MUNICIPAL SEWAGE TREATMENT IN UPFLOW ANAEROBIC FILTER

L. Przywara, B. Mrowiec and J. Suschka

University of Bielsko-Biala, Willowa 2 Street, Bielsko-Biala 43-309, Poland,
(E-mail: *l.przywara@ath.bielsko.pl; bmrowiec@ath.bielsko.pl; jsuschka@ath.bielsko.pl)*

Abstract In this work, an upflow anaerobic filter (UAF) for municipal sewage treatment was used. The studies ware carried out in laboratory scale. The treatment process was operated in psychrophilic conditions. The value of hydraulic retention time (HRT) in anaerobic bioreactor was 48 h and the temperature varied during the investigations from 15 to 20ºC. A real municipal sewage was taken from the treatment plant (WWTP – Tychy), operated in a full scale. The chemical oxygen demand (COD) of raw sewage ranged between 380 and 865 mgO_2/L. The sewage used was additionally polluted with ammonia nitrogen – between 64 and 102 mg NH_4^+/L, phosphate – between 22 and 31 PO_4^{3-}/L as well as sulphates between 15 and 115 $mgSO_4^{2-}$/L. The investigations comprised of three series of different organic loading rates. Depending on values of sewage/organic loading rates 46 -72 % of COD were eliminated at psychrophilic conditions. The presence of ammonia nitrogen and sulphates did not have a negative impact on the process of organic matter degradation. Anaerobic treatment was effective in removing biodegradable organic compounds, but mineral compounds like NH_4^+, PO_4^{3-}, S^{2-} remained in high concentrations. Therefore, these compounds require removing by an additional post-treatment step.

Keywords: biological treatment, anaerobic process, uplow anaerobic filter, municipal sewage

INTRODUCTION

Anaerobic digestion processes have been mainly applied to high strength organic wastewater such as brewery effluent (Connaughton et al., 2006 a), wastewater from the production of protein (Borja R. et al., 2004), phenolic wastewater (Collins G., 2005 b), effluent in the agro-industry (Drriessen, 1999) or sludge from wastewater treatment plants (Foresti et al, 2006, Ferreiro et al., 2003). Low strength organic wastewater, like municipal sewage, has been also treated in anaerobic systems (Donoso-Bravo et al., 2009, Alvarez et al., 2003, 2004, Chernicharo et al. 2001, Torres et al. 2001 Elmitwalli et al., 2001). Advantages and disadvantages of anaerobic sewage treatment are summarized in Table 1 and 2, respectively (Seghezzo et al.,1998).

Usually anaerobic treatment of wastewater is performed as one stage fermentation under mesophilic (25 – 45 ºC) (Connaughton et al., 2006 a, Eskicioglu et al., 2011, Wiegant, 2001) or termophilic (45 – 65ºC) conditions. Research into area of psychrophilic anaerobic treatment is limited (Mckeown et al. 2009, Bodic et al. 2002, Lew et al. 2004, Elmitwalli et al., 2002, Rebac et al., 1999). Under psychrophilic conditions, chemical and biological reactions proceed much slower than under mesophilic conditions. Most reactions in the biodegradation of organic matter require more energy to proceed at low temperatures than at a temperature optimum of 37ºC. However, same reactions, such hydrogenotropic methane production, acetate formation from hydrogen and bicarbonate, require less energy (Lettiga et al., 2001)

Anaerobic treatment of low strength wastewater at low temperatures – the rate of the biological degradation in such system must remain sufficiently high, particularly also at very low substrate level. Viable organism at deeper positions inside the immobilized biomass should not become deprived of substrate and the release of metabolic end-products from the aggregate should proceed easily. This means the absence of serious transport limitations (Lettinga, 1996).

Various physical-chemical factors (temperature, pH, nutrients, ect.) generally strongly affect the anaerobic process and, therefore knowledge in this area is of high importance, mainly because of the fact that the prevailing conditions in an anaerobic reactor are dictated by the imposed process conditions, specific operational measures taken (e.g. supply of chemicals) as well as wastewater characteristics. Very important achievements can be made in the field of the supply nutrients and trace elements (Lettinga et al. 1997).

Apart from the characteristics of wastewater and physical- chemical factors, a potential loading of anaerobic reactors for a specific wastewater are determined by process conditions imposed on the system, i.e. the substrate level maintained in the reactor (Lettinga et al. 1997).

