The Application of Anaerobic Filter for Municipal Wastewater Treatment*

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This paper presents results of the lab-scale anaerobic filter and pilot-scale units of anaerobic baffled filter used for municipal wastewater treatment by low temperature. The lab-scale reactor had a volume of 1.7 dm^3, being operated at hydraulic retention time (HRT) of 12 h and 24 h. The wastewater temperature was adjusted at 23 °C, 15 °C, and 9 °C, respectively. After almost one year of continuous monitoring, the lab-scale upflow anaerobic filter system produced very good results in terms of COD and BOD_5 removal, and also very low solids concentration in the final effluent. The average results of COD and BOD_5 removal varied from 41 to 95 % in dependence on temperature and values of hydraulic retention time.

The pilot-scale experiments were realized in anaerobic baffled filter with total volume of 2 m^3. This reactor was installed on wastewater treatment plant (WWTP) Bratislava-Petržalka and was fed with raw wastewater under HRT of 24 h. The start-up and operation of anaerobic filter was executed under winter climate condition (September 1998—March 1999). The observed COD and BOD_5 removal efficiency was in average 66 % and 68 %, respectively. Very high efficiency was achieved for suspended solids removal – 95 %.

From total 2871 settlements in Slovakia, only 400 of them (these represent *ca.* 53 % of the country population) have own WWTP. Nearly all bigger cities and towns have WWTP; the biggest lack of them is in small settlements. However, in these small communities live quite a large percentage of the population (people living in 1952 settlements with less than 2000 inhabitants represent *ca.* 30 % of the country population). Therefore, it is obvious that there will be a demand to build up a couple of hundreds of small WWTPs. Such situation is valid also for the other Central and Eastern European countries.

For the purpose to find economically and technologically suitable WWTP, our research was aimed also at the use of anaerobic reactors for treatment of municipal wastewater. This technology has been used quite often in recent years mainly in regions with warmer climate. For example, Mexico, Columbia, India, and China have built up a couple of larger WWTPs of this type [1—4].

The development of high-rate reactors redounded to the application of anaerobic treatment of diluted substrates, for example, domestic and municipal wastewater. The key concept of high-rate reactors is based on three fundamental aspects [5]:

– accumulation of biomass by means of settling, attachment to solids (fixed or mobile) or by recirculation. Such systems allow the retention of slowly growing microorganisms by ensuring that the mean solids retention time becomes much longer than the mean hydraulic retention time,

– improved contact between biomass and wastewater, overcoming problems of diffusion of substrates and products from the bulk liquid to biofilms or granules,

– enhanced activity of the biomass, due to adaptation and growth.

To this reactor technology belong, for example, anaerobic contact process, anaerobic filter, downflow stationary fixed-film reactor, upflow anaerobic sludge blanket reactor, fluidized bed reactor, expanded bed reactor, anaerobic baffled reactor, *etc.*

Anaerobic filter (AF) is filled out with a support material arranged in sheet, ring or sphere conformation which provides the best conditions for microbial attachment in biofilm form. The reactor may be operated in upflow or downflow feed mode. Upflow anaero-

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Table 1. Experimental Results Obtained in Municipal and Diluted Wastewater Treatment

General parameters				Influent			Efficiency[a]			
V	θ	HRT	Bv	ρ^{COD}	ρ^{BOD5}	ρ^{SS}	η^{COD}	η^{BOD5}	η^{SS}	Ref.
m^3	°C	h	kg m^{-3} d^{-1}	mg dm^{-3}	mg dm^{-3}	mg dm^{-3}	%	%	%	
0.01	–	17	–	690—890	–	130—340	34—40	–	59—64	[11]
0.016	18—35	24	0.05—0.54	77—1170	44—573	60—543	73	75	73	[9]
3.0	11—25	20—33	0.2	–	176—221	63—213	–	70	–	[7]
10	15—20	2.5—10.5	0.05—0.61	–	60—220	200—250	–	43—63	70—83	[10]
16	22—24	8.6—37	–	–	150—220	62—114	–	81—87	91—97	[12]
102	10—25	12—18	–	132—390	–	–	28—64	57	80	[12]

a) The efficiency evaluated from nonfiltered influent and nonfiltered effluent values.

bic reactor (UAF) is the oldest type of packed reactor first described by *Young* and *McCarty* [6].

