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The influence of lower temperature, influent fluctuations and long retention time on the performance of an upflow mode laboratory-scale septic tank

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ABSTRACT

The influence of temperature in a range of 15–5˚C, fluctuations in soluble chemical oxygen demand (sCOD) and suspended solids (SS) of the influent and also long hydraulic retention times (HRT) of 36 or 50 d on the performance of a laboratory septic tank were studied. A laboratory-scale septic tank with a volume of 20 L, started up at 15˚C was fed with domestic wastewater from two settlements with sCOD up to 450 and up to 2,000 mg/L, respectively. The efficiency of the septic tank was assessed based on pollutant removal and biogas production. A stepwise decrease in temperature by 5˚C in the range of 15–5˚C halved the daily emission of biogas. Removal efficiencies for sCOD and SS were in the range of 74–86 and 86–88%, respectively. An increase in sCOD of influent from 450 to 4,000 mg/L resulted in a decreased performance of the septic tank (to ~25% less). The highest biogas emission was observed at 10˚C and at retention time (36 d), owing to increased consumption of CO_2 and CH_4 by autotrophic microorganisms over the longer retention time (50 d). At the 15˚C, biogas emission was lower than in case of lower temperatures applied. In the range of 15–5˚C, operational temperature did not correlate significantly ($p > 0.05$) with the removal efficiency of sCOD or SS, assuming as a consequence of the long HRT.

Keywords: Anaerobic wastewater treatment; Domestic wastewater; Low temperature; On-site system; UASB-septic tank; Biogas

1. Introduction

Untreated wastewater can cause several problems—such as eutrophication, oxygen consumption and toxicity—when discharged into natural aquatic environments [1]. Domestic sewage is the major source of aquatic pollution in many rural areas, since it is always not practical to construct centralized sewage treatment plants due to financial limitation, sparse population or landscape. For instance, in Finland, approximately one million residents (around 19% of total population) and over one million vacationers are served by on-site treatment systems [2], as are 20% of the United States' population (more than 20 million homes) [3], 12% of Australians and around 14% of Greeks [4]. Various systems for on-site treatment of domestic wastewater appropriate to local conditions have been developed in countries such as Egypt, India, China and Korea [4–8]. Wastewater from sparsely populated areas is often considered not to exceed the natural self-cleaning capacity of the environment;

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therefore strict environmental regulations are seldom applied to minor plants. However, in sensitive ecological systems, legal limitations are applied to minor wastewater treatment plants. For example, the Protection of the Marine Environment of the Baltic Sea Area's (Helsinki Convention) HELCOM recommendation (28E/6) states that all involved countries must apply stringent regulations for on-site wastewater treatment for single family homes, small businesses and settlements of up to 300 population equivalents (p.e.) [9]. Therefore, on-site wastewater treatment would likely form an essential part of comprehensive wastewater treatment and environmental protection worldwide.

Anaerobic technologies are at the core of sustainable decentralized wastewater treatment systems [10]. There is considerable interest in anaerobic wastewater treatment owing to its low operational costs and non-dependency on electricity. An advantage of conventional septic tanks compared to sophisticated aerobic and anaerobic technologies is their simplicity of maintenance and operation. Septic tanks are globally used in on-site systems applying various temperature regimes regardless of wastewater strength or flow-rate [11,12]. Hydraulic and organic shock-loads have little effect on treatment efficiency, and septic tanks have the ability to tolerate long pauses in inflow [13]. The removal of solids from wastewater is further enhanced if the flow of wastewater is converted from a horizontal to an upflow mode [14].

Temperature is an important factor in anaerobic treatment of wastewater, as it induces changes in conversion rates of pollutants and gaseous emissions. Temperature of domestic wastewater changes with season in temperate zones (which includes Estonia and most of the Northern Europe), which is mainly in the range of 15–5˚C, though occasionally even lower. Lower temperatures in the given range are accompanied by changes in the properties (e.g. viscosity, solubility of gases) of the wastewater that need to be taken into account in the design and operation of the treatment system. During colder periods, biological activity is somewhat reduced; while at higher temperatures, some of accumulated organic matter is also converted to biogas, and sludge production is reduced [15].

Studies of septic tank efficiency at lower temperatures are rare [15]. In our study, the objective was to evaluate the effects of lower temperatures (from 15 to 5˚C) and long hydraulic retention time (36 and 50 d) on the performance of a laboratory-scale septic tank simulating on-site domestic sewage treatment. Special attention was given to the effects of lower temperatures on the removal of sCOD and SS regarding shock-loading of organics via the influent. The removal of total nitrogen and phosphorus were also evaluated. Emissions of CH_4, CO_2 [16,17] and minor toxic components such as H_2S and CO were also monitored.

