

UASB reactor followed by constructed wetland and UV radiation as an appropriate technology for municipal wastewater treatment in Mediterranean countries

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Abstract

This paper describes a new wastewater treatment concept which was assessed to be technically and economically feasible for suburban and rural areas in Mediterranean countries. The treatment consists of a two-step anaerobic high-rate reactor like UASB reactor followed by vertical flow constructed wetland (CW) and UV radiation. It fulfills the defined criteria, as meeting the standards for water reuse, costs especially for energy are low, sewage sludge production is limited and operation and maintenance are simple.

Although there are much experience and data available about design and operation of CW and UV radiation, the knowledge about anaerobic treatment of municipal wastewater in UASB reactor at moderate temperature is limited. Therefore bench-scale experiments with pre-settled high-strength municipal wastewater were carried out in a one step UASB reactor of 55 liters. The results show a satisfactory effluent quality at fluctuating HRT. During 9 months of continuous operation, total COD removal was 46% and 60% with HRT of 8 to 16 hours and more than 24 hours, respectively. Below an HRT of 24 hours, the removal of suspended solids was limited, sludge wash-out took place due to fluctuating HRT. The removal of colloidal COD was satisfying with around 60% for all HRT. These results indicate that combined with a second high rate anaerobic reactor and/or a settler after the UASB reactor, constructed wetland and UV radiation, an adequate tertiary effluent for water reuse in irrigation will be achieved.

Keywords

constructed wetland, water reuse, anaerobic treatment, high rate anaerobic reactor, UASB

INTRODUCTION

In Mediterranean countries (MEDA-countries) with serious water shortage, the reuse of treated wastewater is increasingly demanded for different purposes like agriculture and tourism. In rural areas there is often a lack of energy and skilled personnel to run conventional activated sludge systems successfully. Appropriate wastewater treatment with low running costs, easy operation and producing a safe effluent for water reuse purposes are urgently needed.

The EMWater Project (Efficient Management of Wastewater, its Treatment and Reuse in the Mediterranean Countries) aims at increasing efficiency and effectiveness in the wastewater management in the MEDA countries by helping decision makers in choosing the most suitable and

appropriate technology. The beneficiary MEDA-countries of this project are Jordan, Lebanon, Palestine and Turkey. The project has been funded by the EC under the EU-MEDA “Regional Program for Local Water Management” and is co-funded by the German Ministry for Economic Co-operation and Development (BMZ).

Specific tasks being implemented consist in the elaboration of regional policy guidelines for wastewater treatment and reuse, the design and the construction of pilot plants applying appropriate and low cost techniques for demonstration and training purposes, the definition and implementation of an adapted training and capacity building programs (local, regional and web based) for technicians, engineers and employees of authorities and non-government organizations in the field of wastewater treatment and reuse (local stakeholders and professionals).

In this paper, a wastewater treatment cycle for municipal wastewater is presented that was assessed to be appropriate for suburban and rural areas in Mediterranean climate in terms of fulfilling the requirements for long term sustainability and water reuse in irrigation. This treatment concept will be applied on the pilot plant in Turkey within the EMWater project.

The feasibility of the primary anaerobic step was investigated at the Institute of Wastewater Management at Hamburg University of Technology (TUHH) in preliminary experiments. The main objective was to study the performance of a single UASB reactor for the treatment of municipal pre-settled sewage with an average COD concentration of 500-600 mg/l at temperatures of around 20°C. The effect of fluctuating HRT was further investigated.

THE WASTEWATER TREATMENT SYSTEM

In order to assess an appropriate treatment concept for the MEDA-countries and thus for the pilot plant in Turkey, an evaluation was performed as first step. The following criteria were found to be most important for long term sustainability of water reuse concepts in suburban and rural areas of the MEDA countries:

- Affordable; especially low operation costs
- Operable; operation must be easily possible with locally available staff and support
- Reliable; producing a safe effluent for water reuse
- Environmentally sound; little sludge production and low energy consumption
- Suitable in Mediterranean climate (average wastewater temperature in Istanbul 23°C in July and 15°C in January)

The treatment cycle as shown in figure 1 was assessed to fulfil sound these criteria for the following reasons. The operation costs are very limited, consists mainly of pumping costs, no aeration is necessary which represents usually the major financial part. Maintenance can easily be done and educated to local staff.

