Some Properties of Packed Cage RBC System on the Treatment of Synthetic Domestic Wastewater

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Abstract

The study is concerned with the removal of organic matters in terms of COD from synthetic domestic wastewater by using packed cage RBC system. The packed cage RBC reactor consisted of 2 main components, a 43 liters (working volume) cylindrical reactor and 46.8 cm^3 packed cage drum which was fully packed with I-ball polypropylene media (50 mm in diameter). The total surface area of I-ball polypropylene media in packed cage drum was 7.12 M^2. The synthetic domestic wastewater used in this experiment contained glucose (carbon source) and urea (nitrogen source) as the main components. Synthetic domestic wastewater, was used in this study, with initial COD concentrations of 100, 200, 300 and 400 mg/L, respectively. The reactor was operated under various hydraulic retention times (HRT) of 4, 6 and 8 hrs.

The results show that COD removal efficiency decreased when the organic loading was increased or HRT was decreased. At the highest Arial organic loading of 14.49 g COD/M^2-day and lowest HRT of 4hrs, the total and soluble COD removal efficiencies were 77.36% and 84.82%, respectively. On the other hand, the total and soluble COD removal efficiencies were 80.24% and 92.44%, respectively at lowest Arial organic loading of 3.62 gCOD/M^2-day and highest HRT of 8 hrs. The dissolved oxygen in the reactor decreased when organic loading was decreased or HRT was increased. For example, at highest Arial organic loading (14.49 mg/L), the rotating drum could supply enough oxygen (the dissolved oxygen of mixed liquor in the reactor was 3.9 mg/L) to the system. The concentration of suspended solids of effluent was increased when the organic loading was increased or HRT was decreased. Because part of the bio-film came loose from the surface of packed cage drum and media. At the highest Arial organic loading (14.49 mgCOD/M^2-day) and lowest HRT (4 hrs), the suspended solids of effluent was 28 mg/l. But the suspended solid was 8 mg/L at the lowest organic loading (3.62 mgCOD/M^2-day) and highest HRT(8 hrs),

From all of the results above, we believe that the packed cage RBC system might be the best system for treating domestic wastewater due to the reduction of the energy consumption and stabilization of the COD removal efficiencies under unstable COD loading and hydraulic loading. And also, it could solve the problem of suspended solids in the effluents.

Keywords: Total COD, Soluble COD, HRT, Organic loading, Arial organic loading, Volumetric organic loading, Packed cage RBC, RBC.

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1. Introduction

Water pollution is the main problem in the world [1]. The pollutants come from several sources such as housecholds, industries and agriculture. In Thailand, the Choa-phaya river is the main conduit for receiving wastewater from all activities of residential and industrial sectors along the river. About 75% of wastewater which discharged to Choa-phaya river comes from the domestic sector. In the past, wastewater volume discharged into Choa-phaya river, was not so large, the pollutants could be treated by self-purification. But nowadays, the pollutants contaminating wastewater are increasing, because of the increase in the population. The self-purification system can not be used for treating all pollutants. Several methods are used for treating the wastewater before discharge into the river such as anaerobic and aerobic biological processes [1,2]. Each process has advantages and disadvantages dependent on many factors such as quality of effluent, treatment cost, treatment technology, skill of operator, impact and so on [1,2,3,4].

Nowadays, about 80% of wastewater treatment plants for domestic wastewater use activated sludge system [1,2,3,4], because of high removal efficiency, 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 is 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 had many problems [8,9,10] during operation such as maintenance of bio-drum, and oxygen which is supplied into the system by moving of bio-drum is limited [8,9,10,11,12,13]. From above information, we would like to solve all of the problems which commonly occurr in both activated sludge system and RBC system. We tried to use the new type of treatment system, that is, packed cage RBC system.

In this study, we designed and constructed a laboratory scale packed cage RBC system. And we also observed the phenomena and the COD removal efficiencies of the packed cage RBC system during operation with synthetic domestic wastewater which had various concentrations of COD under various HRTs.