Table 1. Advantages of anaerobic wastewater treatment

Advantages	
High efficiency	Good removal efficiency can be achieved in the system, even at high loading rates and low temperatures
Simplicity	The construction and operation of these reactors is relatively simple
Flexibility	Anaerobic treatment can easily be applied on either a very large or a very small scale
Low space requirements	When high loading rates are accommodated, the area need for the reactor is small.
Low energy consumption	As far as no heating of the influent is need to reach the working temperature and all plant operations can be done by gravity, the energy consumption of the reactor is almost negligible. Moreover, energy is produced during the process in the methane form
Low sludge production	The sludge production is low, when compared to aerobic methods, due to the slow growth rates of anaerobic bacteria. The sludge is stabilized for final disposal and has good dewatering characteristics. It can be preserved for long periods of time without a significant reduction of activity, allowing its use as inoculum for the start-up of new reactors.
Low nutrients and chemicals requirement	Especially in the case of sewage, an adequate and stable pH can be maintained without the addition of chemicals. Macronutrients (nitrogen and phosphorus) and micronutrients are also available in sewage, while toxic compounds are absent

Table 2. Disadvantages of anaerobic wastewater treatment

Disadvantages	
Low pathogen and nutrient removal	Pathogens are only partially removed, except for helminth eggs, which are effectively captured in the sludge bed. Nutrients removal is not complete and, therefore a post treatment is required
Long start-up	Due to the low growth rate of methanogenic organisms, the start-up takes longer, as compared to aerobic processes, when no good inoculum is available
Possible bad odors	Hydrogen sulphide is produced during the anaerobic process, especially when there are high concentrations of sulphates in influent. A proper handling of the biogas is required to avoid bad smell
Necessity of post-treatment	Post-treatment of the anaerobic effluent is generally required to reach the discharge standards for organic matter, nutrients and pathogens

Anaerobic digestion technology is an ideal cost – effective biological means for the removal of organic pollutants in wastewater which simultaneously produces gaseous methane as an energy resource (Tabatabaei et al., 2010). The process by which anaerobic bacteria decompose organic matter into biomethane, carbon dioxide, and nutrient-rich sludge involves a step-wise series of reactions requiring the cooperative action of several organisms. It occurs in three basic stages as the result of the activity of a variety of microorganisms. Initially, a group of microorganisms converts organic material to a form that a second group of organisms utilizes to form organic acids. Methane-generating (methanogenic) anaerobic archaea utilize these acids and complete the decomposition process. In the first stage, a variety of primary producers (acidogens) break down the raw wastes into simpler fatty acids. In the second stage, a different group of organisms (methanogens) consumes the organic acids produced by the acidogens, generating biogas as a metabolic byproduct (Tabatabaei et al., 2010).

The ideal situation for anaerobic technology would be the complete removal of pathogens (health protection) and the highest removal COD (environmental protection) with recovery of energy (methane or hydrogen) and compounds of interest: nitrogen (as NH_4^+, NO_2^-, and NO_3^-), phosphorus (as phosphate) and sulfur (as S^0) (Foresti et al.2006).

The development of post-treatment units of anaerobic reactors is not only important to improve the effluent quality for environmental protection, but also to achieve the recovery of resources (Foresti et al.2006).

The effluent quality from anaerobic reactors treating municipal sewage can vary widely depending on several factors, including: local conditions, influent characteristics, reactor design, operational parameters, etc. For example, a general anaerobic reactor effluent quality cannot be defined strictly (Foresti et al.2006).

From most data available, however, anaerobic effluents are normally launched with a COD from 100 to 200 mg/L, total suspended solids (TSS) from 50 to 100 mg/L (Passig et al. 2000,Vieira et al. 2003), ammonia from 30 to 50 mg/L (Torres & Foresti 2001), and phosphorus from 10 to 17 mg/L. Sulphide concentration depended on the influent sulphate concentration and on the extension of the

prevalence of sulphide generation over methanogenesis, as sulphate reduction occurs preferably over methanogenesis when organic carbon is available in the influent (Lens et al. 2000).
Anaerobic reactor effluents still represent a real risk to health (presence of pathogens) and environmental (high-residual COD and nutrients). Consequently, anaerobic reactors must be combined with other technologies in order to pursue the presented ideal situation for municipal sewage treatment (Foresti et al.2006).

The paper focuses on the application of anaerobic treatment system particularly of the upflow anaerobic filter type, for treating very low strength wastewater at low temperature.