2. Materials and methods

2.1. Experimental set-up

The experiments were carried out in a laboratory-scale upflow mode Plexiglas septic tank (active volume of 20 L) that was internally thermostatically controlled (ProfiCool Minimus, National Lab GmbH, Germany) (Fig. 1). The septic tank was covered with a sheet of polyurethane foam to decrease the influence of external temperatures and to avoid photosynthesis. A plastic bag was connected via a pipe to the upper cover of the septic tank in order to collect any gases produced. The septic tank received a calculated amount of wastewater, respectively, to the hydraulic retention times (HRT), manually, through an inflow pipe 5 d a week (every working day). To analyse the effects of temperature on the performance of the septic tank, experiments were carried out in the temperature range of 15–5˚C (±0.1˚C).

The septic tank was fed by untreated domestic wastewater collected from sewers in two small rural settlements in Estonia, denoted as Wastewater 1 and Wastewater 2 with 400 and 170 p.e., respectively. Wastewater 1 had relatively high amounts of SS (Median: 800; Lq: 710; Uq: 850) and sCOD (Median: 2,700; Lq: 2,270; Uq: 3,200) due to the low water consumption and flushing volume at the collection site (70 L/d per capita). Wastewater 2 had lower SS (Median: 284; Lq: 250; Uq:310) and sCOD (Median: 720; Lq: 485; Uq: 860) content. To model the situation of peak season at a recreation facility, shock-loadings of organic matter were added to the wastewater (See Figs. 2a and 2b). The lower strength wastewater (Wastewater 2) was also mixed with wastewater with higher sCOD Wastewater 3 (Median: 3,975; Lq: 2,667.5; Uq: 4,117.5) and high SS (Median: 1,480; Lq: 1,060; Uq: 1,500).

2.2. Sampling and physical–chemical analysis

The influent and effluent were analysed weekly. Content of suspended solids (SS) was determined as the residual mass of particular matter that stayed on a 0.45-μm filter (Himifil, Estonia). Content of organic matter was characterized as soluble chemical oxygen demand (sCOD), as determined by wet chemical oxidation tests using Dr Lange's cuvettes LCK314 and LCK514 (Germany) upon a sample filtered through a 0.45-μm membrane.

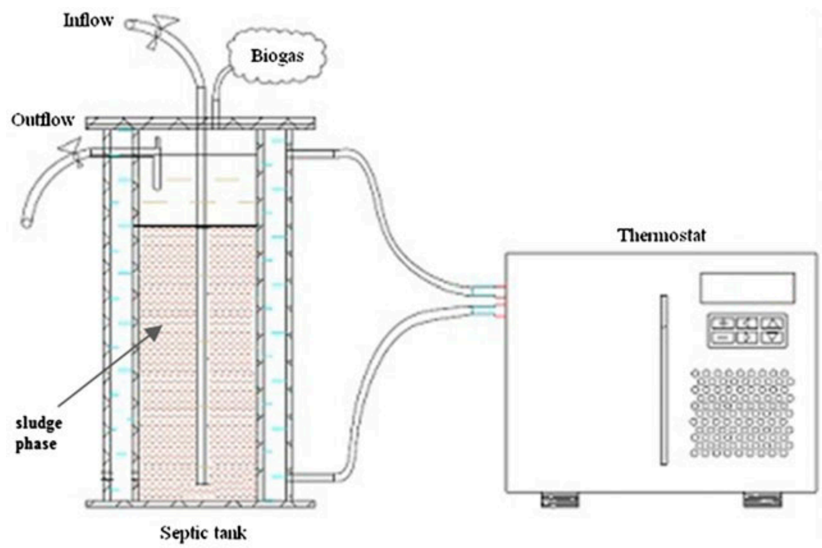

Fig. 1. Scheme of laboratory-scale septic tank.

