Simultaneous Removal of Nitrogen and Organic Matter Using Moving Media Complete Mixing Activated Sludge System

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Summary: This study was carried out to obtain basic parameters for simultaneous removal of nitrogen and organic matter using Moving Media Complete Mixing Activated Sludge (MMCMAS) system with intermittent aeration method. Lab-scale MMCMAS reactor was operated under the variations of organic loading rate and oxic/anoxic time ratio. The organic loading rates were varied at 1, 3, 5 and 7g BOD/m^3.d respectively. Soluble Chemical Oxygen Demand (SCOD) and Soluble Biological Oxygen Demand (SBOD) removal efficiencies were found to be 87% and 95% respectively, and no relationship between organic removal and oxic/anoxic time ratio was observed. Nitrogen removal efficiencies ranging from 76% to 89%, varied widely by oxic/anoxic time ratio. The nitrogen removal was increased by increasing anoxic and oxic time for the organic loading rate below 5 g BOD/m^3. d and 7g BOD/m^3. d, respectively. Sludge production of MMCMAS system with intermittent aeration was 0.16 to 0.36 (g VSS/g BOD removal) averaging 0.27 (g VSS/g BOD removal). This value is relatively lower than the value obtained previously in MMCMAS system with continuous aeration which was 0.38 (g VSS/g BOD removal).

Introduction

Owing to the adverse environmental effects of nitrogen such as eutrophication, toxicity to fish and depletion of dissolved oxygen, the limitation of nitrogen discharge from sewage treatment plant is getting strict with time. In Korea, it is therefore, anticipated that within a few years, the maximum total nitrogen discharge from municipal sewage treatment including ammonia, organic nitrogen, nitrite and nitrate will be less than 20 mg/l. Nitrogen has been removed by add-on to the secondary treatment process. But in this case the cost of construction, operation, supply external carbon and energy for return sludge is very high.

Complete mixing activated sludge system using moving media is one of the most economical processes to remove nitrogen. Facilitating the contact of microbial film of a certain thickness on the surface of a rotating disk with the substrate, the MMCMAS endures shocking and dynamic loading. It provides a proper condition for the growth of nitrifiers and denitrifiers and holds long Sludge Retention Time (SRT) which makes operation easy for high organic loading [1]. Controlling dissolved oxygen (DO) in the reactor with intermittent aeration, the nitrification and denitrification processes can occur in a single reactor. This system with no internal sludge return does not require a large area to occupy. Control over the intermittent aeration time can make the operation easy at the various organic loading rates [2]. The microbes, instead of dissolved air use nitrates as their electrons acceptors, therefore, the cost of aeration is reduced [3].

In MMCMAS system, closely spaced discs are mounted on a common horizontal shaft touching the liquid surface in a long narrow tank. The shaft is rotated at constant speed, thereby allowing the disc to be in contact with the wastewater. As the wastewater containing organic matter, nitrogen, and other nutrients flows through the bioreactor, microorganisms consume the substrates and grow attached to the disc as a biofilm. The rotating action imparts a shear force to the biofilm, keeping its thickness relatively constant by removing the cells generated by consumption of the substrate. This paper examines the performance of MMCMAS

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system with intermittent aeration to control the aeration time of aerobic and anoxic basins and to remove both nitrogen and organic matter simultaneously. The nitrification occurs only in oxic basin while the oxidation of organic matters takes place both in oxic and anoxic basins.

Results and Discussion

Removal efficiency of organic matter

The reactor was operated with stepwise increasing the loading of organic matters as 1, 3, 5 and 7 g BOD/m^3. day and with various ratio of oxic and anoxic time according to the cycle times (Table-1). The study is limited only to the biological removal of the soluble matter. Since there is no provision of the settling tank in the system, therefore, the change of the effluent quality caused by the desorption of microfilm from the rotating disk might downgrade the efficiency of the reactor. The removal efficiencies of organic matters with various loading rates and aeration times are summarized in Table-1. The results of the table show that SCOD and SBOD removal efficiencies of the organic matter were higher than 87% and 95% respectively, throughout the entire runs except run 2. These efficiencies were entirely consistent because the organic loading rate was below 7 g BOD/m^3.d and the F/Mv rate was below 0.30 g BOD/g MLVSS/d. However, in case of run 2, the efficiency was decreased due to the addition of methanol. At low loading rates, the distributions of oxic/anoxic time have no effects on the organic removal efficiencies, while the removal efficiency of the organic matter was relatively constant with the increase of anoxic time because the microbes, instead of DO, use nitrates as their electrons acceptors.

