Application of Granular Activated Carbon-Sequencing Batch Reactor (GAC-SBR) System for Treating Wastewater from Slaughterhouse

Suntud Sirianuntapiboon and Kwannate Manoonpong
Department of Environmental Technology, School of Energy and Materials; King-Mongkut's University of Technology Thonburi, Bangmod, Rasburana, Bangkok10140, Thailand.

Abstract

The maximum COD and TKN adsorption abilities of GAC in slaughterhouse's wastewater with COD concentration of 1000 mg.l^{-1} under normal condition (Jar test system) and SBR system were 915.00 mg.g^{-1} and 48.00 mg.g^{-1} and 916.00 mg.g^{-1} and 54.00 mg.g^{-1}, respectively. The COD and TKN adsorption abilities of used GAC from GAC-SBR system were almost stable. They were reduced only 1.42% and 25.00%, respectively. Both SBR and GAC-SBR systems showed high removal efficiency for treating slaughterhouse's wastewater when the systems were operated under HRT of only 2 days. For example, the COD, BOD_5, TKN and oil and grease removal efficiencies of GAC-SBR system under HRT of 2 days were 95.19%, 98.33%, 74.14% and 90.71%, respectively while, in the SBR system they were 94.08%, 97.99%, 74.29% and 88.57%, respectively. However, GAC in GAC-SBR system could increase the efficiencies and reduce the HRT of the system. For example, at the COD removal efficiency of 95%, the GAC-SBR system was operated under HRT of 2 days, while the SBR system had to operate under HRT of 6 days. The quality of sludge from both SBR and GAC-SBR systems was good under all conditions tested. The sludge volume indexes (SVI) in SBR and GAC-SBR systems were in the range of 65.00-78.00 ml.g^{-1} and 62.00-70.00 ml.g^{-1}, respectively.

For application, SBR system could be used for treating wastewater from slaughterhouses with high removal efficiency. However, the adding of GAC into SBR system could increase the efficiency and reduce of the HRT of the system. Then the GAC-SBR system might be suitable for treating wastewater from slaughterhouses with high efficiency, low HRT operation and good setting of sludge.

Keywords: **Granular activated carbon (GAC), Sequencing batch reactor (SBR), Granular activated carbon-sequencing batch reactor (GAC-SBR), Adsorption.**

***Off print requests to Dr. Suntud Sirianuntapiboon.**

1. Introdction

The suitable wastewater treatment process depends on the types of pollutant [1,2,3,4,5,6,7,8]. The slaughterhouse factory is one of the main industries in Thailand for exporting of chicken meat products. About 344 factories are located in every part of Thailand, especially in and near Bangkok area. The wastewater from this kind of factory contains mainly organic matter (COD or BOD_5), oil and grease and nitrogenous compounds (protein and amino acid).

Activated sludge system (AS) [1] is popular and normally used for treating above kinds of waste water, but several problems occurred during operation such as, high operation cost, fluctuation of removal efficiency and quality of effluent, rising of sludge, sludge bulking and so on. Among them, the rising of sludge and sludge bulking is the main problem in the operation of the activated sludge system. The bio-sludge settles well when the sludge volume index (SVI) is less than 100 $ml.g^{-1}$ or sludge density index (SDI) greater than 1 whereas the SVI is greater than 150 $ml.g^{-1}$ or sludge density index is less than 0.66 indicated settling problem may possibly be bulking [1]. Several results indicate the sludge bulking and raising sludge such as filamentous bulking, non-filamentous bulking and non-bulking sludge [1].

Activated carbon is widely used in water, wastewater, air and air pollution treatments by the physical adsorption mechanism. Furthermore, activated carbon could be used together with biological treatment processes for increasing the removal efficiency. Activated carbon could be used as the media for microorganisms in attached growth system. Several researchers [9, 10, 11, 12, 13, 14, 15] tried to increase the efficiency of the AS system by adding power activated carbon (PAC). The results showed that PAC could reduce the HRT of the system and could adsorb some heavy metals such as Zinc, Copper, Chromium and so on [16,17,18]. But, the effluent contaminated with PAC and PAC was lost from the system by discharging excess sludge[15,16,17].

