Application of Packed Cage RBC System for Treating Waste Water Contaminated with Nitrogenous Compounds

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Abstract

Efficient and suitable conditions of a packed cage RBC system for treating synthetic waste water which contained various concentrations of nitrogenous compounds were investigated. The experiments were done by using a laboratory scale packed cage RBC system. This packed cage RBC system consisted of 2 similar sets of packed cage RBC reactors. Each packed cage RBC reactors was composed of 2 main components, a 43 liter (working volume) cylindrical reactor and a 755.7 cm^3 packed cage drum which contained 436 pieces of square ring polyethylene media (diameter 68 mm). The total surface area of the media was 12.67 m^2. The synthetic waste water was prepared at a fixed BOD_5 concentration of 400 mg/L and BOD_5:N_2 ratios of 100:5, 100:10, 100:20, 100:30 and 100:40, respectively. The packed cage RBC system was operated at 3 rpm packed cage drum rotating speed and the hydraulic retention time(HRT) of each reactor was 2, 3, 4, 5, 6 and 7 hrs, respectively.

The results show that when the organic loading or N_2 loading was increased, the COD and BOD_5 removal efficiency of the system decreased. At the optimal organic loading of 3.26 $gBOD_5/m^2$-d and N_2 loading of 1.30 gN_2/m^2-d, the system gave the highest removal efficiency of BOD_5 and COD of 98.23% and 96.21%, respectively. The NH_4^+ and total N_2 removal efficiency at the optimal organic loading and N_2 loading as mentioned above were 98.97% and 67.07%, respectively. The N_2 removal activity mainly occurred in the secondary stage of packed cage RBC system. The main N_2 removal activity was nitrification. The NH_4^+ in the waste water was changed to $NO_3^-$and $NO_2^-$by nitrifying bacteria (*Nitrosomonas* sp. and *Nitrobacter* sp.). And then part of NO_3^- was changed to N_2 gas by activity of denitrification bacteria. However, the efficiency of packed cage RBC system was limited by the oxygen supply. When the organic loading and N_2 loading of the system increased, the dissolved oxygen in the system rapidly decreased. At the organic loading of 8.14 $gBOD_5/m^2$-d, the dissolved oxygen in the packed cage RBC stage1 was 0 mg/L. The type of microorganisms in the bio-film changed from the aerobic microorganisms (the color of bio-film was red-brown) to be the facultative microorganisms and anaerobic microorganisms(the color of bio-film was dark-brown and dark, respectively). The pH of the system also decreased when the organic loading or N_2 loading was increased.

Key words: **Packed cage RBC, RBC, Biological nitrogen removal, Nitrification, Denitrification.**

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1. Introduction

Water pollution is the main problem in the world [1]. The pollutants in water come from several sources such as domestic, industry and agriculture. The pollutants in waste water are inorganic or/and organic compounds according to the sources of the waste water. For example, the waste water from food processing contains organic substances and the waste water from electroplating contains some heavy metals [2,3,4,5,6,7].

Thailand is an agricultural country. The main industry concerns agricultural products such as frozen sea food products, canning, slaughter houses, meat products and so on. The waste water normally contains organic carbon (starch, sugar, oil, grease and polysaccharide) and organic nitrogen (protein, animo acid and NH_4^+ compounds) [8,9,10,11]. All the pollutants as mentioned above could be treated by biological treatment processes such as anaerobic biological in processes and aerobic biological processes [1,2]. But nowadays, the amount of pollutants which contaminate the waste water is increasing because of the increase in production and demand. Several researchers have tried to develop and improve the conventional treatment processes which are normally used in factories for the purposes of high removal efficiency easy operation and low energy consumption [1,2,3,4,5,6].