As primary treatment, the anaerobic step provides physical as well as biological treatment with a very low sludge production, less than 10% of conventional systems with activated sludge. Sludge disposal which often causes further pollution can be better managed because the sludge is simultaneously stabilised within the high rate reactor (Halalsheh 2002). Its discharge is only necessary once or twice a year and can be applied on the fields according to agricultural needs. Depending on the ambient temperature, one or two high rate reactors, e.g. UASB are required. Because of limited hydrolysis below 15°C, a first reactor is designed to enhance hydrolysis (Sanders et al 2000). Elmitwalli (2000) reported that at a temperature of 13°C an anaerobic filter followed by a UASB reactor is a suitable system for the treatment of domestic sewage.

The small settler after the UASB reactor is designed for investigations about sludge wash-out. Lettinga (2005) proposed such a settler as complementary removal device for suspended solids after the UASB reactor as substantial further improvement in its performance.

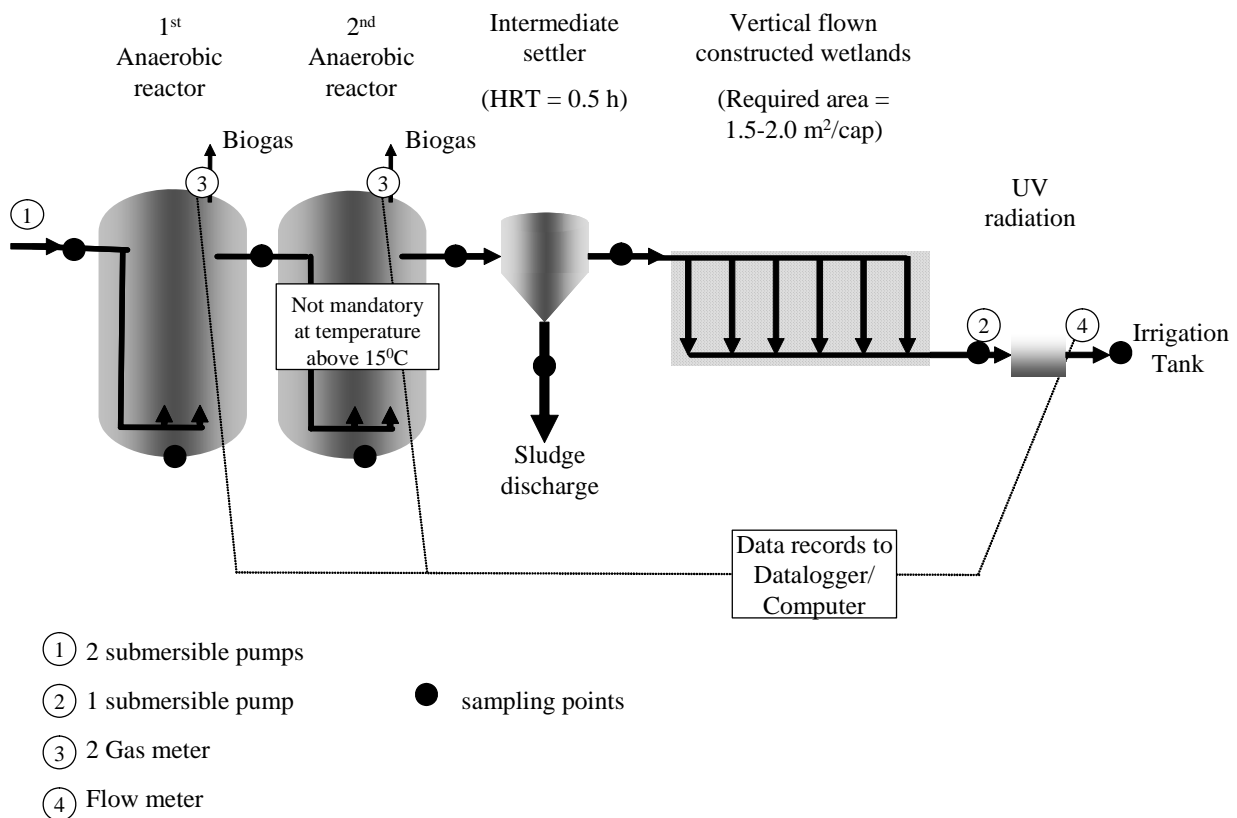


Figure 1. Treatment system for the pilot plant in Turkey

As secondary treatment, constructed wetlands (CW) were chosen to be the basic unit. CW act as biofilters combining physical, chemical and biological treatment and are especially suitable for low diluted water flows (US EPA 2000, Masi 2005) as many plants prove, e.g. CW realised within the SWAMP project (funded by the EU) (SWAMP 2002). Sousa et al (2001) and El-Khateeb and El-Gohary (2003) showed that submerged as well as free water CW are suitable to treat anaerobic effluents to total COD of 60 and 70 mg/l respectively. In the last years, vertical flow CW were developed in Europe which provide aerobic conditions due to intermittent feeding and a better performance than submerged beds or free water CW. Moreover, the vertical flow CW require less space than the other types of CW and other natural systems (Masi 2005). Due to high HRT the operation is reliable and can cope with fluctuating influent flows and temperature. CW need a start up phase of about three months to achieve a reliable effluent standard in terms of COD and TSS reduction. As tertiary treatment, UV radiation as an environmentally sound technology is selected for disinfection because most of the reuse standards require a disinfection step for safety reasons like the WHO guidelines (Mara & Cairncross 1989).