The Sequencing batch reactor system (SBR) is a fill-and-draw activated-sludge treatment system that could apply for treating organic contained wastewater [19,20,21,22,23]. The unit processes involved in the SBR and conventional activated sludge systems were identical. Aeration and sedimentation were carried out in both systems. However, there was one important difference. In a conventional plant, the processes were carried out simultaneously in separate tanks, whereas in SBR operation the processes were carried out sequentially in the same tank.

In this study, we used the GAC-SBR system for treating waste water from the slaughterhouse. The optimum concentration of GAC and the optimum HRT value were determined for observation of the highest removal efficiency. The phenomenon of the system and sludge was also investigated.

2. Materials And Methods

Wastewater of slaughterhouse:

The waste water sample collected from wastewater treatment plant of the slaughterhouse plant in SAHA farm Co., Ltd., Bangkok, Thailand was used in this study.

Granular activated carbon (GAC):

The GAC used in this experiments was CGC-11 (name of manufacturing company) with the mesh size of 8x30 mm^2, total surface area of 1050-1150 $m^2.g^{-1}$ and apparent density of 0.46-0.48 $g.ml^{-1}$.

Chemical adsorption ability test of GAC:

The wastewater from the sump tank of the waste water treatment plant of the slaughterhouse in was used for determination of maximal adsorption capacity of GAC in normal conditions (jar test method) and SBR system. The concentrations of GAC that were used in this experiment were 500, 1,000, 1,500, 2,000 and 2,500 $mg.l^{-1}$. The adsorption capacity of GAC for COD and TKN at different concentrations of GAC were collected and analyzed by using Freundlich's adsorption isotherm equation [6] for the determination of maximal COD and TKN adsorption capacity of GAC.

Sequencing batch reactor (SBR):

The three, ten-liter reactors used in this experiment, were made from acrylic plastic (5 mm thick) as shown in fig.1. The dimension of the reactor was 18 cm in diameter and 40 cm in height. The working volume was 7.5 liters. The low speed gear motors model P 630A-387, 100 V, 50/60 Hz., 1.7/1.3 A (Japan Servo Co. Ltd., Japan) were used for driving the paddle shape impeller. The speed of impeller was adjusted to 60 rpm. One air pump system model EK-8000, 6.0 W (President Co. Ltd., Thailand) was used to supply air for 3 sets of reactors.

Acclimatization of sludge:

Sludge from the central wastewater treatment plant of Bangkok city was used as the starter. The sludge was cultured in wastewater from the wastewater treatment plant of the slaughterhouse for 1 week before using in the experiments.

Operation of SBR and GAC-SBR system:

Concerning the SBR system, 1.4 liters of 10,000 $mg.l^{-1}$ of acclimatized sludge was inoculated in each reactor. And then, fresh wastewater was added up to the maximum capacity (about 7,500 ml) within 1 hr. During feeding fresh wastewater, the system had to be aerated continuously for 19 hrs. And then the aeration of the system was shut down for 3 hrs. After the sludge had fully settled, the supernatant was removed (7,000 ml) within 0.5 hr and the system was kept for 0.5 hrs. After that the fresh wastewater (7,000 ml) was filled into the system and the operation was repeated, as above. For the GAC-SBR system, the operation conditions were similar to the above SBR system, but the 7,500 mg of GAC (final concentration of GAC in each reactor was 1,000 $mg.l^{-1}$ due to the easy operation of the SBR system and maximum adsorption capacity of GAC) was also added in each reactor. The COD concentration of wastewater was controlled to be 1,000 $mg.l^{-1}$.