MATERIALS AND METHODS

The experimental upflow anaerobic filter shown in Fig.1. The reactor consisted of column with an inside diameter 10 cm and height of 150 cm. The column was filled with plastic material. Peristaltic pumps were used for feeding and effluent discharge. The influent was pumped from the separate fed tank to the bottom of the column. The effluent passed though a filter and was collected in the second tank. The reactor has an empty value of 12 L and feedstock was sewage, which characteristics shown in Table 3. A real municipal sewage was taken from the treatment plant (WWTP – Tychy), operated in a full scale. The value of hydraulic retention time (HRT) in the anaerobic bioreactor was 48 h and the temperature varied during the investigations from 15 to 20ºC. The system operated for 2 months and three phases were performed with different organic loading rates (OLR): 0.19 kg COD/m^3 d (I series), 0.32 kg COD/ m^3 d (series II) and 0.26 kg COD/ m^3 d (series III).

For UAF reactors, the anaerobic activated sludge taken from WWTP Bielsko – Biała Komorowice was used as the inoculum. The sludge was exposed to in anaerobic digestion conditions at temperature of 20 ºC for 50 days.

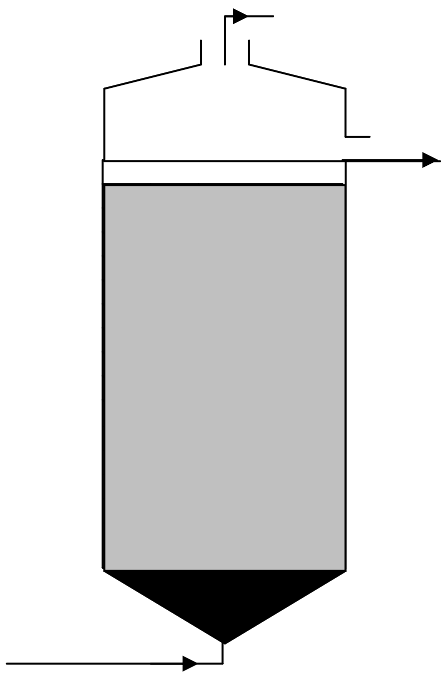

Figure 1. Laboratory model of UAF

Table 3. Characteristics of sewage (influent)

Parameter	Unit		Sewage		
			Series I	Series II	Series III
pH		Range Mean	6.93 - 7.19 6.99	6.99 – 7.21 7.10	7.06 – 7.12 7.09
COD	mgO_2/L	Range Mean	380 - 575 470	750 – 865 807	618 – 680 640
NH_4^+	mg/L	Range Mean	64 - 79 70	80 – 83 82	88 – 102 93
PO_4^{3-}	mg/L	Range Mean	22 - 27 24	27 – 30 29	27 – 31 28
SO_4^{2-}	mg/L	Range Mean	15 - 115 61	70 – 114 92	50 – 55 53

A real municipal sewage was taken from the treatment plant (WWTP – Tychy) which characteristic the chemical oxygen demand (COD) of raw sewage ranged between 380 and 865 mgO_2/L. The sewage used was additionally polluted with ammonia nitrogen – between 64 and 102 mg NH_4^+ /L, phosphate – between 22 and 31 PO_4^{3-}/L as well as sulphates between 15 and 115 $mgSO_4^{2-}$/L.

Analytical techniques

During the experiments influent and effluent parameters – temperature, pH, redox (oxidation-reduction) potential, chemical oxygen demand (COD), NH_4^+, PO_4^{3-}, SO_4^{3-} were monitored and determined according to Standard Methods (Eaton et al., 2005). Samples for chemical oxygen demand (COD) determination were digested in glass vials of Hach Reactor Model 4000. Ammonia nitrogen was measured by the Nessler method. Phosphates were determined using ascorbic-acid - colorimetric technique, and sulphates by the turbidimetric methods. Redox potential, pH were measured electrometrically.

RESULTS

Characteristics of the effluent is given in Table 4.

Table 4. Characteristics of effluent

Parameter	Unit		Sewage		
			Series I	Series II	Series III
pH		Range Mean	6.80 - 7.23 6.95	6.67 – 7.14 6.96	6.92 – 7.11 6.99
COD	mgO_2/L	Range Mean	180 - 220 203	220– 370 283	230 – 350 275
NH_4^+	mg/L	Range Mean	61 - 93 76	73– 102 87	51 – 1150 95
PO_4^{3-}	mg/L	Range Mean	38 - 47 42	29 – 45 39	30 – 38 34
SO_4^{2-}	mg/L	Range Mean	0 0	0 0	10 – 45 25

The COD in the influent varied between 380-575mgO_2/L, 750-865 mgO_2/L and 618-680 mgO_2/L for series I, series II and series III, respectively. However, the COD concentrations in effluent remained almost constant during the first series and amounted to around 200 mgO_2/L, but increased to 280 and 275 mgO_2/L in the second and last series, respectively.

