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LARGE-SCALE ANAEROBIC/AEROBIC TREATMENT PLANTS FOR WASTEWATERS FROM A MOLASSES DISTILLERY, A PECTIN FACTORY, AND STARCH FACTORIES

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ABSTRACT

The operating data and problems of four large-scale anaerobic-aerobic wastewater treatment plants are described. Three of these plants, treating wastewaters from a molasses distillery, a wheat-starch factory, and a potato-starch factory, use fixed-film methane reactors as the anaerobic stage. Two of these reactors are filled with packed blocks of plastic material (well known from aerobic trickling filters) with a specific surface area of 150 m^2/m^3. The fixed-film methane reactors in the potato-starch factory use lava slag as the support media. The companies concerned produced wastewaters which fluctuate greatly in quality and quantity. To guarantee stable degradation and high COD removal, equalizing tanks and low design rates are very important. Some of the wastewaters need additional dosing of trace elements to achieve satisfactory COD removal. All full-scale experience has shown that external anaerobic sludge retention, even when using the fixed-film reactors, is important for the anaerobic system.

KEYWORDS

Industrial wastewater; large-scale wastewater treatment; anaerobic pretreatment; fixed-film methane reactor; plastic block material; extruded plastic material.

INTRODUCTION

This paper introduces various large-scale anaerobic/aerobic wastewater treatment plants treating highly polluted industrial wastewaters. These treatment plants are the first large-scale fixed-film reactors constructed in West Germany for use in the anaerobic pretreatment of distillery and starch wastewaters. An anaerobic/ aerobic wastewater treatment plant with anaerobic high-rate denitrification for the treatment of wastewater from a pectin factory is introduced. This plant was constructed at a time when the advantages of fixed-film reactors were not as well known as they are today.

WASTEWATER TREATMENT PLANT OF THE FIRST EUROPEAN MOLASSES DISTILLERY WITH CONTINUOUS FERMENTATION AND DISTILLATION

In 1986, a molasses distillery in Hannover switched from the usual discontinuous fermentation process to a continuous mode of operation. Normally, the distillery wastes are molasses slops. In this distillery the molasses slops pass into an evaporator operating continuously. The evaporator condensate is the only waste-water to be treated (the thickened slops are sold to a feed-stuff factory). In this way it was possible to decrease the specific sewage volume from 3 m^3/t molasses using batch fermentation to 0.9 m^3/t molasses with a much lower load.

The authorities required that the treatment plant be ready when the factory began operation. Therefore it was impossible to undertake preliminary research with the actual wastewater before the anaerobic/aerobic wastewater treatment plant was constructed, and because this was the first continuously operating distillery in Europe, no wastewater data were available. From data on the wastewater of a laboratory-scale distillery and a discontinuously operating distillery in the Netherlands using an evaporator, it was expected that the wastewater would have a COD of about 4000 mg/l and a BOD_5 of about 3000 mg/l with no solids. Based on positive experience gained with fixed-film reactors in semi-technical experiments (Seyfried and Saake, 1985, 1986), an anaerobic/aerobic plant (Fig. 1) for the pretreatment of the wastewater was constructed with the following dimensions: NaOH dosing station equalizing tank, volume (V) = 100 m^3; acidification tank, V = 140 m^3; fixed-film methane reactor, V = 140 m^3 (75% of the volume is filled with Bio-net 150 support media, plastic blocks with a specific surface area of 150 m^2/m^3); anaerobic settling tank, area = 4.5 m^2; activated sludge tanks cascade, total volume = 48 m^3; final sedimentation, area = 4.5 m^2. The effluent from the treatment plant is treated further in a municipal wastewater treatment plant.