The advantages of AF are as follows [7, 8]:

– The method is suitable for the treatment of low-strength soluble organic wastewater;

– sludge is not returned in difference to the anaerobic activated sludge process;

– the amount of produced sludge is smaller and settleability of the sludge is good;

– the solid retention time can be increased so that an efficient treatment can be performed at low water temperatures;

– relatively good load fluctuation resistance;

– maintenance and management are easy.

The disadvantages of AF are as follows [5, 8]:

– Channelling, *i.e.* formation of preferential paths of liquid flow through reactor;

– dead-zone formation caused by sludge compaction or clogging of matrix interstitial spaces by solids;

– clogging of poorly designed distribution systems.

The efficiency of AF treating municipal and domestic wastewater and the biomass production depends on the character of substrate (character of pollutants and their concentration, suspended solids concentration), temperature, and the characteristic of support material like the specific surface, porosity, and the shape.

Since a little biogas is produced in the treatment process of such diluted substrate, it is economically not effective to use this small amount of biogas for heating, in particular for small WWTPs. This is the reason why it is important to realize the treatment under climate condition.

Some experimental results obtained in the laboratory and pilot scale by treating municipal wastewater are summarized in Table 1.

EXPERIMENTAL

The study of treatment abilities of anaerobic filter was performed in two scales: in the lab-scale and in the pilot-scale models.

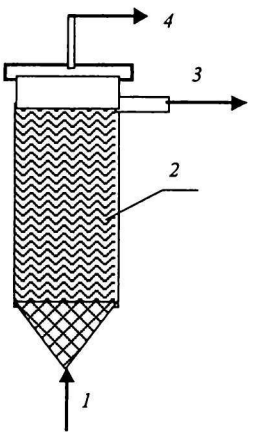

Fig. 1. Laboratory model of upflow anaerobic filter. *1.* Influent, *2.* support material for biomass growth, *3.* effluent, *4.* biogas.

In the lab-scale model, an upflow anaerobic filter (UAF) was used with volume 1.72 dm^3 (Fig. 1). A plastic material (cut isolating tubes of diameter 2 cm and a length of 2—3 cm) filled out the whole volume of the reactor. We studied the treatment abilities under different temperatures (9 °C, 15 °C, and 23 °C) and two different HRT values (24 h and 12 h).

The pilot-scale reactor was a baffled reactor with total volume of 2 m^3 (Fig. 2). Because of the relatively high content of suspended solids (SS) and possibility of clogging of the filling material, the first part of reactor was established like a settler. Here the undissolved organic and inorganic particles were settled down. The accumulated sludge was stabilized here, too. The next four chambers were filled out by plastic filling (0.7 m^3). The size of the plastic filling was changed through the reactor. The wastewater was passing through the reactor alternatively up and down.

During both these experiments we monitored influent and effluent parameters – temperature, pH, COD, BOD_5, SS, volatile fatty acids (VFA), NH_4^+, P-PO_4^{3-}. These parameters were analyzed using the standard methods [13].

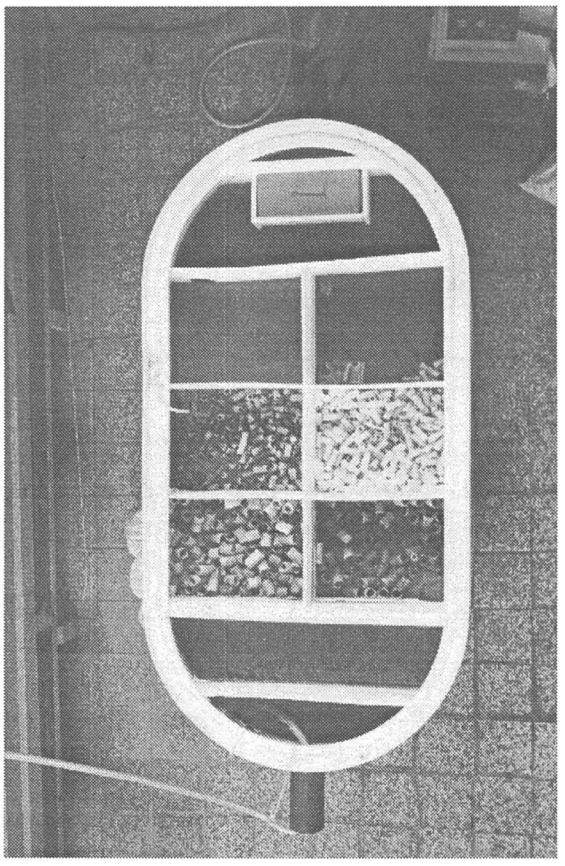

Fig. 2. The pilot-scale reactor at the WWTP in Bratislava-Petržalka.

