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WASTEWATER TREATMENT AT MODERATE TEMPERATURES USING UASB REACTOR

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Abstract:-
The use of anaerobic biodegradation to treat municipal wastewater is a promising technology, because of the relatively low capital expenditures required and the potential to create biogas, which can be used as a source of energy. The UASB reactor is a high-rate system that operates as a suspended sludge blanket system with granular sludge growth system. Treatment occurs at the contact of the up flow passing wastewater with the sludge blanket at the bottom of the reactor and produced biogas is collected at top of the reactor. The effluent could be used for irrigation, because the included nutrients are not affected by the treatment. Much more interesting at actual time are renewable energies and the retrenchment of CO2-Emission. With the anaerobic treatment of municipal wastewater not only the CO2-Emission could be reduced but also gained "clean" energy supply by biogas. Most important for the sustainability of this process is the gathering of methane from the liquid effluent of the reactor, because the negative climate-relevant effect from the outgassing methane is much higher than the positive effect from saving CO2Emission. In this study UASB reactors were used with a flocculent sludge blanket for the biodegradation of the carbon fraction in the wastewater with different temperatures and concentrations. The SMA was determined and evaluated; also the biogas emission was controlled. Also a static modelling for COD fractioning and SMA was done. It could be shown, that the positive effect is much higher for municipal wastewater with high concentrations in hot climate.

Keywords: - *UASB reactors; municipal wastewater; flocculent sludge; COD-Balance, methane solubility; greenhouse effect*

INTRODUCTION

The greatest challenge in the water and sanitation sector over the next two decades will be the implementation of low cost sewage treatment that will at the same time permit selective reuse of treated effluents for agricultural and industrial purposes. Developers should base the selection of technology upon specific site conditions and financial resources of individual communities.

The anaerobic treatment of domestic organic waste is widespread in many countries, particularly in warm climates. Because these countries often lack of energy, the focus lies not on the environmental protection but on the energy recovery in form of biogas. If the municipal wastewater is even treated, aerobic techniques are most common and so energy is required. Opposite to this way, the anaerobic treatment of municipal wastewater not only produces highly demanded energy but also supports the environmental protection.

In a Joint project with other German research institutes funded by the Federal State Ministry for Education and Research (BmBF) the task of ISAH is the investigation of the anaerobic process as environmental sound technique for the treatment of municipal waste water. Therefore three UASB-reactors are installed at the experimental laboratory of ISAH in pilot and half technical scale. This type of reactor is already approved for the treatment of industrial waste water. The same reactors were moved to Cairo to be tested under the moderate temperature in Zenin WWTP in Giza. All results mentioned in this paper taken form the pilot plant built in Hannover. Afterwards these results were compared and confirmed in compliance of the results received from the tests of the same reactors in Cairo.

Table 1: Degradation of nitrogen and phosphorus in the treated municipal wastewater, with granulated sludge from the anaerobic wastewater treatment plant of a distillery as the inoculum of the USAB reactor (Abdel-Halim, 2005)

temperature	total nitrogen elimination		total phosphorus elimination	
[°C]	[%]	[mg/L]	[%]	[mg/L]
30	16.9	10.5	3.6	0.4
20	10.1	6.3	3.4	0.3
14	8.8	5.5	3.2	0.3

The main objective of the project was next to the cleaning of the wastewater in particular the production of biogas as an energy source as well as the reclamation of the nutrients (i.e. nitrogen and phosphorus) contained in the waste water as fertilizers in agriculture. For this the anaerobic treatment is predestined as the fraction of N and P passes almost unabated the reactor. As given in Table 1 only a small amount is used for the anaerobic metabolism by the microorganisms.

Material and methods

The experimental place of ISAH is situated at the municipal WWTP of Hannover– Herrenhausen. Therefore fresh municipal wastewater is collected and pumped in the UASB-pilot plant. Also the pilot plant located in Zenin WWTP was also fed with a fresh wastewater. The investigations are carried out with raw and presettled complex municipal waste water, which composition is characterized in Table 2. The values shown hereafter are the average values received by the UASB overall the testing periods in Hannover. Toxic or inhibiting substances are not included. The reactors were inoculated with flocculent sludge of the anaerobic digester of the municipal WWTP. This inoculum is also used for the SMA-batchtests (Specific Methanogen Activity) which are executed at the ISAH and is well known. The average SS is 25 g/L with an organic fraction of 66%. Toxic or inhibiting substances have not been detected during the SMA tests.

