Preliminary Experiment of Gravel Contact Oxidation Process in the Tropics

Keizrul bin Abdullah
Director General, Department of Irrigation and Drainage,
Ministry of Natural Resources and Environment, Malaysia

Toshikatsu OMACHI
Yachiyo Engineering Co.,Ltd.
2-18-12, Nishiochiai, Shinjuku-ku, Tokyo, 161-8575, Japan
E-mail: omachi@yachiyo-eng.co.jp

Abstract : Natural rivers have water purification functions called Gravel Contact Oxidation Process, which decontaminate river water by biological absorption, oxidation and degradation on riverbed gravels. This function has been developed and applied to many small/medium-sized urban rivers in Japan as one of the direct river water purification methods. However the method hasn't been verified in the tropics, which have different climate conditions and river characteristics. A preliminary experiment carried out at a polluted urban tributary in the outskirts of Kuala Lumpur, Malaysia where an increasing attention has been paid to river environment, showed a good applicability to the tropical conditions as a technically practical water purification measure with some maintenance cares for sludge management.

1. Background

In many urbanizing tropical cities, one of the serious environmental problems is the deterioration of river water quality. The causes are mostly attributed to inadequate sewerage and septic tank system, or ineffective effluent control as well as the increase of industrial and domestic wastewater.

In such cases, especially for small/medium sized urban rivers, river water purification methods are thought to be effective, which are mainly classified into direct river water purification, dilution water introduction, dredging and so on. The captioned "Gravel Contact Oxidation Process (GCOP)" is one of the direct river water purification methods, which make the most of natural self-purification functions decontaminating river water by biological absorption, oxidation and degradation for the pollution loadings on riverbed gravels.

Although the method has been developed and applied to many small/medium-sized urban rivers in Japan, the effectiveness and practicality of this method have yet to be verified in the tropics, which have different climate and river characteristics. For this purpose a preliminary experiment was conducted at the Kuyuh River, one of polluted urban tributaries in the outskirts of Kuala Lumpur, Malaysia.

2. Objectives

The objective of the experiment is to verify the applicability of GCOP to the tropics. The items to be verified are as follows:

1) Effects of GCOP
   - How effective will the method be in the condition of heavily turbid and polluted river water?
   - How sustainable will the water purification function of GCOP be?
2) Maintenance items and frequency
   - What kind of items should be taken into consideration for stable operation and maintenance?
   - How to maintain the water purifying function against sludge accumulation in the facilities?
   - How to respond to the heavy rain during operation?
3) Applicability of GCOP to other rivers in Malaysia based on the findings of water purification effects and operational sustainability.

3. Gravel Contact Oxidation Process

Natural rivers create rapids and pools in their channels by mutual functions of flow and riverbed materials of gravel, sand and silt. Self-purification mechanism of rivers is performed in the way that suspended substances deposit in the pools and pollutants are absorbed onto bio-film formed on the riverbed gravel and degraded into water and carbon dioxide by microorganisms (Fig.-1, Fig.-2). Deposited pollutants in the pools are easily washed away on flooding and rivers return to their previous conditions.

As this function is maintained and balanced between such factors as pollutant quantity, ozone dissolved into river water from the air and water flow, the water quality deteriorates if the more pollutant than the capacity of the self-purification mechanism pours into rivers.

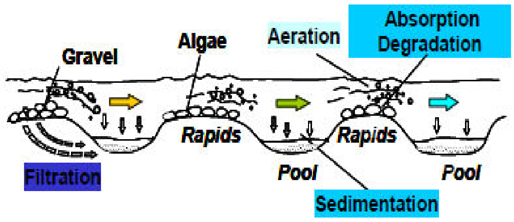

Fig.-1 Self-purification Mechanism of Rivers

4. Project Site

The Klang River has a catchment area of 1,288km2 and a main channel length of 120km running through the Malaysian capital Kuala Lumpur. Although the percentage of sewered population in Kuala Lumpur has already reached nearly 70%, the capability of the sewage treatment plant isn't enough to cover the whole service area. Therefore untreated effluent is being discharged from the plant to rivers as well as sewerage-unconnected household wastewater resulting in very poor river water quality.