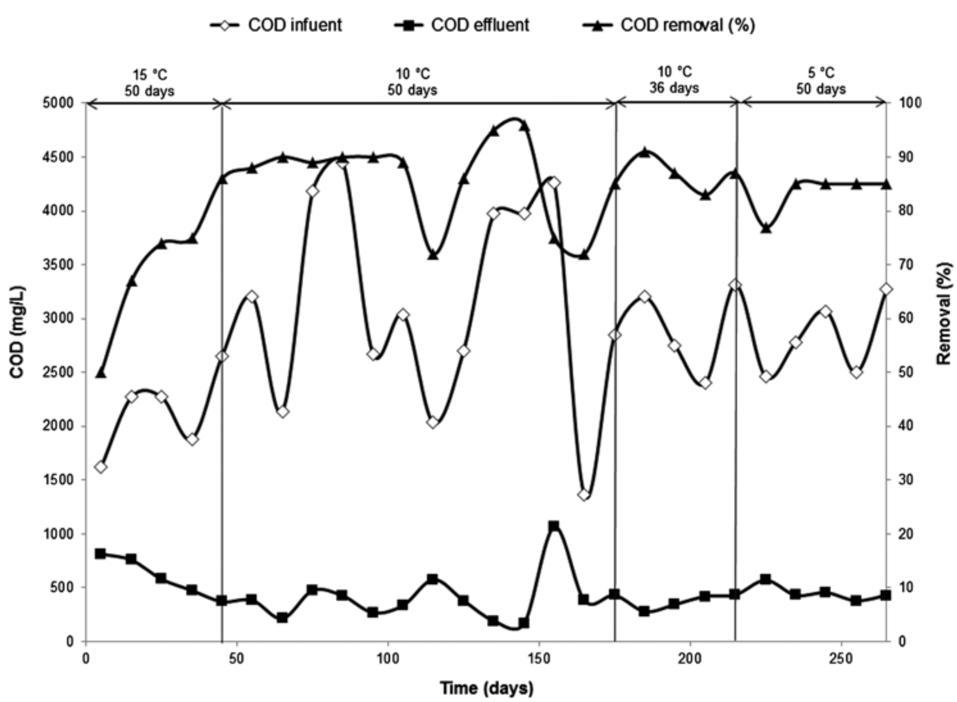

Fig. 2a. Time courses of influent, effluent and removal efficiency of COD.

The content of biodegradable organic matter was measured as biochemical oxygen demand (BOD_7) using dilution methods over a 7-d period [18].

The removal efficiency of the septic tank was calculated as the percentage reduction of each parameter's value (sCOD, SS, NH_4^+-N, PO_4^{3-}-P) between the influent and effluent. Statistical analysis was performed using the program XL Statistics.

Nutrients such as NH_4^+-N and PO_4^{3-}-P, as well as SS, were determined according to standard methods as given in [14]. pH was measured using an electronic probe (Jenway, model 4320, Germany). Volumes of produced gases (CO_2, CH_4, CO and H_2S) were measured using a laboratory gasometer and the composition determined with a gas analyser (Geotechnical Instruments Ltd, model GA 2000, UK).

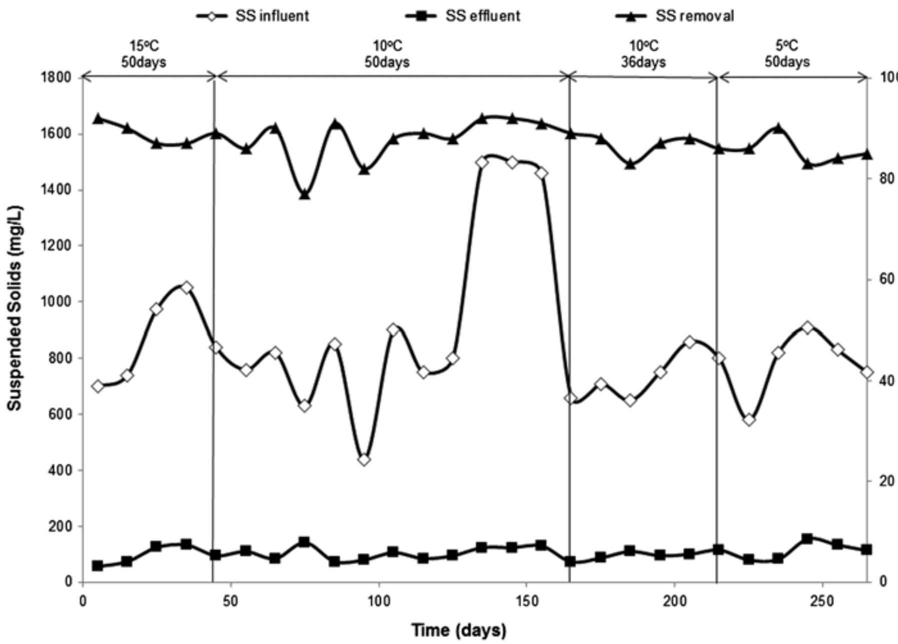

Fig. 2b. Time courses of influent, effluent, removal efficiency of SS.

The starting temperature of the septic tank was 15˚C; moderate sCOD removal efficiencies (74%) in the first 26 d confirmed that anaerobic activity had a long start-up time (1–2 months), as the consortium of bacteria that enable methanogenesis are slow to develop [19]. The longest experiments (~230 d) were carried out at 10˚C, as this is the typical temperature of domestic wastewater in Estonia.

3. Results and discussion

3.1. Removal efficiencies of sCOD and SS

The values for the influents and effluents are summarized in Table 1. The mean values for the influents and effluents and removal efficiencies of sCOD and SS at different temperatures and HRTs are presented in Figs. 2a and 2b. The results showed similar values for sCOD and SS removal efficiency. During the research period over a 1 year, the efficiency of sCOD and SS removal was between 74 and 86 and 86–88%, respectively.

