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UPGRADING AN ANAEROBIC/AEROBIC WASTEWATER TREATMENT PLANT

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ABSTRACT

The given example of an anaerobic/aerobic wastewater treatment plant (WWTP) for a big German brewery shows that it is possible to reduce the discharged values to a very low level, much lower than the minimum requirements of Appendix 11 of the German General Wastewater Administration Rule, which applies to breweries. This means that the present state of technology has been updated.

Tests on a semi-technical scale were carried out and found to be necessary to find the most suitable design for the wastewater treatment plant. Running the tests in the brewery, it became obvious that disinfectants had to be substituted until a stable COD elimination was achieved. Full-scale tests in the plant would not have been feasible. Numerous modifications were carried out in the brewery to reduce the amount of cleaning and disinfectant agents as well as the amount of AOX, EDTA, NTA and aluminium used.

The following article presents the findings of the investigations about the ammonification of organic nitrogen, bulking sludge and substrates for denitrification. Furthermore it demonstrates the low operating costs of anaerobic pre-treatment, even in combination with an aerobic stage and filtration unit.

KEYWORDS

Anaerobic digestion; UASB-reactor; brewery; sand filtration; modifications in the brewery; energy consumption; annual costs; operating costs.

INTRODUCTION

The following article deals with the wastewater treatment of the Licher brewery, which is one of the top 20 breweries in Germany. The content covers first of all background information on the situation which led to the initiation of the project. The tests on semi-technical scale will be discussed followed by the description of the modifications in the brewery which were necessary to prevent the inhibiting of the process of wastewater treatment and also to reduce the damaging impact to the environment. The full scale anaerobic/aerobic wastewater treatment plant will be presented including the design criteria, the effluent data, the removal efficiencies and some specific points of research such as the ammonification of nitrogen, problems with bulking sludge and the investigation of various substrates for denitrification. In conclusion the energy consumption and the operating costs are presented in a detailed table.

INITIATION OF THE PROJECT

Up to November 1994 the wastewater of the Licher brewery was aerobically pre-treated in an equalising tank operating without return sludge. The reduction of COD in the homogenised samples ranged between 60 and 80 %. The effluent from the equalising tank was piped directly to the municipal treatment plant of Lich. Occasionally problems occurred in both plants with bulking sludge. Due to increased governmental restrictions on COD, BOD_5, N and P, the municipal treatment plant had to be modernised. The investment costs were calculated at 47-50 million DM (Birkenstock and Bößendörfer, 1996a) and in total 6-10 workers were required to run the plant. In light of the economic aspects, the brewery decided to build its own wastewater treatment plant. Therefore, in experiments on a semi-technical scale a UASB-reactor and two fixed film reactors were tested simultaneously. The results of these tests determined the design criteria.

After the pilot scale tests had been completed in autumn 1990 application for planning permission for the new plant was submitted and was granted 3 years later. The construction of the anaerobic/aerobic treatment plant took only 13 months. The plant went into operation in November 1994.

The project was conducted by the Institute of Sanitary Engineering and Waste Management of the University of Hanover and aqua consult Ingenieur GmbH, Hanover, with the financial support of the Federal Environmental Agency of Germany.

The aims of the project were: to reduce the wastewater flow, to substitute or reduce the use of substances which have an environmentally damaging impact, to build a wastewater treatment plant which reduces the wastewater concentrations to a scale lower than the minimum requirements of Appendix 11 of the German General Wastewater Administration Rule applicable to breweries. This meant updating the state of technology.

PILOT TESTS ON A SEMI-TECHNICAL SCALE

Over a period of one year (autumn 1989 to autumn 1990) pilot plants on a semi-technical scale were operated at the brewery (Birkenstock, 1991) using fixed-film reactors and a UASB-reactor simultaneously followed by an activated sludge system.

It took some months to find the cause of the poor performance of the anaerobic wastewater treatment system. The COD removal efficiency of the anaerobic reactors was about 80 % in the first week with new pellet sludge. The removal efficiency dropped by about 10 % weekly until an elimination rate of 40 % was achieved. After that the reactors were restarted with new pellet sludge. Analysing AOX it was discovered that some disinfectants used in the brewery caused these problems of decreasing elimination. After the substitution of disinfectant agents containing quaternary ammonia the COD removal efficiency was stabilised.

In the following months the pilot plant had to be modified on several occasions until the optimum was attained. It was determined, that acidification and equalisation, pH-regulation and separation of aluminium sludge were extremely important.

