Effects of SDS on Efficiency of Packed Cage RBC System.

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Abstract

The removal efficiency and phenomena of packed cage RBC system for treating sodium dodacyl sulfate contained wastewater was investigated. The experiments were done by using a laboratory scale packed cage RBC system. The wastewater, was similar to cosmetic industrial wastewater prepared at the fixed BOD_5 concentration at 400 mg/L. And the concentration of SDS in wastewater was 0.05 mg/l, 0.10 mg/l and 0.25 mg/l. The packed cage RBC system was operated under 3 rpm of packed cage drum rotating speed. And hydraulic retention times (HRT) were 8, 12 and 16 hrs.

The results showed that when wastewater was contaminated with SDS, the removal efficiency was decreased. The COD and BOD_5 removal efficiencies at HRT of 16 hrs were 93.90% and 96.27% and 78.58% and 78.61%, respectively, when non-SDS contained wastewater and 0.25 mg/l SDS contained wastewater were used, respectively. The SDS could be removed by this packed cage RBC system at HRT of 16 hrs with removal efficiencies of 80.00%, 79.00% and 73.20% when wastewater was contaminated with SDS at concentrations of 0.05 mg/l, 0.10 mg/l and 0.25 mg/l, respectively. When the initial SDS concentration was increased up to 0.25 mg/l, the SS concentration of effluent from reactor No.1 that operated at HRT of 4 hrs was up to 71 mg/l. It meant that SDS could wash off the bio-film from media. When HRT of system was investigated, the removal efficiency was decreased when HRT was decreased. The BOD_5 removal efficiencies of 0.25 mg/l SDS contaminated wastewater at HRT of 8, 12 and 16 hrs were 62.33%, 73.63% and 78.61%, respectively. But, the BOD_5 removal efficiencies of non-SDS contaminated wastewater at HRT of 8, 12 and 16 hrs were 95.77%, 96.27% and 96.27%, respectively. SDS concentration or HRT value affected the morphology and type of bio-film. At the lowest HRT (8hrs) and highest concentration of SDS (0.25 mg/l), the color of bio-film in reactor No.1 became dark-brown because the type of microorganisms were changed to be anaerobic microorganisms. But, in reactor No.2, the color of bio-film was red-brown and dissolved oxygen was in the range of 3.10-3.50 mg/l, even when the SDS concentration of wastewater was increased up to 0.25 mg/l. It could be suggested that this designed packed cage RBC system might be suitable for treating wastewater that contains BOD_5 and SDS at the concentration up to 400 mg/l and 0.25 mg/l, respectively at the HRT of only 8 hrs.

Keywords: Packed cage RBC system, Activated sludge system, RBC, anionic surfactant, Sodium dodecyl sulfate.

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1. Introduction

Water pollution is one of the main problems in the world[1]. The pollutants in wastewater come from several sources such as domestic, industry and agriculture. The pollutants in wastewater are inorganic or/and organic compounds according to the type of industry. The wastewater from food processing industries contains mainly organic matter, while the wastewater from cosmetic industries contains both organic and inorganic matters. And the wastewater from electroplating contains some heavy metals [2,3,4,5,6,7]. However, cosmetic industries use a lot of surfactant, so the wastewater contains some surfactant.

The cosmetic industries is one of the interesting industries in Thailand. They use many kinds of raw materials for producing cosmetic products such as organic material and surfactant. Several surfactants are used such as nonionic surfactants, cationic surfactants and anionic surfactants which are organic surfactants. But the others are inorganic surfactants. Sodium dodecyl sulfate (SDS) is one of the popular anionic surfactants due to being widely and normally used in cosmetic industries. The wastewater which is produced from this kind of industry is contaminated with not only organic matter but also SDS.

All organic pollutants as mentioned above could be treated by biological treatment processes such as anaerobic biological processes and aerobic biological processes[1,2]. Nowadays, numbers and amount of pollutants became more and more, because of the increae in production and demand. Several researchers have tried to develop new types of wastewater treatment systems from conventional biological treatment systems which are normally used for increasing removal efficiency, easy operation and low energy consumption[1,2,3,4,5,6]. The aerobic treatment system is the main treatment system normally used in the industrial sector. About 80% of wastewater treatment plants in the industrial section are oxidation pond, aerated lagoon and activated sludge system However, the activated sludge system[1,2,3,4] is very popular among them, because of high removal efficiency, and low area requirement. But, the activated sludge system has to be operated under high energy consumption and non-fluctuation of organic loading and hydraulic loading. The rotating biological contractor (RBC)[4] is also one of the interesting systems which are widely used for treating wastewater from domestic and hospitals due to the resistant shock loading, easy operation and low operating cost[5,6,7]. But RBC also has many problems[8,9,10] during operation such as maintenance of bio-drum, and oxygen supply by moving of bio-drum is limited[8,9,10,11,12,13]. For solving the above problem, packed cage RBC system might be one of the suitable treatment systems that could be used. But the limitation of this system are BOD_5 loading, hydraulic loading and stability of bio-film. Then, the surfactant which is a contaminant in wastewater might affect the efficiency of the system due to wash off bio-film from surface of packed cage RBC and increasing of the BOD_5 loading[14,15,16].

