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EXPERIENCES GAINED IN THE OPERATION OF ANAEROBIC TREATMENT PLANTS IN GERMANY

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ABSTRACT

In the western part of Germany there are 77 full scale anaerobic treatment plants treating industrial wastewater. The ISAH (Institut für Siedlungswasserwirtschaft und Abfalltechnik at the University of Hannover) is or was involved in the investigations, the design and/or operation of 14 of these plants. Some industries (sugar beet, starch, pectin, brewery, vegetable) with their special problems with treating their wastewater anaerobically are described. Experiences of how to handle high nitrate concentrations, to treat a mixture of several industrial wastewaters, to prevent or handle lime, magnesium ammonium phosphate (MAP) or aluminium precipitations are reported.

The first municipal wastewater treatment plant combined with a separate anaerobic stage to treat a wastewater mixture of several small factories is described. Something very special about this plant is the construction of the acidification tank. Using the "teapot effect" to enrich the solid material in the centre of the bottom, the solids can be taken from the bottom of the tank and pumped to the municipal sludge digester.

KEYWORDS

Acidification combined with solid removal; food processing industry (beet sugar, starch, pectin, brewery and mixture of several industries); high rate denitrification; lime precipitations; MAP precipitations.

INTRODUCTION

At the moment (August 1993) there are 77 full scale anaerobic treatment plants in Germany treating industrial wastewaters. Thirty-two plants are working with contact processes (anaerobic activated sludge processes), 14 plants with sludge blanket reactors and 15 plants working with fixed film reactors. The other 16 plants have completely stirred tank reactors (CSTR), self-made constructions, sometimes hybrid reactors or the type is simply not named. The first anaerobic treatment plant for a yeast factory was installed 1959 by the Ruhr-River-Association; it was the first anaerobic contact process in the world.

The ISAH is or was involved in the research, design and/or running of 14 of these anaerobic treatment plants. Some of them are already described in detail by Seyfried and Austermann-Haun (1990, 1992). There is experience with all different kinds of reactor systems. The main subject of this paper is the description of typical problems in different industries, and an overview is given below.

TABLE 1. Anaerobic Wastewater Treatment Plants in Germany

Industry	number	type of reactor system			
		contact	UASB	fixed film	others
sugar (beet sugar)	21	16	2	0	3
paper	11	1	8	2	0
cellulose	8	7	1	0	0
alcohol	7	1	1	2	3
rendering plants	5	0	0	5	0
starch	4	1	0	3	0
potato processing	4	1	0	1	2
fruit + vegetable	3	2	0	0	1
yeast	3	1	0	0	2
slaughterhouses	3	0	0	0	3
fruit juice	1	0	1	0	0
breweries	1	0	0	1	0
dairies	1	0	1	0	0
citric acid	1	1	0	0	0
pectin	1	1	0	0	0
mixture of several industr.	1	0	0	1	0
others	2	0	0	0	2
Total	77	32	14	15	16

TABLE 2. Several Industries with their Special Problems and Problem Solutions

Industry	Special problem	Solution
Sugar (beet sugar)	lime precipitation	cyclone
Starch	precipitation of MAP (magnesium ammonium phosphate)	pH-regulation
Pectin	high nitrate concentrations over 1000 mg N l^{-1}	denitrification before methane reactor
Brewery	great pH variations	equalizing tanks, pH-regulation
	aluminium precipitation in the acidification stage	settling tank
Wastewater mixture of Several industries	different small factories with high loaded wastewater and campaign processing industry	anaerobic pretreatment of the wastewater mixture of a brewery, two vegetable and one fish processing factory at the municipal sewage treatment plant

The last example shows the cheapest way to treat a mixture of high loaded wastewater of different small factories. First results of a municipal anaerobic pretreatment plant which started in 1992 are given.

ANAEROBIC TREATMENT IN GERMAN BEET SUGAR FACTORIES

The sugar industry was one of the first industries in Germany which started to work with the anaerobic treatment of its wastewater. The first methane reactor for a sugar factory started to work in 1979. Until 1982 10 anaerobic treatment plants were running in this industry while there were only three other anaerobic reactors running in other industries. Nowadays over 50% of the sugar factories in the western part of Germany clean their wastewater anaerobically/aerobically.