Table 2: Composition of the municipal wastewater at the WWTP Hannover-Herrenhausen after primary settlement (Hinken, 2005; Sperling et al, 2005; DWA, 2000)

Source	COD [mg/L]	BOD [mg/L]	TOC [mg/L]	NH_4-N [mg/L]	org. N [mg/L]	tot. P [mg/L]
WWTP Hannover-Herrenhausen	573.3	279.1	143.5	40.4	21.9	9.9
Sperling et al, raw	600	300	-	25	20	7
Sperling et al, modified with A-131	450	225	-	25	18	6

Pilot Plants

The pilot plant consists of two identical and parallel operated reactors with belonging periphery like pumps, gas meters and power units. As shown in figures 1 and 2, the UASB-Reactors are made of PVC with a height of 1600 mm and a volume of 0.115 m^3 of which effective volume 0.095 m^3 are useable for the sludge blanket.

For each reactor, the input was pumped with a flexible-tube pump and could be varied form nearly 0-0.75 m^3/d. Moreover, the input was tempered by an external heat exchanger within 10°C–25°C. To raise the upstream velocity, and if necessary run the recirculation, a second flexible-tube pump was on standby.

Effluent tanks were installed to quantify the daily volumetric load of the reactors. The produced biogas was measured with drum type gas meters.

Table 3: Measured Parameters in the pilot plants

Measuring Point	Measured Parameter
Influent	SS, total and dissolved COD, pH
Reactor	SS; VSS, Temp, pH
Biogas	Q, CH_4, CO_2
Effluent	SS, total and dissolved COD

Analytics

The analytics during the operation of these pilot plants were focussed on the carbon fraction of the wastewater. The prior experiments at ISAH have shown that there is an adequate supply of nutrients through the wastewater. Table 3 indicates the whole range of examined analyses

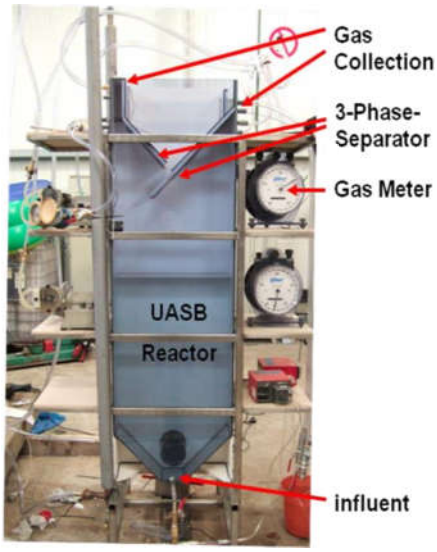

Figure 1: Photo of the UASB Reactor

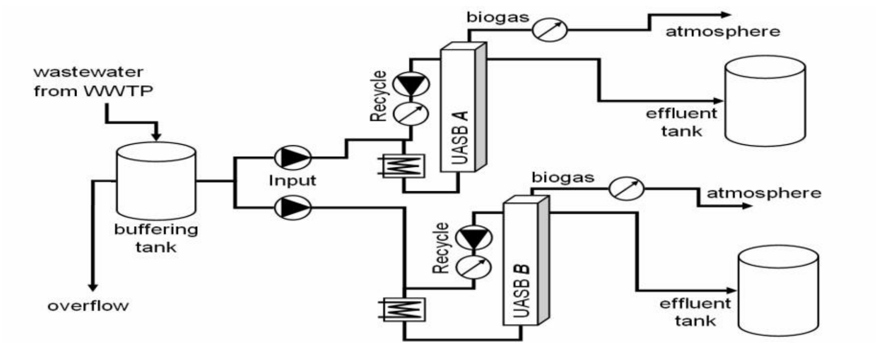

Figure 2: Flow scheme of the pilot plant at ISAH experimental place

Results and discussion

Table 4 shows the results from 400 days of operation of both reactors. In the start-up phase the inoculum was treated with high upstream velocity to wash out the suspended solids, and accumulate the flocculent parts of the sludge. The recycle was reduced to a maximum upstream velocity of v_{up} of 0.9 m/h afterwards. The HRT was constantly reduced in both reactors to determine the achievable minimum. In the penultimate phase this was achieved with an HRT of 4 h. After this, the HRT was raised again to 10 h.