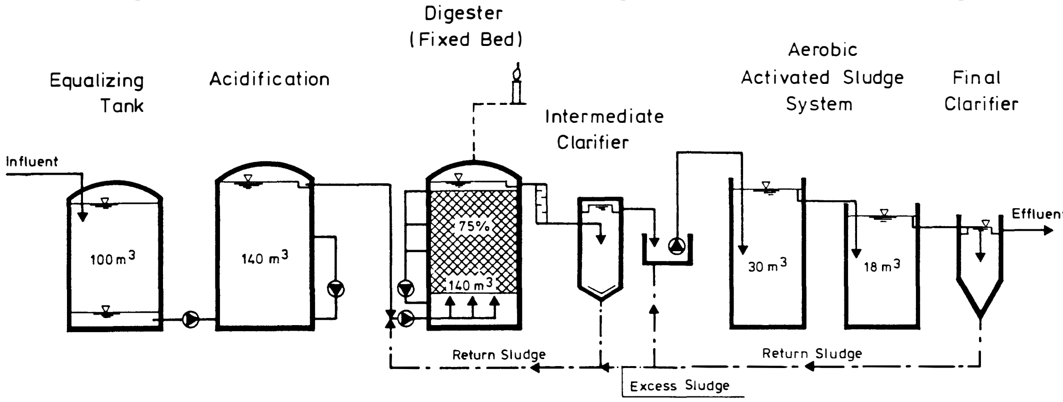

Fig. 1. Flow diagram of molasses distillery anaerobic/aerobic wastewater treatment plant

The distillery and wastewater treatment plant began operation on the same day in March 1986. From March 1986 to December 1987, the distillery operated for about 190 days. Many interruptions occurred, causing difficulties with start-up of the anaerobic treatment plant. Due to this, it became cheaper for the factory to purchase alcohol and refine it than to produce it, because alcohol produced from overproduced agricultural materials was highly subsidized. Problems occurred with the evaporators because of crystallization in pumps and pipes, and wastewater quality was very variable due to molasses slops entering the wastewater. The distillery operated for the last time to date from October to December 1987.

Wastewater Data for the Last Production Period from October to December 1987

The wastewater consisted of the evaporator condensate, and it had the following characteristics: volume = 60 - 80 m^3/d; pH = 3.2; COD = 8 700 - 28 500 mg/l (mean = 18 700 mg/l); BOD = 4 670 - 16 700 mg/l (mean = 10 900 mg/l); total suspended solids (TSS) = 0 (except when molasses slops entered the wastewater). The pure condensate (i.e., without molasses slops) did not contain enough phosphorus, cobalt, chromium, lead, selenium, and molybdenum for successful treatment. However, in practice, only continuous addition of phosphorus was necessary because the other trace elements entered the wastewater in the molasses slops.

Operating Data for October to December 1987

The following operating data were obtained for the methane reactor: volumetric load ($B_{R,COD}$) = 7.5 - 13 kg COD/$m^3 \cdot d$; effluent COD concentration ($C_{e,COD}$) = 1700 - 7800 mg/l (mean = 4350 mg/l); effluent BOD concentration ($C_{e,BOD}$) = 730 - 4170 mg/l (mean = 2060 mg/l); mean COD removal (η_{COD}) = 77%; mean BOD removal (η_{BOD}) = 81%; TSS in liquid phase = 3 g/l; gas production = 0.56 m^3 gas/kg COD removed = 0.33 m^3 CH_4/kg COD removed.

For the activated sludge process, the following data were obtained: mixed liquor suspended solids (MLSS) = 3 - 7 g/l; sludge volume index (SVI) = 140 ml/g; F/M = 0.4 - 1.7 kg BOD/kg TS·d; $C_{e,COD}$ = 600 - 6300 mg/l (mean = 3290 mg/l); $C_{e,BOD}$ = 85 - 3055 mg/l (mean = 1160 mg/l); mean COD removal = 23%; mean BOD removal = 43%.

The overall removal rates for the system were: mean total COD removal = 82%; mean total BOD_5 removal = 89%.

The COD varied greatly, as can be seen in Fig. 2. However, the removal efficiency was still quite satisfactory, despite the overloading of the methane reactor by more than 100%. Problems occurred with the pH in the methane reactor, which often dropped below 6.5. However, after sodium hydroxide was dosed into the buffer tank to increase the pH from 3.2 to 4.0, the pH in the methane reactor was quite stable at about 7.0.