In this study, we designed and constructed a laboratory scale packed cage RBC system. And we also observed the phenomena of the system and the chemical properties of effluent during operation with SDS contained wastewater under various HRT values.

2. Materials and Methods

Packed Cage RBC system: The packed Cage RBC system, was an aerobic moving-bio-film reactor, modified from RBC system and fixed film system. The packed cage RBC system used in this study consisted of 2 similar units of packed cage RBC reactor as shown in fig.1. Each reactor consisted of 42x90x46 cm^3 tank (working volume as 43 liters) and 755.7 cm^3 cylindrical packed cage drum (size: 31cm in diameter and 62 cm in length) The 436 pieces of square ring polypropylene media (The specification of the polypropylene square ring was 68 mm in diameter, 90% of porosity and 190 m^2/m^3 of specific surface area) were packed inside the drum. The 40% of packed cage drum was submerged in wastewater during operation. The speed of packed cage drum was operated at 3 rpm, approximately.

Surfactants: The surfactant used in this experiment was sodium dodecyl sulfate (SDS, commercial grade). This surfactant is an anionic surfactant. It is widely used in cosmetic industries, soap and detergent industries, pharmacutical industries, textile industries and so on.

Synthetic industrial wastewater : Synthetic industrial wastewater used in this study was similar to wastewater from a cosmetic factory in Thailand. The BOD_5 concentration in wastewater was 400 mg/L. The compositions of wastewater were 370.00 mg/l glucose, 23.00 mg/l $(NH_4)_2SO_4$, 0.70 mg/l $FeCl_3$, 13.00 mg/l $NaHCO_3$, 11.00 mg/l KH_2PO_4 and 8.50 mg/l $MgSO_4.7H_2O$, respectively. The concentration of SDS in wastewater were 0.00 mg/l, 0.05 mg/l, 0.10 mg/l and 0.25 mg/l.

Sludge preparation: The sludge used as the inoculum of packed cage RBC system was collected from the sedimentation tank of the central wastewater treatment pant of Bangkok Municipal Authority (sipaya plant). The sludge (10,000 mg/L in concentration) was cultivated in non-SDS contained wastewater for 3 days before using as the inoculum of packed cage RBC system in the start up step.

Start up of packed cage RBC system: The 21.5 liters of sludge suspension (concentration of 10,000 mg/L) was inoculated in each reactor. And then, 21.5 liters of tap water was added to each reactor (final volume as 43 liters). The packed cage RBC drum was run at 3 rpm without feeding new wastewater for 3 day. After that, the non-SDS contaminated wastewater was continuously fed at the flow rate of 50 l/d for 1 week.. After 10 days of operation with non-SDS contaminated wastewater, the bio-film fully built up on the surface of square ring media and surface of packed cage drum. The bio-film on media and drum was 4 mm thick.

Operation of packed cage RBC system under various condition: The system was carried out by continuously feeding wastewater that contained various concentration of SDS as 0.05 mg/l, 0.1 mg/l and 0.25 mg/l. In each experiment, each reactor was operated under HRT of 4 hrs, 6 hrs and 8 hrs. It meant that the whole system was operated under HRT of 8 hrs, 12 hrs and 16 hrs. The effluent and influent of each reactor were collected for chemical properties analysis.

Chemical Analysis: The chemical properties of wastewater as BOD_5, COD, pH, dissolved oxygen (DO), SDS and suspended solid (SS) were analyzed by using analytical methods conducted in accordance with standard method of the waste and waste water examination[17]. SDS in the effluent and influent were analyzed by using cobalt thiocyanate active substance method[17].