A high pH level and considerable pH variation between 7.1 and 11 (mostly about 10) in the influent of the acidification tank caused some problems. Even at a hydraulic retention time of 20 to 27 hours the pH in the effluent of the acidification tank varied between 6.5 and 10.3. With the additional dosage of hydrochloric acid the pH in the acidification tank dropped to a level of about 7 which stabilised the operation of the methane reactors.

As metallic coloured bottle-neck wrapping was used in Germany for premium beers the raw brewery wastewater included aluminium at concentrations of about 12 mg/l. The drop of the pH in the acidification tank caused aluminium precipitation. The aluminium sludge which had good settling properties had to be separated in a settling tank. Otherwise, the granulated sludge in the UASB-reactor would have been covered with aluminium sludge within a few days. In the effluent of the clarifier, the concentration of aluminium was below 1.6 mg/l. The content of aluminium in the separated sludge was about 20 g/kg SS.

Due to continuing insufficient acidification, a second acidification tank was placed behind the clarifier. It was still necessary to regulate the pH at a constant level of 7 in the influent of the UASB-reactor. This resulted in a COD removal efficiency of more than 80 % at volumetric loading rates between 3.5 and 14.9 kg COD/(m³·d) and 6.7 kg COD/(m³·d) on average. The UASB plant proved to be operationally safer and more efficient than the fixed film methane reactors and the conventional full scale high rate aerobic pretreatment. As a result of these investigations, optimal hydraulic retention times of the following were established: 21 hours in the equalisation tank, 2.5 h in the settling tank, 21 h in the first acidification tank, 4.8 h in the second acidification tank, and finally 5 h in the UASB-reactor. The design of the full scale plant was based on these results.

MODIFICATIONS IN THE BREWERY

Between 1990 and 1996 several modifications were carried out in the brewery in order to reduce different damaging environmental effectings to the environment. Some examples are as follows:

Phosphorous. In 1993 phosphoric acid was replaced by nitric acid and in some other cases the usage of phosporous was reduced to a minimum. In this way the concentration of phosphorous was reduced from 60 mg/l to lower than 20 mg/l.

Cleaning and disinfectant agents. Due to the introduction of a consumption control system within the brewery between 1991 and 1995 the application of cleaning and disinfectant agents was reduced by 60 %.

AOX. The substitution of chlorine bleaching by chlordioxide in the bottle washing machine failed due to reasons of microbiology. Sliver lubricants based on alcylamin salts were substituted by sliver lubricants based on surfactants. This reduced the AOX in the wastewater drastically as 3 to 3.5 tonnes of sliver lubricants were used monthly in the brewery. This substitution caused an increase in the concentration of anionic and nonionic surfactants to values of 1.8 mg/l of anionic surfactants and 2.8 mg/l of nonionic surfactants in the total wastewater flow. This demonstrates that it is practically impossible to find a solution without any damaging effect to the environment. It was possible to reduce the overall AOX-concentration in the effluent of the wastewater treatment plant to values of about 40 to 70 μg/l by changing the sliver lubricants and the application of AOX-reduced paints for the label printing in 1996.

EDTA and NTA. During additional investigations the share of the complex forming EDTA and NTA in the wastewater stream was also reduced by the replacement of sliver lubricants. Thus, the share of EDTA and NTA in the remaining COD of the discharged wastewater was reduced to < 0,04 mg COD/l.

Aluminium. To reduce the aluminium concentrations in the wastewater the metallic bottle neck wrapping of premium beer was changed to paper. The aluminium concentration in the wastewater was reduced from 12 to 2.35 mg/l Al.

FULL SCALE ANAEROBIC/AEROBIC WWTP

In November 1994 the three-stage wastewater treatment plant, which combines anaerobic pretreatment, aerobic treatment with nitrogen and biological phosphorous removal as well as a filtration unit, went into operation. The investment costs amounted to almost DM 24 Mio. Of this, DM 5.57 Mio. were subsidised by the Federal Environmental Agency of Germany.

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 nitrogen and biological phosphorous elimination and a sand filtration. The sedimentation is placed before the acidification I, as acidification occurs in the equalisation tank. Therefore aluminium sludge can be separated before the acidification tank. The excess sludge from the UASB-reactors is collected in a pellet storage with a volume of 300 m³. The excess sludge from the aerobic stage is pumped into a thickener (154 m³) and dewatered in a centrifuge. The reactor volumes of the various stages of the wastewater treatment plant can be seen in figure 2. The equalising tank has enough capacity to store the rain water from the area of the factory. The UASB-reactors run with a continuous velocity of 0.6 m/h. This is achieved by recycling reactor effluent into the second acidification tank. The activated sludge system consists of two activated sludge tanks with circulating flow and two final clarifiers, which operate simultaneously. Because of the low BOD:N-ratio, about 30 % of the activated sludge tank is aerated and 70 % of the volume is used for denitrification. The filtration unit consists of 5 continuous flow sand filter.