RESULTS

Lab-Scale Experiments

The UAF was inoculated with a municipal anaerobic digested sludge and the start-up of the reactor was realized at the temperature of about 23 °C, HRT of 24 h. A mixture of synthetic substrate (acetate and D-glucose) and raw municipal wastewater from WWTP Bratislava-Petržalka was used as a substrate. The parameters of influent and effluent are summarized in Table 2.

A very quick start-up of UAF was obtained in the lab-scale experiments. COD removal efficiency of about 70 % was reached in the second week of the start-up. Temperature and HRT were changed to observe influence of HRT and temperature on the treatment efficiency. Dependence of COD removal efficiency on HRT and temperature is shown in Fig. 3. The bigger influence of HRT changing from 24 h to 12 h is demonstrated when the temperature decreases below 10 °C. The decrease of reactor performance below 10 °C under changing HRT can be seen in Table 2, too. The response of the filter on lower HRT – 12 h under 23 °C is already the subject of our research. Concerning results obtained with UAF reactor under temperature about 15 °C and HRT of 12 h (84 % COD, 70 % BOD_5 removal) and 24 h (87 % COD, 91 % BOD_5 removal) we can suppose to achieve similar removal efficiency. The results obtained in the first two weeks (reactor is adapted on substrate and previously worked under temperature about 10 °C) prove very good efficiency of about 80 % of COD removal.

The results prove also very good efficiency in the removal of SS, which reached approximately values of 10—40 mg dm^{-3}. In the whole experiment the concentration of volatile fatty acids (VFA) and the value of redox potential were monitored. The concentration of VFA achieved very low values, which propose a good neutralization capacity of the municipal wastewater. The value of redox potential is a parameter, which shows if the milieu of the process is anaerobic. The monitored redox-potential values in the whole experiment were in average −250 mV. The anaerobic milieu is defined for values below −150 mV, but the optimal redox potential for methanogenic bacteria is −330 mV. It is not possible to obtain the optimal condition for the methanogenic bacteria under such low temperature and low loading rates, which results in the low biogas production.

Pilot-Scale Experiments

Concerning good results obtained with the lab-scale anaerobic filter, simplicity, low investment and

Table 2. Experimental Results from Lab-Scale of UAF for Municipal Wastewater Treatment

			Influent			Effluent			Efficiency[a]		
θ	HRT	Bv	ρ^{COD}	ρ^{BOD5}	ρ^{SS}	ρ^{COD}	ρ^{BOD5}	ρ^{SS}	η^{COD}	η^{BOD5}	η^{SS}
°C	h	kg m^{-3} d^{-1}	mg dm^{-3}	mg dm^{-3}	mg dm^{-3}	mg dm^{-3}	mg dm^{-3}	mg dm^{-3}	%	%	%
8	12	1.00	490	290	230	260	150	30	46	41	80
15	12	1.16	570	290	70	70	34	10	84	70	90
8	24	0.47	540	240	230	170	64	25	64	71	72
15	24	0.60	690	310	–	65	26	–	87	91	–
23	24	0.75	780	440	–	70	30	40	90	95	–

a) The efficiency evaluated from nonfiltered influent and nonfiltered effluent.

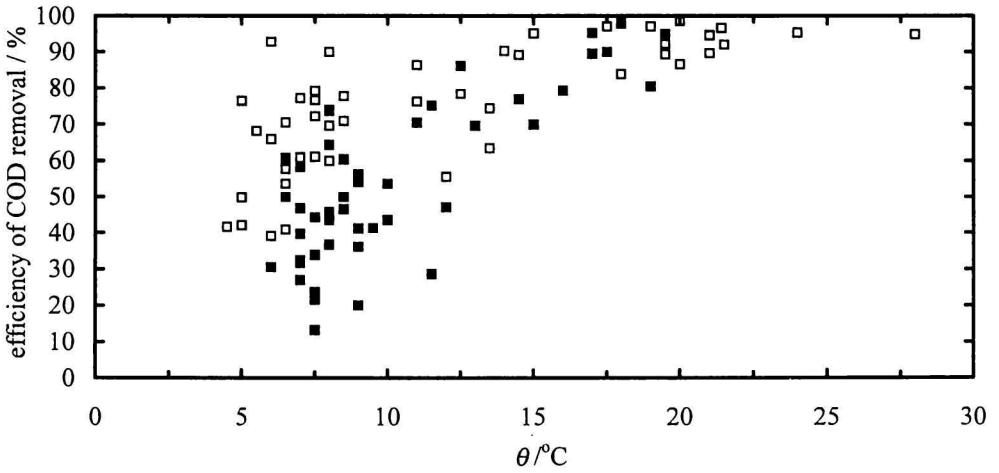

Fig. 3. The influence of temperature and HRT on the treatment efficiency in the lab-scale UAF reactor. □ HRT = 24 h, ■ HRT = 12 h.