3. Results

Effects of SDS on efficiencies of the packed cage RBC system: The packed cage RBC system was operated under HRT of 16 hrs (HRT of each reactor was 8 hrs) with synthetic wastewater which had BOD_5 concentration at 400 mg/l and SDS concentration at 0.00 mg/L, 0.05 mg/l, 0.10 mg/l and 0.25 mg/l. The chemical properties of influent and effluent from each reactor in each experiment are described below:

COD and BOD_5 removal efficiencies : The COD and BOD_5 removal efficiencies of reactor No.1 and reactor No.2 and the whole system were 85.32% and 86.32%, 58.47% and 69.09% and 94.63% and 95.77%, respectively when non-SDS contaminated wastewater was used as shown in table 1. The COD and BOD_5 removal efficiencies of whole system were 92.14%, 81.24% and 78.49% and 93.85%, 85.38% and 78.61%, respectively when the concentrations of SDS in wastewater were 0.05 mg/l, 0.10 mg/l and 0.25 mg/l, respectively as shown in table1. However, when the BOD_5 concentration in effluents were considered, the BOD_5 concentration in effluent was increased up to 101.65 mg/l when initial SDS concentration of wastewater was up to 0.25 mg/l. While the BOD_5 concentration in the effluent was only 17.00 mg/l when non-SDS contained wastewater was used.

Effluent SS: The results are shown in fig.2. The SS of effluent from each reactor was increased when the initial concentration of SDS in wastewater was increased. Effluent SS of reactor No.1 were 15.0 mg/l, 20.0 mg/l, 23.0 mg/l and 30.0 mg/l when initial concentration of SDS in wastewater were 0.00 mg/l, 0.05 mg/l, 0.10 mg/l and 0.25 mg/l, respectively. But, the SS concentration of effluents from reactor No.2 (whole system) was about 15 mg/L in all case of SDS concentration (0.00-0.25 mg/L).

SDS removal efficiencies: The results of SDS removal efficiencies are shown in table2. The SDS could be removed by this biological treatment system. The SDS removal efficiency was decreased when SDS concentration in wastewater was increased. The effluent SDS of

whole system were 0.010 mg/l, 0.021 mg/l and 0.067 mg/l when the initial SDS concentration of influent were 0.05 mg/l, 0.10 mg/l and 0.25 mg/l, respectively.

Effects of HRT and SDS concentration on efficiency of packed cage RBC system: The packed cage RBC system was operated under HRT of 8, 12 and 16 hrs. (HRT of each reactor was 4, 6 or 8 hrs) The initial SDS concentration of wastewater were controlled to be 0.00 mg/l, 0.05 mg/l, 0.10 mg/l and 0.25 mg/l. The effluents from each reactor were collected for chemical analysis. The results are shown below.

BOD_5 removal efficiency: The results are shown in table3. When SDS concentration was increased or HRT was decreased, the BOD_5 removal efficiency was decreased. The BOD_5 removal efficiency of reactor No.1 under HRT of 4, 6 and 8 hrs were 77.36%, 54.13%, 54.13% and 32.34, 77.97%, 72.89%, 60.31% and 37.98% and 86.32%, 73.94%, 60.53% and 41.58%, respectively when the initial SDS concentration in the wastewater were 0.00 mg/l, 0.05 mg/l, 0.10 mg/l and 0.25 mg/l, respectively. The patterns of BOD_5 removal efficiency in reactor No.2 and whole system were also similar to reactor No.1. For determination of effluent BOD_5 of whole system, the results showed that effluent BOD_5 from the experiment which used wastewater containing SDS at the concentration of 0.05-0.25 mg/l were higher than 20 mg/L. In the case of non-SDS contaminated wastewater, the effluent BOD_5 of the whole system were 17.00 mg/l, 15.00 mg/l and 15.00 mg/l when HRT of system were 8 hrs, 12 hrs and 16 hrs, respectively. While, the effluent BOD_5 of whole system were 179.00 mg/l, 125.30 mg/l and101.65 mg/l, respectively when the system was operated with 0.25 mg/l SDS contaminated wastewater at HRT of 8,12 and 16 hrs, respectively.

COD removal efficiency: The results are shown in table 4. The COD removal efficiency patterns in each reactor were similar to the BOD_5 removal efficiency pattern as mentioned above. The COD removal efficiency of the whole system under HRT of 16 hrs were 93.90%, 92.25%, 81.21% and 78.58%, respectively when the initial SDS concentrations in wastewater were 0.00 mg/L, 0.05 mg/L, 0.10 mg/L and 0.25 mg/L, respectively.

