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The evaluation of applicability for development of advanced package system (BioKube) for sewage treatment

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ABSTRACT

Nowadays, more developing countries are facing the serious challenge of treating increasing number of decentralized domestic sewage in rural areas. Domestic sewage in rural areas that do not have public sewers must rely on on-site treatment system to manage wastewater. Therefore, new sewage treatment system for domestic sewage is a social concern in rural areas. In this respect, this study aimed to characterize treated domestic sewage by applying high-flux flat membrane to BioKube reactor consisted of aerobic bio-film media with the automatic control function. The BioKube reactor is separated into four chambers and each chamber contains approximately 584, 157, 487 and 118 L of wastewater, respectively. The removal efficiencies of COD_{Cr}, BOD_5, SS, T-N, NH_4^+-N and T-P were reached 81.5, 84.8, 81.7, 38.3, 84.6 and 40.1%, respectively at a hydraulic retention time of 22 h. In addition to, T-P decreased from 4.03 to 0.01 mg/L by installation of coagulation-membrane reactor on the latter part and SS concentration decreased by approximately 99.9%.

Keywords: Sewage treatment; Package system; Wastewater; Bio-film; Membrane; Water reuse

1. Introduction

Nowadays, more developing countries are facing the serious challenge of treating increasing number of decentralized domestic sewage in rural areas [1]. Domestic sewage in rural areas that do not have public sewers must rely on on-site treatment system to manage wastewater [2]. For instance, the percentage of sewered population is 59.5% in rural areas by 2011 (94.2% in city areas) [3]. As a result, on-site treatment system often do not meet water quality standard and discharge untreated wastewater containing excess nitrogen compounds, lead to the water quality deterioration and eutrophication of water especially in the enclosed watersheds in Korea. Therefore, new sewage treatment system for domestic sewage in rural areas is a social concern [4].

In this respect, this study aimed to characterize treated domestic water by applying high-flux flat membrane to BioKube reactor consisted of aerobic bio-film media with the automatic control function [5]. BioKube system is based on the same basic technology of biological degradation of organic material via natural bacteria living on submerged membrane. The bacteria used for cleaning the wastewater are available in abundance in the wastewater itself [6], so a BioKube

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system cleans the black and grey wastewater using naturally occurring bacteria and micro-organisms in aerobic condition.

2. Materials and methods

2.1. Pilot-scale BioKube reactor

The experiments were carried out in a pilot-scale BioKube reactor (Fig. 1). The BioKube reactor is separated into four chambers (first aerobic zone—first settling zone—second aerobic zone—second settling zone) and each chamber contains approximately 584, 157, 487 and 118 L of wastewater. The height of reactor is 2.2 m and diameter is 1.26 m. Also, this reactor is installed following a pre-settling tank (anoxic tank). Pipeline of recirculated water connects from the treatment plant (BioKube) to the inlet of pre-settling tank. This pre-cleaning process ensures that raw sewage water basically free from particles before entering the cleaning units (aerobic zone). The wastewater is pumped from the pre-settling tank into the first aerobic zone at precisely timed intervals. One of the keys to the unique and stable BioKube cleaning process is based on precise timing of the inflow of sewage water to the cleaning chambers. The wastewater flows through the bio-blocks, where the heterotrophic bacteria break down the organic material in the wastewater. From here, the wastewater is led through a first settling chamber, where the wastewater moves slowly, and the sludge settles through gravitation. From first chamber, the water flows to the second chamber, where this process repeats itself.

Physical conditions in this study are presented in Table 1. Influent flow was set at 1.5 m^3/d with hydraulic retention time (HRT) of 21.5 h. Dissolved oxygen (DO) concentration in aerobic zone was kept at the range of 2–4 mg/L and was aerated by air pump through blower via diffusers.

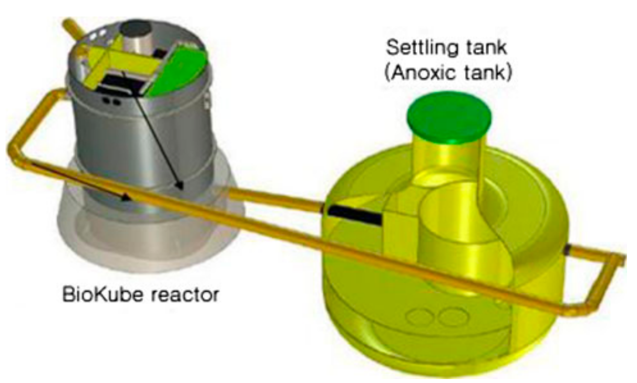

Fig. 1. BioKube system overview.