Nowadays, about 80% of waste water treatment plants for domestic waste water use activated sludge system [1,2,3,4], because of high removal efficiency, and low area requirement. But the activated sludge system has to be operated under high energy consumption, non-fluctuation of BOD_5 loading and hydraulic loading and inefficient nitrogen compounds removal. The rotating biological contractor (RBC) [12,13,14] is also one of the systems which are widely used for treating the waste water from domestic sources and hospital due to the resistance to the shock load, ease of operation and low operating cost [5,6,7]. But the RBC also had many problems [16,17,18,19] during operation such as a) different maintenance of bio-drum, and b) oxygen which is supplied into the system by moving the bio-drum is limited [19,20,21,22].

The waste water treatment plants in the food processing factories (such as canning, meat processing, sea food processing, slaughter houses and so on) consist of anaerobic pond and activated sludge systems. The waste water from the factory is sent to the anaerobic pond for reduction of BOD_5 (about 50-60% reduction) The BOD_5 of effluent from the anaerobic pond is about 400-500 mg/L and the TKN is about 80-170 mg/L and more. The waste water from the anaerobic pond is then treated by activated sludge system. But many problems occur during operation in the activated sludge system such as rising of sludge in the sedimentation tank, high concentration of nitrogen compounds in the effluent and so on [3,4,5,6].

From the above information, we would like to solve all of the problems which commonly occur in both activated sludge system and RBC system. We used the new type of treatment system; the packed cage RBC system, for treating the waste water which contained a high concentration of nitrogen compounds. In this study, we used a laboratory scale packed cage RBC system for treating the synthetic waste water which had various ratios of $BOD_5:N_2$ We also observed the phenomena of the system such as the type of bio-film dissolved oxygen of the system and pH of the system during operation with various ratios of $BOD_5:N_2$. The BOD_5, COD and nitrogen compounds removal efficiency under various conditions of HRT and $BOD_5:N_2$ ratio was also investigated.

2. Materials and Methods

Packed Cage RBC system: The packed Cage RBC system, is an aerobic moving-bio-film reactor, which was 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 square ring polypropylene was 68 mm in diameter, 90% of Porosity and 190 m^2/m^3 of specific surface area) were packed inside of the drum. 40% of the packed cage drum was submerged in waste water during operation. The packed cage drum was operated at 3 rpm, approximately.

Synthetic waste water: The synthetic waste water which was used in this study was similar to the waste water from an anaerobic pond waste water treatment plant of a poultry slaughter house in Thailand. The BOD_5 concentration of the synthetic waste water was 400 mg/L. This synthetic waste water consisted of glucose, $(NH_4)_2SO_4$, $FeCl_3$, $NaHCO_3$, KH_2PO_4 and $MgSO_4.7H_2O$. The concentration of each component in the synthetic waste water is described in table 1 and table 2.

Sludge preparation: The sludge which was used for start up of the packed cage RBC system was collected from the sedimentation tank of the central waste water treatment plant of Bangkok Municipal (sipaya plant). The sludge, which was 10,000 mg/L in concentration, was cultivated in synthetic waste water, which had a BOD_5:N_2 ratio of 100:5, for 3 days before use as the inoculum of the packed cage RBC system in the start up step.

Start up of the packed cage RBC system: 21.5 liters of sludge suspension (concentration of 10,000 mg/L) was inoculated in each reactor of the system. 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 of the raw waste water to the system for 3 days. After that, the synthetic waste water with a concentration of BOD_5 of 200 mg/L was continuously fed at a flow rate of 50 L/d for 1 week. Then the BOD_5 concentration of waste water was increased up to 400 mg/L. After 10 days of operation with synthetic waste water which had a BOD_5 concentration of 400 mg/L, the bio-film had fully built up on the surface of square ring media and surface of packed cage drum. The bio-film on the media and drum was 4 mm thick.

Operation of packed cage RBC system for treating waste water under various conditions: The system was operated by continuously feeding with synthetic waste water which had various BOD_5:N_2 ratio of 100:5, 100:10, 100:20, 100:30 and 100:40, respectively as shown in table 3. In each experiment, each reactor was operated under various HRT values as shown in table 3. The effluent and influent of each reactor were collected for chemical properties determination.

