Aerobic wastewater treatment by cascade trickling

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AEROBIC AND ANAEROBIC wastewater treatments are both well developed and have various types of applications. Most of the applications have been developed to achieve the highest performance in terms of process rate concern. These sophisticated systems are; however, often not affordable for mid- or low-income countries. The "efficient" system should be economical enough within the acceptable level of process performance; therefore, both time and cost should be considered to evaluate process feasibility.

Aerobic processes are normally fast and simple and applied worldwide. The biggest drawback of the aerobic systems is the power requirement for aeration; thus, many researchers and engineers are developing and applying anaerobic wastewater treatment systems. These systems, e.g. upflow anaerobic sludge blanket (UASB), anaerobic baffled reactor (ABR), etc., mainly aim at simple treatment of wastewater, so they may be called as "low-cost anaerobic systems" in order to distinguish them from sludge digestion or fermentation systems. Currently, two-thirds of large-scale anaerobic installations apply UASB [1]. The low-cost anaerobic systems do not require aeration or physical mixing. Water flows in and flows out simply by the usage of water. The disadvantages of low-cost anaerobic options are: 1) no nutrient removal, 2) low pathogen removal and 3) high suspended solids in effluent [3]. Furthermore, the anaerobic treatments can hardly reach to the COD values of less than 50 mg L^{-1} [1]; so post treatment is usually necessary to comply with discharge standard.

Various types of wastewater treatment technologies are classified as Table 1. In this classification, possible post treatments can be aerobic or harvest systems. For aerobic option, currently available systems are either conventional or natural purification type; both of them trail their own advantages and disadvantages. Therefore, the development of low-cost aerobic option will be desirable.

Table 1. Classification of wastewater treatment technologies

	Natural Purification	Low-cost Treatment	Conventional Treatment
Aerobic			Activated sludge
↑	Lagoon		RBC
↓		UASB	Sludge digestion
Anaerobic	Septic tank	ABR	Methane fermentation
Harvest	Reed bed Duck weed		

New approach of micro-aeration emerged to overcome the problems of both conventional aerobic systems and low-cost anaerobic systems. Micro-aeration is an aerobic treatment which minimizes power consumption as much as the process can sustain the aerobic environment. This is the surface aeration system which accelerates oxygen transfer to decompose organic pollutants aerobically.

Trickling is a type of surface aeration, which disturbs surface tension and enhances the renewal of gas-liquid interface. Trickling is found to be the most economical way for low rate aeration of 10 day^{-1} range [2]. The efficiency achieves as high as several hundred kilogram oxygen per kWh.

Materials and methods

Water containers were vertically configured to form a cascade and to trickle downward onto the containers below as described in Figure 1. The containers were placed for water drops to fall 7 cm on the surface below. The first vessel worked as pre-incubator to grow microorganisms to avoid hydraulic washout. The vessel #2 to #15 were aerators in series and they can be added to improve the