2.2. Bio-filters of honeycomb form

The BioKube system treats the sewage biologically. The technology is based on bacterial growth on submerged aerated filter blocks [7]. BioKube consisted of aerobic bio-film media with the automatic control function (Fig. 2). Aerobic zone was filled with plastic media made of polyethylene and the main advantages of these filters are wide surface area and great structural strength. The micro-organisms living on the bio-filter will from time to time be surplus to the requirements and they will die and sink to the bottom. They sink to the bottom in the stagnant part of the aerobic zone and from here the sediments are regularly pumped return to the anoxic tank. Characteristics of bio-film media are presented in Table 2.

2.3. Membrane module

The flat membrane modules, each with an average pore size of 0.2 μm, and an effective filtration area of 204 cm^2, were immersed in the up-flow zone of the reactor [8]. Specifications of membrane module are presented in Table 3.

2.4. Raw wastewater

Raw wastewater was collected from primary settling tank of J Water Recycling Reclamation in Seoul, Korea. Table 4 summarizes the main characteristics of the influent. Sampling was carried out three times per week in four points (influent, pre-sedimentation tank, second aerobic zone and effluent). The sampling gathered based on the Sampling Methods of the United State EPA or Standard Methods [9]. The collected sample transported in low-temperature state and analysed immediately. To evaluate applicability of BioKube, measured COD_{Cr}, BOD_5, SS, T-N, T-P, NH_4^+-N, pH, DO, temperature, etc.

2.5. Analytical methods

Chemical oxygen demand (COD), biochemical oxygen demand (BOD), ammonia nitrogen(NH_4^+-N), total suspended solids (TSS), volatile suspended solids (VSS), total nitrogen (TN) and total phosphorus (TP) were measured according to standard methods (APAH, 2005). Nitrate (NO_3^--N) and nitrite (NO_2^--N) were detected with a HPLC (SHIMADZU, HPLC LC-20A Series). DO and pH were measured using DO/pH meters (YSI, Professional Plus).

2.6. Jar-test

The coagulation process was carried out with 2 L of water samples in jar test. The coagulant used

Table 1
Physical conditions of BioKube

Parameters	First aerobic zone	First settling zone	Second aerobic zone	Second settling zone
Volume of pre-settling tank (m^3)	4.3			
Internal recirculation (%)	200			
HRT (h)	9.3	2.5	7.8	1.9
Volume (L)	584	157	487	118
Air volume (L/min)	42	None	28	None
Influent flow rate (m^3/d)	1.5			

Fig. 2. Bio-filter in aerobic zones.

Table 2
Characteristics of the bio-filter in aerobic zone

Classification (unit)	First aerobic zone	Second aerobic zone
Raw material	Polyethylene	Polyethylene
Standard dimensions (cm)	Approx. 54 × 54 × 55	Approx. 54 × 55 × 55
Horizontal free-flow area (%)	Approx. 70	Approx. 64
Vertical free-flow area (%)	Approx. 22	Approx. 15
Void percentage (%)	Approx. 90	Approx. 82
Net weight (kg/m^3)	Approx. 38	Approx. 60
Density (g/cm^3)	Approx. 0.55	Approx. 0.55
Maximum Tem. (℃)	80	80

aluminium sulphate ($Al_2(SO_4)_3$, Alum, 8%). The coagulant and wastewater were vigorously mixed for 5 min at 120 rpm, followed by slow mixing for 20 min at 30 rpm and then allowed to settle for 30 min. The pH was adjusted with 0.1 M HCl solution or 0.1 M NaOH solution [10]. To calculate the alum dosage of the jar-test at different Al/P mol ratios, experiments were conducted at Al/P mol ratios ranging from 1 to 3 (Table 5).

$$\text{Alum dose (mL)} = (A - B) \times 2\ \text{L} \times \frac{\text{Almol}}{\text{P mol}} \times \frac{\text{AlMW(g)}}{\text{P MW (g)}} \times \frac{\text{AlumMW}}{2 \times \text{P MW}} \times \frac{100}{8}$$

