Sludge transfer point of a UASB-digester system: key to efficient low temperature anaerobic sewage treatment

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Abstract
The up flow anaerobic sludge bed (UASB)-digester system is one promising low temperature anaerobic process for sewage treatment. In this study, the effects of height of UASB sludge transfer (HUST) on performance of a UASB-digester system treating sewage at 15°C were studied. The studied HUSTs were 27, 47 and 67 cm in the UASB sludge bed of 70 cm, from which sludge was transferred to the digester. The biogas production in the UASB reactor increased with a higher HUST. Suspended chemical oxygen demand (COD) removal efficiency and total COD removal efficiencies increased from 52 to 65% and from 30 to 38%, respectively, when increasing the HUST from 27 to 67 cm. Increased HUST resulted in a high VSS concentration of the UASB-digester system. Methanogenic capacity at 15°C of the UASB sludge bed also increased from 9.4 to 11.7 g CH_4 COD/d as HUST increased from 27 to 47 cm.

Keywords
UASB reactor; digester; height of sludge transfer; sewage treatment; low temperature

INTRODUCTION

Anaerobic sewage treatment has advantages of low operation cost, low excess sludge production, and energy recovery in terms of methane production. It will also allow for combination with novel, energy-efficient, nitrogen removal technologies, such as anammox (Hendrickx et al., 2012) and denitrification with dissolved methane (Kampman et al., 2012). However, low temperature results in slow hydrolysis of organic solids, and slow growth and biodegradation rate by anaerobic biomass. A new anaerobic process challenging low sewage temperature is valuable and promising. A UASB-digester system (Figure 1) can achieve a good COD removal efficiency when treating sewage at 15°C as reported by Álvarez et al (2004) and Mahmoud et al (2004). Influent dissolved COD is converted in the UASB reactor at the low temperature. Influent suspended COD is captured by the UASB sludge bed, and is bio-transformed to methane in the mesophilic digester after the UASB sludge is transferred to the digester. Sludge return from the digester to the UASB reactor provides additional anaerobic biomass to the UASB reactor. Heat is required for the sludge transferred from the UASB reactor (15°C) to the digester (35°C). Since the influent suspended COD is concentrated as it is captured by the UASB sludge bed, only a small flow of the UASB sludge needs to be transferred thereby saving energy.

The height of the UASB sludge transfer (HUST) from which sludge is transferred to the digester is important for the operation of a UASB-digester system and particularly for dissolved COD removal in the UASB reactor. Previous studies on the UASB-digester system did not elaborate on the effect of HUST. Mahmoud et al (2004) applied sludge transfer from the top of the UASB sludge bed, but recommended doing this from a lower point since the sludge concentration was higher there. Alvarez et al. (2004) transferred the sludge from 2 different heights, because of available sludge bed height. However, the specific effects of changing the HUST were not shown. In the present work, different HUSTs were tested in a pilot scale UASB-digester system treating real sewage with a temperature of 15°C. The effects on biogas production, COD removal efficiency, VSS concentration and specific methanogenic acivity at 15°C ($SMA_{15°C}$) of the UASB sludge were studied.

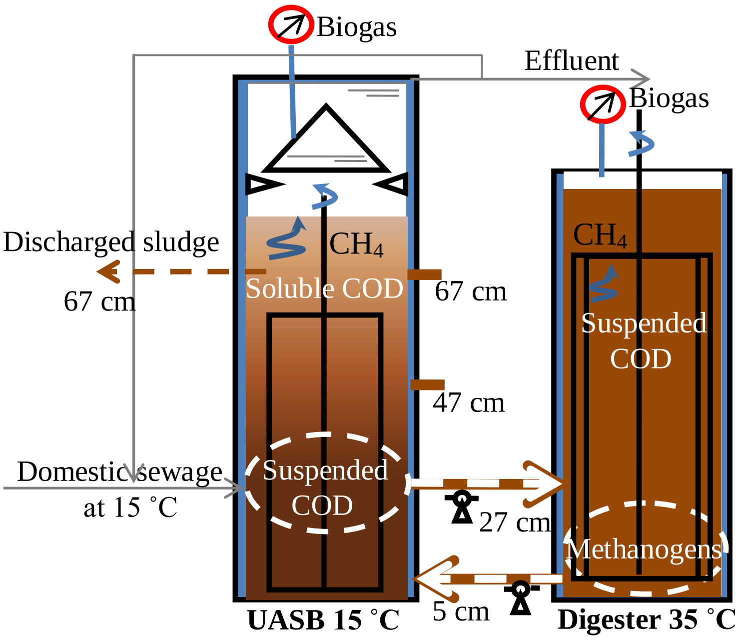

Figure 1. The UASB-digester system treating domestic sewage at 15 ˚C in this study