By saving water and particularly the closing of water recirculation systems, the discharged wastewater could be reduced from 40 m^3 per ton sugar beet to about 0.5 m^3. To keep the water bacteriologically as clean as possible, the pH of the water is adjusted with lime to a pH level of 11, a speciality of the German sugar industry. As a result of the lime dosage the calcium concentrations in the water are in the range of 800 to 2500 mg l^{-1} Ca^{++} depending on the factory. Lime precipitation and incrustations cause problems in all steps of wastewater clarification. Lime precipitation is the reason for the fact that fixed film reactors cannot be used, lamella separators used in methane reactors must be cleaned approximately every three years and only coarse bubble aeration systems can be used in the aerobic stages. Particularly at the inorganic part of the suspended solids (SS) the lime precipitation can be seen. In anaerobic treatment plants running with a pH of about 7.2 it is normal that only 28 to 50% of the SS is organic which means only 28-50% are volatile suspended solids (VSS) at COD sludge loading rates of 0.7 to 1.1 kgCOD $kgVSS^{-1}$ d^{-1}. Our experiences have shown that it is possible to separate lots of lime precipitations by switching a hydrocyclone (Sulzer, Butzbach, FRG) in the recirculation pipe of anaerobic or aerobic systems. The same positive effect could be observed using hydrocyclones in the anaerobic treatment of wastewater in paper factories using waste paper as raw material.

MAGNESIUM AMMONIUM PHOSPHATE (MAP) PRECIPITATION IN ANAEROBIC WASTEWATER TREATMENT PLANTS OF THE POTATO STARCH INDUSTRY

Wastewater of wheat and potato starch factories contains high concentrations of magnesium, nitrogen and phosphate (Table 3). Magnesium, ammonium and phosphate form the slightly soluble salt $MgNH_4PO_4 \cdot 6H_2O$ called magnesium ammonium phosphate (MAP). The formation depends on several factors as there are the concentrations of the elements, the pH, the temperature and the turbulence (Borgerding, 1972). In methane reactors on the one hand the organic nitrogen is changed into ammonium by ammonification, and on the other hand the pH rises by degradation of the organic acids formed in the acidification step. This causes the problem that, especially at places with a higher turbulence (pumps and pipes) or at places with a momentary ascent in pH (degassing of CO_2), MAP precipitation takes place.

Table 3 shows the ammonium, phosphate and magnesium concentrations in the effluent of methane reactors running in a potato and wheat starch factory. The concentration in the original wastewater is called C_o; the concentration in the same water after pH adjustment with NaOH is called C_e. By raising the pH in the batch test MAP precipitation in a N:P:Mg mol ratio of 1:1.4:1.0 takes place without any addition of magnesium or other chemicals.

TABLE 3. Ammonium, Phosphate and Magnesium Concentrations in the Effluent of Methane Reactors of Starch Factories Before and After pH-Regulation

Parameter		Potato Starch Factory			Wheat Starch Factory		
		C_o	C_e	% elimination	C_o	C_e	% elimination
NH_4^+-N	[mg l^{-1}]	436	393	27	641	146	77
PO_4^{3-}-P	[mg l^{-1}]	140	31	78	84	2.3	97
Mg	[mg l^{-1}]	87	9	90			
pH	[--]	6.9	10			9.2	
N:P:Mg mol ratio	[--]	1:0.14:0.12			1:0.9:1.5		

Even at a pH of 7.0 MAP salt is formed. To protect some fixed film reactors running in a full scale anaerobic treatment plant of a potato starch factory (Seyfried and Austermann-Haun, 1990) against MAP precipitations all over the campaign the pH in the methane reactor is kept at exactly 6.9 with hydrochloric acid. The ISAH recommends to connect the methane reactors (lava slag and plastic material) in series and to raise the pH between the two reactors to a level of 9.5 to 10. Only by dosing magnesium all the phosphate and a great amount of the ammonium could be eliminated by forming magnesium ammonium phosphate which reduces the costs of the aerobic post treatment.

If a UASB reactor is used to treat the wastewater of a potato starch factory, MAP precipitation will happen but can be suffered. For this case it is necessary to dose chemicals which prevent coating in pumps and pipes. The MAP crystals are flushed out of the methane reactor and separated in the clarifier of the aerobic stage.