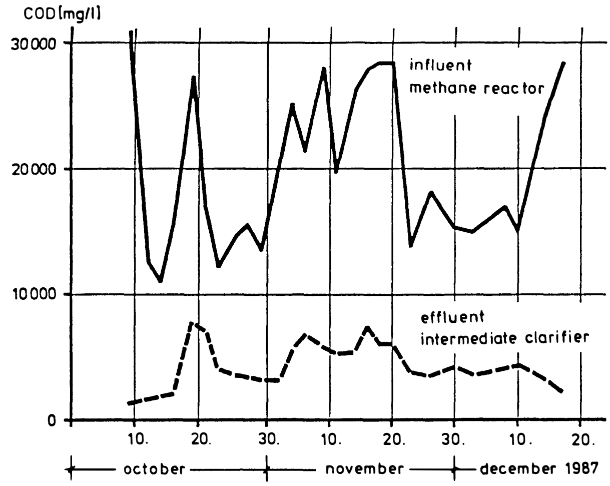

Fig. 2. Operating results for the molasses distillery fixed-film anaerobic digester

Measurements showed it was necessary to have an anaerobic settling tank after the fixed-film reactor, because the type of fixed-bed material used had only a very small filtering effect. With a surface flow rate of 0.5 m/h, 92% of the TSS and 93% of the volatile suspended solids (VSS) were retained in the anaerobic system. Regarding the intermediate settling tank, the TSS of the influent were 2.0 - 2.7 g/l and the TSS of the effluent from the tank were 0.1 - 0.16 g/l.

WASTEWATER TREATMENT PLANT OF A WHEAT-STARCH FACTORY

The good results obtained in experiments with fixed-film reactors (Seyfried and Saake, 1985, 1986; Saake, 1986) led to the construction of a large-scale plant, which has been in operation since autumn 1986. The two-stage plant includes a completely mixed acidification tank which operates with fluctuating water levels, and this therefore also operates as an equalization tank. The heart of the plant is the methane reactor which is filled to 40% of its volume with a packed plastic material known as Bio-net 150 (the same material as was used in the methane reactor of the molasses distillery plant). The anaerobic stage of the plant is completed by an anaerobic settling tank. The aerobic stage consists of a trickling filter, a lamella separator, and a 1000 m^3 unaerated pond. The dimensions of the plant are shown in Fig. 3, and in Table 1, the operating results are compared to those of the preliminary experiments and design data. It was found that fluctuations in the influent COD were relatively great compared to those of the effluent COD (see Fig. 4). This indicates the exceptional stability of this fixed-film reactor under normal loading conditions. The most recent analytical data are from December 1987, and the effluent data have not altered since that date, therefore there has been no need for our institute to undertake further research. The effluent from this plant is further treated in a municipal wastewater treatment plant.

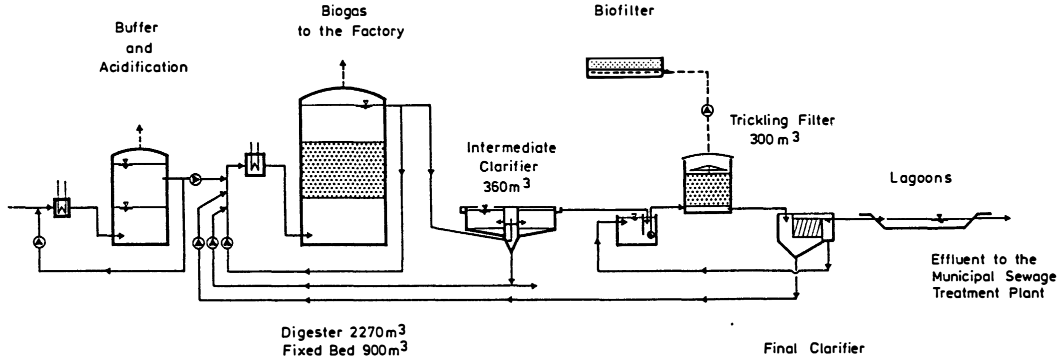

Fig. 3. Flow diagram of the wheat-starch factory anaerobic/aerobic wastewater treatment plant

TABLE 1 Wheat-starch Factory Pilot Experiments, Design Data and Operating Results