Chemical Analysis: The chemical properties of the waste water which was analyzed in this study, were BOD_5, COD temperature, pH, dissolved oxygen (DO) and suspended solid (SS). All analytical methods were conducted in accordance with standard method of waste and waste water examination [23].

3. Results

BOD_5 removal efficiency of packed cage RBC system: The effects of organic loading and N_2 loading on the BOD_5 removal efficiency and BOD_5 effluents from each reactor of the system are shown in table 4. At a fixed N_2 loading of 0.41 gN_2 /m^2-d, the BOD_5 of the effluents from the reactor No.1 and No. 2 when the organic loading was 8.14 $gBOD_5/m^2$-d and 4.07 $gBOD_5/m^2$-d were 72.98 mg/l, 19.8 mg/l and 18.47 mg/L, 10.32 mg/L, respectively. The removal efficiency of reactor No.1, No.2 and the whole system were 81.73%, 72.87% and 95.04% and 95.38%, 44.13% and 97.42%, respectively. But at the organic loading of 4.07 g/m^2-d, the BOD_5 of effluent from reactor No.1 and reactor No.2 of the system at the N_2 loading of 0.20 gN_2 /m^2-d and 1.63 gN_2 /m^2-d were 18.36mg/L, 11.66 mg/L and 23.52 mg/L, 19.13 mg/L, respectively. The removal efficiency of reactor No.1, No.2 and the whole system were 95.45%, 36.49% and 97.11% and 94.15%, 18.66% and 95.24%, respectively. However, the system gave a high BOD_5 removal efficiency at the organic loading and N_2 loading of 3.26 mg/L and 1.30 mg/L. The maximal BOD_5 removal efficiency of reactor No.1, No2 and the whole system were 97.14%, 39.88% and 98.28%, respectively.

COD removal efficiency of packed cage RBC system: The results are shown in table 5. The COD removal efficiency patterns were similar to BOD_5 removal efficiency patterns. At N_2 loading of 0.41 gN_2 /m^2-d, the COD removal efficiencies of reactor No.1, No.2 and the whole system at the organic loading of 8.14 g/m^2-d and 4.07 g/m^2-d were 77.88%, 52.07%

and 89.82% and 90.47%, 37.42% and 94.03%, respectively. But at the fixed organic loading of 4.07 $gBOD_5/m^2$-d, the COD removal efficiency of reactor No.1, No.2 and the whole system with the N_2 loading of 0.20 gN_2/m^2-d and 1.63 gN_2/m^2-d were 91.43%, 33.72% and 94.32% and 88.03%, 37.41% and 92.51%, respectively. However, the system gave a high COD removal efficiency at the organic loading and N_2 loading of 3.26 mg/L and 1.30 mg/L (similar to the optimal condition for removal of BOD_5). The maximal COD removal efficiency of reactor No.1, No2 and the whole system were 93.77%, 39.25% and 96.21%, respectively.

Effects of organic loading and N_2 loading on NH_4^+ removal efficiency: The results are shown in table 6. At the fixed organic loading, the NH_4^+ removal efficiency of reactor No.1, No2 and the whole system at the highest nitrogen loading of 1.63 gN_2/m^2-d and lowest nitrogen loading of 0.20 gN_2/m^2-d were 38.20%, 43.52% and 65.09% and 54.70%, 97.52% and 98.88%, respectively. The optimal NH_4^+ loading and N_2 loading for highest NH_4^+ removal efficiency of the system were 1.22 gN_2/m^2-d and 1.22 gN_2/m^2-d, respectively. The maximal NH_4^+ removal efficiency of reactor No.1 and No.2 and the whole system were 56.33%, 98.78% and 99.47%, respectively.