2. Materials and Methods

Packed Cage RBC: The packed Cage RBC which is one of the aerobic moving-bio-film reactors was modified from RBC system and fixed film reactor for treating domestic wastewater. The laboratory scale packed cage RBC system was designed and constructed as shown in fig.1 and fig.2. The reactor consisted of 42x90x46 cm^3 cylindrical reactor (working volume as 43 liters) and 46.81cm^3 packed cage drum. I-ball polypropylene media (The specification of I-ball polypropylene were: 50 mm in diameter, 94% of Porosity and 170 M^2/M^3 of specific surface area) were fully packed inside the drum (about 436 pieces of media were used for packing). 40% of packed cage drum was submerged in wastewater during operation. The speed of packed cage drum was approximately 3 rpm.

Synthetic domestic wastewater (SDWW): SDWW, used in this study, was similar to the domestic wastewater from Thailand's housing estates. SDWW consisted of glucose, urea, $FeCl_2$, $NaHCO_3$, KH_2PO_4 and $MgSO_4.7H_2O$. The concentration of each component is described in table 1.

Start up the packed cage RBC system: Sludge from Sanko Fastem, Thailand Co.,Ltd was used as inoculum. 21.5 liters of sludge (concentration of 10,000 mg/L) was inoculated in reactor. And then 21.5 liters of tap water was added (final volume was 43 liters). The packed cage RBC drum was operated at 3 rpm without feeding of SDWW for 1 day. After that, the SDWW which had initial COD concentration of 100 mg/L was continuously fed at flow rate of 50 L/day. After 10 days of operation, the bio-film was fully built up on the surface of I-ball media and packed cage drum.

Continuous treating of SDWW in Packed Cage RBC: The experiments were divided into 4 sets due to various COD concentrations of 100, 200, 300 and 400 mg/L. In each concentration of COD, the experiments were done at various hydraulic retention times (HRT) as shown in table 2. and table 3.

Chemical Analysis: The chemical properties of wastewater which were determined were: total COD(COD_T), soluble COD(COD_S), temperature, pH, dissolved oxygen (DO) and suspended solids (SS). All analytical methods were conducted in accordance with standard methods for water and wastewater examination [14].

3. Results

Morphology of bio-film on surface of packed cage drum and media: For starting the system, the concentrated sludge from wastewater treatment plant of Sanko Fastem Thailand Co.,Ltd was used as inoculum. After 10 days of continuous feeding of SDWW, which had COD concentration on the surface of packed cage drum and media as shown in fig.3. The bio-film on the surface of the media and drum was about 1-4 mm in thick. It was found that the color of the bilo-film changed due to COD loading. For example, when Arial organic loading was around 3.62-10.87 gCOD/M^2-day, the color of bio-film red brown to dark brown. But when Arial organic loading increased up to 14.49 gCOD/M^2-day, the color of bio-film became red brown and dark brown.

The chemical properties of influents and effluents from packed cage RBC system: The experiments were carried out by using a laboratory scale packed cage RBC system under various conditions. And the chemical properties of influents and effluents were determined. The results of the experiments are shown below.

Experiment 1: The packed cage RBC system was operated with SDWW which had initial COD concentration of 100 mg/L. The system was run at HRT of 4 hrs and flow rate of 258 L/day. The results are shown in table4. The COD_T and COD_S removal efficiencies were 80.02% and 92.44%, respectively. The pH of effluents were in the range of 7.62-8.02. The effluent SS was 2.0 mg/L. The DO and temperature in reactor was 5.7-6.0 mg/L and 26-28^oC, respectively.

Experiment 2: The packed cage RBC system was operated with SDWW which had initial COD concentration of 200 mg/L, The system was run under HRT of 4, 6 and 8 hrs, respectively and flow rate of 258,172 and 129 L/day, respectively. The results are shown in table5. The COD_T removal efficiencies at HRT of 4, 6 and 8 hrs were 80.58%, 86.82% and 94.59%, respectively. The COD_S removal efficiencies under HRT of 4, 6 and 8 hrs were 84.47%, 87.31% and 95.88%, respectively. The effluents SS were 12.0, 8.0 and 8.0 mg/L when the HRT were 4, 6 and 8 hrs, respectively. The DO in reactor during operation with HRT of 4, 6 and 8 hrs were around 5.30-5.50, 5.40-5.70 and 5.80-6.10 mg/L, respectively.