HIGH RATE DENITRIFICATION

Introduction

Some organically high loaded industrial wastewaters are also highly loaded with nitrate because of the usage of nitric (azotic) acid in the production. In a full scale methane reactor (3500 m^3) of a pectin factory operated as a contact process, the sporadic denitrification or nitrate ammonification led to problems with the COD elimination. As a consequence of this the COD in the effluent of the methane reactor varied between 1,000 and 8,000 mg l^{-1} (Seyfried and Austermann-Haun, 1990)

To solve these problems some investigations about high rate denitrification in lab scale and semi technical scale experiences were done. The main questions and research aims were to find more information about

- the influence of different working temperatures,
- the dependence between pH and denitrification capacity,
- the determination of reaction coefficients and design parameters,
- the amount and nature of the excess sludge and
- the suitable kind of reactor system (fixed film reactor, completely stirred tank reactor (CSTR) or activated sludge process (contact process)).

All investigations including materials and methods as well as all results are described in detail by Bode (1985).

MATERIALS AND METHODS

Reactor systems. Completely stirred tank reactor (CSTR), activated sludge process (contact process) and a fixed film reactor with loosely poured swimming curlers NOR-PAC 5/8" (NSW Umwelttechnik, Nordenham, FRG) as support medium with a specific surface of 200 m^2 m^3. The reactor volume was between 6.5 and 15.2 litres.

Substrate. Wastewater from a pectin factory with high nitrate concentrations caused by nitric acid. 11.2-14.9 g l^{-1} COD, 7.0-9.4 g l^{-1} BOD, 1.2-2.7 g l^{-1} NO_3-N; pH 1-2, temperature 65 °C.

Parameter variation. temperature (T) between 30 and 83 °C; pH between 5.5 and 7.7; hydraulic retention time (HRT) between 0.5 and 15 h; nitrate space loading rate between 2.3 and 84.5 kgNO_3-N m^3 d^{-1}).

Most important results of the investigations

Influence of the temperature. Up to a temperature of 62 °C there was complete denitrification. Between 62 and 72 °C an impairment of denitrification could be found and no more denitrification at a temperature over 80 °C.

pH. Complete denitrification only happens at a pH over 7.0 (Fig. 1).

Reactor system. Big problems caused by clogging showed that the fixed film reactor is not suitable for a high-loaded denitrification system. The highest safety in operation was given using the activated sludge system. Complete denitrification up to space loading rates of 19 kg NO_x-N/(m^3.d) at suspended solid concentrations between 8 and 15 g/l could be found using an activated sludge system working under thermophilic conditions.

Sludge characteristics. The flocculation property of the mesophilic sludge was much more better than the thermophilic.

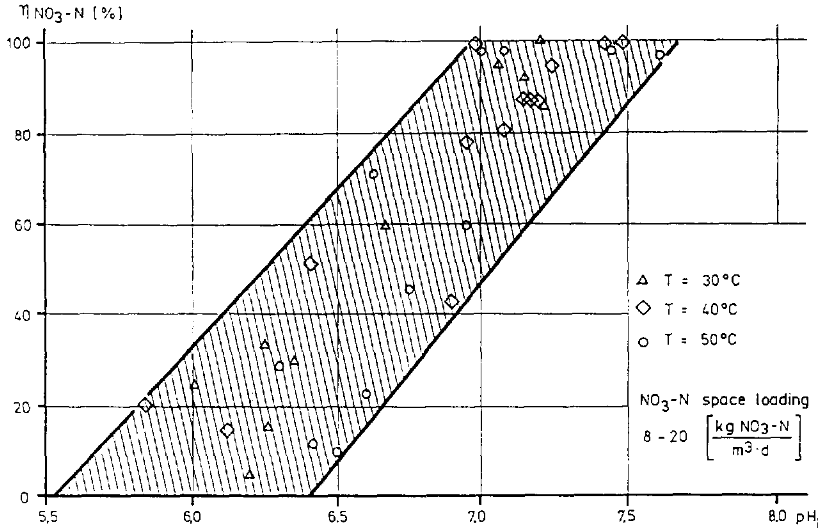

Fig. 1. Relation between NO_x-N elimination and pH in the reactor at different temperatures.

Full scale experiences

Based on the results of the investigations, the existing anaerobic treatment process was adjusted by a high rate denitrification stage, consisting of two denitrification tanks (120 and 80 m^3) and a special separator. This separator is a combination of a flotation tank and a sedimentation tank (Fig. 2), because the sludge sometimes floats and sometimes settles depending on the rest-NO_3. The separated biomass is recycled into the first denitrification tank. The process operates at temperatures between 40 and 50 °C with an inflow water temperature of about 30 °C. The water has to be cooled down after the high rate denitrification to keep a temperature of about 37 °C in the methane reactor.