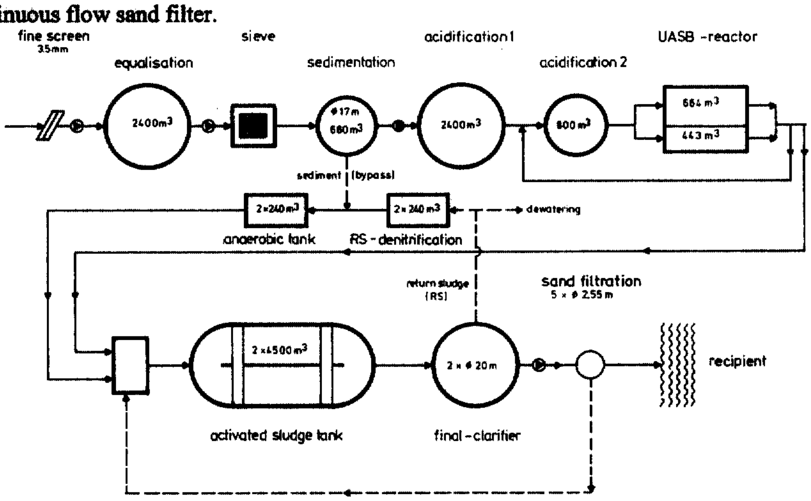

Fig.: 2 Flow diagram of the anaerobic/aerobic wastewater treatment plant in the Licher brewery.

TABLE 1 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 m³/(m² ·h), HRT ⌀ 2.4 h
acidification I	HRT ⌀ 13.2 h
acidification II	HRT ⌀ 5.2 h
UASB-reactors	11 kg COD/(m³ ·d), HRT ⌀ 8.3 h upflow velocity 0.54 m³/(m² ·h)
activated sludge system	0.274 kg BOD_5/(m³ ·d), 0.0684 kg BOD_5/(kg SS ·d)
return sludge denitrification	HRT ⌀ 1.68 h
anaerobic tank for enhanced biological phosphorous removal	HRT ⌀ 1.03 h
final clarifier	flow rate < 1.6 m/h
continuous sand filtration	low rate ⌀ 7.5 m³/(m² ·h), maximum 11.5 m³/(m² ·h)

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

Discharge limits (set down by the government): 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.

Discharge limits (set down by the brewery): COD 50 mg/l, $N_{mineral}$ 9 mg/l, total P 0.5 mg/l. Table 2 shows some average data of 1995, the first year of operation. It is obvious, that the effluent data is not only much better than the governmental discharge limits but also much better than the brewery discharge limits.

Currently, the daily wastewater flow is between 2000 and 3000 m^3/d from Monday to Friday. As there is little or no wastewater on Saturday and none on Sunday, the daily flow in 1995 was 1640 m^3/d on average.

TABLE 2 EFFLUENT DATA OF DIFFERENT STAGES OF THE ANAEROBIC/AEROBIC WASTEWATER TREATMENT PLANT (AVERAGE)

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 rises in the various stages of anaerobic pretreatment.

Trace elements in the raw wastewater were observed. The average concentrations were: 19.45 mg/l K, 131 mg/l Ca, 41.67 mg/l Mg, 1.91 mg/l Fe, 0.11 mg/l Zn, 0.074 mg/l Mn, 2.35 mg/l Al, 0.1 mg/l Cu, 0.013 mg/l Ni, 0.0056 mg/l Co, 0.024 mg/l Cr, < 0.0005 mg/l Mo, < 0.001 mg/l Se. It is obvious that there is a lack of molybdenum and selenite. Up to now molybdenum and selenite have not been dosed. Only iron is dosed into the acidification tank II to an amount of 10 liters $FeCl_3$/day which raises the Fe content by about 1.16 mg/l on average.

50 to 80 % of the filtered COD in the effluent of the acidification I are organic acids. These are mainly acetic and propionic acids in a relation of 0.9:1. Nevertheless the amount of pellet sludge increases. During the last two years hydrochloric acid has had to be dosed only twice. Firstly when there was a loss of NaOH in the brewery and secondly when the acidification I was not in operation. Because the volume is so high in the equalising and acidification tanks, in the influent of the UASB-reactors no pH correction is necessary although pH varies in the influent.

