Renovation of secondary treatment facility into the Step-feed Biological Nitrogen Removal Process by the effective use of the existing structure

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Summery:

In order to improve the water environment in Kyoto city and in the down stream of discharging rivers, suitable advanced treatment processes have been adopted into existing facilities by way of renovation. In the case of the existing secondary treatment facility at Toba treatment plant, the step-feed biological nitrogen removal process was chosen since it can be applied without any large-scale remodeling of the structure of the facility, and can be maintained easily.

Key Wards:

Advanced treatment, Nitrogen removal, Renovation, Step-feed biological nitrogen removal

1. Sewerage works of Kyoto city

(1) Outline

Kyoto city, which has more than 1200 years of history, is located in the midstream of the Yodo River from Lake Biwa to Osaka Bay. The population of the city is around 1.47 million. Almost all of the water required is obtained from Lake Biwa through water channels and all treated effluent from wastewater treatment plants is discharged to the Yodo river water system. As the Yodo River water is used for drinking water by more than 11 million people in Osaka and other cities, the sewerage system has a significant role and its construction has been pursued vigorously. The sewered population ratio as of 2006 is 99.1%. And the sewerage system has contributed to improve the water quality of the Yodo River water system including rivers in the city. However, as further strict design standards concerning BOD, COD, nitrogen and phosphorus will be established for each wastewater treatment plant, additional improvement of effluent quality will be required.

(2) Promotion of Advanced Treatment

Considering of the location of the city, not only nitrogen and phosphorus but color are fixed for the objective constituents of the advanced treatment in order to improve the appearance of river water. Biological removal processes have been applied for nitrogen and phosphorus while ozonation has been applied for color removal.

Because immense construction costs are required for introducing advanced treatment, simultaneous removal processes for nitrogen and phosphorus are applied in case of renovation of the whole structure, and removal processes for one of the constituents is applied in case of renovation of equipment such as diffusers in reaction tanks. As compared with conventional activated sludge systems, biological advanced treatment processes require longer reaction time, so facility volumeter of the advanced treatment generally has to increase. But in Kyoto city, influent volume has been decreasing after a volumetric peak in the early 90^{s} on account of elevation of water saving consciousness, and moving colleges and factories out of the city as well as a lingering recession. Therefore, advanced treatment has been adopted by according as the decrease of influent volume without any expansion of the facility volumeter.

(3) Outline of Toba Wastewater Treatment Plant

The first treatment line of the Toba plant, which is the 9^{th} oldest one in Japan, began operating in 1939. The amount of influent wastewater into the plant is about 63% of the wastewater generated in the city. The present treatment capacity is 975,000m^3/day.

As shown in **Table-1**, there are eleven treatment lines from A to K in the plant. Those treatment lines had been constructed year by year, and conversion works of those lines from conventional activated sludge process into advanced treatment has been promoted stepwise. A-line was converted into the anaerobic-anoxic-oxic (A_2O) process for the nitrogen and phosphorus removal on the occasion of the renovation of whole structure. E and F lines were converted into the anaerobic-oxic (AO) process for the phosphorus removal by way of renovation of diffusers in the reaction tank.

Table-1 Treatment capacity of each line in Toba Plant

TREATMENT LINE	A	B	C	D	E	F	G	H	I	J	K	TOTAL
COMMENCED OPERATION	'97	'64	'66	'67	'69	'71	'73	'76	'79	'84	'89	–
ORIGINAL CAPACITY	–	78	72		90					159	158	989
ADVANCED TREATMENT	A_2O +AO	–	–	–	AO		STEP		–	–	–	–
PRESENT CAPACITY	119	61	57		83		54		90	159	158	975

(Capacity: ＊$10^3 m^3$/Day)

2. Adoption of Advanced Treatment

(1) Renovation Project

① Investigation of introducing process

Low construction and maintenance costs, as well as maintenance efficiency have been the first priority in choosing the advanced treatment process. In case of E and F lines, which have the same structure as G and H lines, the AO process was adopted for the phosphorus removal by installing mixers instead of diffuser plates in reaction tanks.