Statistical analysis for correlations between temperature and HRT with the efficiencies of SCOD and nutrients removal (nitrogen and phosphorus) is shown in Table 2.

3.2. Effect of variations of the reactor temperature

Statistical comparison of the mean values for the removal efficiencies of sCOD, SS, NH_4^+-N and PO_4^{3-}-P at different temperatures mainly yielded in non-significant *t*-test *p*-values (i.e. $p \geq 0.05$) (Table 2). All *p*-values for sCOD, SS, NH_4^+-N and PO_4^{3-}-P exceeded 0.05. Therefore, temperature changes within the range of 15–5˚C showed no correlation with the removal efficiency of organic matter (74–86 and 86–88% for sCOD and SS, respectively) assumingly due to the long HRT that enabled the efficient biodegradation of organics.

Differences in NH_4^+-N were statistically non-significant between 15 and 10˚C; however, between the pairs 15 and 5˚C and 10 and 5˚C, such differences were statistically significant confirmed with *p*-values < 0.05. This confirmed that nitrogen removal, including both nitrification and denitrification, was sensitive to lower temperatures (26% removal at 5˚C compared to 31% at 15˚C), which is in agreement with previous findings [20,21]. In general, the differences of NH_4^+-N concentrations between influent and effluent were low, with removal efficiencies in the range of 22–32% (Table 1).

Comparing to the removal of sCOD and SS, phosphorous removal was relatively unstable, ranging from 38 to 74%; in a few cases, the orthophosphate (PO_4^{3-}) concentration in the effluent was even higher than in the influent. A biomass over-binding of P followed by its release or the mineralization process [20] probably accounted for this result. A study in an integrated UASB system consisting of primary sedimentation, packed-UASB and a plate settler at temperatures > 20˚C reached a phosphorus removal of 65% [8].

Table 1
Influent and effluent characteristics and removal efficiencies (%) of laboratory-scale septic tank at two different HRT values (values for standard deviation are given in brackets)

Temperature, HRT and origin of wastewater	Parameter	Septic tank: Influent concentration AVR (±STD)	Septic tank: Effluent concentration AVR (±STD)	Septic tank: Removal efficiency (%) AVR (±STD)
15°C	$COD_{dissolved}$	2,291 (±514)	514 (±217)	75 (±14)
HRT = 50 d	Suspended solids	841 (±128)	97 (±28)	88 (±2)
Wastewater 1	NH_4^+-N	143 (±13)	111.7 (±20)	31.1 (±3)
	PO_4^{3-}-P	45.5 (±23)	8.76 (±4)	74 (±8.65)
	pH	6.51 (±0.28)	7.15 (±0.4)	–
10°C	$COD_{dissolved}$	3,180 (±944)	410 (±108)	86 (±7)
HRT = 50 d	Suspended solids	728 (±169)	97 (±25)	86 (±5)
Wastewater 2/3	NH_4^+-N	85.3 (±1.91)	55 (±4.24)	32 (±3.2)
	PO_4^{3-}-P	60 (±55.77)	36.7 (±8.37)	75.3 (8.9)
	pH	6.63 (±0.32)	7.02 (±0.3)	–
10°C	$COD_{dissolved}$	2,828 (±373)	413(±98)	85 (±5)
HRT = 36 d	Suspended solids	725 (±101)	98(±13)	86 (±2)
Wastewater 1	NH_4^+-N	117 (±15)	78 (±5.5)	28.9 (±2.1)
	PO_4^{3-}-P	74.2 (±41)	16.2 (±11)	71 (±5.8)
	pH	6.72 (±0.04)	7.25 (±0.1)	–
5°C	$COD_{dissolved}$	2,905 (±336)	424 (±31)	85 (±0)
HRT = 50 d	Suspended solids	828 (±66)	120 (±31)	86 (±3)
Wastewater 1	NH_4^+-N	113 (±18)	83 (±16)	26 (±2.4)
	PO_4^{3-}-P	67 (±40)	41.4 (±17)	74 (8.71)
	pH	6.68 (±0.08)	7.05 (±0.19)	–

Table 2
Statistical analysis comparing certain temperature values and HRTs

p-values found with *T*-tests	COD	Suspended solids	NH_4^+-N	PO_4^{3-}
Influence of temperature				
15 and 10°C	0.06	0.13	0.46	0.09
			0.05[a]	0.25[a]
10 and 5°C	0.39	0.46	0.003	0.17
			0.02[a]	0.19[a]
15 and 5°C	0.12	0.07	0.001	0.15
Influence of HRT				
36 and 50 d	0.39	0.42	0.07	0.21

[a]Temperature 10°C, and HRT = 36 d.