Taking into account the site conditions of river channels, water contamination and site availability for the experimental facility, the project site was chosen among several candidates at the Kuyuh River, one of the tributary of the Klang River, at the confluence with the Midah River. (Fig.-3)

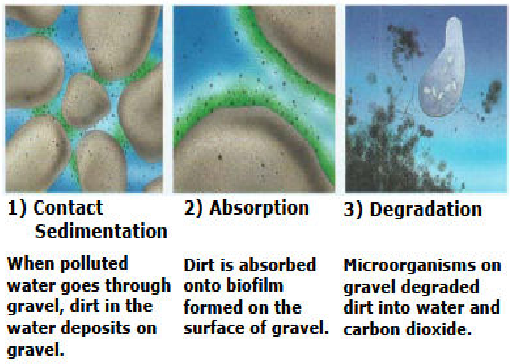

Fig.-2 Purification Mechanism of Gravel Contact Oxidation Process

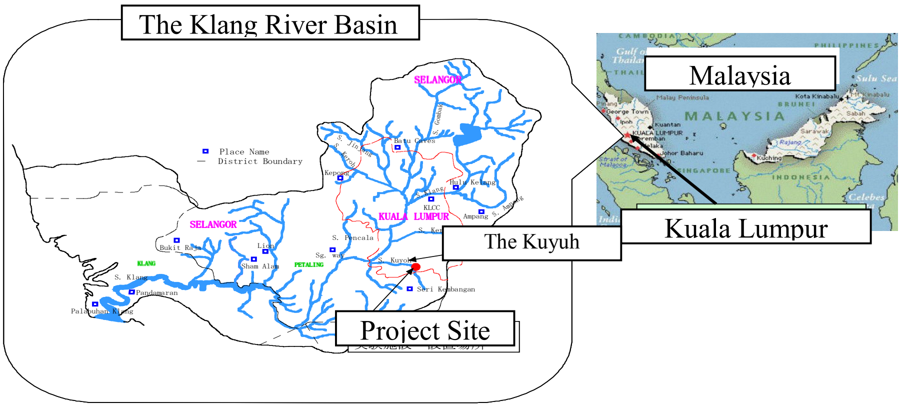

Fig.-3 The Klang River Basin and Project Site

5. Experimental Facilities

Fig.-4 shows the plan of the experimental facility of which dimensions have been decided so that the evaluation of the facility may be properly performed.

First the water of the Kuyuh River is pumped up to the measurement tank and then sent to the reservoir at a rate of 120m3/day to decrease the suspended solids (SS) to the level of the design influent quality. After that the water enters the aerated gravel contact oxidation basin (GCOB) to be purified and finally is discharged through monitoring channel into the Midah River (Fig.-4). The water retention time in the Reservoir, Aerated GCOB and Non-aerated GCOB is 6 hours, 1.5 hour and 0.5 hour in respectively. The basic specifications of the facility are shown in Table-1.

The reason the aeration in the gravel contact oxidation basin is adopted is to extend the adaptability of influent water quality with less DO and higher BOD.