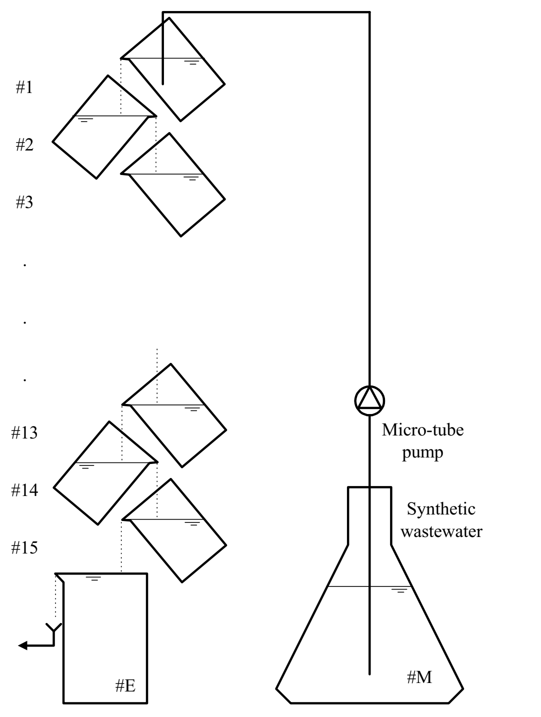

Figure 1. Experimental configuration

Table 2. Experimental schedule

	Glucose mg L^{-1}	NH4Cl mg L^{-1}	Flux L d^{-1}	OC load mgC d^{-1}	HRT h
Trickling No.1	450	115	5.4	972	24
Trickling No.2	150	115	5.4	324	24
Trickling No.3	75	115	5.4	162	24
Trickling No.4	0	115	5.4	0	24
Trickling No.5	300	115	8.5	1020	15
Trickling No.6	150	115	2.7	162	48
Single tank	300	115	2.7	324	55

performance. Synthetic wastewater was continuously fed into the first vessel at constant rate by micro-tube pump to assure designed hydraulic retention time. At the experimental condition, a water drop trickled down every 0.5 to 2 seconds. Wastewater with different organic concentration was prepared to observe the system sensitivity to both organic and hydraulic loads. Relatively low organic concentration was chosen since the aim of the experiment was to polish wastewater effluent from anaerobic processes. The experimental schedule was described in Table 2.

In each experiments, several items were analyzed after steady state had been obtained, which were total organic carbon (TOC), dissolved organic carbon (DOC), ammonium nitrogen (NH4-N), nitrate nitrogen (NO3-N), optical density at 600 nm (OD600), and plate count of coliforms groups. OD600 is an indicator of suspended solid. TOC and DOC were analyzed by TOC analyzer (Shimadzu TOC-5000A), NH4-N by ion chromatograph (Dionex DX-120), NO3-N by UV 220 nm absorbance, and OD600 by spectrophotometer (HACH DR/400U). The results of two consecutive days were averaged.

A single tank experiment was also performed for reference purpose. The synthetic wastewater was fed into the bottom of a container, which had the capacity of 6.2 L, at 2.7 L day^{-1} to form upflow. Both TOC and DOC of influent and top layer of the container were analyzed.

Results

Effect of trickling

The result of single tank experiment is shown in Table 3. The organic removal rates were very low in spite of long hydraulic retention time (HRT) of more than two days.

Table 3. Experimental result (single tank)

	TOC mgC L^{-1}	DOC mgC L^{-1}	OD600
Feed	128.6	129.1	0.039
Effluent	105.4	96.5	0.037
Removal%	18	25	4

Therefore, anaerobic decomposition was found very slow for low strength wastewater.

Figure 2 shows data summary of the trickling experiment No.2. Organic removal was much faster than single tank experiment in spite of shorter HRT. DOC decreased most rapidly and biodegradable DOC seemed to be disappeared at #9. TOC decreased slower but finally reached to the same level as DOC. From #9 to downward, where DOC reached to its bottom, nitrification occurred. This indicates that organic carbon must be consumed before nitrifiers oxidize ammonium to nitrate.

Organic removal

The effect of organic load for DOC removal is shown in Figure 3. All three experiments had the same flux. DOC was continuously removed from high to low concentrations and the process rate was maintained up to very low organic level.

Figure 4 shows the effect of hydraulic load for DOC removal. No.1 and 5, No.3 and 6 had the same (or nearly the same) organic load with different HRT. The DOC decreases between vessels were almost same in both experiments even though HRT were different. The results explain that the dilution rate (or organic concentration) was not important factor to determine the process performance. Therefore, it is presumable that this system will effectively treat low strength wastewater.

Microbial safety

Figure 5 shows the removal of coliform groups in the cascade vessels. All experiments resulted high removal efficiency (2.5 to 4.5log) and final counts were in 10^3 range, which is the same range as wastewater discharge standard. The coliform groups were decreased regardless of DOC concentration in the vessels. The possible reasons of coliform removal are sedimentation and biofiltration in each vessel. These results indicate that it will be possible to comply with the discharge standard by increasing the cascade series.

Nitrification

Figure 6 shows the concentration increase of NO3-N at different organic load. In Figure 6, the take-off point was shifted to lower vessel as the organic load increases. As is explained previously, DOC was consumed before NO3-N started to increase. Once nitrification took place, the process rates were more or less the same since the hydraulic loads and retention times were same.