Effluent SS: The results are shown in fig 3. The effluent SS was increased when SDS concentration was increased. The SS of effluents from reactor No.1 under the HRT of 4, 6 and 8 hrs were 30.0 mg/l, 37.0 mg/l, 50.0 mg/l and 65.0 mg/l, 20.0 mg/l, 25.0 mg/l, 30.0 mg/l and 40.0 mg/l and 15.0 mg/l, 20.0 mg/l, 23.0 mg/l and 27.0 mg/l, respectively when initial SDS concentration in wastewater were 0.00 mg/l, 0.05 mg/l, 0.10 mg/l and 0.25 mg/l, respectively. But, the effluent SS of reactor No.2 under HRT of 4, 6 and 8 hrs were 15.0 mg/l, 20mg/l, 20 mg/l, and 20 mg/l, 15 mg/l, 17 mg/l, 18 mg/l and 19 mg/l and 15 mg/l, 15 mg/l, 15 mg/l and 15 mg/l, respectively when the initial SDS concentration in wastewater were 0.00 mg/l, 0.05 mg/l, 0.10 mg/l and 0.25 mg/l, respectively.

SDS removal efficiencies : The results are shown in table5. The removal efficiencies decreased when the HRT was decreased or SDS concentration was increased. The SDS removal efficiencies in reactor No.1 under HRT of 4,6 and 8 hrs were 52.0%, 44.0%, and 24.0%, 70.0%, 50.0% and 32.0% and 72.0%, 60.0% and 48.0%, respectively when the initial SDS concentration were 0.05mg/l, 0.10 mg/l and 0.25 mg/l, respectively

Dissolved oxygen of system: The results are shown in fig.4. The dissolved oxygen in the reactor No.1 was lower than 1.00 mg/l when the wastewater contaminated with SDS at concentration up to 0.10 mg/l. But when the SDS concentration was increased up to 0.25 mg/l, the dissolved oxygen in reactor No.1 was increased up to 1.00-1.20 mg/l in all cases of HRT. However, the dissolved oxygen in reactor No.2 was in the range of 3.10-3.50 mg/l in all case of HRT values and SDS concentrations.

Effects of HRT and SDS concentration on the morphology of bio-film: The results are shown in table 6, table7 and fig.5. The color of bio-film depended on HRT and concentration of SDS. When the HRT of the system operated with 0.25 mg/l SDS contaminated wastewater, was reduced to 8 hrs, the color of bio-film in reactor No.1 became dark-brown as shown in table6 and fig.5. But, the bio-film in reactor No.2 was red-brown even when the system was operated under the lowest HRT of 8 hrs as

shown in table 6 and fig.5. The bio-film of reactor No.1 was red-brown when the system was operated with non-SDS contaminated wastewater under lowest HRT of 8 hrs as shown in table7. But, the color of bio-film in reactor No.1 became gray-brown to dark-brown when the wastewater contained SDS at the concentration from 0.05 mg/l as shown in table7. However, the color of bio-film in reactor No.2 was still red-brown in all cases of SDS concentration and HRT values.

Discussion and Conclusions: The packed cage RBC system is one of the aerobic treatment systems which could be used for treating both industrial and domestic wastewater[15, 16,17]. The aims of using packed cage RBC system is for solving the problems which normally occur in activated sludge system and RBC system [3,4,5,6,7,8,9]. The advantages of the above system are reduction of energy consumption, easy operation, lower excess sludge production and lower SS concentration in effluent. SDS is normally used in the cosmetic industries and detergent industries. The wastewater from the above industries is contaminated with SDS, which affects the efficiency of biological treatment system. In this study, we tried to use packed cage RBC system for treating the wastewater containing anionic surfactant, especially SDS. (It is similar to wastewater from cosmetic industries[3,4,10,11]. But the surfactant might affect the bio-film due to washed off bio-film from media. In this study, we tried to check effects of SDS and HRT on the removal efficiency and phenomena of packed cage RBC system.

BOD_5 and COD removal efficiencies in packed cage RBC system: The BOD_5 and COD removal efficiencies of non-SDS contained wastewater at highest HRT of 16 hrs were 96.27% and 93.90%, respectively while the BOD_5 and COD removal efficiencies at lowest HRT of 8 hrs were 95.77% and 92.93%, respectively. It could be concluded that the BOD5 and COD removal efficiencies were more than 90% even when the system was operated at lowest HRT (8 hrs). And SDS concentration in wastewater also affected the efficiencies of the system. At the highest initial SDS concentration (0.25 mg/l), the BOD_5 and COD removal efficiencies were reduced to 62.33% and 63.21% and 78.61% and 78.58%, respectively, when the HRT of the system were 8 hrs and 16 hrs, respectively. It meant that SDS could reduce the removal efficiencies of packed cage RBC system [7,10].