Effects of the organic loading and N_2 loading on the total N_2 removal efficiency: The results are shown in table 7. The packed cage RBC system showed the highest total N_2 removal efficiency at an organic loading and N_2 loading of 3.26 $gBOD_5/m^2$-d and 1.30 gN_2/m^2-d, respectively. The maximal total N_2 removal efficiency of reactor No.1, reactor No.2 and whole system were 41.07%, 44.12% and 67.07%, respectively.

Effects of the organic loading and N_2 loading on SS of the effluents: The results are shown in table 8. The packed cage RBC system gave interesting results. The SS of the effluents of the system at all organic loading and N_2 loading were lower than 0.05 mg/L The SS of the effluents of the system were in the range of 0.019-0.038 mg/L.

Effects of organic loading and N_2 loading on the pH of the packed cage RBC system: The results are shown in table 9. When the organic loading was increased, the pH of the system increased. For example, at the organic loading of 3.26 and 8.14 $gBOD_5/m^2$- d the pH of reactor No.1 and No.2 was 6.93, 6.72, and 7.41, 7.33 respectively.

The Effects of organic loading and N_2 loading on the dissolved oxygen of the packed cage RBC system: The results are shown in table 10. At the BOD_5: N_2 ratio of 100:5, when the organic loading or N_2 loading was increased, the dissolved oxygen in the reactor decreased. For example, at the organic loading and N_2 loading of 8.14 $gBOD_5/m^2$- d and 0.41 $gBOD_5/m^2$- d, the dissolved oxygen in the reactor No.1 and No.2 was 0 mg/L and 3.44 mg/L, respectively. But at the organic loading and N_2 loading of 4.07 $gBOD_5/m^2$-d and 0.20 BOD_5/m^2-d, the dissolved oxygen in reactor No.1 and No.2 was 2.71 mg/L and 6.93 mg/L, respectively.

Effects of organic loading and N_2 loading on the morphology of bio-film: The organic loading and N_2 loading affected. on the type of microorganisms in the bio-film on the surface of media and bio-drum. At the lower organic loading and N_2 loading, the color of the bio-film was red-brown. But when the organic loading and N_2 loading were increased, the color of bio-film became dark brown to dark. For example, the color of bio-film was red-brown, dark-brown and dark when the organic loading was 4.07, 5.43 and 8.14 $gBOD_5/m^2$-d, respectively.

4. Discussion

The packed cage RBC system, one of the modified aerobic treatment systems, was modified from the RBC system and fixed film system on the basis of increasing organic and N_2 removal efficiencies. This modified system consisted of 2 similar sets of packed cage RBC reactor as shown in fig.1.

For the COD and BOD_5 removal efficiency of packed cage RBC system, the results are shown in table 4 and table 5. When the BOD_5 and N_2 loading of the system were increased, the COD and BOD_5 removal efficiency decreased. This evidence normally occurred in RBC and activated sludge systems [12,13,14]. However, the results show that at the organic loading lower than 2.33 $gBOD_5/m^2$-d, the packed cage RBC stage 1 was enough to treat the waste water to the standard requirement of the Department of Iindustrial Works of Thailand [24] because the BOD_5 of effluent from the packed cage RBC stage 1 was 12.7mg/L (the standard requirement is not more than 20 mg/L). But when the BOD_5 loading of the system was higher than 4.07 $gBOD_5/m^2$-d, the packed cage RBC stage 2 was needed for treating the waste water to the standard requirement of Department of Industrial Works. However, our packed cage RBC system which consisted of 2 similar sets of reactor could treat waste water which had BOD_5 loading up to 8.14 $gBOD_5/m^2$-d. The BOD_5 of effluents was lower than 20 mg/L.

