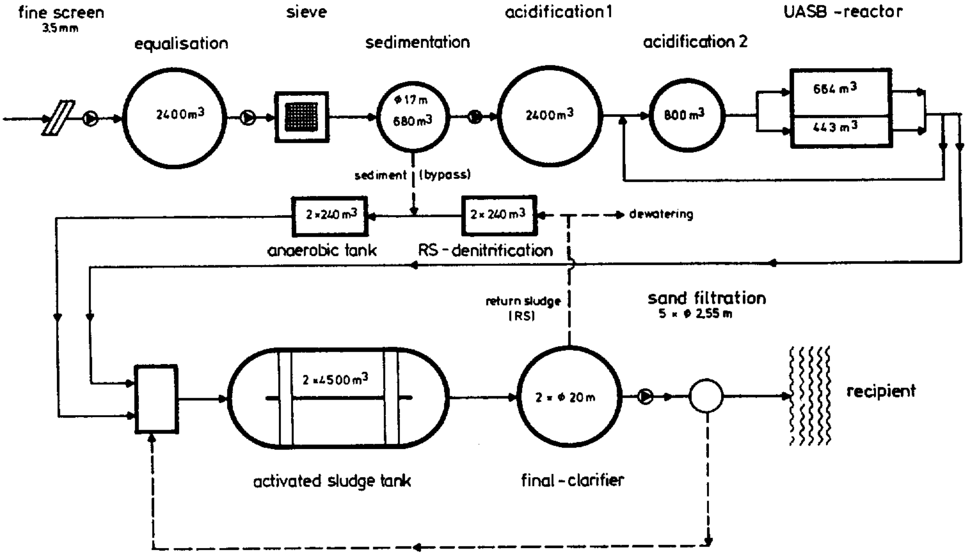

Figure 2. Flow diagram of the anaerobic/aerobic wastewater treatment plant of the Licher brewery.

Table 5. Design criteria of the main steps of the anaerobic/aerobic wastewater treatment plant of the Licher brewery

part of the plant	**design criteria**
equalising tank	HRT min. 11.6 h, max. 15.6 h
sedimentation	flow rate 1.25 $m^3/(m^2 \cdot h)$; HRT ø 2.4 h
acidification I	HRT ø 13.2 h
acidification II	HRT ø 5.2 h
UASB-reactors	11 kg COD/($m^3 \cdot d$); HRT ø 8.3 h upflow velocity 0.54 $m^3/(m^2 \cdot h)$
activated sludge system	0.274 kg $BOD_5/(m^3 \cdot d)$; 0.0684 kg $BOD_5/(kg\ SS \cdot d)$
return sludge denitrification	HRT ø 1.68 h
anaerobic tank for enhanced biological P removal	HRT ø 1.03 h
final clarifier	flow rate < 1.6 m/h
continuous sand filtration	flow rate ø 7.5 $m^3/(m^2 \cdot h)$; max. 11.5 $m^3/(m^2 \cdot h)$

The project is accompanied by the Institute of Sanitary Engineering and Waste Management (ISAH) of the University of Hannover as well as the consultant agency *aqua consult Ingenieur GmbH*, Hannover, with financial support from the Federal Environmental Agency. The main aim is to keep the effluent concentrations below the lowest possible limits.

Design data. Influent flow 4,300-5,950 m^3/d; COD 8,580-13,290 kg/d; BOD_5 5,720-8,860 kg/d.

Limits for discharging: COD 90 mg/l, NH_4-N 10 mg/l, $N_{mineral}$ 18 mg/l, total P 1 mg/l and settleable solids 0.15 ml/l, pH 6.5-8.5.

Self imposed limits for discharging: COD 50 mg/l, $N_{mineral}$ 9 mg/l, total P 0.5 mg/l. Table 6 shows some average data of the first year of operation. It is obvious that the effluent data are well below both the discharging conditions and the self-imposed discharge limits.

Currently, the daily wastewater flow is between 2000 and 3000 m^3 on week-days. As there is no wastewater on Saturdays and Sundays, the overall average of the daily flow in 1995 was 1640 m^3/d.

Table 6. Effluent data of different stages of the anaerobic/aerobic wastewater treatment plant of the Licher brewery

Parameter	unit	influent	acidification I	UASB-reactors	activated sludge system	continuous sand filtration
COD homog.	mg/l	2277	2077	400	33	24
BOD_5 homog.	mg/l	1496	1841	95	5.8	3.6
TKN filtered	mg/l	41	42	49		
NH_4-N	mg/l		10			0.08
NO_3-N	mg/l					4.1
NO_2-N	mg/l					0.02
PO_4-P	mg/l	17		12	0.8	0.21
filterable solids	mg/l		132		21	1.8
COD:BOD_5	--	1.52	1.13	4.2	5.7	6.7
COD:N:P	--	800:14.4:6.0	800:16.2:6			
BOD_5:N:P				100: 51.6:12.6		

The total kjeldahl nitrogen (TKN) is measured in filtered samples. Because of hydrolysis, the concentration increases in the different steps of anaerobic pre-treatment.

