Particulate Matter Accumulation And Energy Recovery In Highly Loaded Enhanced Aerated Lagoons

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INTRODUCTION

Lagoon-based processes are prevalent technologies for wastewater treatment in Canada and the United States. Several thousand installations are currently in operation. Many of these are subjected to load increases as well as more stringent regulations and thus require upgrading solutions. Since the option of increasing the size of aerated lagoon systems is not always feasible due to space restrictions, alternative technologies have been developed for upgrading lagoon systems. The use of support material to promote biofilm growth has been identified as a promising solution [5,12]. Based on the results of a pilot study [3], Bionest Technologies (Québec, Canada) has developed the KAMAK, a solution using an inert self-supported submerged media. The complete KAMAK design includes two aerated biofilm reactor zones (RX1 and 2) as well as three non-mixed zones for sedimentation and accumulation of either raw sewage particulate matter or detached biofilm (CL1, 2 and 3) (Fig. 1). Each zone is separated by a watertight membrane.

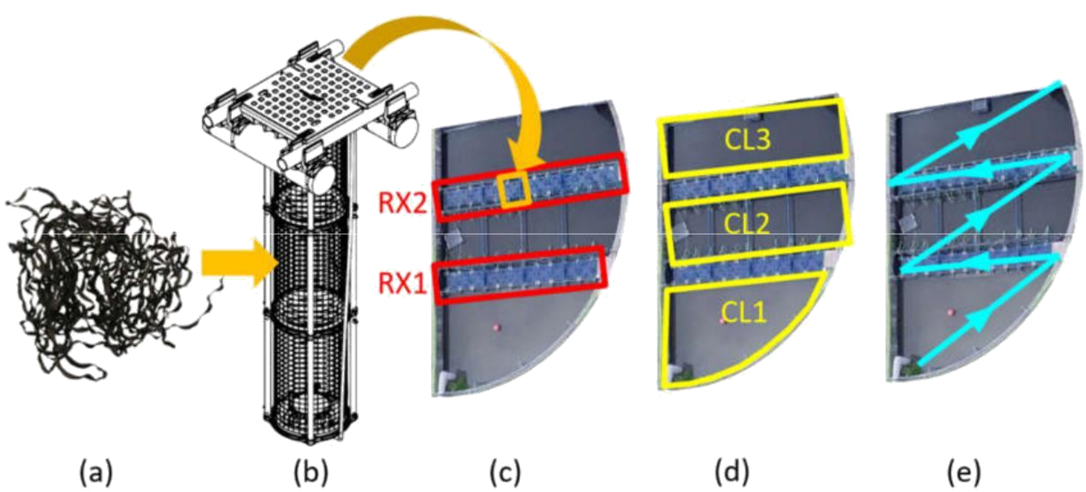

Figure 1: KAMAK system with (a) the BIONEST media, (b) the floating cells, (c) the biofilm reactor zones RX1 and RX2, (d) the settling zones CL1, CL2 and CL3 and (e) the flow diagram

Technologies such as the KAMAK are designed to intensify lagoon treatment by allowing the application of higher loads in the same volume without compromising effluent quality. One of the outcomes of this intensification is the increase of sludge production per unit of treatment volume. This can either be addressed by increasing the sludge removal frequency which would represent an important increase in operational costs [8] or by promoting in situ digestion of the accumulated solids.

Anaerobic digestion of organic particulate matter is a commonly used process for the management of primary and secondary solids. The interest of this process mainly resides in the volatile solids (VS) reduction that it allows and the net energy recovery that is achieved by transformation of VS into methane. Even in psychrophilic conditions such as the ones observed in lagoons located in the North, anaerobic digestion was demonstrated to be an effective process allowing significant decreases in sludge VS content and substantial methane production, especially in highly loaded systems such as manure digesters [6]. However, the potential of anaerobic digestion in upgraded aerated lagoon systems is still to be assessed. This project is carried out to tackle this subject by monitoring the accumulation of particulate matter, its composition and biogas production over different operating temperature conditions varying seasonally.

METHODOLOGY

The project was carried out by studying the settling zones of a full-scale KAMAK system (Fig. 1) fed with raw domestic wastewater from the municipality of Grandes-Piles (300 PE) at an average flowrate of 82 m3/d. It is installed in the first third of the original lagoon to study the potential for upgrade purposes at high loading rates (24 g total CBOD5/m3/d, 11 g soluble CBOD5/m3/d and 23 gTSS/m3/d and an average 0.82 VSS/TSS ratio), i.e. 3 times the original system load.