Experiment 3: The packed cage RBC system was operated with SDWW which had initial COD concentration of 300 mg/L. The system was run under HRT of 4, 6 and 8 hrs, respectively and flow rate of 258, 172 and 129 L/day, respectively. The results are shown in table6. The COD_T removal efficiencies under the HRT of 4, 6 and 8 hrs were 77.01%, 84.40% and 87.84%, respectively. The COD_S removal efficiencies under the HRT of 4, 6 and 8 hrs were. 80.46%, 85.88% and 88.84%, respectively. The SS of effluents were 15.0, 12.0 and 8.0 mg/l when the HRT were 4, 6 and 8 hrs, respectively. The DO in reactor were 4.4-4.6, 5.0-5.2 and 5.7-5.9 mg/L when the HRT were 4,6 and 8 hrs.

Experiment 4: The packed cage RBC system was operated with SDWW which had initial COD concentration of 400 mg/L, The system was run at HRT of 4, 6 and 8 hours, and flow rate of influent of 258, 172 and 129 L/day. The results of chemical analysis are shown in table7. The COD_T removal efficiencies under HRT of 4, 6 and 8 hrs were 77.36%, 77.51% and 86.58%, respectively. The COD_S removal efficiencies under HRT of 4, 6 and 8 hrs were 84.83%, 87.29% and 89.34%, respectively. The effluents SS were 28.0, 18.5 and 22.0 mg/L when the HRT were 4,6 and 8 hrs, respectively. The DO in reactor were 3.9-4.3, 4.8-5.0 and 4.9-5.3 mg/L when HRT were 4,6 and 8 hrs, respectively.

4. Conclusions and discussions

The morphologies of bio-films: As we mentioned above, the bio-film was rapidly grown on the surface of media and drum. The color of bio-film was red brown to dark brown.

It meant that the conditions for starting the system were suitable. And also the brown color of bio-film indicated that the system was fully supplied with oxygen by rotating of packed cage drum [7]. However, after 5-7 weeks of operation, some parts of bio-film had come loose from media and drum because the oxygen could not penetrate into inner layer of bio-film [7]. The Arial organic loading also affected the type of microorganisms. Under the lowest Arial organic loading condition, the aerobic microorganisms were fully grown The color of bio-film became red brown to dark brown. On the other hand, when the Arial organic loading was increased up to 14.49 gCOD/M^2-day, the type of microorganisms were changed to facultative group such as sulfur reducing bacteria [11]. Then, the color of bio-film became grey to white.

The results on removal efficiencies and properties of effluent: By using the packed cage RBC system for treating SDWW, there were several interesting results which were investigated such as:

1.COD removal efficiencies in packed cage RBC system: COD removal efficiencies depended on Arial or volumetric organic loading as shown in table.8. When the Arial or volumetric organic loading were increased, the COD removal efficiency was decreased. The COD removal efficiency was also decreased when the HRT was decreased as shown in table8. However, at highest Arial organic loading of 14.49 gCOD/M^2-day and lowest HRT of 4 hrs, The COD_T and COD_S removal efficiencies were 77.36% and 84.83%, respectively.

2. DO in packed cage RBC reactor: The DO in the reactor was increased when organic loading or Arial organic loading was decreased. For example, at the highest Arial organic loading of 14.49 gCOD/M^2-day and lowest HRT of 4 hrs, the DO in reactor was in the range of 3.9-4.3 mg/L. On the other hand, at the lowest Arial organic loading of 3.62 gCOD/M^2-day and highest HRT of 8 hrs, the DO in the reactor was in the range of 5.80-6.10 mg/L. From all the results above, we could say that the packed cage drum could supply enough oxygen for the system even when the Arial organic loading was up to 14.46 gCOD/M^2-day and HRT was reduced to 4 hrs(4,5,7,8).