DO in packed cage RBC reactor: The DO in reactor No.1 and reactor No.2 showed interesting results as shown in fig.4. The dissolved oxygen in reactor No.1 under HRT of 4 hrs was decreased to 0.10 mg/l when the initial SDS concentration in the wastewater was up to 0.05 mg/l. From the above result, it could be said that SDS would increase BOD_5 concentration in wastewater and reduce the number of microorganisms (MLSS). Then, the condition in the reactor No.1 became anaerobic condition[7,10,15,1618,19]. But, when the SDS concentration of the wastewater was increased up to more than 0.05 mg/l, the DO in reactor No.1 was increased. It might be said that SDS reduced the activity of bio-film, then the use of DO by bio-film was reduced. However, DO in reactor No.2 was increased up to 3.10-3.50 mg/L in all experiments. It meant that SDS concentration in mixed liquid of reactor No.2 did not affect the system

SS of effluents: The SS of effluent was increased when HRT was decreased or the initial SDS concentration was increased. When the HRT of whole system was in the range of 8-16 hrs, the SS of effluents from reactor No.1 were higher than 20 mg/l as shown in fig.3.The effluents SS of reactor No.2 was lower than 20 mg/l. However, the standard concentration of effluent SS by Department of Industrial Works: DIW[20] was not more than 20 mg/l. If we would like to have treated wastewater which has the standard quality as Department of Industrial Works of Thailand's requirement, this type of packed cage RBC system could be used.

The morphologies of bio-films: As we mentioned above, the red-brown bio-film (aerobic microorganisms) in both reactors were rapidly grown after 1 week of cultivation with non-SDS contaminated wastewater under HRT of 16 hrs. It meant that the condition for starting the system was suitable and the system was fully oxygen supplied. However, the types of microorganisms of bio-film were changed to be facultative bacteria as sulfur reducing bacteria and anaerobic bacteria 11,18,19) when HRT of the system was reduced or the SDS concentration increased. Then the bio-film,

which consisted of anaerobic and facultative bacteria, became gray-brown to dark-brown 7,11,18,19). When the SDS concentration was increased up to 0.25 mg/l, the color of bio-film in reactor No.1 was gray-brown to dark-brown even the HRT was up to 16 hrs.

For application, due to the results above, the packed cage RBC system could be used for treating SDS contaminated wastewater that had SDS at the concentration up to 0.25 mg/l, even the condition in reactor No.1 became anaerobic. But the condition of reactor No.2 was still aerobic and the bio-film was resistant to the SDS concentration in mixed liquid of reactor No.2. However, when the qualities of both influent and effluent are considered, the packed cage RBC system which consists of more than 2 units of packed cage RBC drum might be applied.

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Table1: Effects of SDS on COD and BOD_5 removal efficiencies of Packed Cage RBC system.
Packed Cage RBC system was operated at HRT of 16 hrs (HRT of each reactor was 8 hrs). The concentrations of SDS in wastewater were 0.00 mg/l, 0.05 mg/l, 0.1 mg/l and 0.25 mg/l.

Packed Cage RBC System	SDS (mg/l)	COD			BOD_5		
		Influent (mg/l)	Effluent (mg/l)	% Removal	Influent (mg/l)	Effluent (mg/l)	% Removal
Reactor No. 1	0.00	410.00	60.20	85.32	402.00	55.00	86.32
	0.05	409.30	77.19	81.14	411.40	107.30	73.92
	0.1	431.00	116.50	72.97	452.40	179.50	60.32
	0.25	475.30	220.67	53.57	475.20	277.63	41.58
Reactor No.2	0.00	60.20	25.00	58.47	55.00	17.00	69.09
	0.05	77.19	32.19	58.30	107.30	25.30	76.42
	0.1	116.50	80.85	30.60	179.50	66.13	63.16
	0.25	220.67	101.65	53.94	277.63	101.65	63.39
Whole System	0.00	410.00	22.00	94.63	402.00	17.00	95.77
	0.05	409.30	32.19	92.14	411.40	25.30	93.85
	0.1	431.00	80.85	81.24	452.40	66.13	78.61
	0.25	472.50	101.65	78.49	475.20	101.65	73.87

Table2: Effects of SDS on SDS removal efficiency of packed cage RBC system.
Packed Cage RBC system was operated at HRT of 16 hrs (HRT of each reactor was 8 hrs). The concentration of SDS in the wastewater were 0.00 mg/l, 0.05 mg/l, 0.10 mg/l and 0.25 mg/l.