Therefore, what was remarkable about our results was that the temperature only significantly influenced the quantity of the gases formed, without showing a significant effect on its components. Other studies have shown that a temperature range of 18–24°C also had no significant effect on sCOD removal in a UASB-septic tank (HRT = 4 and 29 d) treating black water [22].

3.3. Effect of HRT variations

p-values for both sCOD and SS exceeded 0.05 (Table 2), indicating that retention time (36 d compared to 50 d) of wastewater in the septic tank was not statistically correlated with removal efficiency of organic matter. The same observation was seen for NH_4^+-N and PO_4^{3-}-P, as well. A long hydraulic retention time of nearly 50 d has been shown in other studies to achieve high removal efficiencies of sCOD and NH_4^+-N at 10°C [23,24]. Further studies could clarify the role of HRT in limiting the efficiency of low temperature septic tanks.

3.4. Effects of sCOD variations

The effects of variations of organic loading on the performance of the septic tank were tested when the influent consisted of a wastewater from a slaughterhouse (Wastewater 3) known for its high content in fatty matter (lipids and proteins) was added. Anaerobic digestion of the long-chain fatty acids is often hampered by an interruption of the balance between the metabolic activities that the anaerobic digestion process comprises, because these long-chain fatty acids are potential inhibitors of many of the bacteria involved in anaerobic digestion [3].

The shock test was conducted when in the steady state, the influent feed concentration was the Wastewater 3 (sCOD up to 4,000 mg/L). These shock-loadings of high sCOD and SS using Wastewater 2/3 are noticeable vis-à-vie the influent concentration peaks in Figs. 2a and 2b. Detailed information regarding the sCOD values and its removal efficiencies are given in Table 3.

The mean values for BOD_7/sCOD ratios for both wastewaters (low sCOD Wastewater 2 and high sCOD Wastewater 2/3) were 0.55 (±0.13) and 0.41 (±0.06) between the influent and effluent of the septic tank, respectively. This indicated that the biodegradability of the constituents of Wastewater 2/3 were quite similar to wastewater from a settlement.

The mixed wastewater had high values of sCOD (averagely <2,000 mg O_2/L) and SS (up to 1,500 mg/L) (Table 3). In the steady state, at the temperature of 10˚C, removal efficiencies for sCOD and SS were higher than 90% in the first two weeks of operation. The removal efficiency of sCOD then dropped below 75%, indicating a decrease in the degradation rate of organic matter. At the same time, the removal efficiency of SS remained ~90% over the whole 50-d period. Removal efficiency of sCOD increased again once the septic tank was fed with wastewater containing less organic matter (sCOD ~500 mg O_2/L).

3.5. Gaseous emissions and biogas composition

The biogas emissions calculated per unit volume of septic tank at different temperatures are presented in Table 4. The cumulative volumes of biogas were calculated for each period separately. Calculation of normalized daily emission of biogas per 1 L volume showed that an increase in temperature by 5˚C doubled the daily emission of biogas (Table 4). At the temperature of 10˚C, shortening the HRT from 50 to 36 d increased the daily emission of biogas by up to 9%, suggesting that biogas components might have been consumed by autotrophic bacteria in the case of the longer HRT [25,26] (Fig. 3). CO_2 is used as a carbon source by autotrophic bacteria and some mixotrophic bacteria, while CH_4 is utilized by methanotrophic bacteria [27]. It is important to note that the septic tank had non-optimal conditions low temperatures, fluctuations in the composition of the influent and oxygen content, and absence of external mixing for biogas production. The latter is not the purpose of septic tanks.

3.6. Composition of biogas

The composition of the produced biogas was characterized by CO_2, CH_4, CO and H_2S; the measured concentrations of these gases at different temperatures are presented in Fig. 4.

Septic tank biogas can also contain different gaseous nitrogenous and sulphurous compounds (e.g. amines, mercaptans) [16]. In this study, the carbon dioxide proportion in the biogas ranged from 35 to 50%. The methane content in the biogas ranged from 48 to 65% (Table 5). Similar ranges of contents in the biogas have already been noted by other investigators [28] during studies on the anaerobic treatment of wastewater with sCOD concentrations < 1,000 mg/L.

3.7. COD balance and sludge accumulation in the septic tank

COD in the influent is either converted into biogas, accumulated_in_the septic tank, or remains in the effluent. This can be expressed as:

Table 3
Values of COD and SS and their removal efficiency at 10˚C with HRT = 50 d. Mean values are presented with ±Standard deviation

D	COD (mg O_2/L)			Suspended solids (mg/L)		
	Influent	Effluent	Removal efficiency (%)	Influent	Effluent	Removal efficiency (%)
119	485	56	88	250	80	68
128[a]	3,975	192	95	1,500	124	92
149[a]	3,975	168	96	1,500	124	92
156[a]	4,260	1,065	75	1,460	130	91
163[a]	1,360	381	72	660	73	89
167	460	62	86	225	27	88
Mean	2,420 ± 1,840	320 ± 383	85 ± 10	932 ± 626	93 ± 41	86 ± 9

[a]Mixed wastewater.