3.SS of effluents: The above results showed that SS in effluent increased when the HRT was decreased. For example, when the Arial organic loading was in the range of 3.62-5.44 gCOD/M^2-day, the SS of effluents were not more than 8 mg/L as shown in table8. But the SS in effluents increased up to more than 20 mg/l when the Arial organic loading was higher than 7.25 mg/l because some bacteria fixed on the media (bio-film) had loosened from the media by wash-out mechanism [14]. However, the standard concentration of effluent SS required by Department of Industrial Works [15] is not more than 20 mg/L.

4.Temperature: From the results of the temperature of influents and influents, we believe that the packed cage RBC system did not produce any heat. On the other hand, the rotation of the packed cage drum could reduce the temperature of influents by about 3-5^oC. It meant that this treatment system could treat wastewater which had temperature about 3-5^oC higher than ambient temperature.

From all of the above results, we concluded that the packed cage RBC system might be the best way to solve all the problems which occur in the activated sludge system and RBC system due to the advantages of the packed cage RBC system such as low energy consumption, easy operation and maintenance. And the system could stabilize itself during operation under the fluctuation of COD loading or hydraulic loading.

For application, the packed cage RBC system could treat wastewater which has initial COD concentration up to 400 mg/L. And the system could operate with Arial organic loading up to 14.49 gCOD/M^2-day and lowest HRT of 4 hrs.

5. Acknowledgments

The author wishes to express deep thanks to Dr. Sadahiro Ohmomo, National Institute of Animal Industry, Japan for reading the original manuscript and giving valuable advice, Miss Yuwadee Chaiyachet for her technical And also sincere thanks is given to Department of Environmental Technology, King Mongkut's University of Technology Thonburi for providing the research materials and equipment.

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Table 1. Composition of synthetic domestic wastewater at various COD concentration.

Composition mg/L	Concentration of COD(mg/L)			
	100	200	300	400
Glucose	90.00	190.00	215.00	370.00
Urea	6.50	9.00	18.00	23.00
$FeCl_2$	0.17	0.31	0.45	0.70
$NaHCO_3$	3.10	6.70	9.50	13.00
KH2PO4	3.00	6.00	9.00	11.00
$MgSO_4.7H_2O$	1.90	3.90	6.00	8.50

Table 2. COD concentration of the synthetic domestic wastewater and the HRT values which were used for operating the packed cage RBC in each COD concentration synthetic waste water.

COD Concentration (mg/L)	Hydraulic retention time (HRT) (hrs)
100	4
200	4, 6, 8
300	4, 6, 8
400	4, 6, 8

Table 3. Parameters used for operating packed cage RBC system.

parameter	COD 100 mg/L	COD 200mg/L			COD 300 mg/L			COD 400 mg/L		
	1	2	3	4	5	6	7	8	9	10
HRT (Hour)	4	4	6	8	4	6	8	4	6	8
Flow rate (L/day)	258.00	258.00	172.00	129.00	258.00	172.00	129.00	259.00	172.00	129.00
Organic loading/day (COD/day)	25.80	51.60	34.40	25.80	77.40	51.60	38.70	103.20	68.80	51.60
Arial organic loading (COD/M^2-day)	3.62	7.25	4.83	3.62	10.87	7.25	5.44	14.49	9.66	7.25
Volumetric organic loading (COD/M^3-day)	0.60	1.20	0.80	0.06	1.80	1.20	0.90	2.40	1.60	1.20
Hydraulic loading/area (L/M^2-day)	36.24	36.24	24.16	18.12	36.24	24.16	18.12	36.24	24.16	18.12

Table 4. Chemical properties of the influent and effluent from the packed Cage RBC system when COD concentration of the synthetic waste water fed in the system was 100 mg/L.

The experiment was done under HRT of 4 hrs and flow rate of 258 L/day.