This treatment cycle is not designed to remove nutrients as for irrigation the nutrients like nitrogen, phosphorus and potassium can additionally fertilise the plants when applying the treated water on the fields.

There are sufficient experiences and data available about the treatment performance of CW and UV radiation for municipal wastewater even in cold climate. But there is only limited research on the applicability of UASB reactors at moderate and cold temperature. Since anaerobic treatment efficiency is highly dependent on the temperature, further research at moderate temperature was performed in the following preliminary experiments.

PRELIMINARY EXPERIMENTS

Material and methods

The experiments were carried out at TUHH to get preliminary results for the operation of the Turkish pilot plant. A UASB reactor with a total volume of 55 l was built of PVC with a diameter of 0.15 m. The scheme is shown in figure 2.

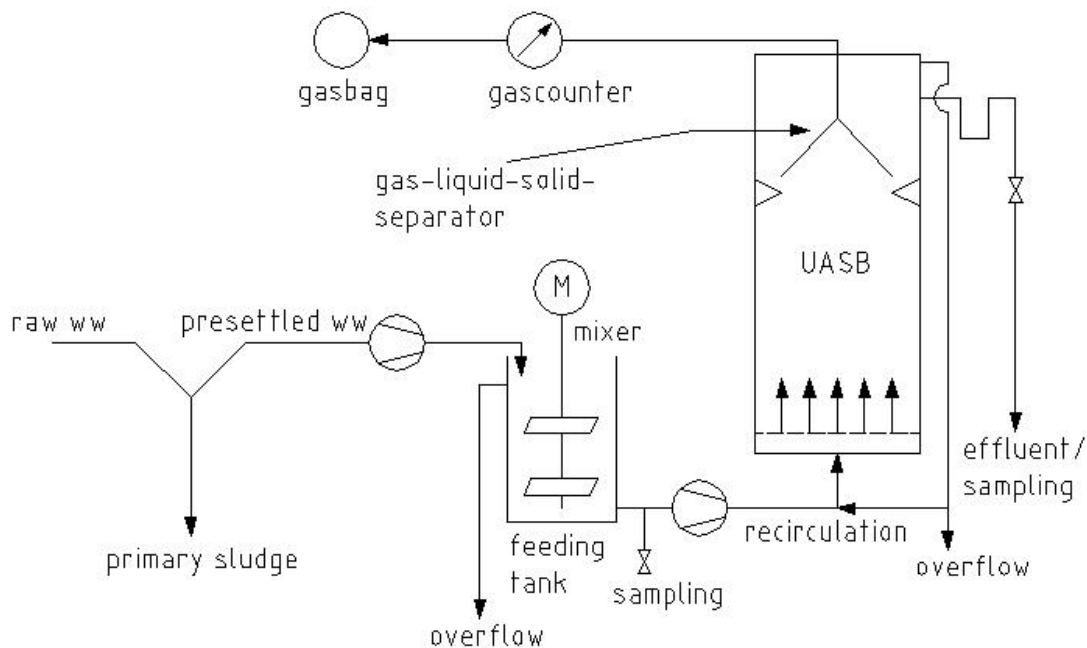


Figure 2. Scheme of the UASB reactor

As influent, raw and pre-settled municipal wastewater from the city of Hamburg was taken. Its characteristics are shown in table 1. The UASB reactor was started with inoculum from a mesophilic digester for primary and secondary municipal sewage sludge and operated continuously 4 months as start-up phase.

For determination of anaerobic biodegradability a batch experiment was carried out firstly. Therefore 100 l of raw wastewater was recirculated for more than 10 days with an upflow velocity of 0.25 m/h. Secondly, the UASB reactor was operated continuously for 9 months with pre-settled wastewater. During the last 4 months, influent and effluent were analysed twice a week (two hours composite samples). The COD was analysed as COD_{total} , COD_{diss} ($< 0.45 \mu m$), COD_{coll} ($0.45 < COD < 25 \mu m$) and COD_{ss} ($> 25 \mu m$) with analytical cuvettes. TSS, NH_4 and TN were measured as described in Standard Methods (APHA 1995).