Table 4 gives some current data about the operating results of the full scale high rate denitrification. The NO_3-N influent concentrations are mostly about 3,000 mg N l^{-1}, the pH-value is between 2.3 and 3. The NO_3-N removal efficiency is always 99% or more and the COD removal efficiency is about 50%.

ANAEROBIC TREATMENT OF BREWERY WASTEWATER

Over a period of one year, semi-technical pilot plants using fixed film reactors with plastic material and a UASB reactor were operated in parallel at a brewery (Birkenstock, 1991). The best results were obtained with a UASB reactor with a COD removal efficiency over 80% at space loading rates between 3.5 and 14.9 kgCOD m^3 d^{-1} and 6.7 kgCOD m^3 d^{-1} on average. The plant proved to be environmentally safer and more efficient than a high rate aerobic pretreatment plant. To reach these very good results we found that the acidification and equalization, the pH-regulation and separation of aluminium precipitation are extraordinarily important.

TABLE 4. Load and Effluent Data of the Full Scale High Rate Denitrification Stage

Parameter	Dimension	Tank 1	Tank 2
Volume	m^3	120	80
HRT	h	4.8	3.2
COD space loading rate	kgCOD m^3 d^{-1}	totally 60	
NO_3-N space loading	kgNO_3-N m^3 d^{-1}	15	0.27
NO_3-N sludge loading	kgNO_3-N kgSS^{-1} d.$^{-1}$	1.2	0.02
Average NO_3-N effluent concentrations	mgNO_3-N l^{-1}	30-40	< 30

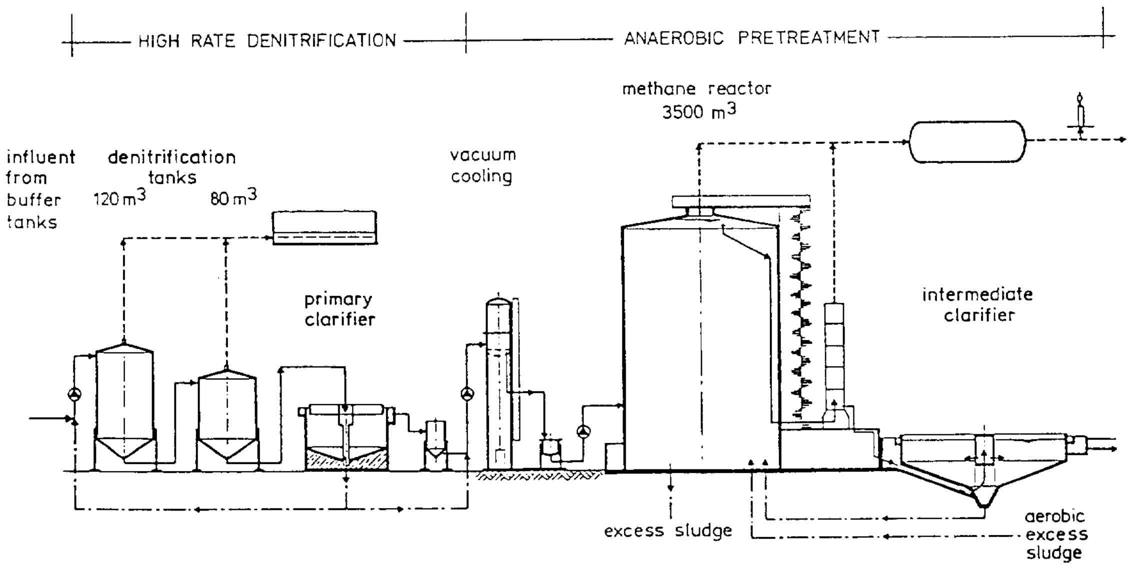

Fig. 2. Flow diagram of the anaerobic part of the wastewater treatment plant of a pectin factory.

A high pH level and great pH variations between 7.1 and 11 (mostly about 10) in the influent of the acidification tank caused some problems. Even at hydraulic retention times of 20 to 27 hours the pH in the effluent of the acidification tank varied between 6.5 and 10.3. The methane reactors ran much more stably from that moment when the pH in the acidification tank was dropped to a level of about 7 with hydrochloric acid.