In case of the renovation of G and H lines, introducing process was investigated by adding Step-Feed Biological Nitrogen Removal Process (STEP), which had been developed by Japan Sewerage Works Agency (JSWA) and was just authorized, as one of the alternative processes. After careful investigation, the STEP process was chosen for the following reasons; 1) Step feed channels are already installed in those treatment lines and large scale construction is not necessary. 2) Equipping mixers in reaction tanks instead of diffuser plates is adequate for a conversion into an advanced treatment process. 3) Nitrogen concentration might not meet the future effluent water quality standard.

② STEP Process

Fig-1 is the illustration of the two-stage STEP process. Half the amount of wastewater flows into the first stage. In the first denitrification tank, nitrified nitrogen in return sludge is mainly denitrified. In the first nitrification tank, ammonium nitrogen in the influent wastewater into the first stage is nitrified. The nitrified liquor flows into the second denitrification tank together with the remaining influent wastewater is denitrified by using organic carbon in the wastewater. In the second nitrification tank, ammonium nitrogen in the remaining half of influent wastewater is nitrified. Theoretical nitrogen removal ratio in the case of a 50% return sludge rate is 67%.

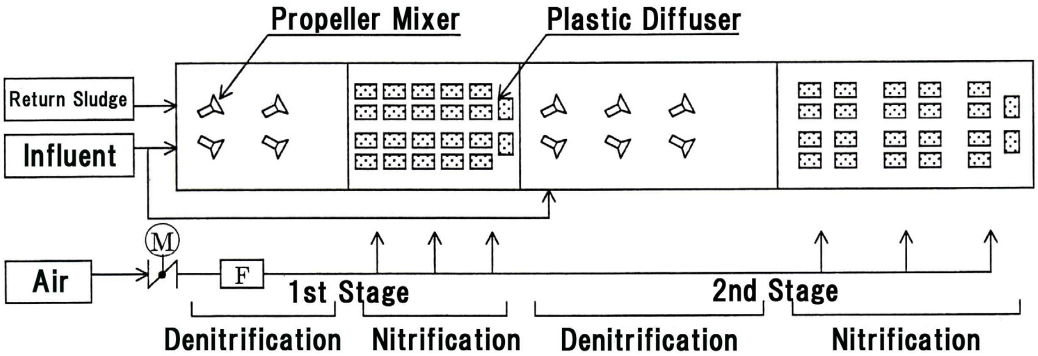

Fig-1 Illustration of the two-stage STEP process

③ Renovation design

Table-2 shows the design factors of the STEP process introduced into G and H lines.

Table-2 Design factors of the STEP process

Number of Stages	2
Volume Ratio of 1st and 2nd Stage	1:1.5
Volume Ratio of Denitrification and Nitrification Tank	1:1
Influent Volume Ratio into 1st and 2nd Stage	1:1
Treatment Capacity	54,000 m³/Day
Return Sludge Ratio	50%

As will be mentioned afterward, the influent loading is relatively low, so two-stage system was adopted for maintaining anaerobic condition in the denitrification tanks. Influent volume ratio into the first and second stages is fixed at 1:1. Tank volume ratio of the first and second stages is set at 1:1.5 in order to equalize solids quantity in both stages. Tank volume ratio of both the denitrification and nitrification tanks is fixed for a general value of 1:1. The designed treatment capacity becomes 54,000 m^3/D which is 60% of the original conventional treatment capacity of 90,000m^3/D.

(2) Renovation works

① Renovation of facilities

Renovation works of G and H line for advanced treatment was carried out by way of renewal of diffusers in reaction tanks. The works of G line were completed in March 2003 after approximately a year of construction, and those of H line were completed in October 2004. **Table-3** indicates the outline of the renovation works. Reaction tanks had been divided into four equal parts by baffle plates before the renovation, and it was re-divided into four parts so as to make the volume ratio of the first denitrification tank, first nitrification tank, second denitrification tank and second nitrification tank into 1:1:1.5:1.5. In the first denitrification tank, 4 propeller type mixers per sub line were installed and in the second denitrification tank, 6 mixers per sub line were installed. As each treatment line consists of 4 sub lines, a total of 40 mixers were installed in each line. In both the first and second nitrification tanks, super fine bubble membrane diffusers made by urethane plastic were installed. Half the amount of wastewater which flows into the second denitrification tank is led through unused step channels by constructing the mouth of the channel near the inlet of the second denitrification tank.