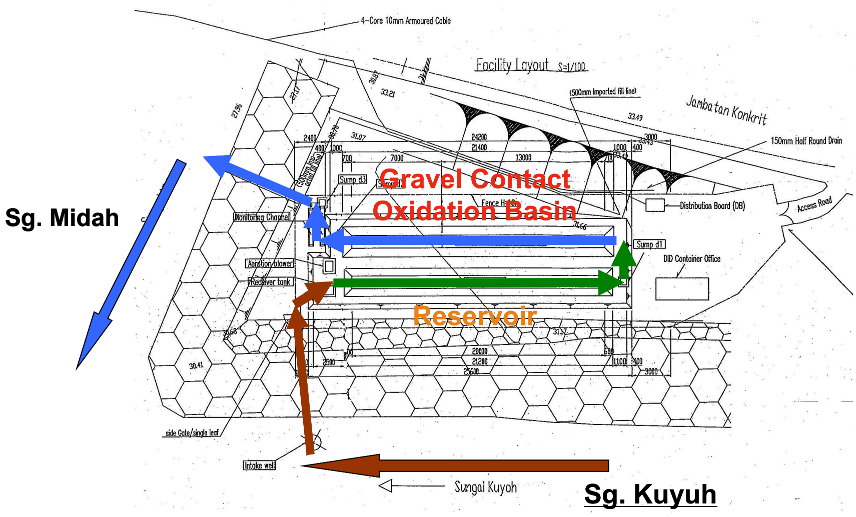

Fig.-4 Plan of Experimental Facility

Table-1 Basic Specifications of the Experimental Facilities

Item	Specification	Reason
(1) Purpose of the experiment	To evaluate the applicability and effectiveness of gravel contact oxidation method in Malaysia	Experiments of the gravel contact oxidation method is necessary in order to apply the method to other countries where weather and river pollution situations differ from those in Japan .
(2) Purification Target	River water of Sg. Kuyuh	Sg. Kuyoh was selected based on the field survey of pollution levels and site situations at six locations within the basin of Sg. Kuyuh.
(3) Design influent quantity	$120m^3/d$ ($=5m^3/hr = 0.083m^3/min$ $=0.0014m^3/s$)	①The basic dimensions are 1m in width and 20m in length so that the scale of the experiment can be considered as a plant. The flow rate was set to be suitable for this purification method. ②The flow rate is 120m3/d which is calculated in the other table.
(4) Design influent quality	BOD: 20mg/l SS: 25mg/l NH4-N: 7.5mg/l VSS: 80% (estimated)	Estimated from the results of pack tests in the field surveys BOD Pack Test ＝22mg/l → 20mg/l NH4-N Pack Test＝6～9mg/l → 7.5mg/l SS and VSS were estimated by visual observation
(5) Treatment Method	Reservoir ＋Gravel contact oxidation method with aeration	Gravel contact oxidation method with aeration was chosen because the river water contains dissolved organic pollutants and the nitrification of NH4-N is necessary. A reserver, which has the functions of grit chamber and oxidation basin, was installed as a stabilization pond in front of the gravel contact oxidation basin.
(6) Effectiveness of the treatment	BOD and SS removal rates: 75%	There removal rate were set at standard purification rates shown in "Guidelines of River Direct Purification (Japan Institute of Construction Engineering, March 1997)".
	NH4-N nitrification rate: about 5mg/l/hr	Considering that the water temperature is around 28℃, this nitrification rate was set based on the same reference as above that says nitrification rate is generally 3 to 6mg/l/hr,
(7) Location	In the sports complex in Kuala Lumpur	At the dry riverbed near the confluence of Sg. Kuyuh and Sg. Midah which belong to Sg. Klang watershed.
(8) Intake method	Pumping	Direct pumping from Sg. Kuyuh
(9) Discharge method	Gravity flow	To discharge to Sg. Midah by gravity flow

6. Methods of Experiment

6.1 Operational Conditions

Experiment was scheduled in two phases, namely 1st monitoring and 2nd monitoring. In the 2nd monitoring intake from the Kuyuh River was increased temporarily from 120m3/day to 180 m3/day for nearly one month.

Table-2 Operational Condition of the Experimental Facilities

Term		Influent quantity	Retention time				Reservoir
			Reservoir	Gravel contact oxidation facilities			
				Aeration part	Non aeration part	Sum	
1st Monitoring	9/2/2004～30/4/2004	120m3/d	6hr	1.5hr	0.5hr	2hr	
2nd Monitoring	2004/7/1～2004/7/18	120m3/d	6hr	1.5hr	0.5hr	2hr	
	2004/7/19～2004/8/8	180m3/d	4hr	1.0hr	0.3hr	1.3hr	
	2004/8/9～2004/9/13	120m3/d	6hr	1.5hr	0.5hr	2hr	
	2004/9/14～2004/9/30	120m3/d	6hr	1.5hr	0.5hr	2hr	Filling with prastic

6.2 Water Quality Test

Water sampling and analysis was conducted at each purification process; measuring tank, reservoir, aerated part of GCOB, non-aerated part of GCOB, outlet to the Midah River. In addition 24-hour water quality survey was also conducted twice at the start and the end of the 1st monitoring.