Removal of Nitrogen

The results of the Table-2 show summaries of the concentrations and removal efficiencies of nitrogen in the effluents of MMCAMAS according to aeration time. Nitrogen removal efficiencies varied according to loading of organic matters and aeration time. At run 1 and 2, the rate of loading

Table-1: Summary of organic removal efficiencies using MMCMS system with intermittent aeration

Runs	O.L.R*	HRT (hrs)	Cycle Time (hrs)	HRT/Cycle time	Oxic/Anoxic Time ratio	Effluents (mg/l)						Organic Removal Efficiency (%)			
						TCOD	SCOD	TBOD	SBOD	TSS	VSS	TCOD	SCOD	TBOD	SBOD
1	1	57.5	8	7.2	4/4	30.2	19.4	2.2	1.0	31	21	87.9	92.2	98.5	99.4
2					4/4	53.0	32.6	14.7	5.9	82	44	80.4	87.9	89.5	95.8
3	3	19.2	8	2.4	4/4	39.7	12.5	6.7	3.0	55	42	85.5	95.4	95.5	98.0
4					3/5	38.3	19.3	2.3	1.0	55	35	85.6	92.7	98.3	99.3
5	5	11.6	8	1.5	5/3	36.7	15.5	7.4	3.0	72	45	87.2	94.6	94.8	97.9
6					4/4	30.1	11.5	8.4	4.1	65	41.0	89.0	95.8	94.3	97.2
7					3/5	39.1	29.2	4.2	2.2	69	39	86.3	89.8	97.1	98.5
8			6	1.9	4/2	29.1	10	5.2	1.6	62	43.5	91.3	97.0	96.4	98.9
9					3/3	39.9	22.6	7.3	1.9	73	43	84.9	91.5	94.9	98.7
10					2/4	58.5	27.7	8.1	2.4	60	33	80.8	90.9	94.6	98.4
11	7	8.2	4	2.1	2.5/1.5	17.8	9.3	8.7	3.6	63.0	46	93.4	96.6	94.1	97.6
12					2/2	60.8	14.8	7.5	3.1	73.0	49	77.7	94.6	95.2	98.0

*O.L.R (organic Loading Rate): g BOD/m^3.d

Table-2: Summary of nitrogen removal efficiencies using MMCMS system with intermittent aeration

Runs	O.L.R*	HRT (hrs)	Cycle Time (hrs)	HRT/Cycle time	Oxic/Anoxic Time ratio	Effluents (mg/l)			Nitrogen Removal Efficiency (%)		
						T-N	TKN	NO_3-N	NH_4-N	T-N	TKN
1	1	57.5	8	7.2	4/4	23	0.3	22.7	0.2	18.4	98.9
2					4/4	5.6	0.7	5	0.4	81.1	97.7
3	3	19.2	8	2.4	4/4	11.8	1.4	10.3	1.4	54.8	94.5
4					3/5	3.1	1.1	2	0.8	89.2	96.1
5	5	11.6	8	1.5	5/3	11.4	3.3	8.1	2.0	55	87.5
6					4/4	6.2	2.3	3.9	1.2	78.3	91.9
7					3/5	6.5	5.9	0.6	3.3	77.6	79.7
8			6	1.9	4/2	19.6	0.6	19	-	33	98.0
9					3/3	9.5	4.7	4.9	1.9	78.2	84.3
10					2/4	4.8	1.2	3.5	0.6	83.4	95.7
11	7	8.2	4	2.1	2.5/1.5	6.5	4.8	1.7	-	76.5	82.5
12					2/2	9.6	9	0.5	4.3	68.9	69.9

*O.L.R (organic Loading Rate): g BOD/m^3.d organic matters was 1g BOD/m^3. d and the ratio of oxic/anoxic time was 4/4. At run 1, because of the lower loading rate of organic matter, T-N removal efficiency was very low, while TKN removal efficiency was high. NO_3-N concentration in the effluent was very high as 22.7 mg/L due to lack of carbon source for denitrification. Therefore, at run 2, methanol as an external source of carbon, was added in the influent and 98% and 81% removal efficiency for TKN and T-N was achieved respectively (Table-2). By calculation, proper dosing rate of methanol is 3g/g of NO_3-N removal. The calculation based on this study showed that the addition of 50 ml methanol per cycle caused deterioration in the effluent qualities. After a series of experiments with varying dose of methanol to maintain effluent qualities, an optimum value of methanol dose was adjusted as 35 ml per cycle time. Even though, adding methanol, TKN removal efficiency was not increased any more, because the amount of methanol dosing was very small and the decomposition through the denitrifiers was very fast and not served for nitrification processes.