For the NH_4^+ and total N_2 removal efficiency, the packed cage RBC system gave interesting results as shown in table 6 and table 7. From the theory, the $(NH_4)_2SO_4$ (N_2 source), added in to the synthetic waste water, was used as the precursor for synthesis of the cell mass and used for energy by oxidation reaction(17,18,19,20). However, from the results from table 6 and table 7, we can confirm that the secondary stage of packed cage RBC system was needed for removal of the N_2 compound from the waste water. But as we knew that the mechanisms for removal of N_2 compound was a 2 stage process: nitrification (NH_4^+ compound was changed to NO_3^- in the aerobic condition) and denitrification (NO_3^- was changed to N_2 gas in anoxic condition). However, for the results of NH_4^+ and total N_2 removal efficiency, we can say that the main reaction in packed cage RBC system for nitrogen removal was nitrification, the denitrification rate was not so high. At an optimal N_2 loading of 1.22gN_2/m^2-d, the total NH_4^+-N2 removal efficiency was 99.47% as shown in table 6.

The packed cage RBC system is also good for controlling the SS of effluents because the effluent SS from each step of the packed cage RBC system is quite low. From table 9, the SS of the effluents from the packed cage RBC step1 and step2 was lower than 0.5mg/L and 0.05 mg/L, respectively. But for the standard requirement of the Department of Industrial Works, the SS of effluent should be less than 30 mg/L.

The organic loading and N_2 loading were also affected by the pH of the system, when the organic loading or N_2 loading was increased, the pH of the system decreased due to the limit of the oxygen supplied and reduction of dissolved oxygen in the system. When the dissolved oxygen was decreased, the type of microorganisms in the bio-film changed as shown in fig.2 At the organic loading of 8.41 $gBOD_5/m^2$-d, the dissolved oxygen of the packed cage RBC system stage 1 was 0 mg/L, the color of bio-film became darker. It meant that the microorganisms of the bio-film changed to be anaerobic microorganisms [7,20,21].

The oxygen supplied into the the packed cage RBC system was also limited by the rotation of packed cage drum. When the organic loading or N_2 loading was increased, the dissolved oxygen in both reactors decreased. This phenomena normally occurred in the activated sludge system and RBC system [1,2,3,5,7].

From all the results above, we can recommend that the packed cage RBC system is the best system for treating waste water due to low energy consumption and high removal efficiency for SS, BOD_5 and N_2 compounds. But this system has a disadvantage in the oxygen supplied. Because, the oxygen supplied to the system, comes from the rotation of the packed cage drum. When the organic loading increased, the dissolved oxygen decreased. When the organic loading increased up to 8.14 $gBOD_5/m^2$-d, the dissolved oxygen in reactor 1 became 0 mg/L, and then the color of bio-film became darker. The type of microorganisms changed to be anaerobic microorganisms. The organic compounds and N_2 compounds removal efficiency of the system decreased and the pH of the system decreased to acid condition (lower than 7).

For applications, the packed cage RBC system could be used as the treatment system for treating industrial waste water or domestic waste water which contains high concentration of N_2 compounds, because the system is stable. The N_2 compounds in the waste water might not affect the system. But if we would like to apply the system for treating N_2 compound in waste water, the serial stage of packed cage RBC reactor is needed. Because, from our experiment, 2 stage of packed cage RBC could change the NH_4^+ compound to be NO_3^- (mainly occurred in secondary stage) If we used more units of packed cage RBC reactor in the system, the activity of stage 3 or 4 would be denitrification.

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Table 1: Chemical composition of synthetic waste water.

Composition	Concentration (mg/L)
Glucose	370.0
$FeCl_3$	0.7
$NaHCO_3$	130.0
KH2PO4	11.0
$MgSO_4.7H_2O$	8.5
$(NH_4)_2SO_4$	varied due to the ratio of $BOD_5:N_2$

Table 2: The concentration of $(NH_4)_2SO_4$ (mg/L) in the synthetic waste water at various ratio of $BOD_5:N_2$.

Ratio of $BOD_5:N_2$	$(NH_4)_2SO_4$ (mg/L)
100:5	94.30
100:10	188.60
100:20	377.10
100:30	565.70
100:40	754.30

Table 3: The parameters used for operation of the packed cage RBC system.