Table 3. Experimental Results from the Pilot-Scale of the Anaerobic Filter at the WWTP Petržalka

				Influent			Effluent			Efficiency[a]		
	θ	HRT	Bv	ρ^{COD}	ρ^{BOD5}	ρ^{SS}	ρ^{COD}	ρ^{BOD5}	ρ^{SS}	η^{COD}	η^{BOD5}	η^{SS}
	°C	h	kg m^{-3} d^{-1}	mg dm^{-3}	mg dm^{-3}	mg dm^{-3}	mg dm^{-3}	mg dm^{-3}	mg dm^{-3}	%	%	%
Range	8—20	20—26	0.24—1.38	224—1264	112—440	140—1098	30—270	20—114	10—46	25—88	23—91	62—99
Average	14	24	0.55	475	229	448	160	73	22	66	68	95

a) The efficiency evaluated from nonfiltered influent and nonfiltered effluent.

operating cost, we decided for application of AF in pilot-scale experiments. The baffled anaerobic filter was installed directly on the WWTP Petržalka. Incoming municipal wastewater flows after passing through the screen into the reactor. The wastewater incoming to the WWTP is collected from one part of Bratislava-Petržalka (*ca.* 120 000 inhabitants) and it is mostly domestic wastewater with negligible fraction of industrial wastewater.

The pilot-scale experiment started in the second half of September 1998. The two first chambers filled with plastic medium were inoculated with municipal anaerobic digested sludge. The initial HRT was set to 1 day, calculated on the volume filled with plastic filling. The first results showed good effluent parameters approximately 40—180 mg dm^{-3} COD in the first month, when the temperature varied from 15 to 20 °C (Fig. 4).

The effluent COD values increased in the winter 1998/99 up to 130—260 mg dm^{-3} due to falling temperature, reaching 8—13 °C in this year time. The influence of temperature on the effluent parameters is shown in Fig. 4. The temperature under 10 °C is often mentioned in the literature as boundary temperature for psychrophilic anaerobic treatment processes. Summary of the obtained results is given in Table 3. The results show very often mentioned property of filter, the very good efficiency in removing of suspended solids even under unfavourable temperature conditions (Fig. 4). The effluent of SS-values reached in the whole start-up concentration of 10—46 mg dm^{-3}. The reactor has a very good neutralizing capacity. pH values in the reactor were ranging between 6.7—8.2. Also the concentration of VFA was very low in the effluent, which indicates a good stability of reactor and nonproblematic decomposition of the pollution.

The first 200 start-up days of operation under unfavourable temperature condition prove relatively good results. We can expect better results in the other months of the year, in which the temperature of wastewater achieves 15—25 °C. It can be supposed that the reactor will provide in the next winter better results after good adaptation of anaerobic population on the substrate and psychrophilic condition. Results obtained in similar research, such as the one performed in Holland [8] verify this assumption.

The reactor response on the changing of HRT will be very interesting. Because of the increasing requirements on effluent parameters in the future, it is necessary to consider the possibility of aerobic post-treatment.