Packed cage RBC system	SDS		
	Influent (mg/l)	Effluent (mg/l)	% removal
Reactor No. 1	0.000	0.000	-
	0.050	0.022	56.00
	0.100	0.040	60.00
	0.250	0.099	60.40
Reactor No.2	0.000	0.000	-
	0.022	0.010	54.55
	0.040	0.021	47.50
	0.099	0.067	32.32
Whole system	0.000	0.000	-
	0.050	0.010	80.00
	0.100	0.021	79.00
	0.250	0.067	73.20

Table3 : Effects of HRT and SDS concentrations on BOD_5 removal efficiency of packed cage RBC system.
Packed Cage RBC system were operated at HRT of 8, 12 and 16 hrs. (HRT of each reactor were 4, 6 and 8 hrs). The concentrations of SDS in wastewater were 0.00 mg/l, 0.05mg/l, 0.10mg/l and 0.25 mg/l.

Packed cage RBC System	SDS (mg/l)	BOD_5								
		HRT of system 8 hrs			HRT of system 12 hrs			HRT of system 16 hrs		
		Inf (mg/l)	Eff (mg/l)	% removal	Inf (mg/l)	Eff (mg/l)	% removal	Inf (mg/l)	Eff (mg/l)	% removal
Reactor No.1	0.00	402.00	91.00	77.36	402.00	88.55	77.97	402.00	55.00	86.32
	0.05	411.70	121.80	70.42	411.70	111.60	72.89	411.70	107.30	73.94
	0.1	454.80	208.60	54.13	454.80	180.50	60.31	454.80	179.50	60.53
	0.25	475.20	321.50	32.34	475.20	294.70	37.98	475.20	277.60	41.58
Reactor No.2	0.00	91.00	17.00	81.32	88.55	15.00	83.06	55.00	15.00	72.73
	0.05	121.80	29.77	75.56	111.60	26.78	76.00	107.30	25.03	76.67
	0.1	208.60	72.08	65.45	180.50	67.45	62.63	179.50	66.13	63.16
	0.25	321.50	179.00	44.32	294.70	125.30	57.48	277.60	101.65	63.38
Whole system	0.00	402.00	17.00	95.77	402.00	15.00	96.27	402.00	15.00	96.27
	0.05	411.70	29.77	92.77	411.70	26.78	93.50	411.70	25.03	93.92
	0.1	454.80	72.08	84.15	454.80	67.45	85.17	454.80	66.13	85.46
	0.25	475.20	179.00	62.33	475.20	125.30	73.63	475.20	101.65	78.61

Table4: Effects of HRT and SDS concentrations on COD removal efficiency of Packed Cage RBC system.
Packed Cage RBC system were operated at HRT of 8, 12 and 16 hrs. (HRT of each reactor were 4, 6 and 8 hrs.). The concentrations of SDS in wastewater were 0.00 mg/l, 0.05 mg/l, 0.10mg/l and 0.25 mg/l.

Packed cage RBC System	SDS (mg/l)	COD(mg/l)								
		HRT of system 8 hrs			HRT of system 12 hrs			HRT of system 16 hrs		
		Inf. (mg/l)	Eff. (mg/l)	% removal	Inf. (mg/l)	Eff. (mg/l)	% removal	Inf. (mg/l)	Eff. (mg/l)	% removal
Reactor No.1	0.00	410.00	70.20	82.88	410.00	65.30	84.07	410.00	60.20	85.32
	0.05	415.50	85.40	79.45	415.50	78.90	81.01	415.50	77.20	81.42
	0.1	430.60	115.10	73.27	430.60	110.60	74.31	430.60	106.60	75.24
	0.25	474.90	258.0	45.67	474.90	239.20	49.63	474.90	220.79	53.51
Reactor No.2	0.00	70.20	29.00	58.69	65.30	26.00	60.18	60.20	25.00	58.47
	0.05	85.40	35.10	58.90	78.90	34.60	56.15	77.20	32.20	58.29
	0.1	115.10	82.10	28.67	110.60	80.80	26.94	106.50	80.90	24.04
	0.25	258.00	174.70	32.29	239.20	109.70	54.14	220.70	101.70	53.92
whole system	0.00	410.00	29.00	92.93	410.00	26.00	93.66	410.00	25.00	93.90
	0.05	415.50	35.10	91.55	415.50	34.60	91.67	415.50	32.20	92.25
	0.1	430.60	82.10	80.93	430.60	80.80	81.24	430.60	80.90	81.21
	0.25	474.90	174.70	63.21	474.90	109.70	76.90	474.90	101.70	78.58

Table5: Effects of HRT and SDS concentrations on SDS removal efficiency of Packed Cage RBC system.
Packed Cage RBC system were operated at HRT of 8, 12 and 16 hrs. (HRT of each reactor were 4, 6 and 8hrs.). The concentrations of SDS in wastewater were 0.00 mg/l, 0.05mg/l, 0.10 mg/l and 0.25 mg/l.