Parameter	Experiment 1			Experiment 2				Experiment 3		
	1	2	3	4	5	6	7	8	9	10
BOD_5 (mg/L)	400	400	400	400	400	400	400	400	400	400
Total N_2 (mg/L)	20	20	20	40	80	120	160	160	160	160
BOD_5:N_2 ratio	100:5	100:5	100:5	100:10	100:20	100:30	100:40	100:40	100:40	100:40
HRT (hrs) -each unit	2	3	4	4	4	4	4	5	6	7
-whole system	4	6	8	8	8	8	8	10	12	14
Flow rate(L/ d)	516.0	344.0	258.0	258.0	258.0	258.0	258.0	206.0	172.0	147.4
Organic loading ($gBOD_5/m^2$-d)	8.14	5.43	4.07	4.07	4.07	4.07	4.07	3.26	2.72	2.33
N_2 loading -gN_2/d	10.32	6.88	5.16	10.32	20.64	30.96	41.28	33.02	27.52	23.58
-gN_2/m^2-d	0.41	0.27	0.20	0.41	0.81	1.22	1.63	1.30	1.09	0.93
Hydraulic loading (L/m^2-d)	40.73	27.15	20.36	20.36	20.36	20.36	20.36	16.29	13.58	11.63

Table 4: BOD_5 removal efficiencies of packed cage RBC system at various N_2 loading and HRTs.

BOD_5:N_2	N_2 loading (g N_2 /m^2-d)	BOD_5inf (mg/L)	Organic loading (g/m^2-d)	Packed cage RBC Stage1		Packed cage RBC Stage2		Packed cage RBC system
				BOD_5eff (mg/L)	%removal	BOD_5eff (mg/L)	%removal	%Total Removal
100:5	0.41	399.4	8.14	72.98	81.73	19.8	72.87	95.04
100:5	0.27	398.8	5.43	66.23	83.39	17.57	73.47	95.59
100:5	0.20	403.8	4.07	18.36	95.45	11.66	36.49	97.11
100:10	0.41	399.4	4.07	18.47	95.38	10.32	44.13	97.42
100:20	0.81	403.1	4.07	15.97	96.04	11.66	26.99	97.11
100:30	1.22	403.6	4.07	20.36	94.96	11.98	41.16	97.03
100:40	1.63	401.9	4.07	23.52	94.15	19.13	18.66	95.24
100:40	1.30	395.0	3.26	11.31	97.14	6.8	39.88	98.28
100:40	1.09	403.1	2.72	14.24	96.47	10.41	26.90	97.42
100:40	0.93	402.0	2.33	12.7	94.84	9.78	22.99	97.57

Table 5: COD removal efficiencies of packed cage RBC at various N2 loading and HRTs.

BOD_5:N_2	N_2 loading (g N_2 /m^2-d)	CODinf (mg/L)	Organic loading (g/m^2-d)	Packed cage RBC Stage1		Packed cage RBC Stage2		Packed cage RBC system
				COD_{eff}	% removal	COD_{eff}	%removal	%Total Removal
100:5	0.41	399.6	8.14	88.55	77.84	40.67	54.07	89.82
100:5	0.27	401.3	5.43	62.98	84.31	35.98	42.87	91.03
100:5	0.20	400.9	4.07	34.34	91.43	22.76	33.72	94.32
100:10	0.41	399.1	4.07	38.05	90.47	23.81	37.42	94.03
100:20	0.81	402.1	4.07	40.29	89.98	22.93	43.09	94.30
100:30	1.22	402.3	4.07	34.52	91.42	22.93	33.57	94.30
100:40	1.63	401.0	4.07	48.01	88.03	30.05	37.41	92.51
100:40	1.30	400.5	3.26	24.97	93.77	15.17	39.25	96.21
100:40	1.09	399.6	2.72	27.83	93.04	17.47	37.23	95.63
100:40	0.93	402.0	2.33	26.54	93.40	16.98	36.02	95.78

Table 6: Ammonia removal efficiencies of packed cage RBC at various BOD_5:N_2 and HRTs.