During the last two years, the sludge loading rate of the UASB-reactors has been about 0.19 kg COD/(kg VSS ·d) on average. In the future it will be raised by reducing the sludge content. The plant was designed for a daily COD load of 14,400 kg/d; the average load was 3,800 kg/d in 1995 and 3,400 kg/d in 1996. Based on the two years of operation the specific anaerobic excess sludge production is 14 g VSS/kg $COD_{eliminated}$ which is 18.5 g SS/kg $COD_{eliminated}$ (VSS content = 73 % on average). There is almost a constant sludge content of 25 to 35 g SS/l between the sample points of 0.5 and 4 m from the reactor bottom.

The methane content in the biogas has always been between 86 and 93 % with a value of 89 % on average. The high alkalinity, based on the usage of NaOH in the bottle washing machine in the brewery, is likely the reason for the linkage of CO_2 in the biogas.

The only critical point of the discharge limits 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 for denitrification is insufficient. The following is dosed into the activated sludge system: an ethanol-water-mixture (COD ≈ 180,000 mg/l, BOD_5 ≈ 114,000 mg/l, total N ≈ 2.3 mg/l), which is a by-product of the production of non-alcoholic beer, the sludge from the primary clarifier (called bypass), the flushing water from the sandfiltration, the water from the thickener and the centrifuge. Between 1995 and 1996 the amount of ethanol-water and bypass was raised to a level of 2.2 m^3/d ethanol-water and 344 m^3/d of sediments from the primary clarifier. Under these conditions about 7 % of the BOD in the influent of the activated sludge system results from the anaerobically pretreated wastewater, 66 % from the bypass (16 % of the total flow) and 25 % from the ethanol-water-mixture resulting in a COD:BOD:N:P-ratio of about 20:9.5:1:0.26.

TABLE 3 EFFLUENT DATA OF THE WASTEWATER TREATMENT PLANT

PARAMETER	UNIT	APPENDIX 11 (breweries)	DISCHARGE LIMITS SET BY GOVERNMENT	DISCHARGE LIMITS SET BY BREWERY	EFFLUENT DATA OF THE WWTP 01.01.96-31.08.96		
					90 % sum*	100 % sum*	2-h-** mixed samples
COD_{homog}	mg/l	110	90	50	28	34	21.8
$BOD_{5\,homog}$	mg/l	25	20	20	3.9	6.3	3
NH_4-N	mg/l	10	10	10	0.2	2.1	0.2
$N_{mineral}$	mg/l	n.d.	18	9	8.3	9.1	7.5
N_{total}	mg/l	n.d.	n.d.	n.d.	10.8	14	12.1
P_{total}	mg/l	2	1	0.5	0.4	0.6	0.4
SS	mg/l	u.r.	n.d.	u.r.	6	14	1.2

$N_{mineral}$ = NH_4-N + NO_3-N + NO_2-N; N_{total} = $N_{mineral}$ + N_{org}; u.r. = under reservation; n.d. = no demand; * daily self control (24-h-samples); ** samples taken from the authorities;

TABLE 4 TOTAL REMOVAL EFFICIENCIES OF THE WASTEWATER TREATMENT PLANT

PARAMETER	UNIT	DESIGN DATA	DISCHARGE OF EQUALISING TANK 01.01.96-31.08.96			ELIMINATION	EFFICIENCY
			minimum	maximum	average	kg/d	%
Flow	m^3/d	4,970	543	3,051	1,514	--	--
COD	kg/d	9,940	287	8,844	4,748	4,708	99.2
BOD_5	kg/d	6,585	191	6,386	3,3380	3,375	99.9
$TKN_{filtr.}$	kg/d	129.5	24.2	116.6	71.2	56.1	78.8
P_{total}	kg/d	99.4	3	64	31	30.5	98.4

POINTS OF RESEARCH

Ammonification of organic nitrogen into ammonia in the anaerobic stage. During the tests on a semi-technical scale in 1990, there were problems 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 various wastewater streams from the different parts of the brewery as well as the basic products and process materials such as label glue were tested. The results of the tests showed that only 35-50 % of the organic nitrogen of yeast was anaerobically 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). There was no ammonification of organic nitrogen of the finished beer. In all other cases and all wastewater streams no problems occurred.

Sliver lubricants, cleaning and disinfectant agents. Batch tests were carried out on all cleaning and disinfectant agents as well as on sliver lubricants, which are used in the brewery, to determine whether they have inhibiting effects on anaerobic and aerobic COD degradation as well as on ammonification. The concentrations, which showed inhibiting effects during testing, are much higher then the actual concentrations of agents, used in the brewery.

