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Integrated System of RBC-lime Precipiatation for Simultaneous Removal of Organics and Nutrients

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회전원판공정과 화학침전공정 조합을 이용한 유기물과 질소 · 인의 동시제거

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국문요약

회전원판공정(rotating biological contactor;RBC)과 화학적 처리공정을 결합한 처리시스템을 이용하여 도시하수내 포함된 유기물과 영양염류를 제거할 경우에 수리학적 부하(hydraulic loading)와 처리수 반송율(recirculation rate)이 시스템 처리효율에 미치는 영향을 알아보고자 하였다. 각각의 수리학적 부하 0.031, 0.0535 및 0.076 $m^3/m^2/d$에서 반송율을 100%, 200%, 300%로 변화시켰고, 질산화에 필요한 알카리도의 보충 및 화학적 처리를 위하여 lime($CaCO_3$)을 가하여 유입수의 pH를 10.4~11.0으로 유지시켰다. 실험결과 수리학적 부하 0.0535 $m^3/m^2/d$에서 BOD, COD의 제거효율이 가장 높게 나타났으며, 질산화 효율 및 질소 제거효율에서는 수리학적 부하 0.035 $m^3/m^2/d$, 반송율 300%에서 가장 높았으며, 반송율별에서는 수리학적 부하를 고려할 때 300% 반송하는 것이 가장 높은 유기물 제거효율을 보였다. 반송율과 수리학적 부하를 증가시킬 경우에 발생되는 슬러지내 유기물 함량은 점점 증가하였고, 수리학적 부하 0.076 $m^3/m^2/d$, 반송율 300%일 경우에는 유기물 함량이 47%로 매우 높았다. 이는 부하증가에 따른 미생물 성장의 증가와 더불어 수리학적 부하 증가에 따른 전단력의 증가가 영향을 미쳤기 때문이다. 인을 제거하기 위하여 pH를 10.4~11.0으로 유지시킨 경우에 인을 90%이상 제거할 수 있었으며, 유출수내 평균 SS농도는 40 mg/l를 상회하였다.

Keywords : Rotating biological contactor, Flocculation-sedimentation, Recirculation rate, Nutrient removal, Hydraulic loading rate

I. Introduction

The rotating biological contactor(RBC) process is gaining popularity, since first installation in West Germany, in the wastewater treatment field as economic alternate to the suspended biological system for the removal of organics, nitrogen and phosphorus from wastewaters. The contactor is slowly rotated with approximately 40 percent of the surface area submerged in the wastewater. Immediately after start-up, microorganisms naturally present in the wastewater began to adhere to the surfaces of media and multifly until, in approximately 1 week, the entire media surface is covered with a 1 to 4 mm thick layer of biomass. The attached biomass would be equivalent to 2,500 to 10,000 mgSS/l in a mixed suspended system. As the contactor rotates, is carries a film of wastewater through the air, resulting in oxygen and nutrient transfer. Additional removal occurs as the contactor rotates through liquid in the tank. Shearing forces cause excess biomass to be stripped from the media in a manner similar to a trickling filter. This prevents clogging of the media surfaces, and biomass is removed in a clarifier. The attached biomass is shaggy with small filament resulting in a high surface area for organic removal to occur. Treated wastewater and stripped biomass pass through each subsequent stage of media. As wastewater passes from stage to stage, it undergoes a progressively increasing degree of treatment by specific biological cultures in each stage, which adapt to the change in wastewater. Initial stages of media, which receive the highest concentration of organic matter, develop cultures of filamentous and non-filamentous bacteria. As concentration of organic matter decrease in subsequent stages, higher life forms including nitrifying bacteria begin to appear, along with various types of protozoans, rotifers, and other predators.[1] Present media consists of high-density polyethylene with a specific surface of 121 m^2/m^3. Single units are up to 3.7 m in a diameter and 7.6 m long, containing up to 9,290 m^2 of surface in one section.[2]