The raw brewery wastewater (mixture of all wastewater streams) includes aluminium at concentrations of about 12 mg l^{-1} as a result of the metallic coloured bottle necks which are used in Germany for the premium beers. While the pH drops in the acidification tank aluminium precipitation take place. It was found that the very good settleable aluminium precipitation has to be removed by a settling tank because otherwise the granulated sludge in the UASB reactor was covered with the aluminium sludge within a few days. In the effluent of the clarifier the aluminium concentrations were under 1.6 mg l^{-1}. The aluminium content of the separated sludge was about 20 g kgSS^{-1}.

Because there was not enough acidification it was decided to switch another acidification tank after the clarifier. We found that it was necessary to regulate the pH to a constant level of 7 in the influent of the UASB reactor. As a result of these investigations we found optimal hydraulic retention times of 27 hours in the equalization and acidification tank, 3 h in the settling tank, 20 h in the acidification and 5 h in the UASB reactor. The full scale treatment plant, the first one to treat brewery wastewater in Germany, will be built in 1994.

ANAEROBIC PRETREATMENT OF DIFFERENT INDUSTRIAL WASTEWATERS IN ONE PLANT

Introduction

The high loaded wastewater streams of a brewery, a fish factory and two vegetable processing factories are anaerobic/aerobically pretreated in one common stage on the area of a municipal sewage treatment plant. The concept and design was made by the ISAH. The industrial pretreatment began in 1992. The industrial part of the wastewater treatment plant consists of a buffering, sedimentation and acidification tank (270-1125 m^3) with solid matter removal, a fixed film methane reactor (1584 m^3), an anaerobic settling tank (495 m^3, 133 m^2) and a trickling filter (820 m^3). Pretreated wastewater can be added at different stages of the municipal treatment plant which is working with nitrification, denitrification and phosphorous-precipitation (Fig. 3).

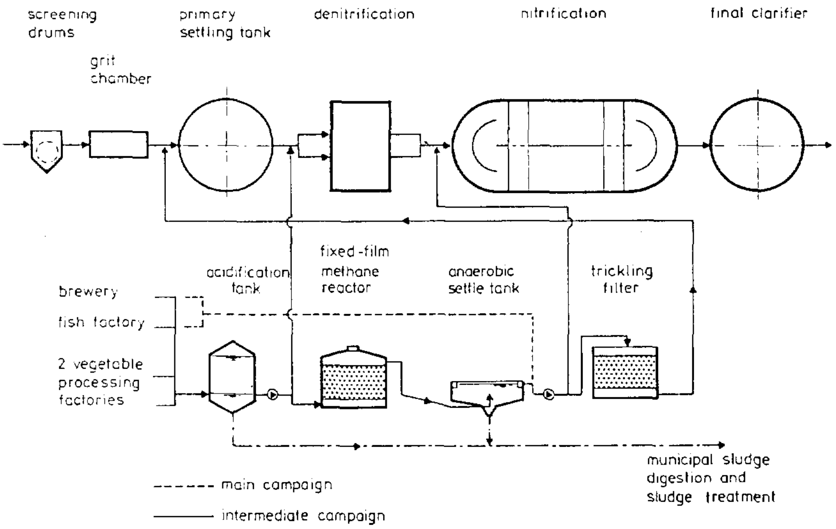

Fig. 3. Flow diagram of the first municipal anaerobic pretreatment of several different industrial wastewaters in one plant.

Wastewater flow and load

The main industrial indirect dischargers are two vegetable processing factories. They work the whole year but they are also campaign industries because the vegetables and the products are changing all over the year and as a consequence of this the wastewater flow and composition varies in a wide range. Vegetable manufacturing can be divided into two periods: the main campaign which lasts from July to December and the intermediate campaign which lasts from January to June. Wastewater flow and load are summarized in Table 5.

During the main campaign only the wastewater of the vegetable processing industry is treated anaerobically. Meanwhile the effluent of the brewery and the fish factory are directly led to the trickling filter (Fig. 3). The rest of the year all industrial wastewaters are treated anaerobically. The design data of the different processing steps are given in Table 6.