Bulking sludge in the activated sludge system. Between January and August 1995, the sludge volume index (SVI) was between 70 and 80 ml/g, despite the very low sludge loading rate. From August to December the SVI climbed to 200 ml/g. The main filament organisms which were detected, were 021N, 0041, *haliscomenobacter hydrossis*, 0092 and 1851. To reduce the SVI to values lower than 100 ml/g, $FeCl_3$ was dosed to an amount of 1.1 l $FeCl_3/m^3$, which means 209 g Fe/m^3. This raised the iron concentration in the activated sludge to 10 %. As a consequence of this, 021N disappeared. The SVI depends on the dosage of iron. When 19 to 57 g Fe/m^3 is dosed, the SVI is between 80 and 115 ml/g. Total filament abundance comes into the category 4 on a scale of 1 to 7. The iron dosage has no effect on the amount of filament organisms of the types 0041, *haliscomenobacter hydrossis*, 0092 and 1851. Due to the iron dosage, there is no further enhanced biological phosphorous removal. Continuous flow lab scale experiments showed the same filamentous organisms. Lab scale experiments showed that the SVI depends on the oxygen concentration. After raising the oxygen concentration to a level of 2, the SVI was below 100 ml/g. In the full scale plant it is necessary to keep the oxygen concentration in the aerated zones at a level of about 1.5 mg/l, because otherwise it is impossible to reach sufficient anoxic zones in the activated sludge tank with circulating flow, which is necessary for denitrification.

Substrates for denitrification. In batch and continuous flow lab scale experiments, several substrates were tested to find the most suitable one for denitrification. The following substrates were tested: raw wastewater taken from the equalising tank, sludge from the primary clarifier, acidified wastewater from the acidification tank I and an ethanol-water-mixture from the light beer production with a COD of about 180,000 mg/l. The lowest COD:N-ratio of 3-4 mg COD/mg N occured using the ethanol-water-mixture. Batch tests showed that the use of the acidified water from the full scale plant, rather than ethanol-water doubled the specific amount of COD, only acetic and propionic acid were used for denitrification. The other substrates caused a higher COD:N-ratio. In all cases filamentous bacteria were found. The type and amount of filamentous organisms varied according to the following: sludge loading rate, oxygen concentration and the substrate used for denitrification. The highest SVI occured using the ethanol-water-mixture. The lowest was achieved using the raw wastewater out of the equalising tank. It can be concluded that there is no ideal substrate for denitrification.

TABLE 5 FILAMENTOUS ORGANISMS FOUND IN LAB-SCALE EXPERIMENTS USING DIFFERENT SUBSTRATES FOR DENITRIFICATION

CARBON SOURCE	FILAMENTOUS ORGANISMS
ethanol-water-mixture	types 021N, 0041, 0092, 1851
raw wastewater taken from the equalising tank	dominant type 0092 and *H. hydrossis*, types 0041 and 021N subdominant
sludge from the primary clarifier	dominant type 0092 and *H. hydrossis*, types 0041 and 021N subdominant
acidified wastewater out of the acidification tank I	types 021N, 0041, 0092, 0803, 1851

Energy consumption and operating costs. The total energy consumption of the anaerobic/aerobic wastewater treatment plant is 2.62 kWh/m³ wastewater or 1.58 kWh/kg BOD_5 removed. In 1995 on average, 74.5 % (average from January to August 1996 = 68,3 %) of this energy consumption was covered by the energy which is produced from biogas. This leads to an energy demand of only 0.67 kWh/m³ or 0.4 kWh/kg BOD_5 removed. The treatment plant is directly controlled in the factory by automatic data transfer. Only one person works a few hours a day in the plant when the sludge is dewatered. Analytical control is carried out in the brewery. Table 6 shows an overview of the annual costs.

As a consequence of this, the specific operating costs for the current wastewater flow are 2.04 DM/m³ (560,000 m³/a) respectively 1.17 DM/kg BOD_5 (975,000 kg BOD_5/a). Including capital costs the total specific costs are 5.16 DM/m³ respectively 2.97 DM/kg BOD_5. This is inexpensive considering the high quality of the discharged water. In the future the specific costs will be reduced considerably, when planned full capacity is reached.

TABLE 6 ANNUAL COSTS [DM/ANNUM]

Capital charges	1,750,000 DM/a
Maintenance	300,000 DM/a
Electricity	30,000 DM/a
Consumption $FeCl_3$, coagulation aid, chemicals and materials for the lab e.g.	240,000 DM/a
Sludge disposal	150,000 DM/a
Gas	60,000 DM/a
Personnel costs	300,000 DM/a
Administration	40,000 DM/a
Tax	1,000 DM/a
Wastewater charges	20,000 DM/a
Total annual operating costs	2,891,000 DM/a

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