Parameter	Influent	Effluent	Removal efficiency (%)
HRT (hr)	4	4	-
Temp (°C)	29.0-30.5	26.0-28.0	-
pH(mg/L)	7.42-7.59	7.62-8.02	-
SS (mg/L)	-	2.0	-
DO* (mg/L)	-	5.7-6	-
COD_T(mg/L)	102.50	20.25	80.02
COD_S (mg/L)	102.50	7.75	92.44

* Dissolved oxygen of mixed liquor in the reactor

Table 5. Chemical properties of the influent and effluent from the packed Cage RBC system when COD concentration of the synthetic waste water fed in the system was 200mg/L.

The experiment was done under various values of HRT (4, 6 and 8 hrs) and various flow rates (258,172 and 129 L/day)

Parameter	Influent			Effluent			Removal efficiency(%)		
HRT(hr)	4	6	8	4	6	8	4	6	8
Temp (°C)	28-29	28-30	25.5-28	26-27	23-25	-	-	-	-
pH	7.50 - 7.80	7.50 - 7.70	7.50 - 7.80	7.58 - 7.91	7.52 - 7.82	7.89 - 8.18	-	-	-
SS (mg/L)	-	-	-	12.0	8.0	8.0	-	-	-
DO*(mg/L)	-	-	-	5.30 - 5.5	5.40 - 5.70	5.80 - 6.10	-	-	-
COD_T(mg/L)	206	201	194	40.00	26.50	10.5	80.58	86.82	94.59
COD_S(mg/L)	206	201	194	32.00	25.50	8.00	84.47	87.31	95.88

* Dissolved oxygen of mixed liquor in the reactor

Table 6. Chemical properties of the influent and effluent from the packed Cage RBC system when COD concentration of the synthetic wastewater fed in the system was 300 mg/L.

The experiment was done under various HRT (4, 6 and 8 hrs) and various flow rates (258,172 and 129L/day).

Parameter	Influent			Effluent			Removal efficiency (%)		
HRT (hrs)	4	6	8	4	6	8	4	6	8
Temp(°C)	28-30	28-30.5	28-30	25-27	25-28	25-27	-	-	-
pH	7.3 - 7.7	7.5 - 7.8	7.3 - 7.7	6.89 - 7.72	7.48 - 8.28	7.89 - 8.09	-	-	-
SS (mg/L)	-	-	-	15.0	12.0	8.0	-	-	-
DO (mg/L)	-	-	-	4.4 - 4.6	5.0 - 5.2	5.7 - 5.9	-	-	-
COD_T(mg/L)	304.50	304.50	298.00	70.00	47.50	36.25	77.01	84.40	87.84
COD_S (mg/L)	304.50	304.50	298.00	59.50	43.00	33.25	80.46	85.88	88.84

* Dissolved oxygen of mixed liquor in the reactor.

Table 7. Chemical properties of the influent and effluent from the packed Cage RBC system when COD concentration of the synthetic waste water fed in the system was400 PPM.

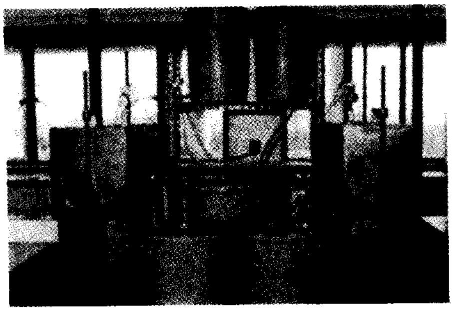
The experiment was done under various values of HRT (4, 6 and 8 hours) and various flow rate (258,172 and 129L/day).