Effects of HRT on the efficiency of SBR and GAC-SBR systems:

The experiments were carried out in each reactor under HRT of 2, 4, 6 and 8 days. Both SBR and GAC-SBR systems were operated under MLSS (sludge) concentration of 2,000 $mg.l^{-1}$ and SRT of 10 days. And the GAC concentration in GAC-SBR system was 1,000 $mg.l^{-1}$. The wastewater used in these experiments had COD concentration about 1,000 $mg.l^{-1}$. The influents and effluents of the systems were collected for determination of the chemical properties.

Chemical analysis:

The chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), Total kjeldahl nitrogen (TKN), mixed liquor suspended solids (MLSS), pH, dissolved oxygen (DO) and sludge volume index (SVI) of influents and effluents were determined by using standard methods for the examination of water and wastewater [24].

3. Results

Chemical properties of slaughterhouse wastewater:

The wastewater of SAHA Farm Co., Ltd. was produced about 25.7 $l.bird^{-1}$. The chemical properties of wastewater from this factory are shown in table1. The average BOD_5/COD and TKN of influent of influent were 1444.00 $mg.l^{-1}$, 910.00 $mg.l^{-1}$ and 186.00 $mg.l^{-1}$, respectively. The average BOD_5/COD ratio of above wastewater was 1:1.58. The BOD_5 loading of this factory were 1,520.60 $kg.d^{-1}$ and 23.04 $g.bird^{-1}$.

TKN and COD adsorption abilities of GAC:

The results are shown in table2. The maximal COD and TKN adsorption capacities of GAC in normal condition (jar test method) were 915.00 $mg.l^{-1}$ and 48.00 $mg.l^{-1}$, respectively. But the maximal COD and TKN adsorption capacities of GAC in SBR system were 916.00 $mg.l^{-1}$ and 54.00 $mg.l^{-1}$, respectively. The adsorption ability of GAC was almost stable when it was operated in the SBR system for 1 month. The COD and TKN adsorption abilities of used GAC were about 98.58% and 75.00% of the abilities of the fresh GAC, respectively.

Effects of HRT on efficiency of SBR and GAC-SBR Systems:

The experiments were carried out in 3 sets of 10 liter reactors with working volume of 7.5 liters. The final concentration of sludge (microorganisms) and GAC in the reactor were controlled as 2,000 mg $l^{-1}$and 1,000 mg l^{-1}, respectively. Both SBR and GAC-SBR systems were operated with SAHA farm Co., Ltd. wastewater that had COD concentration at 1,000 mg l^{-1} under HRT of 2, 4, 6 and 8 days. Several interesting results were investigated as follows:

COD removal efficiency: The results of COD removal efficiencies of both SBR and GAC-SBR systems under various HRT are shown in table3, table4 and fig.2. At the first day operation, COD removal efficiencies of GAC-SBR > SBR> GAC in all HRT conditions tested as shown in table 3. For example, the COD removal efficiencies of GAC, SBR and GAC-SBR within 2 days of operation on the first day were 88.83%, 93.09%, 94.62%, respectively as shown in table 4. At the steady state, COD removal efficiency of GAC-SBR was higher than of SBR system in all HRT conditions tested. The COD removal efficiencies of SBR system under HRT of 2, 4, 6 and 8 days were 94.08%, 89.86%, 94.51% and 94.94%, respectively, while they were 95.19%, 91.57%, 95.55% and 96.51%, respectively in GAC-SBR system (table 4). However, the COD concentration of effluent from both SBR and GAC-SBR systems were not more than 80 $mg.l^{-1}$

BOD_5 removal efficiency: The results are shown in table4. The BOD_5 removal efficiency in GAC-SBR system was higher than in SBR system in all HRT conditions tested. The BOD_5 removal efficiencies of GAC-SBR systems under HRT of 2, 4, 6 and 8 days were 98.33%, 91.57%, 98.18% and 98.83%, respectively, while they were 97.99%, 97.07%, 91.56% and 98.20%, respectively in SBR system. The effluent BOD_5 from both SBR and GAC-SBR systems at steady state under all HRT conditions tested were less than 20 $mg.l^{-1}$.