Table 4
Average daily emissions of biogas from the septic tank (per 1L of reactor) calculated for each period of the operating reactor, at different temperatures and HRT

Temperature (°C)	HRT (d)	Duration of measurements (d)	Cumulative volume of emitted biogas for the given period (L)	Normalized daily emission of biogas for the given period (mL/L/d)
Wastewater 1				
5	50	18	1.9	5.3
10	50	61	15.6	12.8
10	36	140	38.8	13.9
15	50	35	15.5	22.2
Wastewater 2				
10	50	49	5.1	5.2

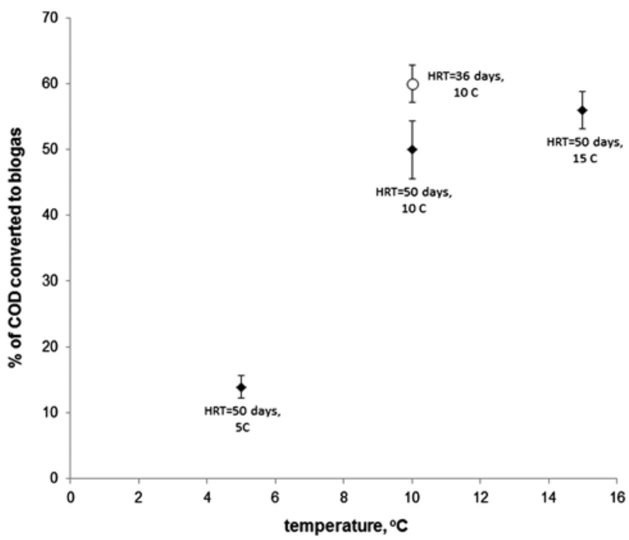

Fig. 3. Percentage of COD released as biogas at certain temperatures.

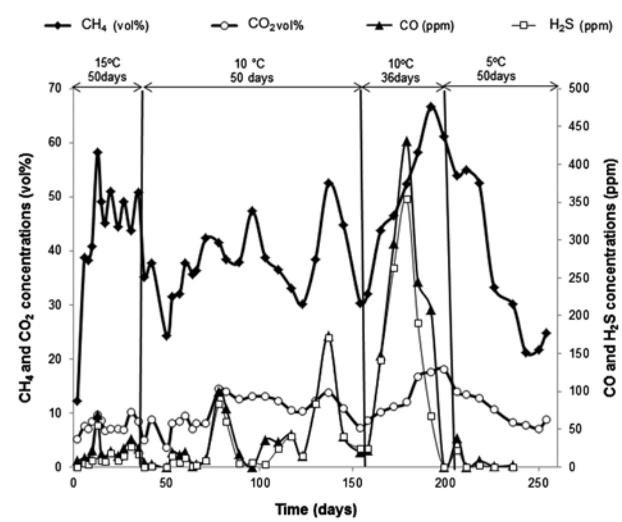

Fig. 4. Components of biogas emission: methane, carbon dioxide, carbon monoxide and hydrogen sulfide.

$$COD_{influent} = COD_{biogas\,CH_4} + COD_{biogas\,CO_2} + COD_{biogas\,CO} + COD_{accumulated\_in\_septic\_tank} + COD_{effluent}$$

To characterize the carbon balance, the COD mass balance, sludge accumulation and calculated sludge accumulation factor (Y_{acc}) are presented in Table 6. (Y_{acc}) includes cell yield, SS entrapment, adsorption and flocculation of the colloidal and soluble matter [29,30].

The low sludge accumulation values found emphasized one of the advantages of septic tanks, i.e. low sludge production. At 5°C, Y_{acc} was ten times higher than at 10°C, which was also previously reported by Luostarinen et al. [15]. The sCOD converted into

Table 5
Gases (%) in the biogas

Percentage of gases in biogas (%)	Biogas at 15°C, HRT = 50 d	Biogas at 10°C, HRT = 50 d	Biogas at 10°C. HRT = 36 d	Biogas at 5°C, HRT = 50 d
CH_4	65.10	56.87	54.42	48.60
CO_2	34.58	42.95	44.40	50.78
CO	0.33	0.32	1.18	0.62