Table-3 Monitoring Items and Frequency

Scope			1st Monitoring (9/2/2004-30/4/2004)	2nd Monitoring (1/7/2004-30/9/2004)
Water quality survey	Measurement items	*In situ*	Water temperature、Color、Odor、Transparency、pH、Turbidity、DO、Conductivity、NH_4-N	
		Laboratory	BOD,D-BOD,SS,VSS, COD_{Cr},NH_4-N,NO_3-N, T-N,T-P, Fecal coliform	DO,BOD,D-BOD, SS,VSS,COD_{Cr}, NH_4-N,NO_3-N,T-N, T-P,MBAS, Fecal coliform
	Frequency		12	5
Tracer survey			2	2
Sludge disposal			0	1

7. Results

7.1 Water Quality of the Kuyuh River

Table-4 shows the results of water quality of the Kuyuh River for 1st and 2nd monitoring altogether. Through both monitoring period the water temperatures were continuously high between 26.5 and 30.7℃ which were favorable for microorganism purifying river water. Compared with the Malaysian water quality standards, the water quality of the Kuyuh River is much contaminated. In 24-hour water quality test, sudden surges of pollution loads were admitted. The reason is considered as rain or upstream human activities like construction works.

Table-4 Results on Influent Water Quality

Parameter	Water Quality of Influent			Water Quality Standard
	Ave.	Min	Max	
NH_4-N(mg/l)	7.58	2.88	11.20	V
BOD(mg/l)	25.0	8.1	67.4	V
COD_{Cr}(mg/l)	82.8	34.0	186.0	Ⅳ
DO(mg/l)	3.7	0.68	6.0	Ⅲ
pH	7.2	6.6	7.8	I
Conductivity(μS/m)	310	118	424	Ⅱ
SS(mg/l)	322.9	21.0	1200.0	V

7.2 Water Purification Effects

7.2.1 Evaluation of Water Purification Function

Table-5 shows the change of average water qualities at intake, the end of reservoir and the end of GCOB under each experimental condition from 1st monitoring to 2nd monitoring. The following have become clear from the results:

- Although the purification effect was kept at high level during the 1st monitoring, the purification efficiency was reduced after the influent volume was increased in the 2nd monitoring.

- The purification efficiency wasn't recovered to the level of 1st monitoring even after the sludge removal and the operational conditions of the 1st monitoring proved to be more suitable to achieve higher purification efficiency compared to the condition in the 2nd monitoring.

In the 1st monitoring the results showed that the removal rate of SS, NH4-N and Fecal Coliform exceeded 90% and BOD more than 70%.