The advantage of an RBC process are the low power input to supply oxygen to the biomass and the high biomass concentration and sludge age attained with fixed medium. Due to its greater flexibility, low retention time, low sludge production, easy operating and maintenance, more RBC systems are adopted in treating wastewater. In case of United State and Canadian, 70percent of the RBC systems installed are used for carbonaceous BOD removal only, 25 percent for combined carbonaceous BOD removal and nitrification, and 5 percent for nitrification of secondary effluent.[3-5] Factors affecting performances of the RBC are hydraulic loading, media arrangement, rotating velocity, retention time, and temperature and so on. Among these hydraulic loading is very important factor, since the RBC exhibits approximately frist order kinetincs for the removal of carbonaceous BOD, oxidation of ammonia nitrogen, and removal of ultimate oxygen demand.[6,7] This means that at a specific hydraulic loading, a specific percentage removal of BOD will occur independent of the organic loading. Consequently, the primary design criteria is hydraulic loading and not organic loading as is often practiced with the activated sludge and trickling filter process. Researchs on the RBC have been carried out by many investigators. In the treatment of domestic wastewater, performance increase with liquid volume to surface areas up to 0.0049 m^3/m^2, and no improvement was noted above this value.[2] Poon et al.[8] reported various factors controlling the performance of RBC treatment to maximize BOD and suspended solids removal. Torpet et al.[9] extensively studied carbonaceous removal, nitrification and oxygen limitation. Nitrogen removal efficiency of RBC and correlated it with hydraulic loading and retention time, organic and ammonia loading, pH, temperature, staging, disk speed and the volume to surface area ratio were extensively investigated.[10,11] Phosphorus has been removed from the wastewater by RBC process using lime, alum and ferric salts.[12] Phosphorus removal varies from 0 to 20%, and can be increased substantially by adding chemicals to the primary clarification unit or to the reactor tank. As with all biological units, alkalinity and pH must be acceptable for efficient operation.[1]

The objective of this study was to evaluate performance of a combined treatment of lime addition and the RBC process for simultaneous removal of organics, nitrogen and phosphorus at different hydraulic loadings and recirculation rates.

II. Materials and Method

The bench scale plexiglass RBC unit consisted of three stages each having a basin with a dimension of 12×11.5×6.5 cm, 8 disks of 4 mm thickness and 10 cm diameter. The disks in all units were spaced equally with a 1 cm. They were rotated mechanically at a constant speed of 2 rpm yielding

Table 1. RBC unit specifications

• Number of stages	3	• Disk surface area per stage(cm^2)	1,256
• Number of disks per stage	8	• Submerged area(%)	55
• Disk diameter(cm)	10	• Liquid volume per stage(l)	0.9
• Disk thickness(cm)	0.4	• Disk rotating speed(Rev/min)	2
• Disk spacing(cm)	1.0	• Peripheral speed of disk(cm/sec)	1.5
		• Volume/surface ratio(m^3/m^2)	0.007

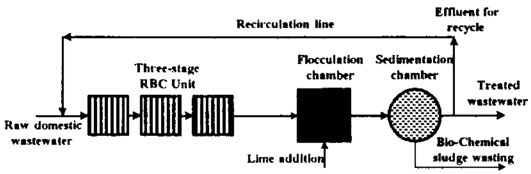

Fig. 1. Schematic diagram of flow pattern of laboratory system.

a peripheral speed of 1.04 cm/sec. The RBC unit specifications are listed in Table 1.

An schematic presentation of RBC process was illustrated in Fig. 1. The general scheme of the treatment process includes the RBC unit, chemical treatment followed by sedimentation, and effluent recirculation unit. The raw wastewater was collected from a wastewater treatment plant after grit removal. The wastewater was pumped to the RBC unit by a peristaltic pump at feed rates of 8, 14, and 20 m*l*/min resulting in hydraulic loading of 0.031, 0.054, and 0.076 $m^3/m^2/d$ and hydraulic retention times of 5.6, 3.2 and 2.3 days, respectively. The disks were submerged with 55% of the area under wastewater giving a volume to surface area ratio of 0.007 m^3/m^2. During the period of the study lime was added using a peristaltic feed pump to maintain a pH of 10.4-11.0 in the reactor. Similarly the effluent was recirculated at a selected rate of 100, 200 and 300% of the raw influent by another peristaltic pump.