Parameter*	Pilot experiments	Design data minimum	Design data mean	Design data maximum	Operating results, October 1987
Anaerobic Stage					
Q, m^3/d	-	195	260	325	240
$C_{o,COD}$, g/l	-	45	45	45	37.5
$C_{o,BOD}$, g/l	-	30	30	30	23.3
$B_{d,COD}$, kg/d	-	8775	11700	14625	9000
$B_{d,BOD}$, kg/d	-	5850	7800	9750	5586
$B_{R,COD}$, $kg/m^3 \cdot d$	5 - 7	3.9	5.2	6.4	4.0
$B_{R,BOD}$, $kg/m^3 \cdot d$	-	2.6	3.4	4.3	2.5
η_{COD}, %	88 - 95	90	85	80	97
η_{BOD}, %	90 - 96	95	90	85	98
$C_{e,COD}$, mg/l	-	4500	6750	9000	1000
$C_{e,BOD}$, mg/l	-	1500	3000	4500	480
Aerobic Stage					
$B_{d,BOD}$, kg/d	-	293	780	1463	115
$B_{R,BOD}$, $kg/m^3 \cdot d$	2.5 - 4.0	1.0	2.6	4.9	0.4
$C_{e,COD}$, mg/l	1500 - 3000	-	-	-	900
$C_{e,BOD}$, mg/l	800 - 1500	-	-	-	235
$\eta_{tot.COD}$, %	-	-	-	-	98
$\eta_{tot.BOD}$, %	-	-	-	-	99

*Q = influent volume; C_o = influent concentration; B_d = load; B_R = volumetric load; η = removal efficiency; C_e = effluent concentration

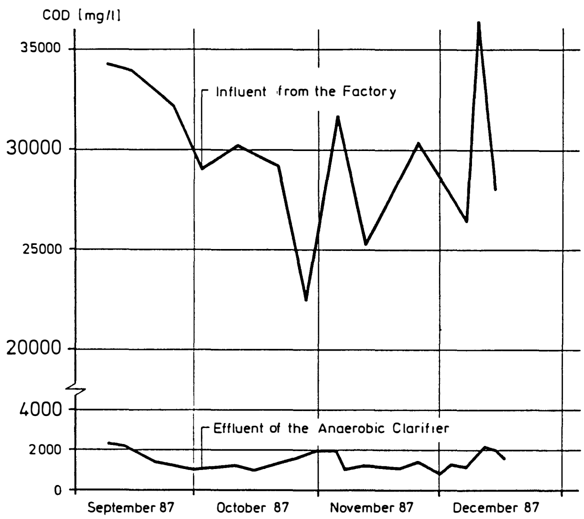

Fig. 4. Operating results of the anaerobic plant of a wheat-starch factory

During start-up of the treatment plant, it became obvious that the starch production process had changed somewhat, and the addition of trace elements was necessary. Cobalt and nickel were added occasionally when necessary, and since this time the efficiency of the methane reactor has been above 95%.

It should not be concealed that there were some problems with the anaerobic settling tank during start-up. Although it was dimensioned with a very low surface flow rate, q_A, of 0.15 m/h, most of the anaerobic sludge was carried over from the anaerobic settling tank and could not be returned to the reactor. A separator (centrifuge) from the factory was installed between the methane reactor and the anaerobic settling tank, and since then problems of poor sludge retention have not recurred. After stable conditions were reached, the separator was removed.

Experience has shown that packed plastic blocks with a specific surface area of 150 m^2/m^3 used as the fixed-bed material have a low filtering ability. Therefore, external sludge retention by an anaerobic settling tank, a separator, or flotation is still necessary to retain the anaerobic sludge in the system. Good results were obtained with a new kind of floating extruded plastic material of the Bio-net type which has almost the same surface area as the original media. This new material was used in a semi-technical anaerobic/aerobic treatment plant at a winery rack (blenders). A comparison was made between three reactors (completely mixed; fixed-film reactor filled with plastic blocks; and, fixed-film reactor with the floating plastic material), and the results showed that the floating material led to improved sludge retention in the reactor. The TSS of the effluent were 0.2 g/l with the floating material, compared to 3.4 g/l in the completely mixed reactor and 5.6 g/l in the fixed-film reactor with the block material. Further experiments will be carried out to investigate the effects of this new floating material.

WASTEWATER TREATMENT PLANT OF A POTATO-STARCH FACTORY

During the construction of a new potato-starch factory, a KWU anaerobic fixed-film reactor wastewater treatment plant was also constructed. Figure 5 shows the dimensions of the different reactors. The following operating data were the basis for dimensioning (without cleaning water): wastewater flow = 86 m^3/h (2060 m^3/d); average influent COD concentration = 17 000 mg/l; average influent COD load = 34 640 kg/d; average influent BOD_5 concentration = 11 500 mg/l; average influent BOD_5 load = 23 080 kg/d.