Table4: Selected operation data from the reactors (Mean values from both plants)

phase	HRT [h]	SLR [kgCOD/(kgVSS·d)]	CH_4 [L_N/kgCOD$_{rem}$]	Temp [°C]	COD-eliminaton [%] tot.	diss.	part.
1 start-up	31	0.11	152	25	70	74	67
2 start-up	25	0.13	255	23	59	55	62
3 steady state	25	0.14	247	25	65	63	66
4 steady state	17	0.12	207	26	70	64	75
5 steady state	9	0.14	222	25	66	73	59
6 max. load	4	0.33	209	22	56	65	48
7 low Temp.	10	0.12	287	21	60	77	47

After the first start-up phase, in which the inoculums from the anaerobic digester had to adapt to the conditions in the UASB-tanks reactors, a methane-yield of more than 200 L_N CH_4/kg $COD_{removed}$ was reached.

COD fractioning

For the interpretation of the results the total COD_{tot} is fractionated as follows:

$$CODtot = COD\ part + CODdiss + CODCH4 \quad \text{(Equation 1)}$$

Where:

- COD_{part}, (particulate COD), calculated as the difference of COD_{tot} and $COD_{diss,tot}$ minus $COD_{CH4,\ gas}$
- COD_{diss}, (dissolved COD), calculated as the difference of $COD_{diss.tot}$ and dissolved methane as $COD_{CH4,diss}$
- COD_{CH4}, (methane as COD), calculated as the sum of $COD_{CH4,\ gas}$ (measured methane in biogas) and $COD_{CH4,diss}$

With these fractions was generated a simplified balance model of the anaerobic COD- elimination within the UASB reactor on the following assumptions:

- COD_{part} will remain mostly in the reactor and partially be hydrolysed, but a part of it is washed out depending on HRT
- The remaining fraction of the COD_{part} will be disintegrated and hydrolysed to COD_{diss} in the reactor.
- COD_{diss} will be, according to the maximum SMA of the sludge, converted to COD_{CH4}

With these assumptions the COD degradation could be confirmed by the balance model with a total error of lower than 10 % (relating to the total COD-Elimination).

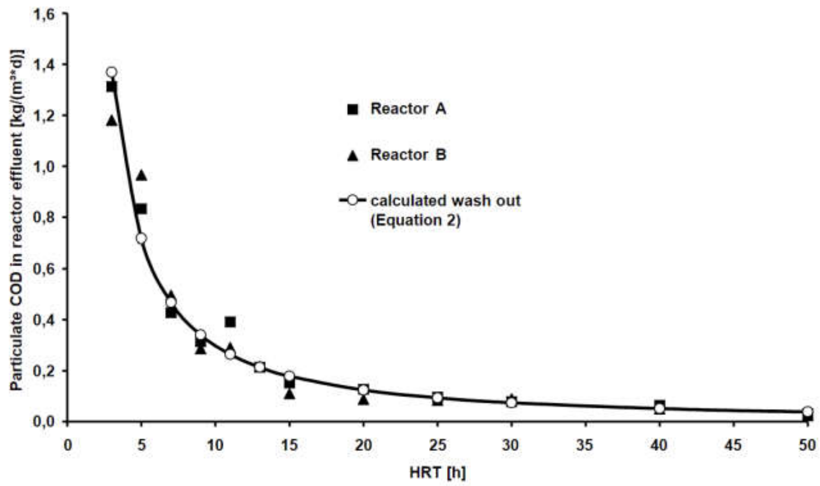

Figure3: CODpart in reactor effluent

Wash-out of particulate COD_{part}

The wash-out of the COD_{part} depends above all on the HRT. In order to quantify the amount of cash-out of COD_{part}, the empirical equation from Sperling et al (2005) was transferred from effluent solids concentration to the load of COD_{part}. Equation 2 and Fig. 3 provide the modified formula for the washed out COD:

$$\mathbf{LCOD,\ part = 5{,}9 \cdot VReactor \cdot HRT(-1{,}294)} \qquad \text{[kg/d] (Equation 2)}$$

Equation 2 describes the inverse proportional dependency of the particulate, washed out COD load from HRT which is confirmed by the comparison of the measured COD load in both reactors and the calculated washed out load of COD_{part} (figure 3.)