Influent and effluent samples were collected daily and analyzed for temperature, pH, suspended solids, organic nitrogen, ammonia, nitrite, nitrate, phosphate, BOD and COD. The wastewater in the reactor was analyzed for pH, total solids, and total volatile solids. Influent flow rate, recirculation rate, and chemical flow rate were checked daily basis. The general scheme of the study is presented in Table 2.

The chemical analyses were performed according to Standard Methods for the examination of water and wastewater.[13] Total nitrogen removal was calculated based on the following formula.

$$[(Q_{in} \times \Sigma N_{org} + NH_3 + NO_x) + (Q_r \times \Sigma N_{org} + NH_3 + NO_x)] - [[(Q_r + In) \times Cs \times \%VSS \text{ of } 8/100] + Q_e \Sigma N_{org} + NH_3 + NO_x] = Q_{in} \Sigma(N_{org} + NH_3 + NO_x) + Q_r \Sigma(N_{org} + NH_3 + NO_x)$$

Table 2. Operating scheme of RBC system used in this study

Influent flow rate(m*l*/min)	Hydraulic loading rate ($m^3/m^2/d$)	Recirculation rate(%)
8	0.031	100
		200
		300
14	0.054	100
		200
		300
20	0.076	100
		200
		300

Where
R=Nitrogen removal(%)
Q_{in}=Influent flow(*l*/d)
Q_r=Recirculation flow(*l*/d)
Q_e=Effluent flow(*l*/d)
N_{org}=Organic nitrogen(mg/*l*)
NH_3=Ammonia nitrogen(mg/*l*)
NO_x=Nitrate nitrogen(NO_3)+Nitrite nitrogen (NO_2)(mg/*l*)
MLSS=Mixed liquor total suspended solids in the reactor(mg/*l*)

Organic nitrogen in the reactor was assumed to be 8% of the volatile solids. This assumption is based on other investigation.[14]

III. Results and Discussion

1. Characteristics of influent domestic wastewater

Three recirculation rates of 100, 200 and 300% were studied at each hydraulic loading to obtain the most feasible operational requirement for the removal of carbonaeous nitrogen and phosphorus removal. The typical physicochemical characteristics of the influent is listed in Table 3. The pH of the influent was between 7.4 and 7.9. Total suspended solids in the influent ranging from 131 to 249 mg/*l*, and the volatile suspended solids were between 109 and 168 mg/*l*. About 65 to 92% of the total suspended solids constituted volatile matter. BOD of the influent ranged from 90 to 170 mg/*l*, and COD was between 300 to 430 mg/*l*.

Table 3. Physical-chemical characteristics of wastewater(average value)

Parameters	Hydraulic loading rates($m^3/m^2/d$)								
	0.031			0.054			0.076		
	100%	200%	300%	100%	200%	300%	100%	200%	300%
SS(mg/l)	140	131	193	175	184	216	245	249	220
VSS(mg/l)	129	109	142	121	124	140	176	168	162
BOD(mg/l)	149	148	165	107	128	111	89	122	167
COD_{cr}(mg/l)	407	323	406	428	349	301	323	355	406
NH_3-N(mg/l)	12.3	9.2	10.2	12.3	13.1	13.0	11.3	10.0	9.7
NO_x-N(mg/l)	0.1	0.1	0.1	0.1	0.23	0.38	0.1	1.53	0.1
Org.-N(mg/l)	8.9	6.9	10.5	8.7	9.3	9.7	8.2	7.04	7.4
T-P(mg/l)	6.2	4.7	4.6	5.6	4.6	4.4	4.6	4.7	4.8
pH	-	-	-	7.4	7.9	-	-	-	-
Alkalinity($mgCaCO_3/l$)	-	-	-	200	275	-	-	-	-
Dissolved solide(mg/l)	-	-	-	2,500	4,000	-	-	-	-
Hardness(mgCa/l)	-	-	-	600	750	-	-	-	-
Hardness(mgMg/l)	-	-	-	300	450	-	-	-	-