MATERIALS AND METHODS

UASB-digester reactor. The UASB-digester system as shown in Figure 1 consisted of a 50 L UASB reactor and a 38 L digester, and more details are given in Zhang et al. (2012). The system had already been operated for > 11 months before the start of this research. Sludge recirculation rate was fixed at 5.2 L/d (2.6 % of the 200 L/d influent flow rate). Sludge return point from the digester to the UASB reactor was fixed at 5 cm. The height of the UASB reactor was 100 cm and the height of the sludge bed was controlled at max. 70 cm. A HUST of 27, 47 and 67 cm was studied in three periods. During period 1 (sludge transfer point at 27 cm), sludge recirculation rate was temporarily increased to 25 L/d (days 71-167), thus data were not shown. Effluent circulation over the UASB reactor was applied in period 1 and was stopped from period 2 onwards, which resulted in compaction of the sludge bed. Sludge recirculation was temporarily stopped in period 2 (days 30-59) as the height of the UASB sludge bed was below the HUST.

Waste water. The UASB-digester system was fed with domestic sewage from the Bennekom waste water treatment plant, which was collected once a week and stored in a cooled (5°C) closed container. COD composition of the sewage is shown in Table 1.

Table 1. Influent COD concentrations (in mg/L, standard deviation in brackets), n = number of samples

HUST (cm)	n	COD total	COD suspended	COD colloidal	COD dissolved
27	12	605 (133)	282 (868)	82 (32)	241 (50)
47	27	582 (116)	268 (71)	78 (16)	246 (44)
67	6	714 (189)	377 (117)	64 (11)	272 (88)

Batch experiment. Tests of $SMA_{15\,°C}$ of the UASB sludge were performed as described in Zhang et al. (2012). Sludge samples for these tests were collected at a height of 47 cm.

Analyses. VSS and TSS of the UASB sludge and the digester sludge were determined according to

APHA (2005). COD tests were performed using DrLange test kits. Biogas composition was determined on a GC as described in Zhang et al. (2012). The amount of dissolved methane in the UASB effluent was calculated using Henry's law.

RESULTS AND DISCUSSION

Increased UASB biogas production at a higher HUST

Increasing the HUST resulted in a clear increase in biogas production in the UASB reactor (Figure 2). The average biogas productions at the height of 27, 47 and 67 cm were 0.9, 2.8 and 2.8 L/d. The increased biogas production was the result of the increased methanogenic capacity (SMA × VSS) (as discussed later). In addition, it was also explained by a larger amount of dissolved COD originating from partial hydrolysis of the captured suspended COD, due to its longer retention in the UASB reactor. Gas production in the digester decreased with an increase in HUST: in period 1 biogas production was 7.1 L/d in the digester. Increasing the height of UASB sludge transfer (HUST) to 47 and 67 cm (period 2 and 3) resulted in lower digester biogas productions of 3.2 and 3.7 L/d respectively.

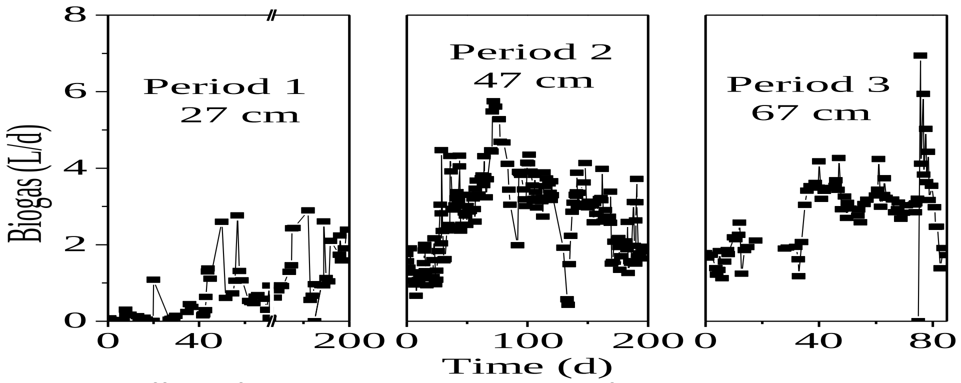

Figure 2. Effects of HUST on biogas production of the UASB reactor in the system

Improved COD removal with increased HUST

Figure 3 shows that average suspended COD removal efficiencies were 52, 57 and 65 % at the HUST of 27, 47 and 67 cm. The improved efficiencies were probably because the UASB sludge bed was compact and high when transferring the sludge at high position, which enabled good capture of the suspended COD. Overall methane production from the removed COD decreased and was 74, 58 and 44 %, showing that suspended COD accumulated as the HUST increased (as confirmed by the increased VSS concentrations, Table 2).