Table 6
COD balance and sludge accumulation

	Total COD, entering reactor, gCOD	Total COD, leaving from reactor, gCOD	COD removed, gCOD	COD, methane gCOD	Sludge accumulation, gCOD	Y_{acc} gVSS/g COD removed
Temp. 15℃, HRT 50 d	8.96 (100%)	0.56 (6.27%)	8.39 [100%]	6.66 (74%) [79%]	1.73 (19%) [21%]	0.14
Temp. 10℃, HRT 50 d	10.77 (100%)	0.41 (3.81%)	10.36 [100%]	7.59 (70%) [73%]	2.77 (26%) [27%]	0.18
Temp. 5℃, HRT 50 d	3.34 (100%)	0.42 (12.69%)	2.91 [100%]	0.43 (13%) [15%]	2.48 (74%) [85%]	0.6
Temp 10℃, HRT 36 d	25.63 (100%)	0.41 (1.61%)	25.22 [100%]	22.80 (89%) [90%]	2.42 (9%) [10%]	0.06

Notes: The above parameters were calculated using the following equation:
(1) COD removed = Total COD o–Total COD out.
(2) COD methane = 2.857*L methane production from excel Table.
(3) Sludge accumulation = COD removed–COD methane.
(4) Y_{acc} = COD sludge accumulation/(COD removed × 1.41*)* 1 g sludge VSS is equal to 1.41 gCOD.
(5) Percentage in (-) when they are compared to total COD.
(6) Percentage in [-] when they are compared to COD removed.

methane and carbon dioxide in this study was in the range of 13–89% of the total sCOD entering the septic tank (Table 6).

4. Conclusions

(1) Septic tank operation temperature had no statistically significant influence on the removal of sCOD and SS in the temperature range 15–5℃ ($p > 0.05$), since the long HRT enabled efficient removal of sCOD and SS. The removal efficiencies for sCOD and SS were between 74–86 and 86–88%, respectively.
(2) At 10℃, the removal efficiencies were relatively stable and similar for sCOD and SS, with a mean removal efficiency value of 86% (±7) even for the shorter HRT of 36 d. However, shock-loading of organics for longer than 2 weeks decreased the effectivity of the performance of the septic tank.
(3) As gaseous emissions from septic tanks may be environmentally important, emissions of CH_4, CO_2, CO and H_2S were monitored. Increasing the temperature by 5℃ doubled the daily emission of biogas. At a temperature of 10℃, shortening the HRT from 50 to 36 d increased the daily emission of biogas by up to 9%.
(4) CH_4 emissions stabilized within 10 d of the start-up of the septic tank at 15℃, after which the content of methane stayed between 45 and 50% vol. At 10℃, CH_4 content in the produced biogas was between 30 and 60% vol. when the HRT equalled 36 d, and between 30 and 45% vol. when HRT equalled 50 d.
(5) Our study shows that septic tank can achieve a sufficient sCOD removal required for small treatment facilities even at a psychrophilic temperature range and thus can be used to reduce pollution from sparsely populated areas.

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References

[1] A. Sonune, R. Ghate, Developments in wastewater treatment methods, Desalination 167 (2004) 55–63.
[2] V. Somogyi, V. Pitas, E. Domokos, B. Fazekas, On-site wastewater treatment systems and legal regulations in the European Union and Hungary, Agric. Environ. 1 (2009) 57–64.
[3] J.E. Scandura, M.D. Sobsey, Viral and bacterial contamination of groundwater from on-site sewage treatment systems, Water Sci. Technol. 35 (1997) 141–146.
[4] M.K. Sharma, A.A. Kazmi. Performance evaluation of a single household anaerobic packaged system for onsite domestic wastewater treatment, Desalin. Water Treat. (2015) 1–10, doi: 10.1080/19443994.2015.1029004.