The organic load applied to the system was 4.98 to 15.98 $g/m^2/d$, and 12.45 to 49.02 $g/m^2/d$, respectively for BOD and COD. Ammonia nitorgen in the influent was between 9.2 and 13.1 mg/*l* and organic nitrogen was in the range of 6.9 to 10.4 mg/*l*. Nitrite and nitrate combined as NOx was present only in traces except on instance when it was 1.53 mg/*l*.

2. Characteristics of treated wastewater

Table 4 lists the physico-chemical characteristics of the treated effluent. Due to chemical addition, the effluent pH was in the range of 7.4 to 11.4. Effluent SS from 47 to 180 mg/*l*, and VSS were in the range of 18 to 38 mg/*l*. The high solids concentration in the effluent resulted from poor floc formation and inadequate overflow rate. However, these values are typical values reported by water pollution Control Federation.[1] It is believed that this low concentration of SS from the combined system reflects possibility of size reduction of the secondary clarifier to produce good effluent, since solids separation occurs by discrete particle settling with no hindered or solids compression zone. In the influent, 64.8 to 92% of solids represented volatile matter whereas only 20.9 to 38% of the solids in the effluent were volatile. This indicates that the major portion of effluent SS were generated in the chemical reactor therefore this problem can be overcomed by the subsequent addition of neutralization process in the treatment system. Effluent BOD ranged from less than 5 mg/*l* to 14

Table 4. Physical-chemical characteristics of effluent from conbined system(average value)

Parameters	Hydraulic loading rates($m^3/m^2/d$)								
	0.031			0.054			0.076		
	100%	200%	300%	100%	200%	300%	100%	200%	300%
pH*	9.8~11	9.7~11	9.7~11.3	9.5~10.8	9.9~10.8	9.9~11	9.8~10.3	9.8~10.4	9.6~10.6
SS(mg/l)	47	62	82	67	67	77	117	77	180
VSS(mg/l)	18	21	24	23	22	19	35	27	37.7
BOD(mg/l)	8	10.1	<5	<5	<5	<5	<5	5.5	14.3
COD_{cr}(mg/l)	51	42.2	40.2	49.7	43.2	47.7	72.3	66.0	78.7
NH_3-N(mg/l)	2.31	0.98	0.78	5.69	3.08	6.68	4.40	6.30	7.30
NO_x-N(mg/l)	1.33	1.84	1.58	1.06	2.0	2.45	0.61	0.64	0.23
Org.-N(mg/l)	0.56	0.39	1.70	1.22	1.70	1.90	1.40	3.06	2.44
T-P(mg/l)	0.26	0.40	0.29	0.55	0.31	0.25	0.21	0.20	0.23

*Presented values are range.

mg/*l*. Similarly COD data show a concentration range of 40.2 to 78.7 mg/*l*. The effluent quality in terms of BOD remained around 5 mg/*l* at an organic loading range of 5~8 g/m^2/d or between 13 g/m^2/d and 30 g/m^2/d as COD. Since BOD and COD were removed considerably in the first stage, recirculation ratio had little significance on organic load reduction through recycled-treated wastewaters except at the higher hydraulic loading of 0.0761 m^3/m^2/d. Concentration of total nitrogen were always below 10 mg/*l*, and organic nitrogen and ammonia nitrogen was significantly nitrified by RBC unit. Noticeable denitrification was also observed in the effluent from the combined system, and this results indicate that RBC unit is effective for organics and nitrogen removal. Phosphate concentration in all operating condition was always below 0.55 mg/*l*, and this was combined effect of biological and chemical treatment using lime.