Table-3 Outline of the renovation works

	before renovation	after renovation	
Partition	1 : 1 : 1 : 1	1 : 1 : 1.5 : 1.5	
Diffusion and Mixture	Ceramic Diffuser pore 400μm	1st Denitrification Tank	Propeller type Mixer, 4units/tank
		1st Nitrification Tank	Urethane Diffuser Plate, pore 150μm
		2nd Denitrification Tank	Propeller type Mixer, 6units/tank
		2nd Nitrification Tank	Urethane Diffuser Plate, pore 150μm
Step Feed Channel	Unused	use by constructing inflow gates	

② Construction cost

Table-4 shows the equipment and construction costs of the renovation into the STEP process, and those of the suppositive renovation into the conventional process of which treatment capacity is 90,000m^3/D. The construction costs per treatment capacity of the STEP process is 65% higher than that of the conventional process. But the construction cost itself is actually almost the same for both processes due to the high cost of diffusers compared with mixers, and due to the unnecessary of construction of the new step channel.

(3) Efficiency of introducing STEP process

① Influent water quality

Table-5 indicates the influent quality into the reaction tank of G and H line. Water quality of all constituents, except suspended solids, is lower than those researched by Japan Sewerage Works Agency (Technical evaluation report of STEP Process, 2002) and Public Works Research Institute (Report of investigation project for facility design of advanced treatment, 2003). This is mainly caused by dilution of the influent wastewater due to a high underground water level. Maintenance of the biological nitrogen removal processes under such low pollutant loading is supposed to be difficult because the low loading makes anaerobic conditions hard to maintain in the denitrification tank

Table-4 Equipment and construction costs of the renovation into STEP process

		STEP Process			Conventional Process		
		Quantity	unit cost	cost	quantity	unit cost	cost
equipment cost	diffuser	half of tank	52,000	208,000	whole tank	77,000	308,000
	mixer	40	2,000	80,000	-	-	-
	inlet weir	8	4,000	32,000	4	4,000	16,000
	others	-	-	12,000	-	-	12,000
	total	332,000			336,000		
construction and other cost		308,000			308,000		
total cost		640,000			644,000		

(:10^3 yen)

	STEP Process	Conventional Process
treatment capacity	54,000 m^3/D	90,000 m^3/D
total cost/capacity	11,900 yen/m^3	7,200 yen/m^3

Table-5 Influent water quality into reaction tank

	Toba Plant	Report by JSWA	Report by PWRI
	Average in 2005	Range	Average
BOD	47	60～147	121
SS	37	37～185	61
T-N	14	19～29	25
NH_4-N	8.8	14～19	16
T-P	1.4	2.9～4.3	3.45
PO_4-P	0.6	1.6～1.9	1.67

(: mg/L)

② Operational condition

Table-6 shows the operational condition of the STEP process in G line as well as the AO process and conventional process for comparison. Average return sludge ratio is 49% which is almost the same as the designed value of 50%. Average MLSS in reaction tank is 1,210mg/L which is quite low due to the low influent pollutant loading and is almost same as both the AO and conventional processes. Average ratio of supplied air volume per treated wastewater is 1.9. In winter season, as influent loading becomes rather high, so the ratio rises to 2.2 in order to keep MLDO in required degree.

Table-6 Operational condition of each process

	STEP			AO	Conventional
	Average	Max	Min		
Influent Volume (m^3/D)	49,230	53,140	40,010	66,980	62,330
Return Sludge Ratio (%)	49	51	43	24	35
HRT in Reaction Tank (hr)	12.6	14.0	11.8	9.1	9.7
MLSS (mg/L)	1,210	1,400	1,050	1,120	1,180
BOD-SS Loading (kg/kg D)	0.08	0.10	0.05	0.11	0.10
A-SRT (Day)	7.2	11.0	5.9	9.7	11.6
Air Volume Ratio (m^3/m^3)	1.9	2.2	1.6	2.9	2.3

(: monthly average in fiscal year 2005)

③ Treatment result

In **Table-7**, the mean value of influent and effluent water quality of each treatment process, as well as the removal rate, is shown from the period of April 2005 to March 2006.