BOD_5:N_2	N_2 loading ($g N_2/m^2$-d)	NH_4^+ (mg N_2/L)	NH_4^+ loading (gN/m^2-d)	Packed cage RBC Stage1		Packed cage RBC Stage2		Packed cage RBC system
				NH_4^+ eff (mgN_2/L)	%remval	NH_4^+ eff (mgN_2/L)	%removal	%removal
100:5	0.41	20.24	0.41	14.85	26.63	0.52	96.50	97.43
100:5	0.27	20.94	0.27	13.63	34.91	0.56	95.89	97.33
100:5	0.20	19.56	0.20	8.86	54.70	0.22	97.52	98.88
100:10	0.41	40.12	0.41	17.42	56.58	0.43	97.53	98.93
100:20	0.81	80.49	0.81	37.82	53.01	0.93	97.54	98.84
100:30	1.22	120.60	1.22	52.66	56.33	0.64	98.78	99.47
100:40	1.63	160.51	1.63	99.20	38.20	56.03	43.52	65.09
100:40	1.30	159.58	1.30	55.94	64.95	1.65	97.05	98.97
100:40	1.09	161.50	1.09	99.07	38.66	71.41	27.92	55.78
100:40	0.93	161.49	0.93	100.66	37.67	68.12	32.33	57.82

Table 7: Total N_2 removal efficiencies of packed cage RBC system at various BOD_5:N_2 and HRTs.

BOD_5:N_2	Organic loading (g/m^2-d)	Nitrogen (mgN_2/L)	Nitrogen loading (gN_2/m^2-d)	Packed cage RBC Stage1		Packed cage RBC Stage2		Packed cage RBC system
				N_2eff (mgN_2/L)	% removal	N_2eff (mgN_2/L)	% removal	% Total removal
100:5	8.14	20.24	0.41	17.01	15.96	12.54	26.28	38.04
100:5	5.43	20.94	0.27	15.44	26.27	12.63	18.20	39.68
100:5	4.07	19.56	0.20	14.06	28.12	8.31	40.90	57.52
100:10	4.07	40.12	0.41	29.63	26.15	16.08	45.73	59.92
100:20	4.07	80.49	0.81	55.16	31.47	31.36	43.15	61.04
100:30	4.07	120.60	1.22	72.65	39.76	48.19	33.67	60.04
100:40	4.07	160.51	1.63	112.22	30.09	93.22	16.93	41.92
100:40	3.26	159.58	1.30	94.04	41.07	52.55	44.12	67.07
100:40	2.72	161.50	1.09	123.96	23.24	95.36	23.07	40.95
100:40	2.33	161.49	0.93	124.65	22.81	96.39	22.67	40.31

Table 8: Suspended solid in the effluent of packed cage RBC system in various $BOD_5:N_2$ ratio, organic loading and nitrogen loading.

$BOD_5:N_2$	HRT (hrs)	Organic loading (g/m^2-d)	Nitrogen loading (gN_2/m^2-d)	Suspended solid (SS) in packed cage RBC system	
				stage1 SS eff	stage2 SS eff
100:5	2	8.14	0.41	0.373	0.038
100:5	3	5.43	0.27	0.249	0.029
100:5	4	4.07	0.20	0.124	0.023
100:10	4	4.07	0.41	0.125	0.019
100:20	4	4.07	0.81	0.135	0.026
100:30	4	4.07	1.22	0.130	0.018
100:40	4	4.07	1.63	0.130	0.022
100:40	5	3.26	1.30	0.164	0.019
100:40	6	2.72	1.09	0.238	0.026
100:40	7	2.33	0.93	0.206	0.023

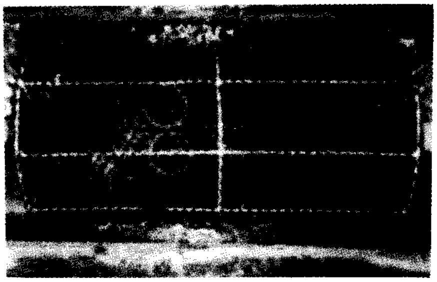
Table 9: pH in packed cage RBC reactor during operation with various $BOD_5:N_2$ rate, organic loading and nitrogen loading.