During the investigation period, no sludge was discharged. The reactor temperature was operated at the ambient temperature, between 18 and 25°C. Due to the local conditions, it was not possible to control the upflow velocity so that the HRT was fluctuating between 3 hours and more than 24 hours during the investigation period.

Results and discussion

Influent characteristics

The influent wastewater is a typical municipal wastewater with high domestic influence and low diluted due to limited drinking water consumption which is in Hamburg 113 l/(cap*d) (HWW 2005). These wastewater characteristics are also typical for rural areas of water limited regions like the MEDA-countries.

Table 1. Characteristics of raw and pre-settled wastewater, average values in mg/l with standard deviation

	COD total	COD diss	COD coll	COD ss	TOC	Total N	NH₄-N	TSS
Raw wastewater	1005 ± 134	209 ± 59	264 ± 70	450 ± 134	271 ± 32	96 ± 24	62 ± 15	240 ± 83

Anaerobic biodegradability

Within the batch recirculation experiment, the maximal anaerobic biodegradability can be calculated. In table 2 the removal ratios are given. Colloidal, dissolved COD, NH₄-N and TSS were not measured explicitly. The total COD removal is 85% and in the typical range for municipal wastewater with high domestic influence. There is a very good correlation with TOC.

Removal of colloidal COD is often limited in single UASB reactors. However, COD_{coll+diss}-removal in this UASB reactor of 79% is a high value as compared to that reported by Wang (1994), Elmitwalli (2000) and Mahmoud (2002). This high removal of COD < 25 µm might be due to difference in the definition of colloidal COD. They defined that COD_{coll} ranges between 0.45 µm and 4.4 µm and not 25 µm.

Suspended COD is removed to a major part (86%), but still the effluent was not clear which is a drawback of anaerobic treatment of municipal wastewater. Even reaching the maximal anaerobic biodegradability a post-treatment is required to produce a high quality clear effluent.

Table 2. Anaerobic biodegradability

	COD total	COD coll+diss	COD ss	TOC	Total N	NH₄-N	TSS
Maximum Removal	85 %	79 %	86 %	82 %	18 %	-	-

The removal of total N is in the usual range of anaerobic treatment, N is needed for biomass production and is therefore found in the suspended particles.

COD and TOC removal

Figure 3 shows the COD mass balance in the raw wastewater, influent and effluent of the UASB reactor. The sludge-COD was not measured but calculated based on the raw wastewater-COD. As expected there is a significant removal of COD_{ss} in the sedimentation step but only limited removal of COD_{diss} and COD_{coll}. In the UASB reactor there is almost no further removal of COD_{ss} but COD_{diss} and COD_{coll} is converted to CH₄ and anaerobic sludge as seen in figure 3.

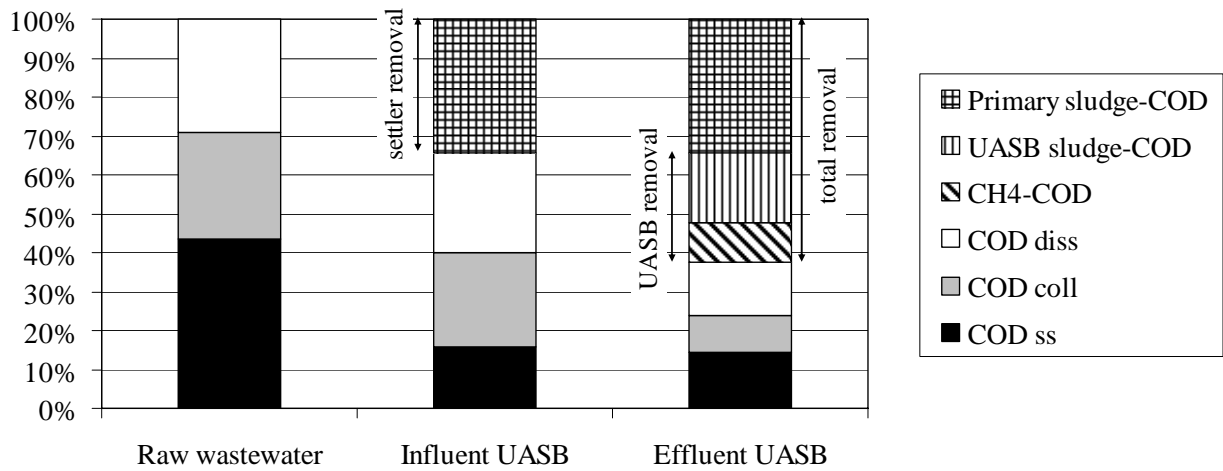


Figure 3. Mass balance for COD

When looking on the effluent characteristics (table 1) there is a high variation in all parameters which are caused by the significantly fluctuating HRT. Therefore the removal efficiency of the UASB reactor was analysed according to HRT (see table 3).