At run 3 and 4 (Table-2), the loading rate of organic matters was 3 g BOD/m^3. d and the ratios of oxic/anoxic time were 4/4 and 3/5 respectively. TKN removal efficiencies at run 3 and run 4 were similar i.e., 94% and 96% respectively. The comparison of the T-N and TKN removal is given in Figure 1. This figure shows a marked variation in the removal efficiencies of the T-N compared to a low and steady decrease in TKN. Upto run 4, there was no appreciable decrease in the removal of TKN but later on the variations increased, however, remained in the range 80-98% until run 11. T-N removal efficiency at run 4 was 89%, which is 34% higher than the efficiency at run 5, which was 55%. The concentration of NO_3-N in the effluent at run 4 was 2 mg/L, which is 25% lower than the effluent at run 5.

At run 5, 6 and 7, the reactor was operated with the organic loading rate of 5 g BOD/m^3. d, one cycle time of 8 hours and the ratio of oxic/anoxic time was 5/3, 4/4 and 3/5 respectively. At run 6 and run 7, T-N removal efficiencies were same as 78%. At run 5 the removal efficiency of TN and TKN were 57% and 88% respectively. This result of the run 5 was due to the short anoxic time, in other words, the denitirification didn't happen sufficiently, therefore, the concentration of NO_3-N in effluent was 8.1 mg/L. At run 6, the nitrification happened sufficiently, TKN removal efficiency was 92% and NO_3-N concentration in the effluent was 3.9 mg/L. At run 7, TKN removal efficiency was 80% (Figure 1) and the denitrification happened sufficiently, NO_3-N concentration was 0.6 mg/L. T-N removal efficiency was 78% for both at run 6 and 7.

The operations of run 8,9 and 10 were carried out under the conditions of 5 g BOD/m^3.d loading rate, 6 hours cycle time and 4/2, 3/3 and 2/4 of oxic/anoxic ratio respectively. At run 8, TKN removal efficiency was 98%. But due to insufficient denitrification, T-N removal efficiency was reduced to 33%. NO_3-N concentration of the effluent was 19 mg/mL.

For run 9, T-N removal efficiency was 68% (Figure 1) and TKN removal efficiency was 84%. T-N removal efficiency at run 10 was 83% and this value is higher than those at run 8 and 9 because of the low concentration of NO_3-N in effluent i.e., 3.5 mg/L. TKN removal efficiency at run 10 was 96%. Therefore, at 5 g BOD/m^3.d loading rate like as at 3 g BOD/m^3. d, with the longer anoxic time relative to the oxic time, higher T-N removal efficiencies could be achieved. In cases of run 11 and run 12, the organic loading rate was 7 g BOD/m^3 . dy and the oxic/anoxic time ratios were 2.5/1.5 and 2/2 respectively.

At run 11 and 12, T-N removal efficiencies were 76% and 69% respectively (Figure 1). The

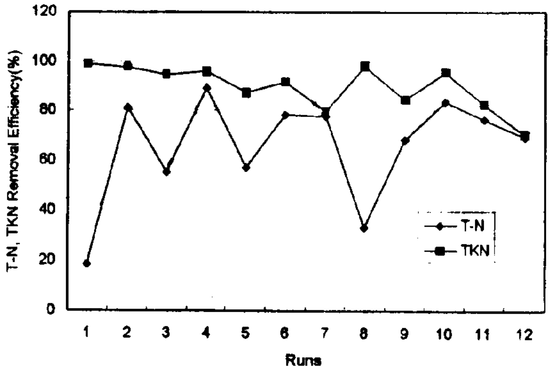

Fig. 1: T-N and TKN removal efficiencies with respect to each run

efficiency at run 11 was higher than run 12 by 7% because of longer oxic time at run 11 than at run 12. The efficiencies of TKN were 82% for run 11 and 70% for run 12 and NO_3-N concentrations in the effluent were 1.7 and 0.5 mg/L respectively. In run 11 and 12, because of high organic loading rates, carbon sources for denitrification could be obtained within a short anoic time in comparison with low organic loading rate. But dissolved oxygen would be used preferentially by heterotrophic microorganisms for catabolism of organic substances, therefore, sufficient oxic time should be maintained for nitrification process to be complete. Resultantly, an effective control of oxic and anoxic time for the intermittent aeration process is an important factor. Excessive or insufficient aeration results lower nitrogen removal efficiencies and waste of energy. Hence, the factors like concentration of organic matters. TKN of influent and the intensity of aeration must be taken into consideration during the operation of the reactor. TKN removal efficiency was influenced by SRT, loading rate of organic matters and aeration intensity especially retention times for nitrifiers.