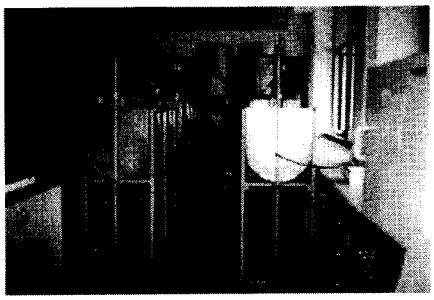
Packed cage RBC System	SDS mg/l	SDS(mg/l)								
		HRT of system 8 hrs			HRT of system 12 hrs			HRT of system 16 hrs		
		Inf. mg/l	Eff. mg/l	% removal	Inf. mg/l	Eff. mg/l	% removal	Inf. mg/l	Eff. mg/l	% removal
Reactor No.1	0.00	0.000	0.000	-	0.00	0.000	-	0.000	0.000	-
	0.05	0.050	0.024	52.0	0.05	0.015	70.0	0.050	0.014	72.0
	0.1	0.100	0.056	44.0	0.10	0.050	50.0	0.100	0.045	55.0
	0.25	0.250	0.190	24.0	0.25	0.170	32.0	0.250	0.130	48.0
Reactor No.2	0.00	0.000	0.000	-	0.00	0.000	-	0.000	0.000	-
	0.05	0.0240	0.011	54.2	0.022	0.014	36.4	0.014	0.005	64.3
	0.1	0.0560	0.028	50.0	0.058	0.021	63.8	0.045	0.016	64.4
	0.25	0.190	0.100	47.4	0.170	0.055	67.7	0.130	0.030	76.9
whole system	0.00	0.000	0.000	-	0.00	0.000	-	0.000	0.000	-
	0.05	0.050	0.011	78.0	0.05	0.014	72.0	0.050	0.005	90.0
	0.1	0.100	0.028	72.0	0.10	0.021	79.0	0.100	0.016	84.0
	0.25	0.250	0.085	60.0	0.25	0.058	76.8	0.250	0.030	88.0

Table 6: Effects of HRT of the system on morphology of bio-film of system were operated with 0.25 mg/l SDS contained wastewater at HRT of 8,12 and 16 hrs

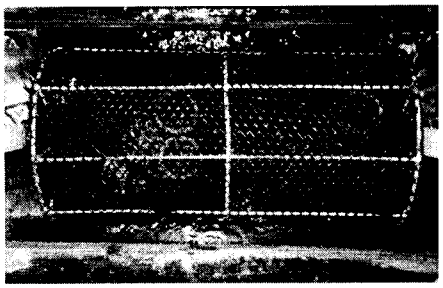
Packed cage RBC System	Morphology of Bio-film at various HRT values		
	HRT 8 hrs	HRT 12 hrs	HRT 16 hrs
Reactor No.1	dark-brown(Fig.5a)	gray -brown	gray- brown
Reactor No.2	red-brown (Fig.5b)	red-brown	red-brown

Table7: Effects of SDS concentration on morphology of bio-film at HRT of 8 hrs (HRT of each reactor was 4 hrs.).

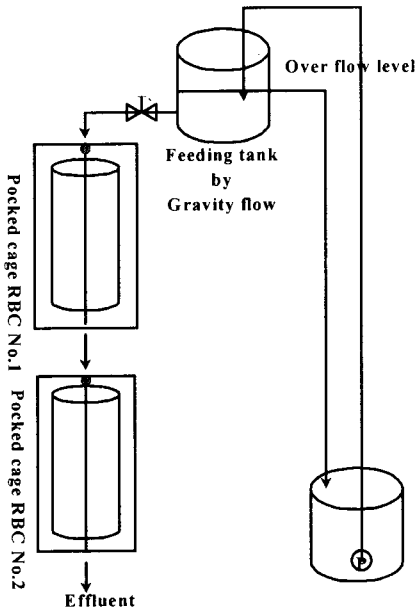
Packed cage RBC System	Morphology of Bio-film at various SDS concentration			
	0.00 mg/l of SDS	0.05 mg/l of SDS	0.1 0 mg/L of SDS	0.25 mg/l of SDS
Reactor No.1	red-brown	gray-brown	dark -brown	dark -brown
Reactor No.2	red-brown	red-brown	red-brown	red-brown



A: Whole system of packed cage RBC system



B: Packed cage drum



C: Diagram of the packed cage RBC system

Fig.1: The packed cage RBC system.