Table 3. COD and TOC removal with standard deviation

	HRT of UASB reactor in hours (h)			
	3 - 8 h	8 - 16 h	16 - 24 h	24 - 30 h
COD total	27% ± 24%	46% ± 19%	47% ± 19%	60% ± 11%
COD diss	40% ± 12%	43% ± 21%	40% ± 25%	40% ± 20%
COD coll	61% ± 24%	62% ± 22%	40% ± 29%	66% ± 15%
COD ss	sludge washout		55% ± 36%	64% ± 39%
TOC	29% ± 30%	42% ± 18%	39% ± 24%	39% ± 15%
Expected COD total after additional settler	53% ± 24%	60% ± 16%	61% ± 13%	70% ± 6%

The high standard deviations show a high variation in the COD removal. However, the trend becomes obvious, the COD removal for HRT > 16 hours was very good with COD_{total} of 47% and 60% respectively. The total COD removal is comparable to that reported by Halalsheh (2002) in the treatment of concentrated sewage in a one step UASB reactor at moderate temperature. Although it was already pre-settled wastewater, a very good removal of COD_{coll} of 40% and 66% was achieved. Even at

HRT below 16 hours, the removal of COD_{coll} of 61% and 62% was very high. This confirms the results of the anaerobic biodegradability test (see table 2). The difference compared to other research may be due to the different definition of colloidal COD. Due to the unstable conditions, there was a significant wash-out of COD > 25 µm at HRT < 16 hours.

As COD consists of settleable solids (> 25µm), addition of a settler after the UASB reactor, as proposed for the pilot plant in Turkey (figure 1), will result in removal of the washed COD_{ss} from the UASB reactor. Accordingly, COD_{total} as high as 60% can be achieved at UASB-HRT of 8-16 hours with a settler addition after the UASB reactor.

The UASB reactor showed a stable and efficient removal of COD_{diss} (40-43%) at different HRTs. Compared to the anaerobic biodegradability of COD_{coll+diss} (see table 2) and values of 54% and 65% for domestic wastewater from Last & Lettinga (1992) and Elmitwalli et al. (2001), there is still an anaerobic removal potential of COD_{diss} of more than 11%. Therefore, a two-step UASB reactor will result in a higher removal efficiency of COD_{diss}.

TOC represents the organic substances similar to COD, but does not correlate always to the total COD values. For the COD analyse more volume of water (some ml) is needed than for determination of TOC (one drop). As influent and effluent contain considerable amounts of suspended solids, the COD measurement is therefore more reliable.

Nitrogen removal

Nitrogen as main nutrient in domestic wastewater is not removed by sedimentation or anaerobic digestion as you can see in table 1. This was expected as nutrient removal is not required for further reuse in irrigation. The increase in NH₄-N during the treatment is caused by the conversion of organic nitrogen to ammonium, due to protein hydrolysis.

Biogas composition

The biogas produced in the UASB reactor contains 80% methane, 16% nitrogen and 4% CO₂ which are typical concentrations for a high rate anaerobic process applied on municipal wastewater. Similar values can be found in Elmitwalli (2000).

CONCLUSIONS

The evaluation indicates that high-rate anaerobic treatment like the UASB reactor followed by constructed wetlands and UV radiation is an appropriate and cost efficient wastewater treatment for suburban and rural areas of the MEDA-countries. If adapted to ambient temperature, it is an easy operable and sustainable treatment cycle.

The preliminary experiments with pre-settled high strength wastewater show that at ambient temperature around 20⁰C and a fluctuating HRT between 3 and 30 hours, the removal of COD_{total} is varying between 27% and 60%. To obtain a stable performance it is however recommended to keep the HRT stable. Improved with a second high rate anaerobic reactor and/or an additional settler after the UASB reactor, this treatment concept with CW and UV radiation is expected to meet the standards for water reuse in irrigation. Nutrient removal is not an issue in this context because nutrients like N, P and K can partly replace the use of chemical fertiliser.

Further detailed research about the anaerobic treatment of municipal wastewater under Mediterranean conditions are recommended and will be carried out in the pilot plant in Istanbul, Turkey, within the EMWater project.

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