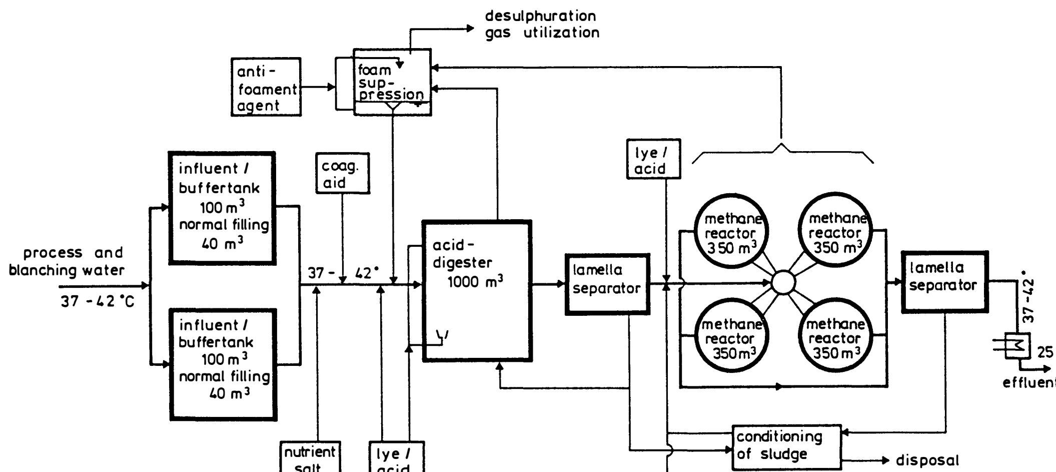

Fig. 5. Flow diagram of the anaerobic wastewater treatment plant of a potato-starch factory (KWU)

The reactors (4 x 350 m^3) were filled with lava slag with a size of about 20/40 mm. The effluent COD and BOD, after a short preliminary experiment, were expected to be: average effluent COD concentration = 3550 mg/l (effluent standard = 4600 mg/l); average effluent COD load = 6900 kg/d (standard = 9480 kg/d); average effluent BOD_5 concentration = 1200 mg/l; average effluent BOD_5 load = 2470 kg/d.

The plant has been operating since autumn 1987, however, only preliminary results can be reported because the starch factory is still in the start-up period. The influent data are in the expected range, but are subject to large fluctuations. The fixed-film reactors are very sensitive to fluctuations. However, since the volumetric load is in the range of 20 - 30 kg COD/m^3·d, this is not surprising. The average efficiency is about 50%, somewhat lower than the 70 - 80% estimated, and data on the effluent from the treatment plant are shown in Fig. 6. This industrial treatment plant receives only 50% of the factory wastewater flow, but 80 to 90% of the waste load.

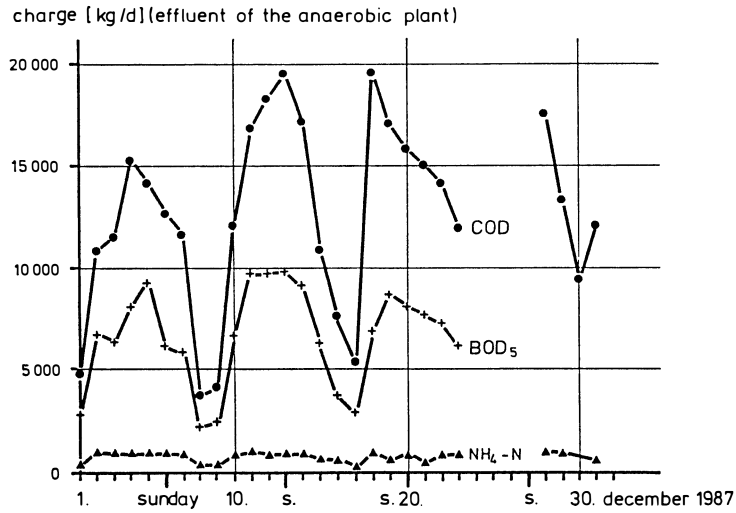

Fig. 6. Operating results (effluent load) of the anaerobic wastewater treatment plant of a potato-starch factory

The plant effluent is treated further at a municipal wastewater treatment plant, which has to treat it to a high level. Therefore, the community was forced to build a large, adequately dimensioned, wastewater treatment plant to treat the anaerobically pretreated wastewater from the factory. This plant consists of a 200 000 m^3 buffer lagoon, four aerated tanks (7500 m^3 each), two final clarifiers, and a polishing pond of 6000 m^3. To date, this municipal wastewater treatment plant had been able to treat the high loads from the anaerobic plant.