3. Effect of Hydraulic loadings and recirculation rate on Organics removal

Fig. 2 and Fig. 3 shows the effect of hydraulic loadings and recirculation rate on BOD, COD removal, respectively. In the present studies, 89.9 to 98.9% of the BOD was removed at various hydraulic loadings and recirculation rates. The best BOD removal was observed at recirculation rate of 300% and hydraulic loading rate of 0.031 m^3/m^2/d. This higher removal of BOD was attributed to the reduction in organic loading through increase in total flow rate of wastewater resulting decrease of organic strength in raw domestic wastewater. This results also show three stage of RBC unit is very effective in organic removal, and staging is a factor affecting BOD removal. Antonie and Van Aacken[15] also recommended more than two stages of treatment to obtain high BOD removal. COD removal decreased with increase in organic load i.e. hydraulic loads mainly due to increase in solids concentration in the effluent, since increase in hydraulic loading rate created increase in shear force between attached biomass on rotating discs and hydraulic flow resulting the increase of biomass sloughing as listed in Table 4. The effluent quality, as shown in Table 3, in terms of BOD remained around 5 mg/*l* at an organic loading range of 5~8 g/m^2/d or between 13 g/m^2/d and 30 g/m^2/d as COD, and this low BOD concentration was favorable condition on nitrification of ammonia nitrogen as reported by Richard.[16] Experience gained with full-scale RBC plants has shown that nitrifying bacteria cannot compete effectively for space in the biofilm until the concentration of soluble organic matter is below 15 mgBOD/*l*, and it has been shown that maximum nitrification rates are not achieved until the soluble BOD_5 concentration is less than 5 mg/*l*.[16]

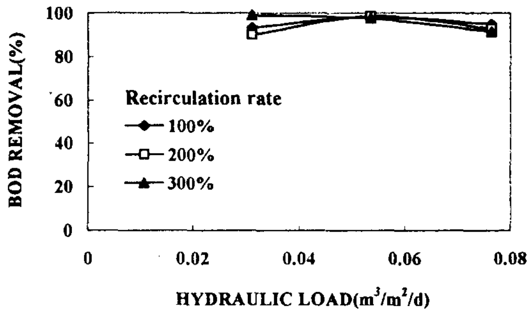

Fig. 2. Changes in BOD removals at various hydraulic loading with respective recirculation rates.

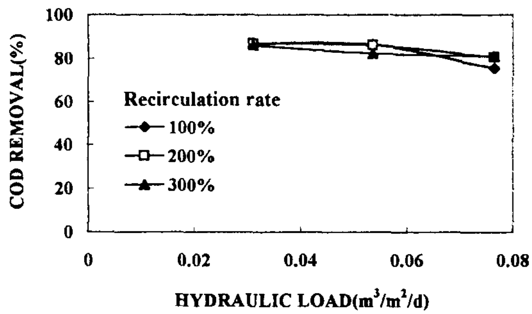

Fig. 3. Changes in COD_{cr} removals at various hydraulic loading with respective recirculation rates.

Fig. 4 shows volatile solids in the chemical reactor against hydraulic loadings. Through most of the organic matter was removed in the first three stages of RBC, however as hydraulic loading increased the solids washout from RBC units also increased. This increase can be observed from the increase in the volatile content in the reactor with the recycle rate increase. Poon et al.[8] obtained an effluent BOD of 30 mg/*l* in an RBC

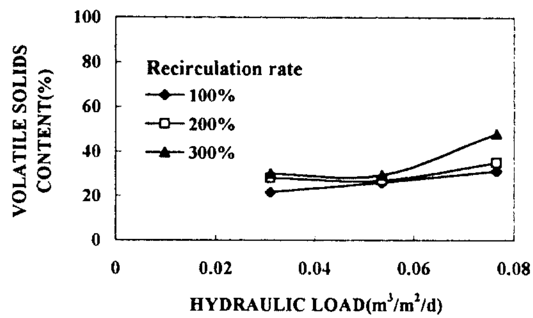

Fig. 4. Changes in volatile solids content of flocculation chamber at various hydraulic loading with respective recirculation rates.