Disintegration and hydrolysis of COD_{part}

The COD_{part} which remains in the reactor will be partially disintegrated and hydrolysed to $COD_{diss,hydr}$. The size of this fraction depends on the VSS/SS –ratio and is mainly influenced by temperature. The HRT does not affect this process because the UASB works as a sedimentation tank and therefore the solid retention time (SRT) is decoupled from HRT. With a VSS/SS-ratio of 0.67 the amount of transformed COD can be calculated on the basis of Dimowski, 1981:

$$\mathbf{LCOD,\ diss,hydr. = LCOD,\ part,\ retained \cdot 0,\ 06\ T\ (0,\ 67)} \text{ [kg/d]} \qquad \text{(Equation 3)}$$

Moreover, this $COD_{diss,hydr}$ and the COD_{diss} from the input are an available source for the Conversion into methane.

Biological degradation of COD_{diss} to CH_4

The specific methanogenic activity (SMA) and the amount of biomass in the reactor, measured as VSS, are the basic parameters which affect the maximum degradation from COD_{diss} to methane. The temperature also influences this process, as shown in the modified Arrhenius-equation by van Haandel and Lettinga (1997)

$$K(t) = K_{30} \cdot 1.11^{(T-30)} \qquad \text{(Equation 4)}$$

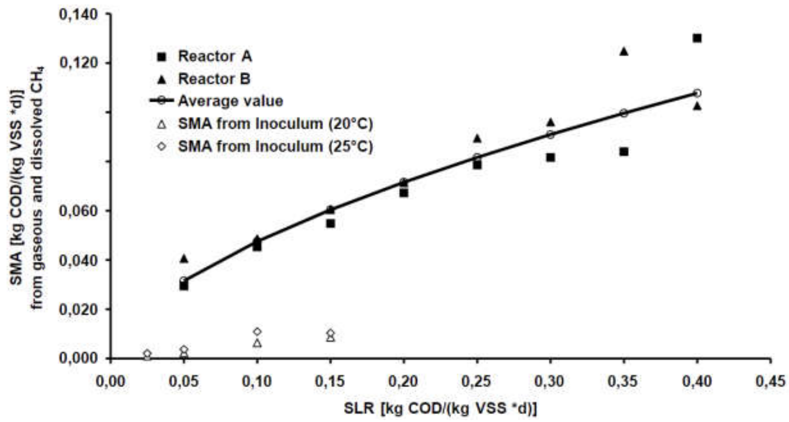

Figure4: Specific methanogenic activity (SMA)measured with SMA-batch tests and UASB pilot plant

Preliminary SMA-batch tests, carried out before the start-up phase, showed that the degradation rate of the inoculum, while treating municipal wastewater, is affected less than given in Equation 4 (Fig.4).Instead of the empirical factor 1.11 in equation 4 a factor of 1.08 was calculated from the SMA-batch tests. Figure 3 also indicates the SMA obtained from the pilot plant operation in dependency of SLR.

A comparison of both SMA has main two interesting aspects:

- Within the temperature range of 21-26°C by pilot plant operation the observed temperature influence on SMA was very low.
- The SMA determined from the pilot plant is 6 times higher than the SMA of the batch-test with the inoculum from the digester, which is caused by the adaption of the inoculum to the municipal wastewater which has a higher contingent of easily degradable dissolved COD than excess sludge in the digester.

On the basis of the data shown in Figure 3 the SMA is set in correlation to the Sludge Loading Rate (SLR). In conjunction with the amount of VSS in the reactor the biodegraded COD_{diss} per day can be calculated:

$$\mathbf{LCOD,\ CH4. = LVSS \cdot 0{,}185\ SLR\ (0,\ 59)} \text{ [kg/d]} \qquad \text{(Equation 6)}$$

Comparison of measured and calculated COD-Removal

Fig. 5 shows the measured COD-elimination of each 7 pilot plant operation phases (black column). For comparison the calculated COD elimination, based on the above defined fractioning, is added (dashed columns). Also the deviation between these values is given in this Figure.

To calculate the COD elimination only 5 parameters have to be measured: volumetric load [m³/d], COD [mg/L] (fractionated in COD_{part} and $COD_{diss,tot}$), Temperature [°C] and volatile suspended solids [kg VSS]. With these parameters could also be determined all other values like HRT or SLR.