WASTEWATER TREATMENT PLANT OF A PECTIN FACTORY

This factory produces various types of pectin depending on the applications required. Pectin has similar properties to polysaccharides and it occurs in nature in the middle lamella between the cell walls of adjacent plant cells. It is used in the food industry as a thickener and as a jelly base (in jam, etc.). At the end of the production process, the water used has to be treated before being discharged to the Baltic Sea.

The wastewater resulting from pectin production contains approximately 100 mg/l pectin and approximately 150 mg/l alcohol. The bulk of the organic matter is comprised of natural compounds such as carbohydrates, protein, organic acids, and lipids. Additionally, the wastewater retains a high concentration of nitrate from the extraction process which uses nitric acid.

An anaerobic stage was designed as the first step in the water treatment process, utilising a 3500 m^3 completely mixed reactor with a detention time of 6 days and a settling tank located after the reactor for sludge recycling (Fig. 7).

Many problems occurred with this system in operation. In addition to the large fluctuations in the concentrations of organic acids, settleable solids, and COD (8 000 - 22 000 mg/l), and in the BOD to COD ratio (0.14 - 0.89) in the influent, the biggest problems were caused by the high levels of nitrate, up to 2500 mg NO_3-N/l. The nitrate caused periods of denitrification and sometimes ammonification in the methane reactor which led to large fluctuations in the COD (between 1000 and 8000 mg/l) of the effluent from the anaerobic stage. To overcome these problems, a three-stage process was developed, based on the results of a research programme.

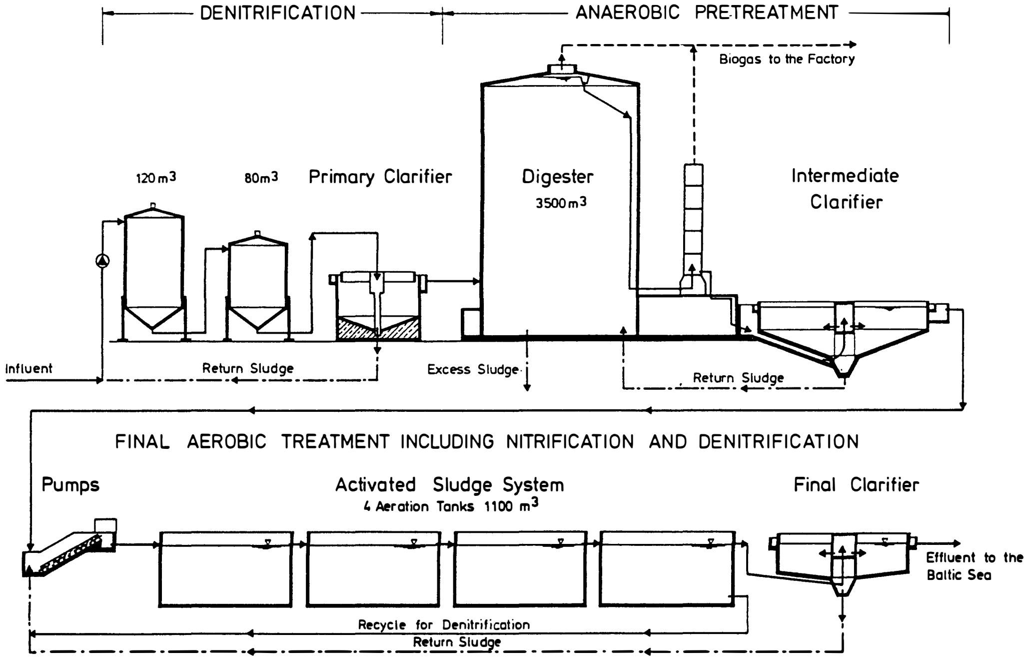

Fig. 7. Flow diagram of the pectin factory anaerobic/aerobic wastewater treatment plant