TKN removal efficiency: The results are shown in table3, table4 and fig.3. The results show that the TKN removal efficiency in GAC-SBR system was higher than in SBR system. On the first day of operation, the TKN removal efficiency of SBR>GAC-SBR>GAC. TKN removal efficiency of GAC, SBR and GAC-SBR systems on the first day of operation under HRT of 2 days were 50.00%, 72.06% and 75.00% , respectively. At the steady state, the TKN removal efficiencies of GAC-SBR under HRT of 2, 4, 6 and 8 days were 74.14%, 76.47%, 80.20% and 81.11%, respectively, while they were 74.29%, 70.51%, 73.27% and 75.56%, respectively in SBR system as shown in table4. The TKN concentration of effluents from both SBR and GAC-SBR systems were not more than 30 $mg.l^{-1}$ in all HRT conditions tested.

SS removal efficiency: The results are shown in table4 and fig.5. The SS removal efficiencies of GAC-SBR system were higher than SBR system. Then, the SS concentration of effluent from GAC-SBR system would be lower than from SBR system. The SS removal efficiencies of GAC-SBR system under HRT of 2, 4, 6 and 8 days were 97.62%, 93.94%, 99.88% and 97.74%, respectively, while they were 94.08%, 89.86%, 94.51% and 94.94%, respectively in SBR system. However, when the HRT of the system was considered, the results are shown in table 4. The SS concentration of effluent from both SBR and GAC-SBR system under all HRT conditions tested (excepted for SBR of 4 and 6 days) were not higher than 20 $mg.l^{-1}$.

Phosphorus removal efficiency: The results are shown in table4. The phosphorus removal capacities of both SBR and GAC-SBR systems were highest at HRT of 2 days. The total phosphorus (TP) concentration in effluent from both SBR and GAC-SBR systems were about 6.00 $mg.l^{-1}$. TP removal efficiencies of GAC-SBR systems under HRT of 2, 4, 6 and 8 days were and 40.00%, 22.22%, 20.00% and 22.22%, respectively, while they were 40.00%, 11.11%, 15.00% and 22.22%, respectively in SBR system. However, the TP concentration of effluents from both SBR and GAC-SBR were lower than 9 $mg.l^{-1}$

Oil and grease removal efficiency: The results are shown in table4. The oil and grease removal efficiency of GAC-SBR system was higher than of SBR system. The oil and grease removal efficiencies in GAC-SBR systems under HRT of 2, 4, 6 and 8 days were 90.71%, 92.59%, 92.35% and 93.33%, respectively while they were 88.57%, 81.48%, 87.65% and 91.67%, respectively in SBR system. However, the oil and grease concentration in effluents from both SBR and GAC-SBR systems were still higher than 5 mg l^{-1} even the HRT of the system was up the 8 days.

Sludge volume indexes (SVI): The results are shown in table 5. Both SBR and GAC-SBR systems showed good results for sludge settling during sedimentation state. The SVI of SBR and GAC-SBR systems under HRT of 2, 4, 6 and 8 days were not more than 80 $ml.g^{-1}$ of sludge. And the system did not show any problem in bulking sludge and rising sludge.