Table-5 Water Purification Effects under Different Conditions

Items			Data amount	Influent (A)	Effluent from the reservoir (B)	Effluent (C)	Removal ratio (%) Reservoir 〈(A-B) /A〉	Whole facility 〈(A-C) /A〉
1st Monitoring	Transparency	(cm)	11	6.6	8.3	38.5	—	—
	SS	(mg/l)	11	283.3	109.3	8.5	61.4%	97.0%
	Turbidity	(NTU)	11	177.7	98.4	28.7	44.6%	83.8%
	BOD	(mg/l)	11	22.2	14.7	6.5	33.8%	70.7%
	D-BOD	(mg/l)	11	11.3	8.0	3.9	29.4%	65.3%
	DO	(mg/l)	11	3.5	3.1	4.8	—	—
	NH4-N	(mg/l)	4	6.86	6.75	0.54	1.6%	92.1%
	Fecal Coliform	(cfu/100ml)	4	3.9×10^4	3.5×10^4	1.0×10^3	8.2%	97.3%
Stard of 2nd Monitoring	Transparency	(cm)	3	10.4	12.0	28.7	—	—
	SS	(mg/l)	1	66.0	83.0	7.0	0.0%	89.4%
	Turbidity	(NTU)	3	204.5	158.1	37.2	22.7%	81.8%
	BOD	(mg/l)	1	10.6	9.3	9.3	12.3%	12.3%
	D-BOD	(mg/l)	1	5.4	5.7	5.5	0.0%	0.0%
	DO	(mg/l)	3	4.1	5.1	5.7	—	—
	NH4-N	(mg/l)	1	4.87	4.56	0.01	6.4%	99.8%
	Fecal Coliform	(cfu/100ml)	1	5.4×10^3	1.3×10^4	3.8×10^3	0.0%	29.6%
Inflow quantity 180m^3/d	Transparency	(cm)	3	3.3	4.7	11	—	—
	SS	(mg/l)	1	1190	202	39	83.0%	96.7%
	Turbidity	(NTU)	3	698	217	86	68.9%	87.7%
	BOD	(mg/l)	1	67.4	60.5	13.4	10.2%	80.1%
	D-BOD	(mg/l)	1	34.2	30.8	7.8	9.9%	77.2%
	DO	(mg/l)	3	3.8	4.6	2.4	—	—
	NH4-N	(mg/l)	1	9.15	8.11	4.05	11.4%	55.7%
Reset Inflow quantity 120m3/d	Transparency	(cm)	3	9.7	5.3	11.3	—	—
	SS	(mg/l)	1	248	184	28	25.8%	88.7%
	Turbidity	(NTU)	3	211	165	-	21.8%	—
	BOD	(mg/l)	1	18.3	22.0	14.1	0.0%	23.0%
	D-BOD	(mg/l)	1	9.2	9.9	6.5	0.0%	29.3%
	DO	(mg/l)	3	3.6	4.7	5.4	—	—
	NH4-N	(mg/l)	1	9.16	8.98	3.03	2.0%	66.9%
	Fecal Coliform	(cfu/100ml)	1	2.8×10^3	5.3×10^3	1.3×10^3	0.0%	53.6%
Before sludge disposal	Transparency	(cm)	3	1.0	2.7	8.0	—	—
	SS	(mg/l)	1	805	150	32	81.4%	96.0%
	Turbidity	(NTU)	3	242	159	-	34.3%	—
	BOD	(mg/l)	1	23.5	17.1	14.8	27.2%	37.0%
	D-BOD	(mg/l)	1	5.5	8.1	6.5	0.0%	0.0%
	DO	(mg/l)	3	4.6	5.5	5.0	—	—
	NH4-N	(mg/l)	1	9.50	9.30	4.00	2.1%	57.9%
	Fecal Coliform	(cfu/100ml)	1	2.3×10^4	1.4×10^4	8×10^2	39.1%	96.5%
Filling reservoir with plastic bottles (After sludge disposal)	Transparency	(cm)	3	6.2	9.7	15.8	—	—
	SS	(mg/l)	1	43	42	24	2.3%	44.2%
	Turbidity	(NTU)	3	81	56	56	30.9%	30.9%
	BOD	(mg/l)	1	29.9	16.0	10.0	46.5%	66.6%
	D-BOD	(mg/l)	1	7.8	7.0	2.9	10.3%	62.8%
	DO	(mg/l)	3	3.6	4.9	6.1	—	—
	NH4-N	(mg/l)	1	11.2	8.28	0.26	26.1%	97.7%

Note1) Average value was calculated except 2/12.
Note2) Results of 24hr survey on 28-Apr. was treated average value as one data.
Note3) DO was measured with waterlogger(YSI6600).

7.2.2 Comparison with Malaysian Water Quality Standards

Compared the 1st monitoring purification results with the Malaysian Water Quality Standards, the effects can be expressed by the improved level of water standard classifications as follows:

- At the end of reservoir, the level of COD and SS were improved from Level Ⅳ to Level Ⅲ.
- At the end GCOB, NH4-N, BOD, COD and SS were improved from the end of reservoir by one or two levels with NH4-N from Ⅴ to Ⅲ, BOG from Ⅴ to Ⅳ, COD from Ⅲ to Ⅱ, SS from Ⅲ to Ⅰ. DO and fecal coliform remained in the same level through; the quality of these two was also significantly improved.