Figure 2 shows the relationship between SRT and TKN removal efficiency. TKN removal efficiencies varied as SRT changed. The data in Figure 2 indicate two distinctive features. Firstly, the nitrification started from 3 days and varied up to 5 days, and secondly, there was no change seen later on between days 9 and 27. The results of the present study are identical with that of Jenkins and Garrison [4] who reported that nitrification could be started at SRT of 3 days and completed at SRT of 10 days.

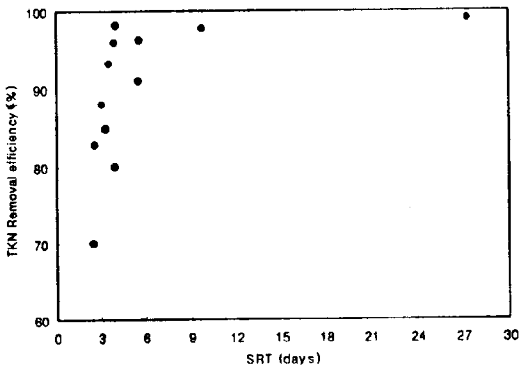

Fig. 2: TKN removal efficiency vs. SRT

Sludge Production

The microbes which have participated in this process are attached bacteria, free swimmers, stalk ciliates (which are generally found in activated sludge process) and nematodes that could be seen with longer SRT.

Table 3 shows the characteristics of microorganisms in MMCMAS reactor, concentrations and ratios of suspended and attached microorganisms, sludge production and F/Mv ratio. Figure 3 shows the variations of concentration of

Table-3: Characterization of microorganisms in MMCMS reactor

Runs	O.L.R 1)	F/M v2	Total (mg/l)		Suspended (mg/l)		Biomass Attached (mg/l)		VSS/SS %	Ratio of Component %		Sludge Production 3)
			SS	VSS	SS	VSS	Dry	Vol		Attached	Suspended	
1	1	0.06	1661	1056	476	353	1185	702.7	63.6	71.4	28.6	0.14
2		0.05	1583.0	1085	423	423	1090.0	662.4	68.5	68.9	31.1	0.36
3	3	0.14	1814	1361	278	278	1355	1082	75.0	74.7	25.3	0.3
4		0.15	1806	1159	183	183	1496	975.6	64.2	82.9	17.1	0.25
5		0.19	2149	1534	325	325	1537	1209	71.4	71.5	28.5	0.34
6		0.23	2177	1336	289	289	1625	1047.0	61.4	74.7	25.3	0.29
7		0.16	2270	1845	287	287	1736.0	1558	81.3	76.5	23.5	0.28
8	5	0.17	2412	1710	400	400	1791	1310	70.9	74.3	25.8	0.32
9		0.27	1620.0	1098	258	258	1284	840.5	67.8	79.3	20.7	0.31
10		0.17	2293	1833	189	189	1906	1644	80.0	83.1	16.9	0.23
11		0.30	2248	1413	268	268	1620	1145.0	62.9	72.1	27.9	0.33
12	7	0.27	2335.0	1661	407	407	1710	1254	71.1	73.3	26.8	0.33

1) O.L.R (Organic Loading Rate): g/m^{3}d)
2) F/Mv:g BOD MLVSS/d
3) Sludge Production: g VSS/g BODrem.