4. Discussions And conclusions

The slaughterhouse wastewater from SAHA farm Co., Ltd. was produced about 25.7 $l.bird^{-1}$. The BOD_5 loading are about 1,520.60 $kg.d^{-1}$ and 23.04 $g.bird^{-1}$. The BOD_5:COD and the BOD_5:TKN ratios were 1:1.58 and 4.89:1, respectively. At the BOD_5:COD ratio of 1:1.59, the biological treatment process could be applied [2,3,4,5]. But, the conventional AS system might be not suitable for treating wastewater that contained a high ratio of BOD_5:TKN as 5:1 [1,6,7,8,19,20,21]. The SBR system was introduced for treating above slaughterhouse wastewater. And GAC could be added in SBR system for increasing the efficiency of the system [1,9,10,11}. The GAC could show the high adsorption abilities for both COD and TKN in slaughterhouse wastewater as shown in table 2. And the SBR system was more suitable than the in jar test system, because the fully aerating condition in SBR system could help GAC to adsorb the impurities (TKN and COD) easily. Then, the TKN and COD adsorption abilities in SBR condition were 12.50% and 0.11% higher than in jar test condition, respectively. It was found that the adsorption ability of GAC was almost stable after 1 month of operation in GAC-SBR system. Because, the GAC could be self regenerated by biological regeneration mechanism [10]. It was also found that the sludge (microorganisms) of SBR system could absorb the COD and TKN with high efficiency as shown in table 3. Then, it could be concluded that the adsorption activities occurred in both GAC and bio-sludge [9,10,11]. In the SBR and GAC-SBR systems, HRT was effected to the removal efficiency as shown in table 4- table 5. And the HRT of the HRT of 2 days was suitable for operating SBR and GAC-SBR system for treating slaughterhouse wastewater containing the COD at the concentration of 1,000 $mg.l^{-1}$. The GAC could also increase the removal efficiency of SBR system due to the adsorption ability of GAC and the use GAC as the media for microorganisms to attach. For observation the quality of the sludge in both SBR and GAC-SBR systems during operation under HRT of 2, 4, 6 and 8 days, the sludge in both systems was easily precipitated with low-sludge volume index value. The sludge volume index of sludge in SBR and GAC-SBR systems were in the range of 68.00-78.00 $ml.g^{-1}$ of sludge and 62.00-70.00 $ml.g^{-1}$ of sludge, respectively. This means that the sludge in both systems was good quality, because, the SVI was lower than 100 $ml.g^{-1}$ of sludge [11,16]. Also both systems did not show any raising sludge and bulking sludge problems during operation when the waste water contained high concentration of nitrogenous compounds (BOD_5:TKN ratio as 5:1).

For application, it is be suggested that the SBR system be used for treating high nitrogenous compounds contained wastewater especially, slaughterhouse wastewater. For increasing of the efficiency of SBR system and quality of sludge, the GAC might be used. GAC could be used for increasing efficiency and reducing of HRT of SBR system due to physical adsorption ability and large surface area for microorganisms to attach (attached growth system). Then, the GAC-SBR system might be the most suitable wastewater treatment system for treating slaughterhouse wastewater or high nitrogenous compounds contained in wastewater.

5. Acknowledgement

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6. References

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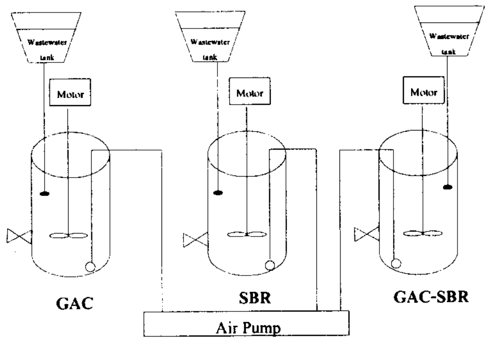

Fig.1: Flow diagram of SBR system.