Sludge heights were periodically measured using two techniques. First, conventional Sludge Judge (SJ) measurements were performed monthly at different locations in each zone. Second, a sonar allowing continuous measurement was used twice a year to measure more precisely the distribution of the sludge in each zone. At the end of the monitored period, a sludge removal operation was carried out to stop the observed TSS releases in the effluent that were caused by a too high sludge blanket level.

Total solids (TS) and VS [1] were measured on sludge grab samples taken monthly with the SJ. Operating parameters (DO, pH and temperature) were monitored using portable probes.

Biogas was captured using a floating hood. Gas volumes were measured over different periods of time (4 to 25 days) depending on the accumulation rate. The hood was alternately installed in each of the three sedimentation zones over the monitored period. Gas composition (CH4, CO2, O2 and H2S content) was measured each time the hood was moved with a multiple gas portable measuring device with infrared sensors (Sewerin Multitec 520).

RESULTS

The sludge accumulation profile over 21 months is presented on Fig. 2b for CL2, the central zone of the system. As can be seen from this profile, the large variation between the measurements over the zone (SD and Fig. 2a) makes the variation of accumulation rates in relation to temperature not statistically significant (P-value>0,05). However, a tendency that the average accumulation is lower during warm periods than during the rest of the year can be observed. An important part of this tendency can potentially be attributed to solids digestion occurring more significantly under warm temperatures as shown by the gas production data presented in Tab. 1. Indeed, gas production is highly related to temperature with production being 2.3 to 3.0 times higher during warm periods compared to the rest of the year. The highest measured methane production rate (17 l CH4/m2/d in CL3, August 2017) is however lower (12% to 343%) than rates previously measured in anaerobic lagoons operated at temperatures similar to the studied warm periods conditions [4,11,9].

Table 1: Operating parameters, sludge characteristics, biogas production and composition

		CL1				CL2				CL3			
	Units	Warm conditions (July to September)		Intermediate and cold conditions (October to June)		Warm conditions (July to September)		Intermediate and cold conditions (October to June)		Warm conditions (July to September)		Intermediate and cold conditions (October to June)	
		Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD
Temperature	°C	19.3	1.1	9.1	4.9	19.5	1.1	8.5	5.0	19.5	1.1	8,4	5.0
Overlying water DO	g/m³	0.9	0.9	6.1	3.3	2.6	1.9	8.6	3.9	0.5	0.4	5.8	3.9
Overlying water pH	-	6.8	0.6	7.1	0.4	6.8	0.6	7.0	0.4	6.8	0.5	6.9	0.4
Sludge pH	-	6.1	0.1	n.d.	n.d.	6.6	0.2	n.d.	n.d.	6.5	0.1	n.d.	n.d.
TS	%	5.9	1.4	6.4	3.0	6.1	1.7	5.9	2.4	5.2	1.3	5.1	1.7
VS/TS ratio	-	0.42	0.08	0.49	0.17	0.43	0.08	0.48	0.10	0.47	0.05	0.53	0.06
Biogas production	l/m²/d	14.7	1.1	5.7	n.d.	14.4	5.9	6.3	4.1	18.6	5.6	6.2	4.3
CH_4 proportion	%	66.1	n.d.	54.8	n.d.	65.5	7.3	55.6	16.8	69.9	2.5	67.4	7.6
CO_2 proportion	%	4.0	n.d.	3.0	n.d.	1.8	1.3	3.1	1.9	1.7	1.2	3.0	1.4
O_2 proportion	%	0.1	n.d.	0.0	n.d.	0.2	0.3	0.6	0.5	0.6	1.0	0.0	0.0
H_2S concentration	ppm	102	n.d.	69	n.d.	0	0.5	2	4.0	7	12.7	4	4.9

From the sonar measurement results presented in Fig. 2a and 2b, it can also be seen that sludge accumulation did not follow the same tendency in every sedimentation zone. In CL1, sludge heights were relatively constant over the monitored period. This can be explained by the fact that a low intensity aeration system was installed prior to the study for odour control. This potentially hindered settling and favored suspension of solids and their transport through CL1. In CL3, average accumulation rate was constant over the first monitored year, independent of the variation of temperature. This can potentially be explained by the initial lower sludge quantity in this zone causing substrate limitation and insufficient biomass for a proper start-up of the digestion during the warm period of 2016. A lower methanogenesis was measured in CL3 compared to CL2 during this period. On the contrary, during the second warm period (2017) when sludge levels were at their peak in every zone (results not shown), gas production was higher in CL3 than CL2. During this second warm period, as observed in CL2, the average accumulation rate was clearly decreased in CL3 before the sludge removal operation (results not shown).