3. Results and discussion

3.1. Treatment efficiency

The profiles of the influent concentration and removal efficiency of COD_{Cr}, BOD_5, SS, T-N, NH_4^+-N and T-P distribution for sewage during the operation period are indicated in Fig. 3. As shown in Fig. 3(a), the COD_{Cr} concentration in the influent ranged from 87.6 to 209.1 mg/L. The average of COD_{Cr} concentration of effluent and removal efficiency was 27.4 mg/L and 81.5%, respectively. The concentration of BOD_5 (Fig. 3(b)) in the influent ranged from 42.7 to 115.8 mg/L, with an overall average of 84.8% in terms of the removal rate. The influent SS concentration was maintained at 39.3–169.0 mg/L. Moreover, the

Table 3
Specifications of membrane module

Parameters	Specifications	Membrane module
Membrane material	PES (polyethersulphone)	
Membrane type	MF	
Pore size (μm)	0.2	
Module type	Flat sheet membrane	
Chemical resistance (as NaOCl, mg/L)	5,000	
Pure flux	4,375	
Frame size (cm^2)	204	

Table 4
Characteristics of raw wastewater (mg/L)

Parameters	Minimum	Maximum	Average
Tem. (℃)	16.0	27.7	25.5
pH	6.5	7.8	7.1
DO	0.4	2.7	1.7
COD_{Cr}	87.6	209.1	148.6
BOD_5	42.7	115.8	81.4
SS	39.3	169.0	80.3
T-N	23.3	56.5	34.6
NH_4^+-N	12.0	52.0	25.9
T-P	2.80	7.22	4.03
PO_4^{3-}-P	1.57	6.52	3.11

variations in the concentration of SS resembled that of COD variation, with a steady removal efficiency reaching 94.5% after 83 d (overall removal efficiency was 81.7% on average). In terms of organic matter, effluent concentration met emission standard limits after 40 d. The regionally permitted limits for small scale (50–500 m^3/d) sewage discharges are summarized in Table 6.

The change of T-N and NH_4^+-N concentration is illustrated in Fig. 3(d) and (e). The average NH_4^+-N concentration of influent and effluent was 25.9 and 3.7 mg/L, respectively. Although the influent contained more ammonium, NH_4^+-N was almost 98% removed constantly under the steady state (after 80 d). As shown in Fig. 4, the consumption of ammonium was 80% between anoxic and second aerobic zone by nitrification [11]. As an overall comparison, the low concentration of ammonium in effluent was confirmed the nitrification under anoxic condition at the presence of low-oxygen concentration, which could be attributed to the presence of nitrifying bacteria or anaerobic ammonium oxidation bacteria [12,13].

The mechanism of nitrification and denitrification is very complicated. The main products of these processes are nitrite, nitrate and nitrogen gas, which are created in sequential reactions [14]. However, some by-products (NO, N_2O) may be produced during nitrification and denitrification [15]. In this study, the measurement of NO or N_2O was not detected and might have contributed to nitrogen loss in the nitrification and denitrification processes [16].

The concentration of T-N in influent and effluent was 34.6 and 21.9 mg/L, respectively. Though low T-N removal efficiency (38.3%), this result was better than general sewage treatment process, which was

Table 5
Characteristics of raw wastewater

BioKube eff. con. (A)	Target T-P con. (B)	Al/P (mol ratio)	Alum dose (mL)
2.48	1.00	1.0	0.20
		1.5	0.31
		2.0	0.41
		2.5	0.51
		3.0	0.61