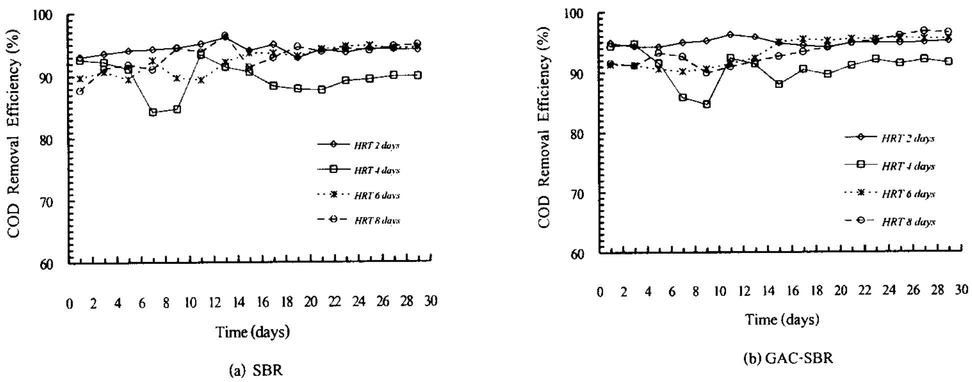

Fig.2: The COD removal efficiency profiles of SBR (a) and GAC-SBR(b)systems under HRT of 2, 4, 6 and 8 days.

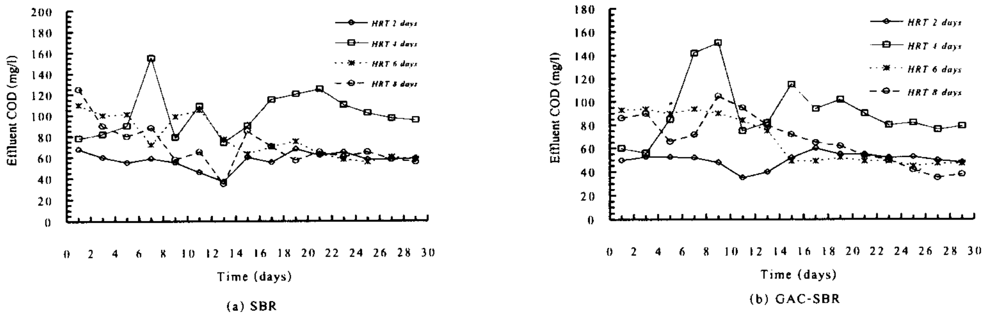

Fig.3: The effluent COD profiles of SBR (a) and GAC-SBR (b) systems under HRT of 2, 4, 6 and 8 days.

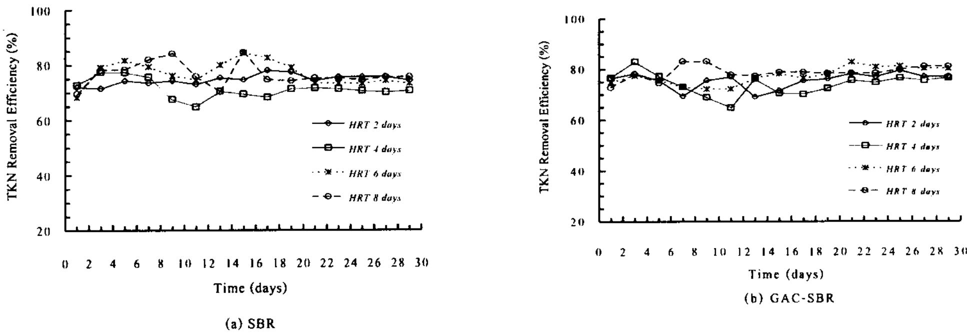

Fig.4: TKN removal efficiency profiles of SBR (a) and GAC-SBR (b) systems under HRT of 2, 4, 6 and 8 days.

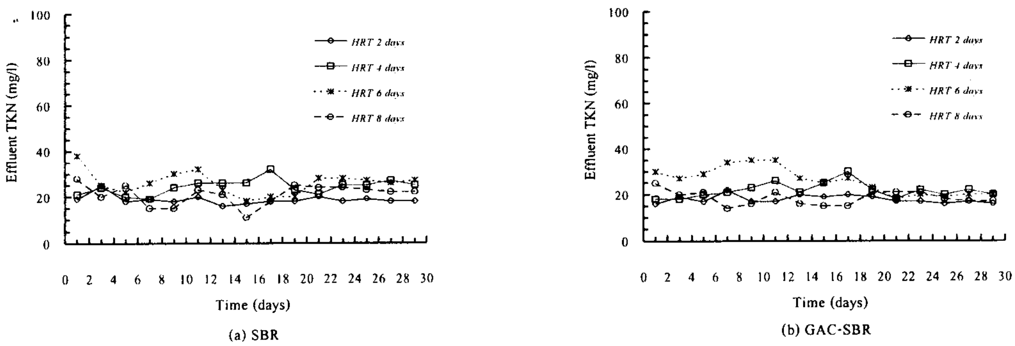

Fig.5: Effluent TKN profiles of SBR (a) and GAC-SBR (b) systems under HRT of 2, 4, 6 and 8 days.