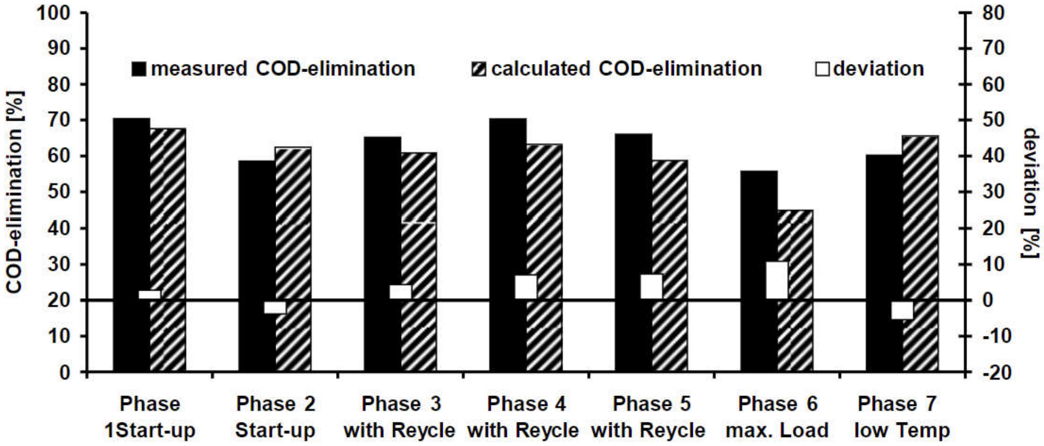

Figure 5: Comparison between measured and calculated COD removal

For all phases is perceptible a good correlation between the measured and calculated values. In phase 6, with the maximum load, and therefore limited degradation efficiency, the deviation rises up to 11 %. With decreasing HRT usually the SLR increases, and the biomass exceeds its maximum SMA. But based on the necessary contact time between the COD_{Diss} and the biomass, HRT becomes the limiting factor.

Greenhouse effect of the dissolved methane

Besides carbon dioxide, methane is one of the major greenhouse gases with a 21-times higher Global Warming Potential (GWP) (European Commission, 2001), so it is essential to consider the $CH_{4\ emission}$ of the reactors.

The methane in the produced biogas is collected and burned in a combined heat and power plant to gain electricity and heat. Moreover, as municipal wastewater could be labelled as a “renewable” raw material, a “negative” GWP could be attributed to this part of methane. Total different is the situation of the dissolved methane in the liquid phase. Depending on temperature, Henry´s Law and the biogas composition, up to 35 mg/L CH_4 (rsp 140 mg/L COD) could be dissolved. Within the pilot plant operation values between 20 – 25 mg/L CH_4 were reached.

To enhance the amount of “negative” GWP with anaerobic WWT as much CH_4 as possible has to be collected and used for energy production. Table 5 gives the greenhouse gas emission for three different scenarios. The first scenario is the basic scenario of wastewater treatment in Germany with an emission of nearly 40 kg CO_2/(P*a). If wastewater is treated with a plant comparable to the described pilot plant a small surplus in form of “negative” GWP could be gained. If we try to use the most energy-efficient strategy to treat the wastewater, a surplus of negative 25 kg CO_2/(P*a) could be reached (as shown in the second scenario).

Table5: Greenhouse gas emission of WWTPs at different treatment scenarios (Process data base: Keller and Hartley (2003); Greenfield and Batstone (2005))

Treatment scenario	kg CO_2/ kg (COD resp. N)	kg CO_2/ (Person * a)
1: basic scenario:		
activated sludge (C-Elimination)	1,44	42,05
activated sludge (N-Elimination)	6,58	24,02
mesophil anaerobic digestion of sludge	-1,10	-26,50
total emission		**39,57**
2: anaerobic treatment with ANAMMOX		
psychrophil anaerobic digestion	-1,36	-44,68
ANAMMOX	2,47	9,02
aerobic post treatment	1,44	10,51
total emission		**-25,15***
3: anaerobic treatment for irrigation, without usage of dissolved biogas		
psychrophil anaerobic digestion	-1,36	-44,68
dissolved CH_4 in WWTP Effluent (CO_2-equivalent due to GWP)		38,63
total emission		**-6,05**

* This calculation bases on the supposition, that all dissolved CH_4 in the effluent could be used. With no use of the dissolved CH_4 the plant would emit 13.48 kg CO_2/(Person * a)

Equivalent produced energy = 11.1 (fuel value*) per m3 wastewater per day based on average 67% methane concentration. 40 % of this value could be taken as clean electricity. * Fuel value according to (ATV-DWVK, 2002; Bischofsberger et al, 2004; Pesta, 2004).