$BOD_5:N_2$	HRT (hrs)	Organic loading (g/m^2-d)	Nitrogen loading (gN_2/m^2-d)	pH in each reactor in packed cage RBC system		
				pH Inf.	Stage1 pH eff.	Stage2 pH eff.
100:5	2	8.14	0.41	7.29	7.41	7.33
100:5	3	5.43	0.27	7.26	7.4	7.31
100:5	4	4.07	0.20	7.3	7.5	7.7
100:10	4	4.07	0.41	7.25	7.38	7.14
100:20	4	4.07	0.81	7.24	7.07	6.72
100:30	4	4.07	1.22	7.38	7.08	6.72
100:40	4	4.07	1.63	7.45	7.39	6.77
100:40	5	3.26	1.30	7.47	6.93	6.72
100:40	6	2.72	1.09	7.26	6.59	6.2
100:40	7	2.33	0.93	7.28	6.24	6.01

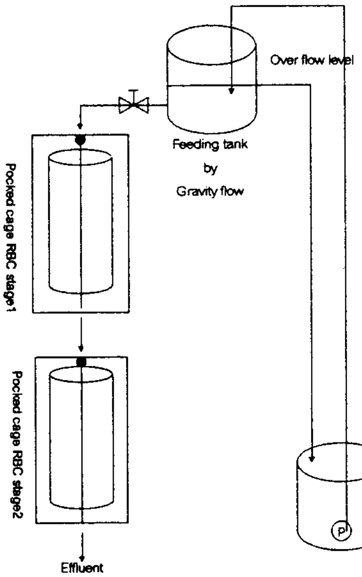
Table 10: Organic loading and Nitrogen loading on dissolved oxygen in the reactor of packed cage RBC system.

$OD_5:N_2$	HRT (hrs)	Organic loading (g/m^2-d)	Nitrogen loading (gN_2/m^2-d)	Dissolved oxygen in packed cage RBC system (mg/L)	
				stage1	stage2
100:5	2	8.14	0.41	0	3.44
100:5	3	5.43	0.27	1.91	5.29
100:5	4	4.07	0.20	2.71	6.93

A: Whole system of packed cage RBC system

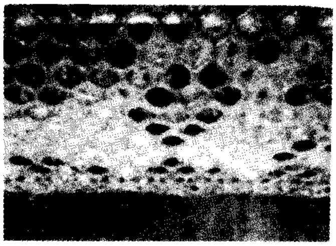


B: Packed cage drum

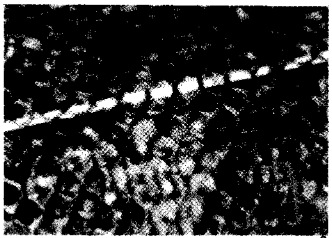


C: Diagram of the packed cage RBC system

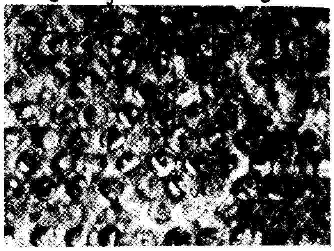
Fig 1 : The packed cage RBC system



A: Organic loading as4.07 $gBOD_5/m^2$-d



B: Organic loading as 5.43 $gBOD_5/m^2$-d



C: Organic loading as 8.14 $gBOD_5/m^2$-d

Fig2. Effects of organic loading on the morphology of biofilm on packed cage drum