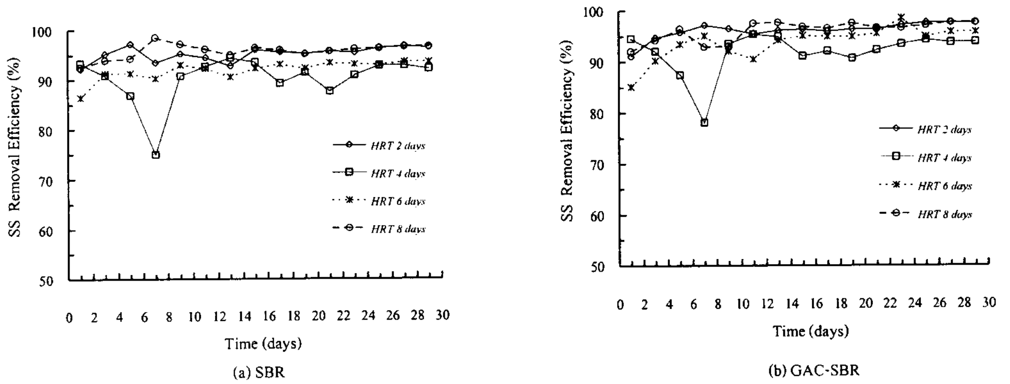

Fig.6: SS removal efficiency profiles of SBR (a) and GAC-SBR (b) systems under HRT of 2, 4, 6 and 8 days.

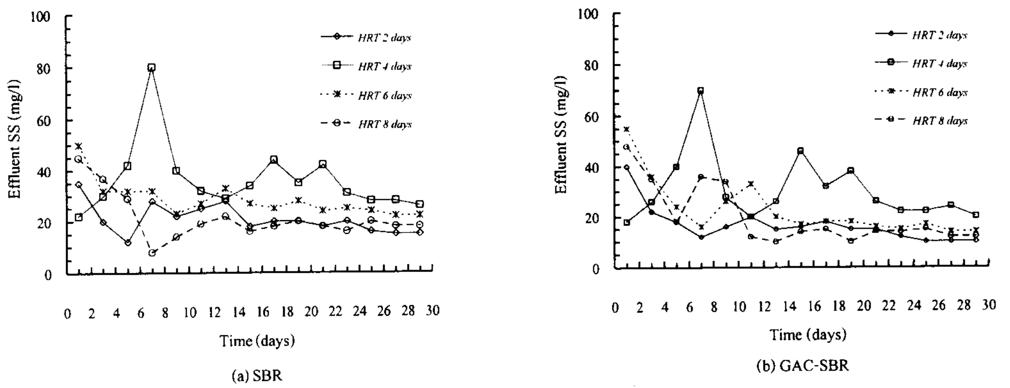

Fig.7: Effluent SS profiles of SBR (a) and GAC-SBR (b) systems under HRT of 2, 4, 6 and 8 days.

Table1: Chemical properties of wastewater from slaughterhouse of SAHA Farm Co., Ltd. The experimental details were described in the text.