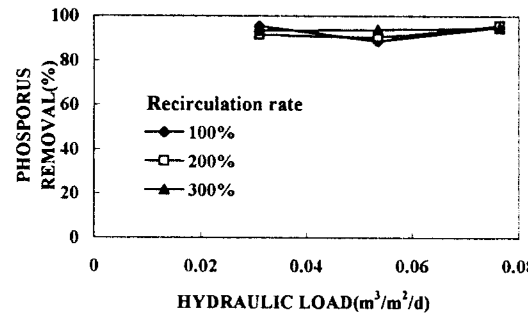

Fig. 5. Effect of hydraulic loading and recirculation rate on the total phosphorus removal.

unit without chemical addition at an organic loading of 8 g/m^2/d, whereas in the present study, the effluent BOD was consistently less than 5 mg/*l* which can be attributed to the addition of chemical precipitation in the process.

4. Effect of Hydraulic loadings and recirculation rate on Nutrients removal

Lime has been extensively used for phosphorus removal in various treatment system, but very few attempts have been made to combine simultaneous chemical treatment with RBC for nutrient removal, particularly for the removal of phosphorus. Though simultaneous, combined and post precipitation are practiced in removing phosphorus from wastewater, combined precipitation is widely considered as more economical and practical. In terms of phosphorus removal RBC unit followed by lime treatment(chemical-physical treatment), it was ranging from 88.6 to 95.7% as illustrated in Fig. 5. When the pH was maintained around 10.4 nearly complete removal of phosphorus was achieved besides improved removal of organic matter as a result of calcium phosphate precipitation. The solubility of solids formed as $CaCO_3$ from the chemical addition must be adjusted to high pH value above 10 to achieve low soluble orthophosphate residuals. This is indeed largely borne out by practical experience with the lime precipitation of phosphorus from wastewater. The pH values of≤10.5 are commonly used to achieve low phosphate residuals. Because, at these values, the bicarbonate alkalinity of the wastewater react with the lime.[16] It is also should be noted that it was not observed in biological growth in the RBC unit because of lime addition was practiced as a post precipitation only, although pH values of≥10 was used in this study. However, it would be need to adjust the pH if raw domestic wastewater will be treated with lime for phosphate removal. Horskotte et al.[17] devised the so-called ATTF process in which lime precipitation of raw sewage was followed by a nitrifying activated sludge process which no pH adjustment was required. The aeration basin pH was in the range 7.3~8.7 with a primary effluent pH of 11.5.

The nitrogen load applied ranged from 0.0762 to 3.615 g/m^2/d and was calculated as the sum of total nitrogen from influent and recirculation volume as listed in Table 5. Nitrogen removal was the difference between the sum of nitrogen concentration in the influent, recirculation volume, effluent and reactor solids. The nitrogen content of the reactor solid is adopted from out earlier observations to be 8% of the reactor VSS. In Table 5, except for the 200% recirculation rate, nitrogen removal decreased with increasing hydraulic load. At 200% the increase and decrease in nitrogen removal was attributed to higher nitrification at hydraulic loading of 0.054 m^3/m^2/d. Further nitrogen removal efficiency in general decreased with the increase in nitrogen loading. Table 4 shows the concentration of various forms of nitrogen in the effluent. The ammonia concentration was less than 1 mg/*l* at hydraulic loading of 0.031 m^3/m^2/d, and at 200 and 300% of

Table 5. Nitrogen loading in the RBC process

Hydraulic loading ($m^3/m^2/d$)	Recirculation rate (%)	Nitrogen loading ($g/m^2/d$)	Nitrogen removal (%)
0.031	100	0.766	68.0
	200	0.811	67.0
	300	1.035	70.5
0.054	100	1.517	59.5
	200	1.936	69.7
	300	2.989	62.5
0.076	100	2.181	49.7
	200	2.966	54.8
	300	3.615	55.5

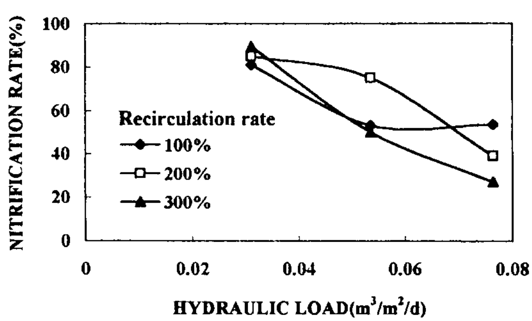

Fig. 6. Effect of hydraulic loading and recirculation rate on ammonia nitrogen removals.

recirculation rate.