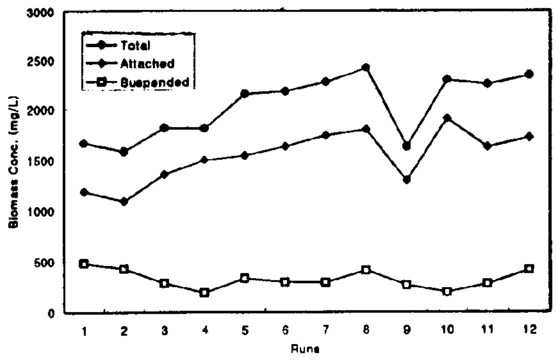

Fig. 3: Variation in biomass concentration along with different runs

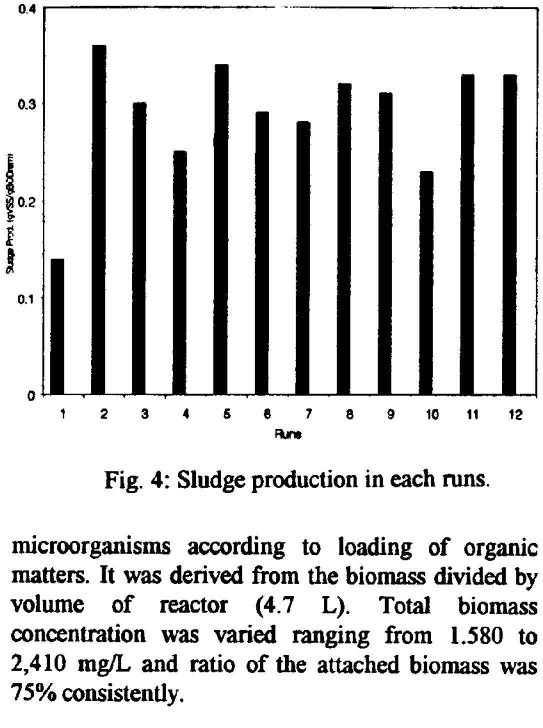

Fig. 4: Sludge production in each runs.

microorganisms according to loading of organic matters. It was derived from the biomass divided by volume of reactor (4.7 L). Total biomass concentration was varied ranging from 1.580 to 2,410 mg/L and ratio of the attached biomass was 75% consistently.

Relationship between the sludge production according to loading rate of the organic matters and the various aeration times has been shown in Figure 4. The range and average of sludge production was 0.16 to 0.36 g VSS/g BODrem and 0.27 g VSS/g BODrem respectively. This average value is smaller than the average value from the result of experiment in continuous aeration process of kim [5] by 0.11 g VSS/g BODrem.

The sludge production was dependent on anoxic time, increase in time caused decreased in production. The reason to this could be attributed to the fact that the rate of sludge production in nitrate respiration is smaller than that in oxygen respiration and the rate of substrate usage in nitrate respiration is higher than that in oxygen respiration. This conclusion is identical with the report of Samuel *et al.*, [6] in which catabolism by the nitrate respiration produces less sludge than in oxygen respiration below 10 days of SRT.

Experimental

A schematic diagram of lab-scale MMCMAS reactor is in Figure 5. Material for the rectangular reactor is acryl glass and its dimension is 13.7 cm wide, 26 cm long and 37.5 cm high. At the bottom of the reactor, aerators were installed and controlled by timer to kept aeration time periodically. Baffles were set up in a way that they would not offer any hindrance for the biomass on the surface of moving media during aeration process. A slope of 20 degree was maintained at the bottom of the reactor to prevent any possible sludge accumulation.

13 moving disks, each with a diameter 12 cm and area 0.294 m^2, were installed at an interval of 1.5 cm length. Effective volume of the reactor was about 4.7 L and ratio of the volume and area was about 15.6 (L/m^2). The speed of the motor for the rotating disc was controlled by the speed controller. Circulation of the disk speed was maintained at about 15 rpm keeping in view the result of the previous studies [7] conducted for continuous aeration that suggested 5-15 rpm as the optimum speed at a low organic loading rate, as in such conditions rise in the speed of rotating discs had not effect on the efficiency of organic removal.

Temperature of the reactor was kept at 20°C and wastewater inlet into the reactor was regulated by peristaltic pump. A sample of synthetic wastewater was prepared with settled domestic waste water having fat free powder milk as a source of carbon and ammonium sulfate $(NH_4)_2SO_4$ as a source of nitrogen in order to hold BOD of 150 mg/L and TKN 30 mg/L $NaHCO_3$ was used to maintain the alkalinity of the system.