50 to 80% of the filtered COD is found as organic acids in the effluent of the acidification I, mainly acetic and propionic acids in a relation of 0.9:1. Nevertheless, pellet sludge does emerge. Size and shape have been the same since the start-up with a pellet sludge mixture from a brewery and a paper mill. During the last year hydrochloric acid had to be dosed twice, once when there was a loss of NaOH in the brewery, and once when the acidification I was not in operation. Because of the large volume of the equalising and acidification tanks, there is a stable pH-value in the influent of the UASB-reactors without any pH correction instead of pH-variations in the influent.

The only critical point in regard to the discharging conditions is the nitrate. Because the BOD_5:N:P ratio is 100:51.6:12.6 in the effluent of the UASB-reactors, the amount of carbon available for denitrification is insufficient. An ethanol-water-mixture (COD $\approx$ 180,000 mg/l, $BOD_5 \approx$ 114,000 mg/l, total N $\approx$ 2.3 mg/l), a by-product from the production of alcohol-free beer, is dosed into the activated sludge system as well as the sludge from the primary clarifier, the flushing water from the sand filtration, and the water from the thickener and the centrifuge. About 25% of the BOD in the influent of the activated sludge system results from the anaerobically pre-treated wastewater, 20% from the bypass (1.6% of the total flow) and 52% from the ethanol-water-mixture.

Some aspects of research and emerging problems

Ammonification of organic nitrogen into ammonia in the anaerobic stage. During the semi-technical tests in 1990, problems occurred with the ammonification of organic nitrogen. Although there were no problems in the full scale plant, lab-scale experiments were carried out. In anaerobic batch tests the different wastewater streams from the different parts of the brewery were observed; so were the basic products and process materials, such as label glue. It was found that the ammonification of yeast is difficult. Only 35-50% of the organic nitrogen was converted into NH_4-N (conditions: pH 7, COD 5000-8000 mg/l, organic nitrogen 40-60 mg/l at the beginning of the tests, duration 140 hours). In all other cases, no problems occurred.

Bulking sludge in the activated sludge system. Between January and August 1995, the sludge volume index (SVI) was between 70 and 80 ml/g, which is a very good result. This was due especially because of the very low sludge loading rate. From August to December, it climbed up to 200 ml/g. The main filament organisms which could be detected were 021N, 0041, *haliscomenobacter hydrossis*, 0092 and 1851. To reduce the SVI to values below 100 ml/g, $FeCl_3$ is dosed up to an amount of 1.1 l $FeCl_3/m^3$ which means 209 g Fe/m^3 to raise the iron concentration in the activated sludge up to 10%. As a consequence, 021N disappeared. Nowadays the SVI depends on the iron dosage. At an amount of 19 to 57 g Fe/m^3, the SVI is between 80 and 115 ml/g. The total filament abundance has the category 4 on a scale from 1 to 7. Filament organisms of the types 0041, *haliscomenobacter hydrossis*, 0092 and 1851 still exist in the same amount as without ion dosage. Ion dosage does not increase the degree of biological phosphorus removal.

Operation expenses. The total energy consumption of the anaerobic/aerobic wastewater treatment plant is 2.62 kWh/m^3 wastewater. In 1995, 74.5% of this energy consumption was covered by the energy produced from the biogas. This leads to an energy demand of only 0.67 kWh/m^3. The treatment plant is directly controlled in the factory by automatic data transfer. Only one person is working a few hours a day at the plant. As a consequence, the operation expenses (without capital costs) were 1.19 DM/m^3 during the first year of operation, which is very cheap, especially in regard to the high quality of the discharged water.

CONCLUSION

The examples given show that anaerobic sludge blanket reactors can be used in fruit juice factories with large seasonal variations, as well as in breweries. In both cases, semi-technical tests were done to elicit the most favourable design data, which vary considerably depending on the wastewater. The tests done in the brewery showed that disinfectants had to be changed until a stable COD elimination could be reached. It would be too expensive to make these exercises in the full scale plant. The wastewater concentrations tend to be consistently low, even though the respective parts of the anaerobic treatment plants and their design are different. In both cases, the COD removal efficiency in the UASB-reactors was consistently above 80%, with the operation costs being very low.

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