The investigations comprised of three series of different organic loading rates. Depending on values of sewage/organic loading rates, between 46 and 72 % of COD was eliminated at psychrophilic conditions.

The COD concentrations in the influent and effluent of the upflow anaerobic filter for series I is presented in Figure 2.

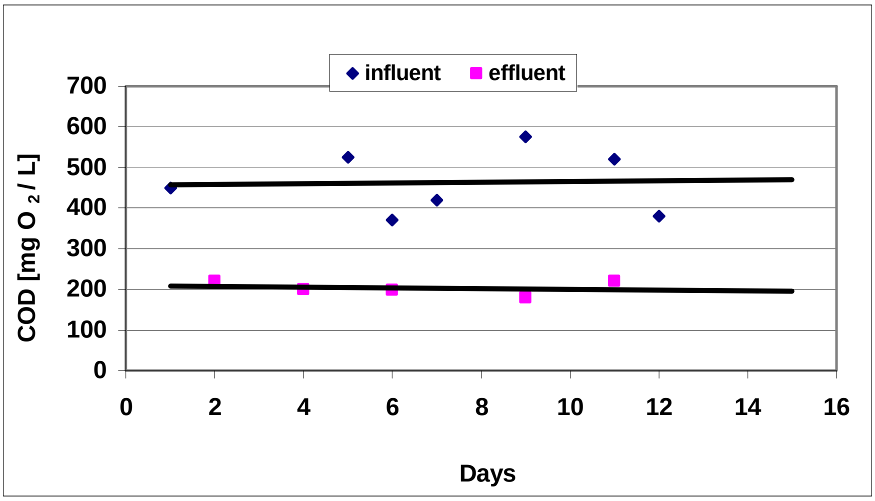

Fig. 2. COD concentrations in the influent and effluent of the upflow anaerobic filter (series I)

Figure 3 and Figure 4 presents COD concentrations in the influent and effluent of the upflow anaerobic filter for series II and series III, respectively.

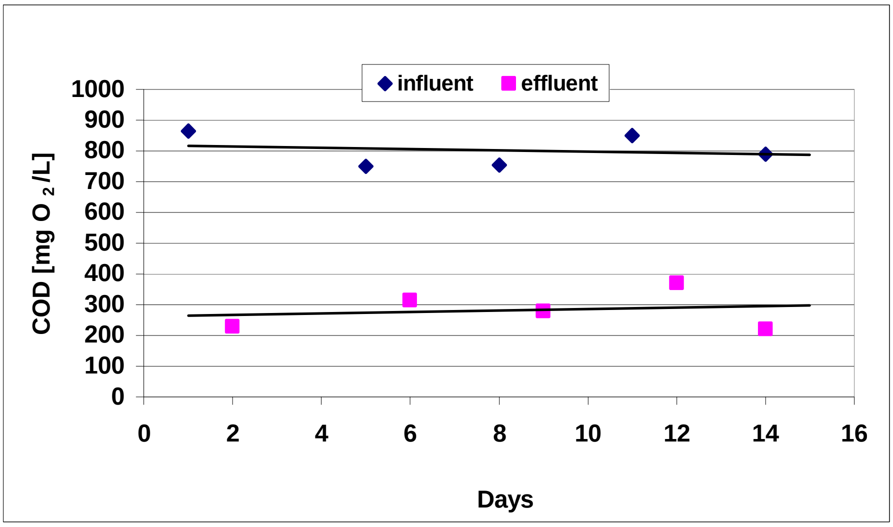

Fig. 3. COD concentrations in the influent and effluent of the upflow anaerobic filter (series II)