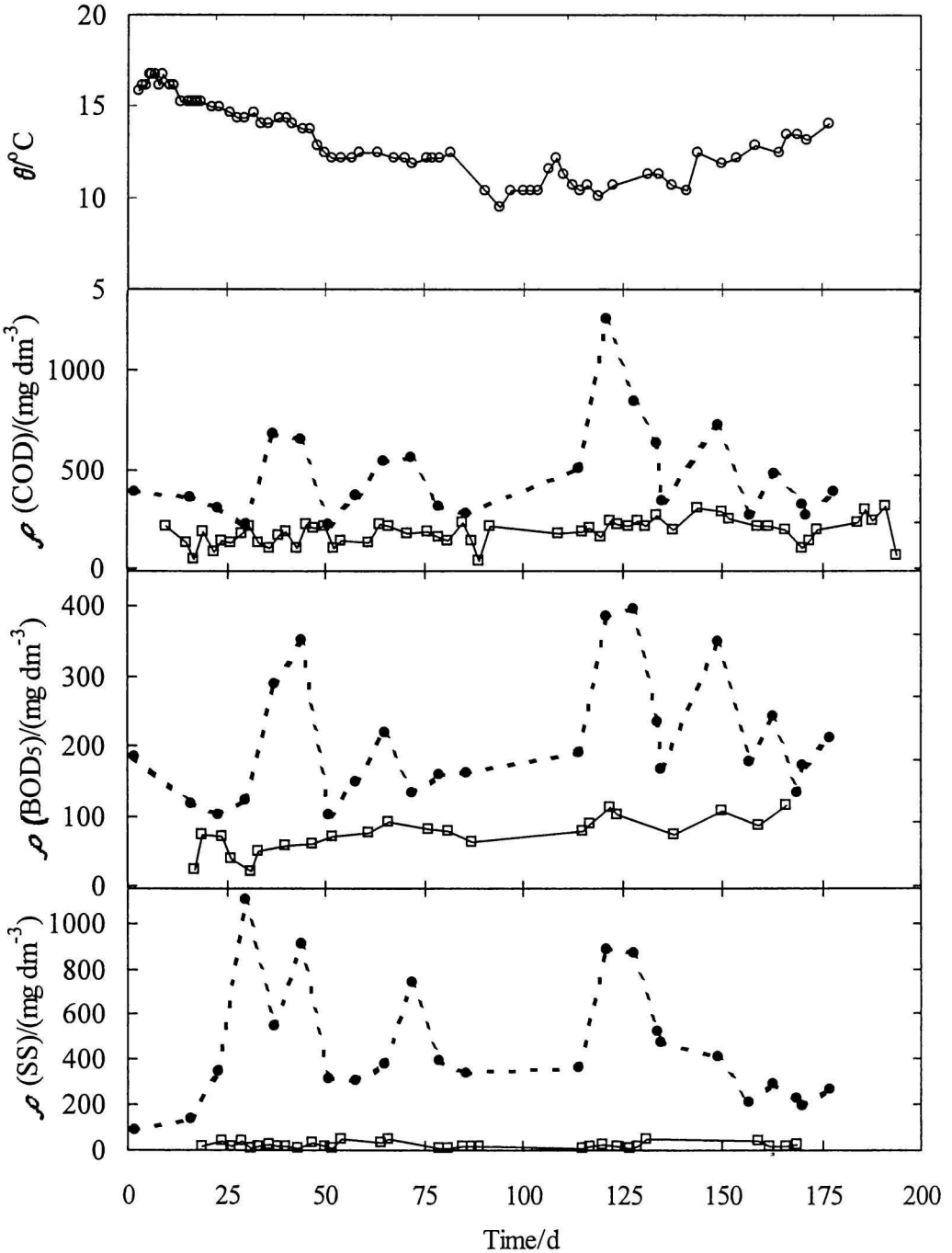

Fig. 4. Temperature, influent and effluent of COD, BOD_5, and SS concentration in the pilot-scale anaerobic filter. ○ Temperature, ● influent (24-h mixture), □ effluent.

CONCLUSION

The presented research was focused on the real application of anaerobic filter reactor for municipal and/or domestic wastewater treatment. Process of wastewater treatment was performed at ambient temperature. The practical research was oriented to two scales: lab-scale experiments and the pilot-scale application.

Main results obtained in the lab-scale reactor were as follows:

– Anaerobic wastewater treatment process is suitable for municipal and/or domestic wastewater;

– COD removal efficiency is dependent mainly on temperature and hydraulic retention time. Under low values of HRT the removal efficiency is more boldly influenced by temperature;

– The lab-scale model was operated without any technological problems. The start-up process was realized by 23 °C and was very fast (two weeks);

– Under ambient temperature it is possible to obtain relatively high COD and BOD_5 removal efficiency.

Concerning very good experience from the lab-scale model, we decided for application of anaerobic baffled filter in pilot-scale experiments. Main results obtained in the full-scale reactor were as follows:

– Very good start-up process was observed at the temperature of 20 °C. High COD and BOD_5 removal efficiency was obtained in the first months of operation despite low ambient temperature (8—15 °C);

– Decrease of COD and BOD_5 removal efficiency was observed with decreasing temperature;

– The pilot-scale reactor worked during the whole experiments without any technological problems. No significant changes of pH, VFA were observed in anaerobic reactor.

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