Table-7 Water quality and removal rate

	Influent	STEP	AO	Conventional
C-BOD (mg/L)	47	1.0	1.6	1.9
SS (mg/L)	37	1.1	1.3	2.3
T-N (mg/L)	14	4.1	8.4	8.4
NH_4-N (mg/L)	8.8	0.0	0.3	0.2
N Removal Rate (%)	—	70.0	39.0	39.0
T-P (mg/L)	1.4	0.58	0.22	0.67
PO_4-P (mg/L)	0.60	0.52	0.13	0.57
P Removal Rate (%)	—	57.6	83.6	50.6

a. Nitrogen removal

Effluent total nitrogen concentration of the STEP process is 4.1mg/L which is less than half value of the AO and conventional processes. As for the removal rate, 70% on average is achieved in the STEP process which is almost identical to the theoretical value, while only 40% is achieved in the AO and conventional processes. **Fig-2** shows a breakdown of the nitrogen removal rate.

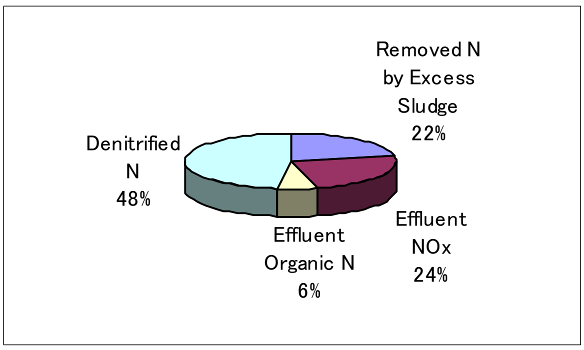

Fig-2 Breakdown of nitrogen removal rate

Of this 70% total, 48% of nitrogen is removed by denitrification and 22% of it is removed by excess sludge.

As shown in **Fig-3**, the nitrogen removal rate decreases to 63% in summer season. In order to progress denitrification smoothly, organic matter concentration is regarded as an important factor and the BOD/N ratio required for denitrification is reported to be at least 2 to 3gBOD/gN. As shown in **Fig-4**, the minimum ratio is 3.7gBOD/gN in Toba plant, and as for ratio the sufficient value is maintained.

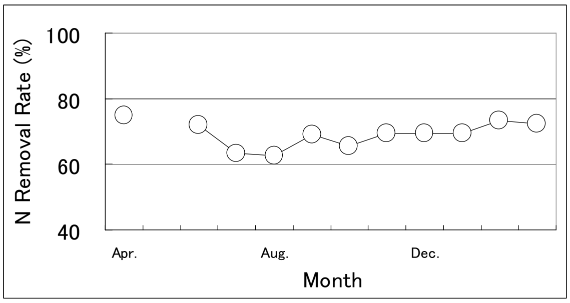

Fig-3 Variation of nitrogen removal rate

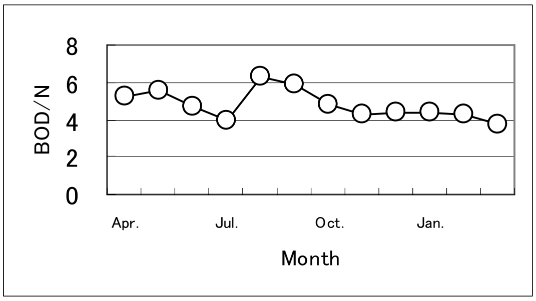

Fig-4 Variation of BOD/N ratio

But the relationship between influent BOD concentration and the nitrogen removal rate shown in **Fig-5** indicates that both have a strong relation and the nitrogen removal rate decreases as influent BOD decreases.