I.e. for a 500 m^3/d anaerobic wastewater treatment plant (5000 P.E.) treats similar municipal wastewater concentrations (500-600 mg/L COD "550"):

The Produced methane gas = 500 x 67 = 33500 L/d (33.5 m3/d).

The produced energy from biogas = 148.75 KWh/d

- Energy demand for UASB reactor = 0.08** KWh/kg $COD_{removed}$

= 0.08 x (550x500/1000)

= 22 KWh/d

** According to (TBW-GTZ, 2001)

Therefore, the excess electricity production can be used for feeding of the equipment's, pumping, and machines in the plant (assumed to be 70% of that of HH wastewater treatment plant; 0.7 x 0.42 KWh/m3 influent wastewater). - Energy demand for the plant (exclusive UASB) = 0.7 x 0.42 x 500 = 147 KWh/d and 169 KWh/d in total. I.e. the energy produced from the biogas can cover ca. 88% of the total required energy.

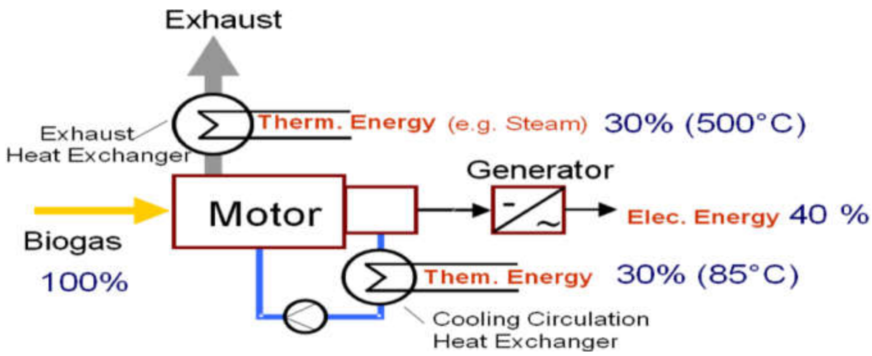

Figure 6: Conversion of Biogas into Energy

If methane gas is not used for bioenergy generation, it must be combusted (flared), otherwise the CH4-gas stripping will influence the global warning and greenhouse effect. To prevent that a part of methane may be taken as a carbon source for denitrification process (if N-removal is applied).

Conclusion

The sma-batch tests as well as the operation of the pilot plant showed that digested sludge is absolutely adequate as inoculum for UASB-based treatment of municipal wastewater. Though sludge granulation wasn't achieved in the pilot plant, the SMA of the established sludge was after the start-up phase 6 times higher and reached over 50 % of the activity of granulars (measured in Abdel-Halim, 2005).

Although the SMA of the flocculent sludge is lower, the flocculent sludge blanket has a main advantage compared to Granulars. The flocculent sludge blanket works as a filter bed, retains solids, prevents the wash-out and hydrolysis them. After over 400 days of pilot plant operation basic parameters for the COD balance of anaerobic treated presettled municipal wastewater were evaluated. As next these static design parameters should be implemented in a dynamic model of the process in this case.

the combination of the biological process with the physical process of the three-phase- separation would be the main challenging point. Until now there is only a narrow range for the temperature from 21°C - 26°C. Future operations with the next generation of the pilot plant are running with wide range of reactor temperature to represent correct the influence according to the Arrhenius-equation.

With the effluent a relevant part of the produced methane leaves dissolved and at present unutilised the reactor. This means not only a loss of energy but also, due to the high GWP of methane, a huge emission of greenhouse gas. The CO_2-Balance of the treatment- system would be effective improved by the use of the dissolved methane from the effluent. This could be done by stripping the methane from the effluent and the reusing for combustion. This and other studies show, that the anaerobic treatment of municipal wastewater should be considered as environmental sound alternative to "standard" aerobic treatment. The development of these anaerobic treatment should be pushed consequently, especially regarding the focus on the reduction of greenhouse gases.

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