For CL2 and CL3, the observation of significant decreases (P-value<0.05) in the average VS/TS ratio between the warm periods and the rest of the year also demonstrate the occurrence of (VS) digestion in the sedimentation zones during the warm periods. For CL1, however, the variation of sludge composition was not significant as the composition variance was higher.

Average operating conditions listed in Tab. 1 were not in the range suggested [7,10] for optimal anaerobic activity during the active periods. The average overlying water and sludge pH were always equal or below 6.8. pH below this value is known to be inhibitory for methanogenic activity [7]. Moreover, during the warm periods, average DO in overlying water was significant for the three zones. The highest DO concentrations were found of the lowest average biogas production rates. Finally, H2S in concentrations exceeding the inhibition thresholds of methanogenic activity [2] were observed in the gas phase over CL1. However, sulfide concentrations should be directly measured in the sludge to confirm this in hypothesis.

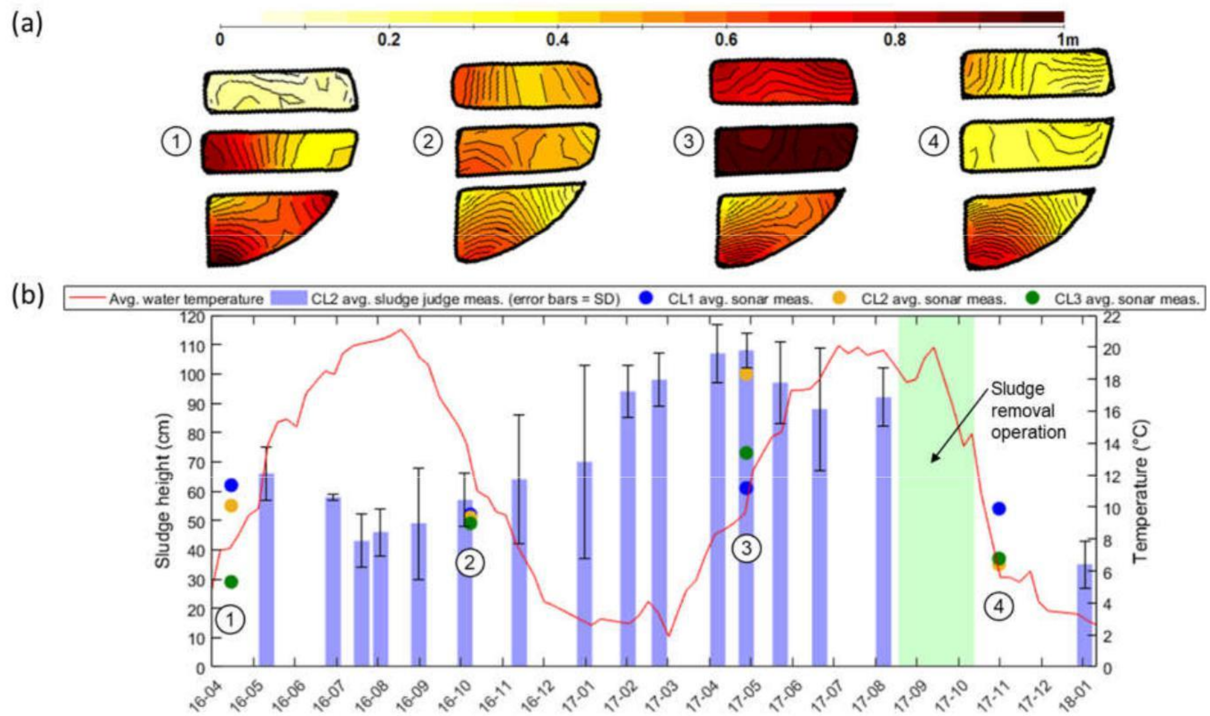

Figure 2: (a) Sludge distribution in the sedimentation zones and (b) sludge height evolution over a 21-month monitoring period

CONCLUSION

Methanogenic activity was found to be significantly higher during warm periods (>17°C) in an enhanced aerated lagoon subjected to seasonal temperature variations. An average methane production of 11 l CH4/m2/d was measured for these periods. The high gas production coincided with a downward trend in solids accumulation. A maximization of the methane production for optimal energy recovery in the system could be pursued by adjusting the key operating parameters identified as potentially limiting: temperature, pH and presence of DO or sulfide.

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