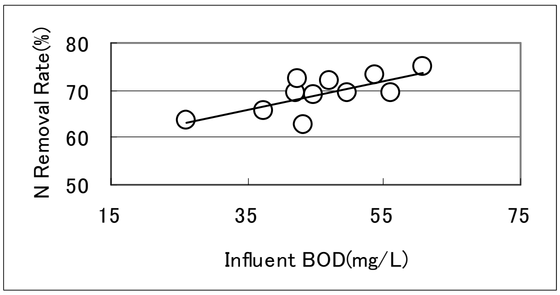

Fig-5 Influent BOD and N removal rate

This means that even if the BOD/N ratio is sufficient, it is difficult to keep anaerobic conditions in the denitrification tank when MLDO concentration in the nitrification tank come to be excessive, especially in summer season on account of low BOD loading.

b. Operational and maintenance cost

In **Table-8**, power consumption for mixers in the denitrification tank, air supply in the nitrification tank of the STEP process, and that for air supply in the conventional process is shown.

Table-8 Comparison of power consumption in reaction tank

		STEP	Conventional
Power for Mixer	(kWh/D)	1,633	–
Power for Blower	(kWh/D)	1,755	2,689
Total Power	(kWh/D)	3,388	2,689
Influent Volume	(m^3/D)	49,230	62,330
Power for Blower/Influent Volume	(kWh/m^3)	0.036	0.043
Total Power/Influent Volume	(kWh/m^3)	0.069	0.043

Even though the power consumption for blower per influent volume of the STEP process (0.036kWh/m^3) is lower than that of the conventional process (0.043kWh/m^3), total power consumption by adding the consumption for mixers (0.069kWh/m^3) becomes higher. Therefore, intermittent operation of mixers has been investigated and a blower with inlet-vanes has been adopted in order to reduce power consumption.

3. Conclusion

As a result of introducing the STEP process into the existing conventional facility at Toba plant by way of renovation of diffusers, it was found that even though the construction cost of the STEP process per treatment capacity is 65% higher than that of the conventional process and the power consumption of the process per influent volume is higher than that of the conventional process by 60%, a nitrogen removal rate of approximately 70% which is almost identical to theoretical value, was achieved.

Kyoto city will be promoting the adoption of the advanced treatment steadily and will also be investigating its efficient operation and maintenance.

Renovation of secondary treatment facility into the Step-Feed Biological Nitrogen Removal Process by effective use of the existing structure

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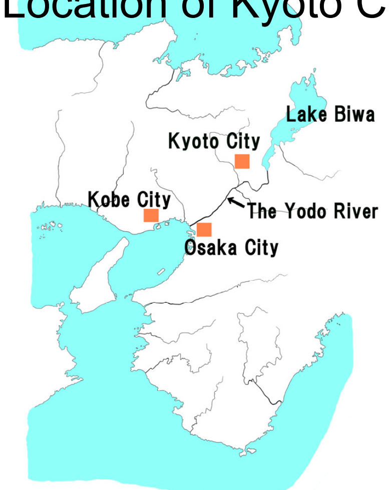
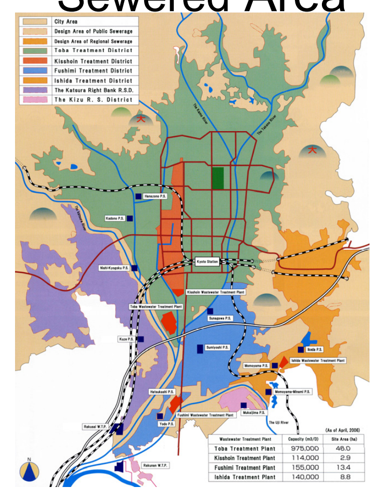
Kyoto City

- More than 1200 years of history,
- Around 1.4 million of population,
- Located in midstream of the Yodo River,
- The Yodo River water is used for drinking by more than 11 million people in the lower part of the river,