[5] D. Tian, H. Lim, J. Chung, H. Jun, Nitrogen and phosphorous removal in an anerobic (UASB)-aerobic (ABF) sewage treatment system, Desalin. Water Treat. 53 (2014) 2856–2865.
[6] H. Feng, L. Hu, Q. Mahmood, C. Fang, C. Qiu, D. Shen, Effects of temperature and feed strength on a carrier anaerobic baffled reactor treating dilute wastewater, Desalin Water Treat. 239 (2009) 111–121.
[7] F.A. Nasr, B. Mikhaeil, Treatment of domestic wastewater using modified septic tank, Desalin. Water Treat. (2014) 1–9, doi: 10.1080/19443994.2014.961174.
[8] S.I. Abou-Elela, M.A. El-Khateeb, M.E. Fawzy, W. Abdel-Halim, Innovative sustainable anaerobic treatment for wastewater, Desalin. Water Treat. 51 (2013) 7490–7498.
[9] HELCOM, 2007. HELCOM Recommendation 28E/6. Retrieved from http://www.helcom.fi/Recommendations/Rec%2028E-6.pdf. (Lastly visited 17 August 2015)
[10] T. Elmitwalli, G. Zeeman, G. Lettinga, Anaerobic treatment of domestic sewage at low temperature, Water Sci. Technol. 44(4) (2001) 33–40.
[11] F.A. Nasr, B. Mikhaeil, Treatment of domestic wastewater using conventional and baffled septic tanks, Environ. Technol. 34 (2013) 2337–2343.
[12] J.J. Bogte, A.M. Breure, J.G. van Andel, G. Lettinga, Anaerobic treatment of domestic wastewater in small scale UASB reactors, Water Sci Technol. 27 (1993) 75–82.
[13] G. Lettinga, Sustainable integrated biological wastewater treatment, Water Sci. Technol. 33(3) (1996) 85–98.
[14] F. Hammes, Y. Kalogo, W. Verstraete, Anaerobic digestion technologies for closing the domestic water, carbon and nutrient cycles, Water Sci. Technol. 41(3) (2000) 203–211.
[15] S. Luostarinen, W. Sanders, K. Kujawa-Roeleveld, G. Zeeman, Effect of temperature on anaerobic treatment of black water in UASB-septic tank systems, Bioresour. Technol. 98(5) (2007) 980–986.
[16] L.R. Diaz-Valbuena, H.L. Leverenz, C.D. Cappa, G. Tchobanoglous, W.R. Horwath, J.L. Darby, Methane, carbon dioxide, and nitrous oxide emissions from septic tank systems, Environ. Sci. Technol. 45 (2011) 2741–2747.
[17] J. Keller, K. Hartley, Greenhouse gas production in wastewater treatment: Process selection is the major factor, Water Sci. Technol. 47 (2003) 43–48.
[18] APHA (American Public Health Association), Standard Methods for the Examination of Water and Wastewater, (sixth ed.), Washington DC, USA, 1985.
[19] A.S. Bal, N.N. Dhagat, Upflow anaerobic sludge blanket reactor–A review, Indian J. Environ. Health 43(2) (2001) 1–82.
[20] C. Zhiqiang, Q. Wen, H. Guan, R. Bakke, R. Nanqi, Anaerobic treatment of domestic sewage in modified septic tanks at low temperature, Environ. Technol. 35 (2014) 2123–2131.
[21] S. Zou, S. Yao, J. Ni, High-efficient nitrogen removal by coupling enriched autotrophic-nitrification and aerobic-denitrification consortiums at cold temperature, Bioresour. Technol. 161 (2014) 288–296.
[22] M. Al-Shayah, N. Mahmoud, Start-up of an UASB-septic tank for community on-site treatment of strong domestic sewage, Bioresour. Technol. 99 (2008), pp. 7758–7766.
[23] W.J. Jewell, Anaerobic sewage treatment. Part 6, Environ. Sci. Technol. 21 (1987) 14–21.
[24] H. Rizvi, N. Ahmad, F. Abbas, I.H. Bukhari, A. Yasar, Sh. Ali, T. Yasmeen, M. Riaz, Start-up of UASB reactors treating municipal wastewater and effect of temperature/sludge age and hydraulic retention time (HRT) on its performance, Arabian J. Chem. (2014), doi: 10.1016/j.arabjc.2013.12.016.
[25] I. Zekker, E. Rikmann, T. Tenno, A. Seiman, A. Loorits, K. Kroon, M. Tomingas, P. Vabamäe, T. Tenno. Nitritating-anammox biomass tolerant to high dissolved oxygen concentration and C/N ratio in treatment of yeast factory wastewater, Environ. Technol. 35(12) 2012 1565–1576.
[26] I. Zekker, E. Rikmann, T. Tenno, K. Kroon, P. Vabamäe, E. Salo, L. Loorits, S.S.D.C. Rubin, S.E. Vlaeminck, T. Tenno. Deammonification process start-up after enrichment of anammox microorganisms from reject water in a moving-bed biofilm reactor-Environ. Technol. 34(23) 2013 3095–3101.
[27] C. Kampman, T.L. Hendrickx, F.A. Luesken, T.A. van Alen, H.J. Op den Camp, M.S. Jetten, G. Zeeman, C.J. Buisman, H. Temmink, Enrichment of denitrifying methanotrophic bacteria for application after direct low-temperature anaerobic sewage treatment, J. Hazard. Mater. 227–228 (2012) 164–171.
[28] T. Elmitwalli, Sludge accumulation and conversion to methane in a septic tank treating domestic wastewater or black water, Water Sci. Technol. 68 (2013) 956–964.
[29] S.R. Wilhelm, S.L. Schiff, J.A. Cherry, Biogeochemical evolution of domestic wastewater in septic systems: 1, Ground Water 32 (1994) 905–916.
[30] C. Polprasert, P. Kemmadamrong, F.T. Tran, Anaerobic baffle reactor (ABR) process for treating a slaughterhouse wastewater, Environ. Technol. 13 (1992) 857–865.