Chemical properties of wastewater from slaughterhouse of SAHA Farm Co., Ltd.												
Flow rate ($M^3.l^{-1}$)	**COD** ($mg.l^{-1}$)	**BOD_5** ($mg.l^{-1}$)	**BOD_5** loading ($Kg.d^{-1}$)	**BOD_5 per COD**	**TKN** ($mg.l^{-1}$)	**BOD_5 per TKN** ($mg.l^{-1}$)	**TP** ($mg.l^{-1}$)	**Oil & Grease** ($mg.l^{-1}$)	**SS** ($mg.l^{-1}$)	**Number of Bird** (birds)	**Volume per Bird** ($l.birds^{-1}$)	**BOD_5 per Bird** ($g.birds^{-1}$)
1,671.00	**1,440.00**	**910.00**	**1,520.60**	**1:1.58**	**186.00**	**4.89:1**	**15.00**	**133.00**	**580.00**	**64,972**	**25.70**	**23.04**

Table2: The comparison of COD and TKN removal efficiencies of GAC in SBR system and normal Condition (Jar test method).
The experimental details were described in the text.

Condition o f GAC	Removal efficiency of GAC (mg/g of GAC)			
	COD (mg. $gGAC^{-1}$)	% relative value	TKN (mg .g GAC^{-1})	% relative value
GAC in SBR system	916.00	100.11	54.00	112.50
GAC in Jar test system	915.00	100.00	48.00	100.00
Used GAC in Jar test system	902.00	98.58	36.00	75.00

Table3: Comparison of COD and TKN removal efficiencies in SBR and GAC-SBR systems at first day of cultivation.
The experimental details were described in the text.

Type of treatment system	Removal efficiency (%)							
	2 days		4 days		6 days		8 days	
	COD	TKN	COD	TKN	COD	TKN	COD	TKN
GAC	88.83	50.00	88.94	50.65	88.85	51.67	89.03	52.26
SBR	93.09	72.06	92.63	72.73	89.78	68.33	87.76	69.57
GAC-SBR	94.62	75.00	93.95	76.62	91.36	70.83	91.58	69.57

Table4: Effects of HRT on Efficiency of SBR and GAC – SBR system at steady state.

Parameters		HRT of System							
		2 days		4 days		6 days		8 days	
		SBR	GAC-SBR	SBR	GAC-SBR	SBR	GAC-SBR	SBR	GAC-SBR
COD	Effluent (mg .l^{-1})	59.00	48.00	95.00	79.00	58.00	47.00	55.00	38.00
	Removal efficiency (%)	94.08	95.19	89.86	91.57	94.51	94.55	94.94	96.51
BOD	Effluent (mg .l^{-1})	12.00	10.00	18.00	15.00	11.00	9.00	12.00	8.00
	Removal efficiency (%)	97.99	98.33	97.07	91.57	91.56	98.18	98.20	98.83
TKN	Effluent (mg .l^{-1})	18.00	16.00	25.00	20.00	27.00	20.00	22.00	17.00
	Removal efficiency (%)	74.29	74.14	70.51	76.47	73.27	80.20	75.56	81.11
SS	Effluent (mg .l^{-1})	15.00	10.00	26.00	20.00	22.00	14.00	18.00	12.00
	Removal efficiency (%)	94.08	97.82	89.86	93.94	94.51	99.88	94.94	97.74
Total phosphorus	Effluent (mg .l^{-1})	6.00	6.00	8.00	7.00	8.50	8.00	7.00	7.00
	Removal efficiency (%)	40.00	40.00	11.11	22.22	15.00	20.00	22.22	22.22
Oil & Grease	Effluent (mg .l^{-1})	16.00	13.00	30.0	12.00	21.00	13.00	10.00	8.00
	Removal efficiency (%)	88.57	90.71	81.48	92.59	87.65	92.35	91.67	93.33

Table5: Effects of HRT on sludge volume index of SBR and GAC-SBR Systems.

Parameter	HRT of system							
	2 days		4 days		6 days		8 days	
Type of system	SBR	GAC-SBR	SBR	GAC-SBR	SBR	GAC-SBR	SBR	GAC-SBR
SVI (ml. g of $sludge^{-1}$)	68.00	62.00	75.00	70.00	78.00	65.00	68.00	62.00