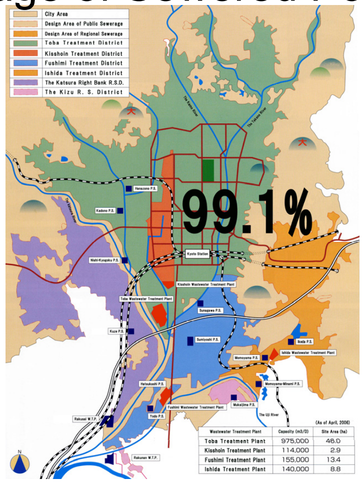
Location of Kyoto City



Sewered Area



Percentage of Sewered Population



Adoption of Advanced Treatment

- Nitrogen
- Phosphorus
- Color

Adoption of Advanced Treatment

- Nitrogen
  Anaerobic-anoxic-oxic process
  Step-feed biological nitrogen removal process
- Phosphorus
- Color

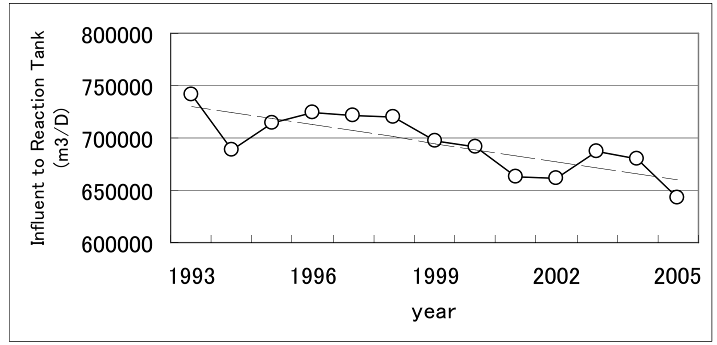
Adoption of Advanced Treatment

- Nitrogen
- Phosphorus
  Anaerobic-anoxic-oxic process
  Anaerobic-oxic activated sludge process
- Color

Adoption of Advanced Treatment

- Nitrogen
- Phosphorus
- Color
  Ozonation

Decrease of Influent Wastewater

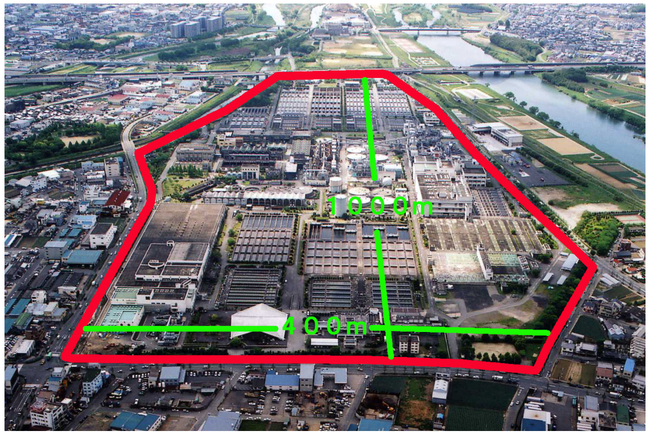


Toba Wastewater Treatment Plant

- Started operation → 1939
- Treatment area → 8,191 ha
- Population in the area → 771,200
- Treatment capacity → 975,000 m^3/D