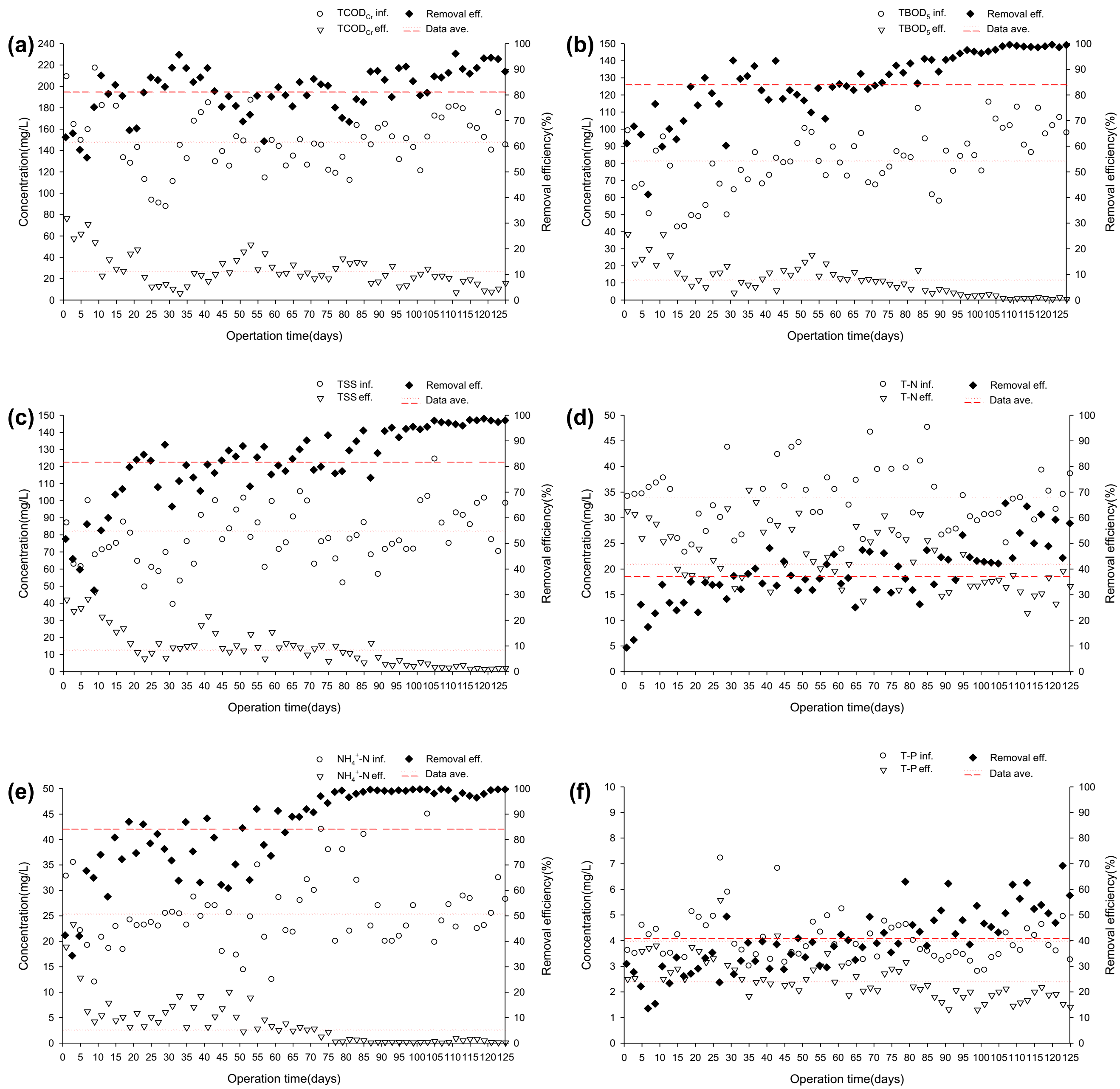

Fig. 3. Concentration and removal efficiency in BioKube reactor (a) COD_{Cr}; (b) BOD_5; (c) SS; (d) T-N; (e) NH_4^+-N; and (f) T-P.

Table 6
The effluent standard limits (50–500 m^3/d)

BOD (mg/L)	≤10
COD (mg/L)	≤40
SS (mg/L)	≤10
T-N (mg/L)	≤20
T-P (mg/L)	≤2
Total coliforms (MPN/mL)	≤3,000
Toxic unit (TU)	1

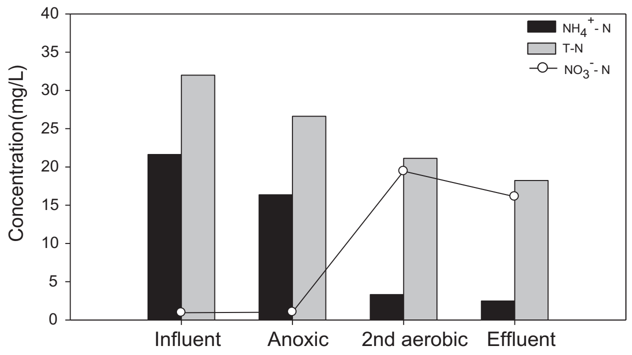

Fig. 4. Nitrogen concentration in each zone.