The effect of hydraulic load was explained in Figure 7. Experiment No.3 and 6 had the same organic load. NH4-N concentration was same in both experiments. The NO3-N concentration started to rise at the same point but No.3, which had higher hydraulic load, had higher reaction rate. The reaction rate of nitrification is a function of NH4-N and dissolved oxygen (DO). Since NH4-N level was same in both experiments, DO flux seemed to have accelerated the overall process. As is explained previously, trickling

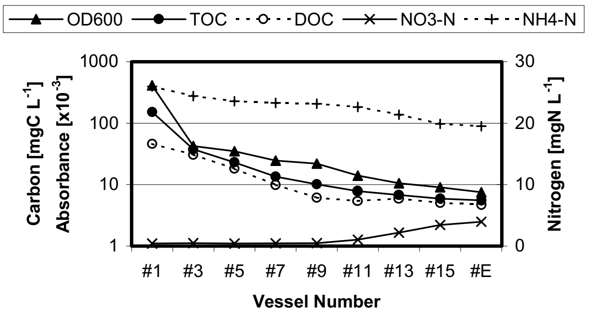

Figure 2 Experiment result (trickling at 5.4 L d-1, Glucose 60 mg L-1)

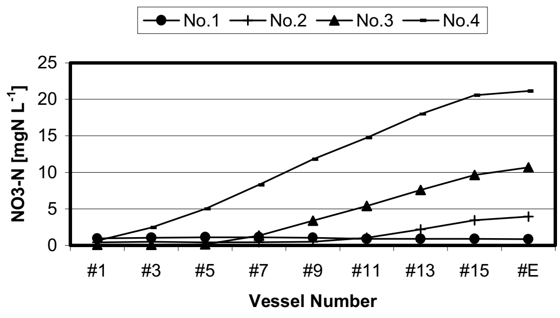

Figure 6 Effect of organic load for nitrification

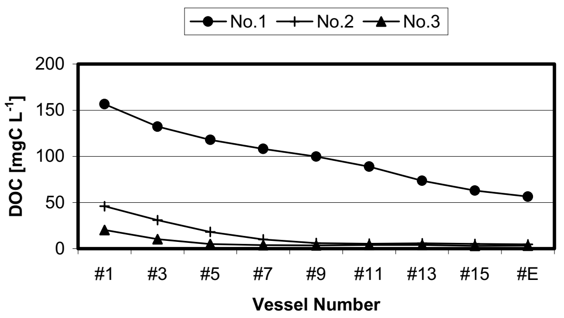

Figure 3 Effect of organic load for DOC removal

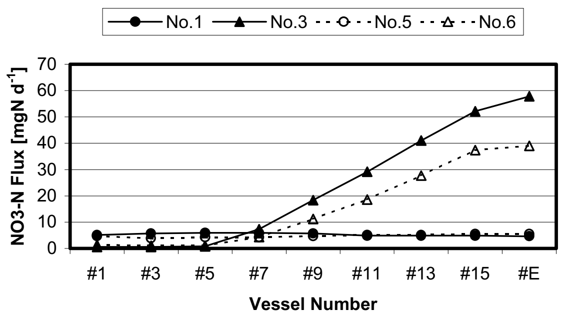

Figure 7 Effect of hydraulic load for nitrification

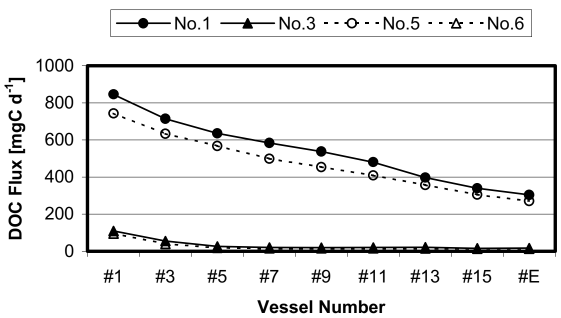

Figure 4 Effect of hydraulic load for DOC removal

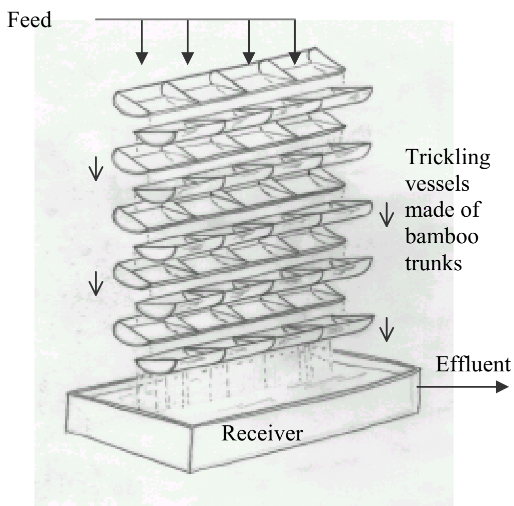

Figure 8 Possible configuration of cascade trickling

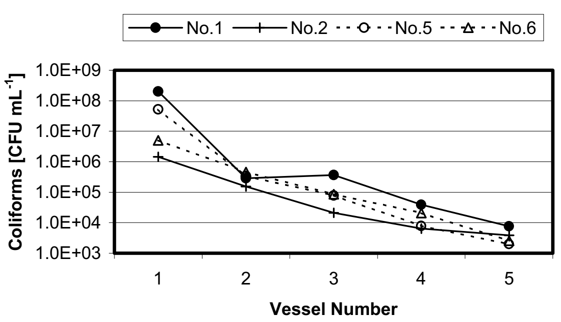

Figure 5 Removal of coliform groups

Figure s 2 - 8.

accelerates oxygen transfer at water surface. Higher hydraulic load enhances DO flux and compensates, to some extent, shorter HRT.

The organic load of both No.1 and 5 was too high and DOC remained at the effluent. This resulted no nitrification on both experiments.

Solid removal

OD600 of all experiments were very low at the level of 0.01 to 0.03 in the final vessel (#E). Most of the solids were settled in each vessel, and suspended solids seemed to be trapped by the biofilm at trickling tips.

Discussion

Capacity and limitation

The only running cost of the system is the power input for lift pump, which is much less than the power input for aeration of activated sludge process. Effluent organic carbon can be removed almost completely; the residual seems to be non-biodegradable. Coliforms decreased approximately 3 to 4log level. At certain condition, nitrification can occur in trickling vessels, but the process rate is affected by HRT and flux.