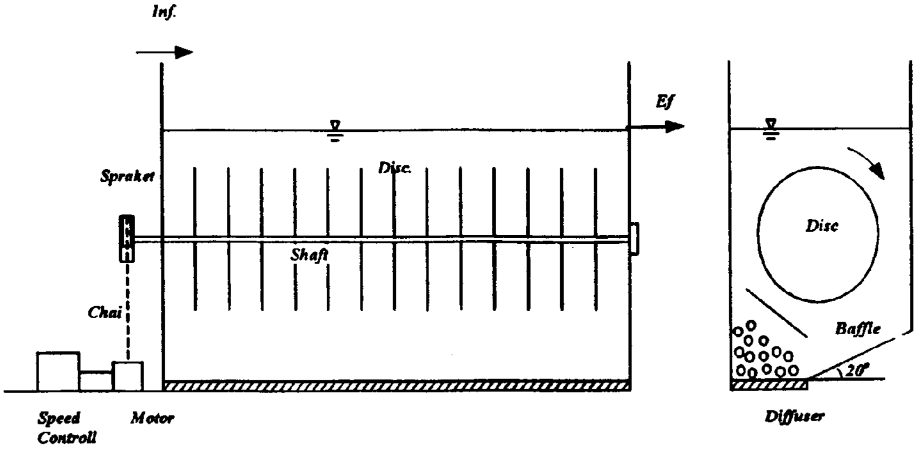

Fig. 5: Schematic diagram of MMCMS reactor

Table-4: Operating conditions of MMCMS process

Runs	O.L.R.*	HRT (hrs)	Cycle time (hrs)	HRT/Cycle Time ratio	Oxic/Anoxic time ratio	Remarks
1	1	57.5	8	7.2	4/4	
2					4/4	Methanol added
3	3	19.2	8	2.4	4/4	
4					3/5	
					5/3	
5	5	11.6	8	1.5		
6					4/4	
7					3/5	
8			6	1.9	4/2	
9					3/3	
10					2/4	
11					2.5/1.5	
12	7	8.2	4	2.1	2/2	

*O.L.R(organic Loading Rate): g BOD/m^3.d

During the operation of reactor, the loading of organic matter was increased gradually in steps ranging from 1 to 7 g BOD/m^3 .d. Denitrification by endogenous expiration was not much enough at the loading rate of 1 mg BOD/m^3.d, therefore, methanol was added as an external source of carbon. Details of operating conditions are shown in Table 4. Effluents were collected from the sampling port and analyzed for various parameters according to Standard Method [8].

The microbial growth was measured both for the suspended microorganisms in the reactor and for the attached microorganisms on the disks. In mixed liquid suspended solid (MSS), some flocs were big enough to settle down in the reactor but their amount was negligible. The attached ones were sampled from the surface of several disks after draining MLSS from the reactor. Total concentration of the microbes was calculated from the division of the sum of the suspended and attached microorganism in a bulk volume of the reactor.

Conclusion

A Lab-scale MMCMAS reactor was operated at various organic loading rates of 1,3,5 and 7 g/m^3 d while varying the oxic/anoxic time ratio. The results of these studies are concluded that the SCOD and SBOD removal efficiencies were 87% and above 95% respectively. The data showed that there was no relationship between oxic/anoxic time ratio and organic removal efficiency, because there was no difference in the rate of catabolism between the use of nitrates and DO as an electron acceptors.

Nitrogen removal efficiencies were varying from 76 to 89%, nitrogen removal efficiency was increased with the rise of anoxic and oxic time for the organic loading rate below 5g BOD/m^3 .d and 7 g BOD/m^3 d respectively. The concentration of microorganisms in the reactors were found to be in range (1,580 to 2,410 mg/L) of which 75% portion remained to the disck. This portion wasn't influenced by organic loading rate.

The sludge production rates of MMCMAS with intermittent aeration varied from 0.16 to 0.36 g VSS/g BOD removal whose average comes to 0.27 g VSS/g BOD removal which is comparatively lower than the MMCMAS with continuous aeration by about 0.11g VSS/g BOD removal. Sludge production using Nitrate as electron acceptor was smaller than that of using dissolved oxygen.

References

1. Takashi Osada, Kiyonori Hada and Yasuo Haras, *Wat. Res.*, **25**(11), 1377 (1991).
2. In-Seok Seo, Sang-III Lee, *J of KSEE* **17**(7), 636 (1995).
3. A.L. Dawing, *J. Int. Sew. Purif.* 130 (1964).
4. D. Jenkins, *J. WPCF*, **40**, 1905 (1968).
5. Hong-Tae Kim, "A Moving Media Complete Mixing Activated Sludge System", Doctorol Dessertation, Kyungpook National Univ., Taegu, Korea (1993).
6. Samuel A. McClintock, Joseph H. Sherrad, John T. Novak, *J.WPCF*, **60**(3), 342 (1964).
7. A.A. Friedman, "Effect of disc rotational speed on RBC efficiency", proceeding of 28th Perdue Indust. Waste Conf. Ann Arbor Science (1973).
8. AWWA, APHA, WPCF, "Standard Methods for the Examination of Water and Waste Water" 18th Ed., American Public Health Association, New York (1992).