10–35% in rural areas. Also, T-N was about 50% removed and the effluent concentration was showed 16.7 mg/L under the steady state (after 85 d).

The influent T-P concentration ranged from 2.80 to 7.22 mg/L, with an overall average of 40.1% in terms of the removal rate (Fig. 3(f)). However, the T-P removal efficiency increased gradually to over 50% and the effluent T-P concentration decreased eventually to 1.8 mg/L under steady state. In order to evaluation for reuse of wastewater, the coagulation process was carried out with 2 L of BioKube effluent samples in jar-test apparatus.

3.2. The results of jar-test

The coagulation process using aluminium sulphate ($Al_2(SO_4)_3$, Alum, 8%) was evaluated in search of the optimum working dose of coagulant [17]. Fig. 5 shows the variation of COD_{Cr}, T-N, T-P and PO_4^{3}-P with Al/P mol ratio. The lowest concentration was achieved at 1.5 Al/P mol ratios, without significant differences in the 2.0–3.0 Al/P mol ratios. According to this, optimum coagulant doses were determined at 1.5 Al/P mol ratios.

3.3. Application of coagulation reactor and membrane

Coagulant and flat membrane were applied to the BioKube effluent. Coagulant was the optimum doses of 0.31 mL as a result of jar-test and summarizes the main parameters after coagulation- membrane process in Table 7. After coagulation-membrane process was significantly below the recommended water reuse criteria in all parameters. However, T-N concentration exceeded limit value of 10 mg/L. The coagulation-membrane process was yielded COD_{Cr}, BOD_5, SS, T-N and T-P values of 15.10, 0.86, 0.01, 10.02 and 0.01 mg/L, corresponding to removal efficiencies of 95.0, 99.3, 99.9, 68.7 and 99.8% for samples, respectively.

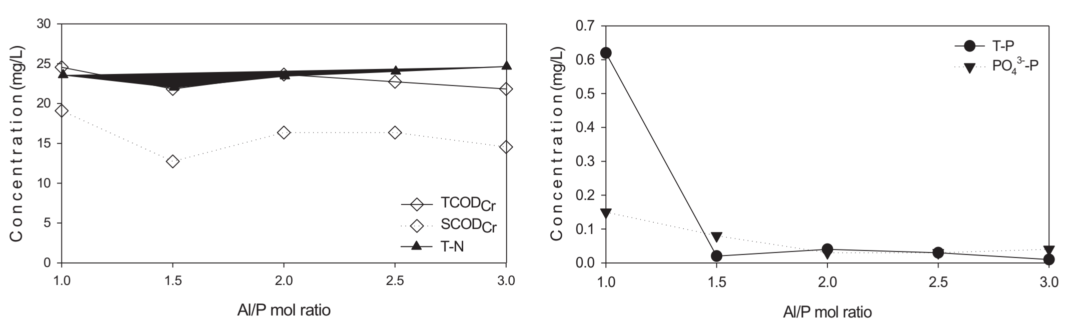

Fig. 5. Results of jar-test.

Table 7
Removal efficiency with coagulant and flat membrane

Parameters	Raw wastewater (mg/L)	BioKube eff. (mg/L)	Coagulant eff. (mg/L)	Membrane eff. (mg/L)
COD_{Cr}	148.61	27.4	17.88	15.10
BOD_5	81.44	11.2	1.59	0.86
SS	80.34	13.9	2.00	0.01
T-N	34.55	21.9	12.12	10.02
T-P	4.03	2.47	0.09	0.01

4. Conclusions

The feasibility of a pilot-scale BioKube reactor for treatment of low-strength rural areas wastewater was demonstrated. High-removal efficiencies of COD_{Cr}, BOD_5 and SS were achieved like 81.5, 84.8 and 81.7%, respectively. The ammonia nitrogen removal was one of the main mechanisms in the BioKube system. So, NH_4^+-N was almost 98% removed constantly under the steady state. This might have occurred as a result of the attachment and precipitation on filter materials. However, T-N was removed 38.3% during the operation time. An addition of carbon source and pH control in raw wastewater is necessary to achieve efficient denitrification rate and T-N removal mechanism. Lastly, the BioKube system was required to meet the water reuse criteria in all parameters by installation of coagulation-membrane reactor on the latter part. Both T-P and SS concentration decreased by approximately 0.01 mg/L, corresponding to removal efficiency of 99.8 and 99.9%, respectively.

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