7.2.3 Concentration Change of SS and NH4-N

High concentration of influent SS was much reduced by deposition in the reservoir to some 100 mg/l and further decreased in GCOB.

NH4-N remained same level in reservoir and was dramatically removed in GCOB with the increase of NO3-N which means NH4-N was nitrified into NO3-N. More than 5mg/l/hr of the nitrification velocity, which is faster than in Japan, was observed in the both the 1st and 2nd monitoring presumably due to activated microorganism by higher river water temperature.

7.3 Effect of Sludge Disposal on the Recovery of Water Purification Function

Although the design sludge accumulation for six months was 200kg with influent volume 120m3/day, influent SS 20mg/l, removal rate of SS 75%, sludge accumulation exceeded the design value of 200kg two month after the start of intake in the 1st monitoring because of higher SS of the river water.

In the 2nd monitoring influent volume was temporarily increased for three weeks from 120m3/day to 180 which resulted in a decline in purification effects, and the cause is supposed to be the sludge accumulation in GCOB. After the sludge removal the transparency was temporarily improved, but didn't reach the same level as the beginning of the 2nd monitoring. Therefore the influent volume of 180m3/day that is 1.5 times the design value is thought to be excessive for the scale of the facility.

8. Summary

8.1 Effectiveness of "the Gravel Contact Oxidation Process" in the Tropics

1) Influent Water Quality of the Klang River

- Average water quality during the experiment of 1st and 2nd monitoring was the level of heavily contaminated with BOD 25mg/l, SS 320mg/l, DO 3.7mg/l, NH4-N 7.6mg/l. The value of BOD, DO and NH4-N were the same level as design influent conditions, but SS was 13 times the designed value due to the upstream river improvement works.

2) Water Quality Improvement

Before the sludge accumulation reaches the design value, the following were proved:

- High level of water purification effects were verified with more than 90% of SS, NH4-N and Fecal Coliform, over 70% of BOD removed.
- The improvement of DO, Transparency, Turbidity and smell were also made sure.
- Nitrification of NH4-N was more active than in Japan probably due to constantly higher river water temperatures.
- Above effects correspond to the shift from one or two lower levels of the Malaysian Water Quality Standards except a few items, which also significantly improved.
- The water purification functions of each part of the facility were the deposition of suspended substances in the reservoir, and the removal of dissolved pollutants such as NH4-N and D-BOD in the Aerated GCOB.
- Although the river water intake volume was increased to 1.5 times in the 2nd monitoring, the effect of increased intake volume couldn't be evaluated because of the extremely high concentration of SS and sludge accumulation in the GCOB during the experiment.

3) Sludge Disposal for Sustainable Operation

- Given the excessive sludge accumulation in GCOB, the water purification function declined.
- In order to maintain NH4-N purification function, it's significant that sludge accumulation in GCOB is kept within the design level by means of aerated sludge disposal with suitable interval.
- Since the SS concentration of intake water is high with the possibility of inflow of fine silt that is unable to be removed in usual reservoirs, and the speed of sludge accumulation in the GCOB is much faster than in Japan even with the reservoirs for pre-deposition, it's desirable that enough capacity of reservoir is planned if there is large spaces with a reasonable price available.
- As the SS concentration of effluent of aerated sludge disposal is quite high, the aerated sludge disposal should be conducted during heavy rains.

8.2 Applicability to other Rivers in Malaysia and Future Prospect

There are many rivers with the same river conditions as the Kuyuh River even in the Klang River basin, the GCOP is technically considered to be applicable to these rivers.

Generally the quality of discharged treated water from water purification plant is not satisfactory, because of the simple treatment methods of sewerage and septic tank, and insufficient operation and maintenance. Besides, as the purpose of those facilities is to dispose of organic substances, NH4-N concentration of treated water is still high, while the GCOP was proved effective in the NH4-N removal. Therefore the combination of sewerage, septic tank and the aerated GCOP is thought to be effective and practical in these countries' river water improvement.