On the basis of the experimental data, the existing anaerobic treatment process was completed by constructing a pre-denitrification stage and an anaerobic post-treatment. Biomass is recycled into the denitrification reactor from a separator, from which sludge can be withdrawn from the top as well as the bottom, since a significant part of the sludge tends to float due to nitrogen gas bubbles. The process operates at temperatures between 40 and 50°C with a detention time of about 6 hours. The NO_3-N concentration is decreased to between 5 and 30 mg/l, even when the influent concentration is as great as 2800 mg/l. Table 2 shows the average results achieved during a seven-month period. Influent concentrations quite often differ from the values given, depending on the type of pectin being produced.

The aerobic stage produced results which were in the range predicted from the laboratory and semi-technical scale experiments. Nitrification of the remaining ammonia is achieved, but there are still some problems to be overcome, as denitrification has not so far occurred in the first unaerated tank as was planned.

The performance of the anaerobic stage was much improved and more stable when denitrification could occur in a controlled manner in the high rate denitrification stage instead of in the anaerobic reactor itself. At present, the average effluent COD is about 1500 mg/l, whereas before the pre-denitrification stage was added it was about 2700 mg/l.

The results achieved by this plant over 18 months are quite satisfactory, as shown by the average values in Table 2. The denitrification of nitrate prior to the anaerobic stage has led to better and more stable anaerobic treatment, so that operation of the final aerobic treatment stage is now very simple.

TABLE 2 Full-scale Process and Operational Results of the Anaerobic/Aerobic Wastewater Treatment Plant of the Pectin Factory

Treatment stage	Volume, m^3	Area, m^2	Detention time, h	COD, mg/l	BOD, mg/l	NH_4-N, mg/l	NO_3-N, mg/l
Denitrification							
Reactor I	120		4				
Reactor II	80		3				
Separator	165	64	5.5	8500		80	20
Anaerobic Stage							
Reactor	3500		117				
Clarifier	480	175	16	1500	350	230	1
Aerobic Stage							
Denitrification	1100		37				
Aerator	1100		37				
Tank I	1100		37				
Tank II	1100		37				
Clarifier	290	95	10	500	5	1	30-220
TOTAL	9000		300 (12.5 d)				

Influent: flow = 30 m^3/h; COD = 13 500 mg/l; NH_4-N = 30 mg/l; NO_3-N = 1000 mg/l

CONCLUSIONS

The new fixed-film reactor techniques have many advantages but it is necessary to have realistic loading rates to achieve a stable process and high COD removals of over 90%. All full-scale experience has shown that an anaerobic settling tank after the fixed-film reactor is important to retain the anaerobic sludge in the system. External sludge retention is important because the fixed film grows relatively slowly on the fixed-bed material, especially during the start-up period.

REFERENCES

Saake, M. (1986). Abscheidung und Rückhalt der Biomasse beim anaeroben Belebungsverfahren und in Festbett-Reaktoren. Veröffentlichungen des Instituts für Siedlungswasserwirtschaft und Abfalltechnik der Universität Hannover, Heft 68.

Seyfried, C.F. and Saake, M. (1985). Verfahrenstechnik der anaeroben Abwasserreinigung. 3. Hannoversche Industrieabwasser-Tagung. Oktober 1985, Universität Hannover, unveröffentlicht.

Seyfried, C.F. and Saake, M. (1986). Technik der anaeroben Behandlung von Industrieabwasser. Wiener Mitteilungen, Wasser-Abwasser-Gewässer, Bd. 65, C 1-74.

Seyfried, C.F. (1985). Die biologische Behandlung schwieriger Industrieabwässer - Beispiele aus Forschung und Praxis. Korrespondenz Abwasser, 32 (11), 932-939.

Seyfried, C.F. (1988). Der Festbettreaktor. Wiener Mitteilungen, Wasser-Abwasser-Gewässer, Bd. 73, 105-131.

Seyfried, C.F. (1988). Verfahrenstechnik der anaeroben Abwasserreinigung - Theorie und Praxis. Preprints Verfahrenstechnik der mechanischen, thermischen, chemischen und biologischen Abwasserreinigung. 17 - 19 Oktober 1988, Baden-Baden, 99-136.