On the other hand, the system has several limitations. Overall process rate is much slower than conventional processes. Therefore, large-scale application is not practical. The process still requires electricity to lift up wastewater for 1 to 2 m unless the wastewater flows out at high level. And the most important concern is possible hazard of splashing by wind blow.

Appropriate technologies are not versatile options which are applicable at any situation. Knowing the limitations will, instead, clarify their possibility and applicability.

Applications

Cascade trickling is an aerobic process with minimum power requirement. It has especially high performance for pathogen and solid removal. Therefore, final polishing is the most prospective application. The post treatment of anaerobic treatment is a possible option and UASB is especially suitable since the effluent from UASB reactor comes out at the highest point of the reactor.

It can also be used as a nitrifier for nitrogen removal facilities.

Possible design

Figure 8 is a possible configuration of cascade trickling facility. Bamboo trunks will be promising material for trickling vessels. The capacity can be adjusted by tilting the trunks, and each trunk can be easily removed for cleaning since they are detached each other. Vessels can be added to upward in order to improve process performance; it does not require additional space since it is vertical configuration. The trickling fall and flow rate will be also important factors for better performance.

Conclusions

Followings are found by cascade trickling experiments.

- Cascade trickling is a prospective technology for final polishing process of wastewater treatment.
- Cascade trickling is especially effective for pathogen and solid removal.
- Organic removal is efficient up to very low concentration level.
- After DOC is consumed, nitrification occurs and it is accelerated if the flux is increased.

Trickling is the most economical method for surface aeration and it achieves maximum removal rate at minimum power input. It is very effective to remove organic pollutants and can be applicable to many wastewater treatment configurations.

Reference

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