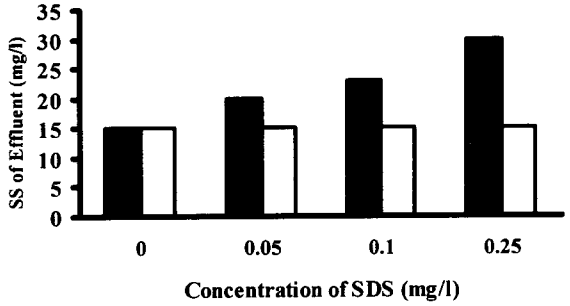


Fig.2: Effects of SDS on effluent SS in Packed Cage RBC system.
Packed cage RBC system was operated HRT of 16 hrs (HRT of each reactor was 8 hrs).
The concentration of SDS in the wastewater were 0.00 mg/l, 0.05 mg/l, 0.10 mg/l and 0.25 mg/l.
Symbols: ■; Reactor No.1, □; Reactor No.2.

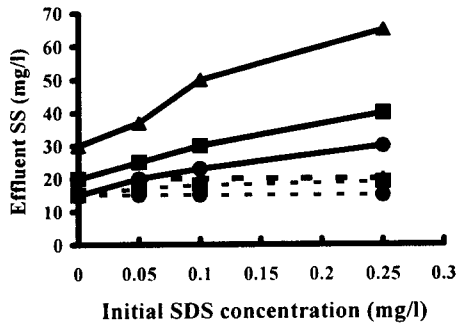


Fig.3: Effects of HRT and SDS concentration on the effluent SS of packed cage RBC system.
Packed Cage RBC system were operated at HRT of 8, 12 and 16 hrs(HRT of each reactor was 4, 6and 8 hrs).
The concentration of SDS in the wastewater were 0.00 mg/l, 0.05 mg/l, 0.10 mg/l and 0.25 mg/l.
Symbols: ▲; HRT 4 hrs, ■; HRT 6 hrs, ●; HRT 8 hrs, ——; reactor No.1, ----; reactor No.2

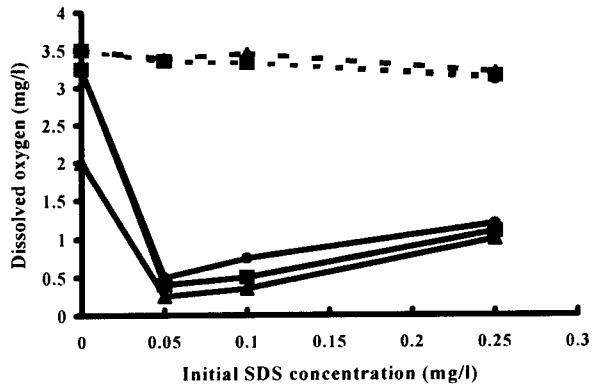
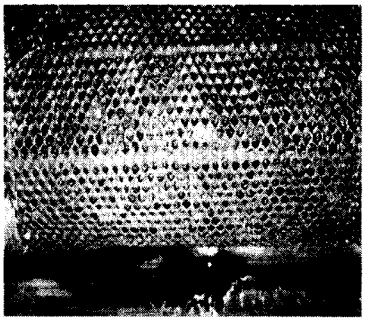
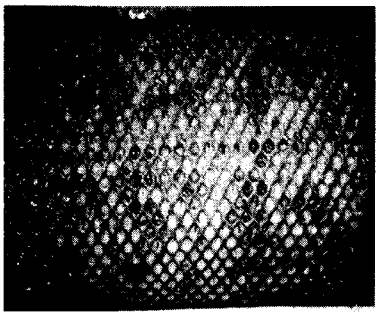


Fig.4: Effects of HRT and SDS concentration on dissolved oxygen in packed cage RBC system.
Packed Cage RBC system were operated at HRT of 8, 12 and 16 hrs(HRT of each reactor was 4, 6 and 8 hrs).
The concentration of SDS in wastewater were 0.00 mg/l, 0.05 mg/l, 0.10 mg/l and 0.25 mg/l.
Symbols: ▲; HRT 4 hrs, ■; HRT 6 hrs, ●; HRT 8 hrs,——; reactor No.1, ·····; reactor No.2.



A: Morphology of bio-film on packed cage drum in reactor No.1



B: Morphology of bio-film on packed cage drum in reactor No.2

Fig.5:Morphology of Bio-film on the packed cage drum, was operated with 0.25 mg/l SDS contained wastewater at HRT of 8 hrs.