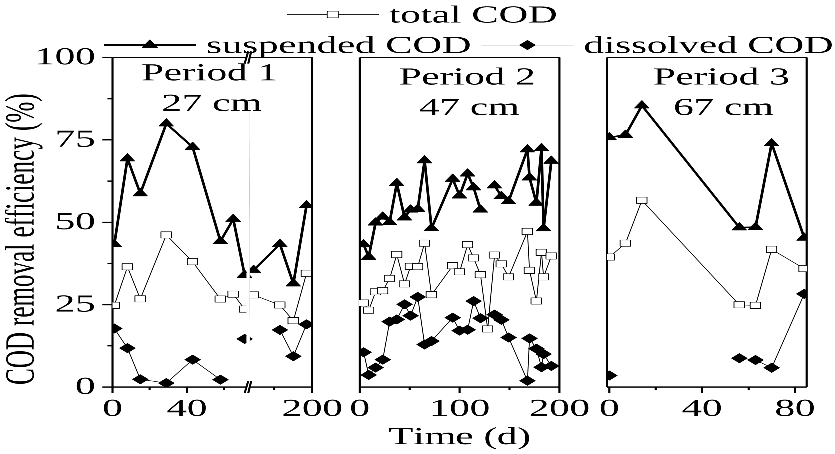

Figure 3. Effects of HUST on COD removal efficiency of the UASB-digester

As a result, total COD removal efficiency increased to 30, 34 and 38 % at the studied HUSTs. Due to the slow accumulation, the system had not yet reached steady state yet. Longer term experiments will show whether this accumulated COD can be eventually efficiently converted to methane. The low total COD removal efficiencies in this study were due to the relatively low UASB reactor (100 cm). Other, higher, reactors have shown higher total COD removal efficiencies of 51-66 % (Mahmoud et al., 2004, Álvarez et al., 2004).

In period 2, dissolved COD removal efficiency initially increased, but later decreased again. This was caused by a net dissolved COD production, due to hydrolysis of the accumulated suspended COD in the UASB sludge bed. The methanogenic capacity of the sludge bed was still insufficient to convert this additional dissolved COD.

Higher solids concentration and improved methanogenic capacity of UASB reactor at a higher HUST

Table 2 shows that VSS concentrations increased in the UASB reactor. It is hypothesized that suspended COD capture in the UASB reactor was improved due to the higher solids concentration in the sludge bed, by allowing more adsorption onto the sludge. Additionally, due to (partial) hydrolysis of this captured suspended COD, the extracellular polymeric substances may contribute to a better suspended COD capture. Confirmation of these hypotheses is part of ongoing research.

Table 2 Effects of HUST on VSS concentration and $SMA_{15\ ^{\circ}C}$ of the sludge in the UASB-digester (SMA unit: mg CH_4 COD/ (g VSS d), standard deviation was in brackets)

H (cm)	Time	VSS (g/L)					Time	SMA	VSS/ TSS
	d	11.5 cm	27 cm	47 cm	67 cm	digester	d	$_{15\ ^{\circ}C}$	
27	40	15	11(0.4)	9	8 (0.1)	9 (0.1)	40	33 (1.0)	0.73
47	199	23 (0.2)	16 (0.2)	15 (0.3)	--	12 (0.2)	293	30 (1.0)	0.74
67	63	44 (0.2)	38 (0.2)	21 (0.2)	0.2 (0.1)	7 (0.5)	476	15 (0)	0.72

As shown in table 2, $SMA_{15^{\circ}C}$ of the UASB sludge decreased with increased HUST. However, total methanogenic capacity of the UASB reactor increased from 9.4 to 11.7 g CH_4-COD/d as the HUST increased from 27 to 47 cm, and was 10.5 g CH_4 COD/d as the HUST further increased to 67 cm.

CONCLUSION

A higher height of UASB sludge transfer (HUST) has a positive effect on the performance of a UASB-digester system treating sewage at 15°C. It resulted in: 1) Higher biogas production rate in the UASB reactor; 2) Improved COD suspended removal efficiency; 3) Higher solids concentration in the UASB reactor and 4) Increased methanogenic capacity of the UASB sludge bed.

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