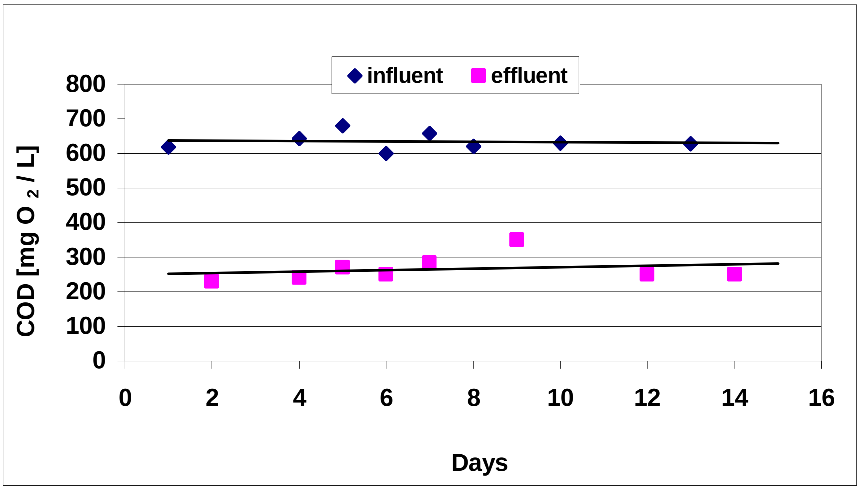

Fig. 4. COD concentrations in the influent and effluent of the upflow anaerobic filter (series III)

Despite the highest organic loading rates (OLR) - 0.32 kg COD/ m^3 d for series II organic matter removal efficiencies increased on average 59 % (series I and series III) to 62% (series II).

Therefore, 59– 62 % COD removal can be achieved at HRT 48 hours at ambient temperatures of 10 - 20 ^oC. However, other authors (Bodic et al. (2000), Manariotis et al. (2005)) which used in their experiments similar conditions to ours (temperature) reported results comparable to our observations.

Bodik et al. (2000) studied the performance of an upflow anaerobic treating domestic wastewater, obtaining organic matter removal efficiency between 46 – 90 %. The reactors were tested at two different HRT 10 and 20 h and three different temperatures 9, 15 and 23 ^oC, respectively. Temperature has a dominant influence on the efficiency of removal of organic pollutants in UAF. High efficiency of the removal independent on observed values of HRT, were obtained at 23 ^oC. A lower temperature (15 or 9 ^oC) caused decreasing of the removal efficiency with a slight negative change in HRT values (Bodic et al., 2002).

Manariotis et al. (2005) treated municipal wastewater (mean COD 442 mg/L), under a wide range of hydraulic retention time (HRT ranged from 3.1 to 0.3 d) and the organic loading rate ranged (OLR) from 0.115 to 1.82 kg COD/m^3d) and operating conditions, for example temperatures 25 and 15 ^oC. At the higher temperature and HRT of 1.0 d, removal efficiencies reached levels of 74 to 79 % for COD. Temperature reduction by 10 ^oC resulted in lower removal efficiencies for organics. At a 1.0 d HRT, COD removals decreased from 53 to 40 %.

At temperatures higher than 20 ^oC and HRT in the range of 6 – 10 h, removal efficiencies from 65 % to 80 % for COD have been obtained by Wiegant (2001) and Foresti (2002).

The other characteristics, which was monitored at less frequent intervals, indicated that the ammonia nitrogen concentration increased in the filter effluent by 2 % to 8 %, on average. It was the effect of hydrolysis process of organic nitrogen. Phosphates were in the range of 19 % to 42 % higher in the filter effluents, compared to the corresponding influent level. Sulphates concentration was lower in the effluent, with the average reduction ranging from 50 % (series III) to 100% (series I and II). The sulphates present in the wastewater have been reduced to sulphides.

The pH value ranged from 6.93-7.21 in the raw wastewater and from 6.67 to 7.23 in the treated effluents. The pH remained at constant level during the experimental period.

The presence of ammonia nitrogen and sulphates did not have a negative impact on the anaerobic process of organic matter degradation. The rate of biological degradation in such system remains sufficiently high, particularly also at very low substrate level.

SUMMARY

Anaerobic treatment represents very feasible treatment technology for a very wide range of wastewater, varying from very high to very low strength and from relatively very hot (50 ^oC) to cold (even < 10 ^oC) temperatures. Anaerobic treatment of domestic wastewater particularly looks attractive in uplow anaerobic filter concept. UAF system are particularly studied to low temperatures (< 20 ^oC) and very low strengths of organic matter (<1000 mgO_2/L). Apart from a satisfactory treatment efficiency in terms of COD, sulphates reduction was achieved.

Depending on the organic loading rates, an average 59 – 62% COD can be removed at 10 - 20 ^oC. The presence of ammonia nitrogen and sulphates did not have a negative impact on the process of organic matter degradation, but mineral compounds like NH_4^+, PO_4^{3-}, S^{2-} remained in high concentrations. Therefore, these compounds require to be removed by an additional post-treatment step. Based on the observed results, the use of UAF seems to be a potential technology for municipal wastewater pre-treatment, in practice.

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