TABLE 5. Wastewater Flow and Load of the Main Industrial Indirect Dischargers

Main industries	Campaign July-December Flow [$m^3\ d^{-1}$]	Load [kgCOD d^{-1}]	Intermediate Campaign January-June Flow [$m^3\ d^{-1}$]	Load [kgCOD d^{-1}]
Brewery	230	390	230	390
Fish factory	105	330	105	330
Vegetable processing 1	150	1500	90	260
Vegetable processing 2	230	4000	110	320
Total	715	6220	535	1300

TABLE 6. Design Data of the Anaerobic Treatment Plant

Industrial pretreatment							
Acidification methane reactor							
Campaign				Intermediate Campaign			
Flow m^3/d	Load kg COD/d	OLR kg COD/m^3.d	HRT d	Flow m^3/d	Load kg COD/d	OLR kg COD/m^3.d	HRT d
380	5500	4.5-14.5	0.7-3.2	535	1300	4.5-14.5	0.5-2.3
270	4000	2.5	5.8	380	930	0.59	4.2
Trickling filter							
Flow m^3/d	Load kg BOD/d	OLR kg BOD/m^3.d	SFR m/h	Flow m^3/d	Load kg BOD/d	OLR kg BOD/m^3.d	SFR m/h
840	1110	1.4	1.5	384	325	0.41	1.5

OLR = Organic Loading Rate; HRT = Hydraulic Retention Time; SFR = Surface Flow Rate

Design of the full scale anaerobic treatment plant for different wastewaters

Equalization, sedimentation and acidification tank. The liquid volume in the tank varies between at least 270 m^3 and a maximum of 1125 m^3. This tank has several functions i.e. equalization of wastewater flow and concentrations, acidification and removal of solid material. The solid matter removal is realized by a tangential inflow which induces a motion of rotation in the tank and brings the solids down to the middle of the conical bottom of the tank (teapot effect). The separated solid matter from the acidification tank is led to the municipal sludge digester (flush-out reactor). A part of the acidified wastewater from this tank is directly led to the denitrification tank if there is not enough organic carbon to bring down the nitrate concentrations. This bypass is daily regulated by hand.

Fixed film methane reactor. The liquid volume of the fixed film methane reactor is 1584 m^3. The upper 4.8 m of the volume (34% of the effective volume) is filled with loosely poured swimming curlers called BIO-NET (NSW Umwelttechnik, Nordenham, FRG) as support medium with a specific surface of 100 $m^2\ m^3$.

There is a vacuum degassing unit between the fixed film methane reactor and the conventional anaerobic settling tank. The separated anaerobic sludge can be returned into the methane reactor or pumped into the municipal sludge digester or the post thickener.

Trickling filter. The high-rate plastic media biological filter has the function of a buffer system to obtain stable COD concentrations in the influent of the activated sludge system. The support medium in the trickling filter is called SESSIL (NSW Umwelttechnik, FRG) with a specific surface of 100 m^2 m^3.

Operating results of the full scale anaerobic treatment plant for different wastewaters

Because there is a lack of money for investigations in Germany only a few analytical data are available. Table 7 gives an idea about the load and efficiency of the anaerobic pretreatment. The average data of September 1992 are presented. Only the wastewater of the two vegetable processing factories (607 m^3 d^{-1}) are led to the acidification and the methane reactor. The water of the two fish factories and the brewery (together 224 m^3 d^{-1}) are pumped to the trickling filter. A bypass of 366 m^3 d^{-1} is directly led from the acidification tank to the denitrification tanks of the aerobic plant and 9 m^3 d^{-1} are taken from the bottom of the acidification tank to the municipal sludge digestion plant. In September 1992 on average the acidification tank was filled to 81% of its volume which means 909 m^3.

TABLE 7. Average Data of Wastewater Flow and Load of the Anaerobic Pretreatment Plant in September 1992

Parameter	Units	Acidification	Methane Reactor	Trickling Filter
Flow	m^3 d^{-1}	607	232	456
Temperature	°C	28.5	36.1	24.9
COD space loading	kgCOD m^3 d^{-1}	7.6	1.7	
HRT	d	1.5	6.8	
COD effluent	mg l^{-1}	11,400	2,176	
COD removal effic.	%	--	81	

It can be seen that the system is underloaded and that the design load has not yet been reached. We think that it is possible to lead the whole industrial wastewater to the acidification tank and to the fixed film methane reactor throughout the year. The main discharger, a vegetable processing factory, decided to enlarge the production, which seems to be no problem for the anaerobic pretreatment stage.

CONCLUSIONS

Since 1958 when the first full scale anaerobic wastewater treatment plant started to work, lots of investigations were done in this field which resulted in 77 methane reactors running in the western part of Germany treating industrial wastewater. This overview about experiences gained in the operation of anaerobic treatment plants in Germany shows that each industry has its own specific problems. Investigations have to be done to find solutions. Furthermore it could be shown that it is possible to treat several different industrial wastewaters together in one plant, something very interesting for small factories, especially in the food and/or campaign industry.

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