Parameter	Influent			Effluent			Removal efficiency(%)		
HRT (hr)	4	6	8	4	6	8	4	6	8
Temp	31-29	28-30	27-29	26-28	24-27	23-25	-	-	-
pH	7.20 - 7.50	7.50 - 7.80	7.50 - 7.80	7.16 - 7.61	7.42 - 7.81	7.68 - 7.99	-	-	-
SS (mg/L)	-	-	-	28.0	18.5	22.0	-	-	-
DO* (mg/L)	-	-	-	3.90 - 4.30	4.80 - 5.00	4.90 - 5.30	-	-	-
COD_T(mg/L)	402.00	393.50	380.00	91.00	88.50	51.00	77.36	77.51	86.58
COD_S (mg/L)	402.00	393.50	380.00	61.00	50.00	40.50	84.83	87.29	89.34

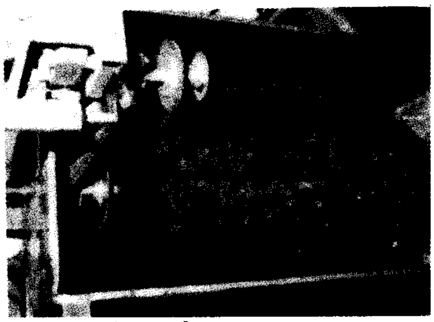
* The dissolved oxygen of mixed liquor in the reactor.

Table 8. Relationship between the COD_T and COD_S removal efficiencies and effluent SS and Arial organic loading.

Parameter	Arial organic loading (g COD/M²-d)									
	HRT 4 hrs				HRT 6 hrs			HRT 8 hrs		
	3.62	7.25	10.87	14.49	4.83	7.25	9.66	3.62	5.44	7.25
%COD_T removal	80.02	80.58	77.01	77.36	86.82	84.40	77.51	94.59	87.84	86.58
%COD_S removal	92.44	84.47	80.46	84.83	87.31	85.88	87.29	95.88	88.84	89.34
Effluent SS	2.0	12.0	15.0	28.0	8.0	12.0	18.5	8.0	8.0	22.0

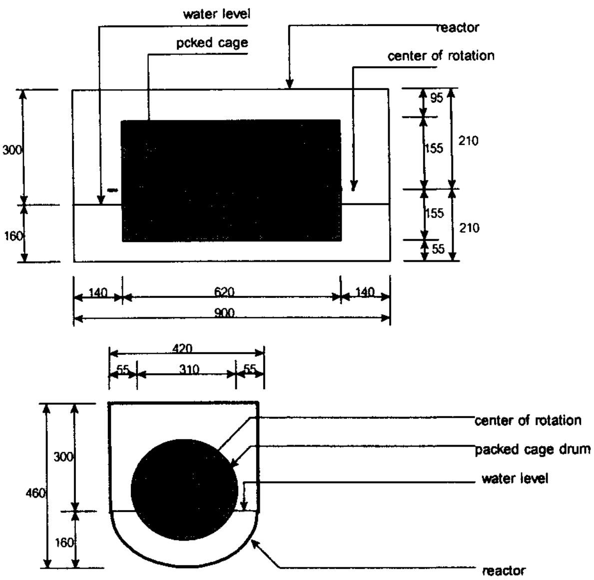


A: The packed cage RBC system



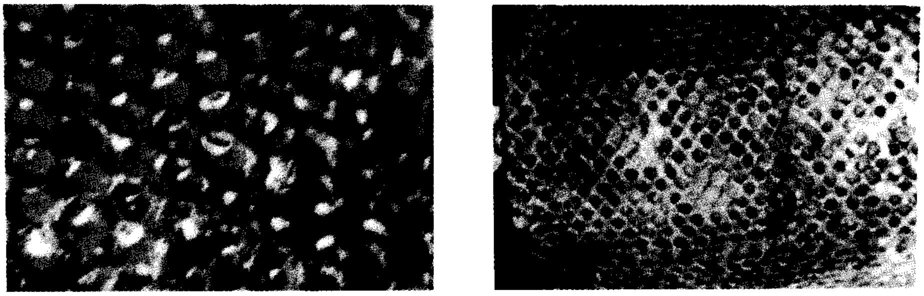
B: Packed cage drum

Fig.1 Laboratory scale packed cage RBC system.



Cross section of the packed cage RBC system

Fig.2 Diagram of packed cage RBC system.



A: Arial organic loading at 10.87 gCOD/M^2-d

B: Arial organic loading at 14.49 gCOD/M^2-d

Fig.3 Characteristics of the bio-film on the packed cage drum under different Arial organic loading.