Fig. 6 shows ammonia removal or nitrification rate against hydraulic loading at different recirculation rates. Ammonia removal of over 89% was caused by the combined effect of nitrification, biomass incorporation and volatilization of high pH. High removal rate was achieved at a hydraulic retention time of 5.62hours. The correlation between nitrification or ammonia removal and hydraulic loading and retention time has been reported by Zeng et al.[10] Shundar et al.[18] who obtained 94% ammonia removal over 4 hours detention time reported that ammonia removal was directly proportional to hydraulic retention time, and inversely proportional to the loading rate. In this study, ammonia and nitrogen in the effluent increased with increasing hydraulic load. The ammonia removal has not affected in proportion to increase in nitrite and nitrate concentration in the effluent, which can be attributed to the simultaneous nitrification and denitrification as reported in RBC by Masuda et al.[19]

Nitrite and Nitrate concentration in the effluent gradually decreased as the hydraulic loading increased, substantiating the fact that hydraulic loading and retention times are significant factors I nitrogen removal using RBC. Ito and Matuso[20] studying the relationship between nitrification and organic loading and the influence of recirculation in nitrogen removal, found that 40 to 53% recirculation improved nitrogen removal efficiency by 10%. Odegaard and Rusen[21] reported improvement in ammonia removal by increasing the recycle ratio. However, they recycled the effluent through submerged RBCs unlike in the current studies. Figure 5 shows that a hydraulic loading of 0.0311 $m^3/m^2/d$, ammonia removal was 79.8, 84.5 and 89.2% for 100, 200 and 300% recirculation rate, respectively.

IV. Summary

Laboratory-scale experiments were conducted using a three-stage rotating biological contactor unit followed by lime precipitation and sedimentation with effluent recycle to the first stage. The purpose of this study was to evaluate the effects of hydraulic loadings of 0.031~0.076 $m^3/m^2/d$ and recycle ratio of 1 to 3 on the simultaneous removal of organics and nutrients from domestic wastewater. Lime was added to maintain pH of 10.4~11.0 in the coagulation-flocculation reactor.

Results showed that the highest nitrogen removal rate of 70.5% occurred at the lower hydraulic loading of 0.031 $m^3/m^2/d$ at a recirculation

rate of 300%, and similarly, highest nitrification occurred at the same hydraulic loading and recycle ratio. Concentration of ammonia nitrogen in the effluent was less than 1 mg/l at the same operating conditions for higher nitrogen removal. Whereas, high BOD and COD removal was observed at hydraulic loading rate of 0.054 $m^3/m^2/d$, and high removal of organic matter was evident from the consistent low COD and BOD value. Results obtained from the operating condition of higher loading rate, 300% of recycle rate showed the highest removals. Increasing in recycle rate and hydraulic loading rate increased the volatile solids fraction of the sludges generated to the extent of 47% at 0.076 $m^3/m^2/d$ hydraulic loading and 300% recirculation rate. Since pH in the flocculator was maintained at the pH of 10.4~11.0, above 90% removal of phosphorus was obtained. Average concentration of suspended solids was always maintained over 40 mg/l in the effluent. Therefore an RBC unit operating at a hydraulic loading near 0.031 $m^3/m^2/d$ with a recycle rate of 300% is a viable and feasible alternate conditions to produce an effluent with relative low organic matter and phosphorus, provided that there is a neutralization unit to control the pH and SS of the effluent.

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