Photo of Toba Wastewater Treatment Plant

Area of the Plant

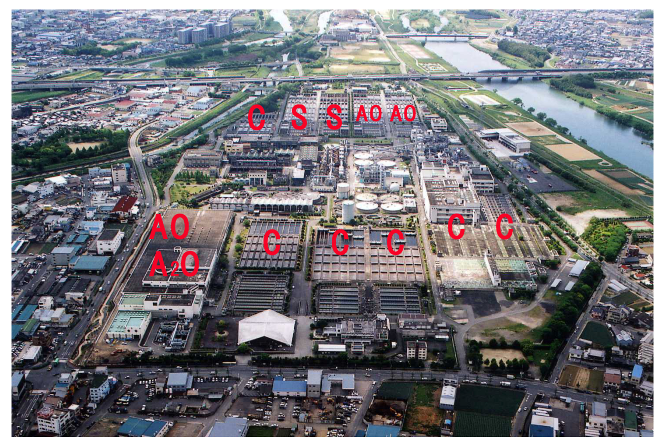


Treatment Lines

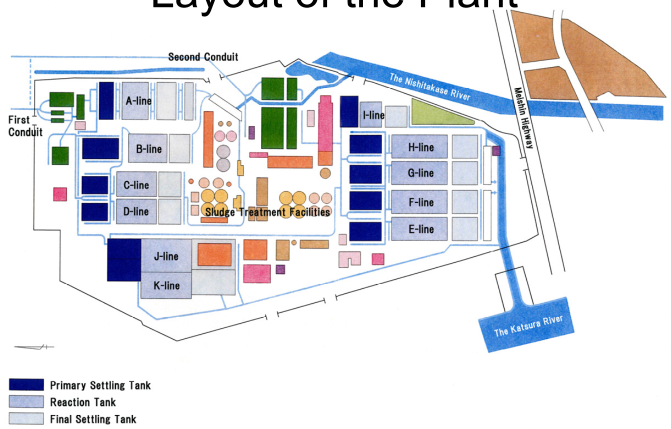
Treatment Capacity of Toba Treatment Plant

TREATMENT LINE	A	B	C	D	E	F	G	H	I	J	K
ORIGINAL CAPACITY (*10^3m^3/D)	–	78	72	72	90	90	90	90	90	159	158
ADVANCED TREATMENT	AO A_2O	–	–	–	AO	AO	S	S	–	–	–
PRESENT CAPACITY (*10^3m^3/D)	119	61	57	57	83	83	54	54	90	159	158

Treatment Processes



Layout of the Plant



Reasons of Choosing STEP Process

1) Step feed channels are already installed in those treatment lines.
2) Equipping mixers instead of diffuser plates is adequate for a conversion into an advanced treatment process.
3) Nitrogen concentration might not meet the future effluent water quality standard.

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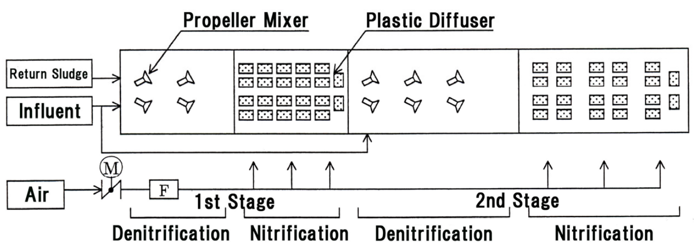
Illustration of two-stage STEP process



Design Factors of STEP Process

Number of Stages	2
Volume Ratio of 1st and 2nd Stage	1 : 1.5
Volume Ratio of Denitrification and Nitrification Tank	1 : 1
Influent Volume Ratio into 1st and 2nd Stage	1 : 1
Treatment Capacity	54,000 m^3/D
Return Sludge Rate	50%

Influent Wastewater Quality

	Toba Plant	Report by JSWA	Report by PWRI
	Average in 2005	Range	Average
BOD	47	60～147	121
SS	37	37～185	61
T-N	14	19～29	25
NH_4-N	8.8	14～19	16
T-P	1.4	2.9～4.3	3.45
PO_4-P	0.6	1.6～1.9	1.67

Outline of Renovation Works

	before renovation	after renovation	
Partition	1 : 1 : 1 : 1	1 : 1 : 1.5 : 1.5	
Diffusion and Mixture	Ceramic Diffuser pore 400 μm	1st Denitrification Tank	Propeller type Mixer, 4units/tank
		1st Nitrification Tank	Urethane Diffuser Plate, pore 150 μm
		2nd Denitrification Tank	Propeller type Mixer, 6units/tank
		2nd Nitrification Tank	Urethane Diffuser Plate, pore 150 μm
Step Feed Channel	unused	use by constructing inflow gates	

Cost for Renovation

		STEP Process		Conventional Process	
		quantity	cost	quantity	cost
equipment cost	diffuser	half of tank	208,000	whole tank	308,000
	mixer	40	80,000	-	-
	others	-	44,000	-	28,000
	total	332,000		336,000	
construction cost		308,000		308,000	
total cost		640,000		644,000	

(10^3 yen)

	STEP Process	Conventional Process
treatment capacity	54,000 m^3/D	90,000 m^3/D
total cost/capacity	11,900 yen/m^3	7,200 yen/m^3

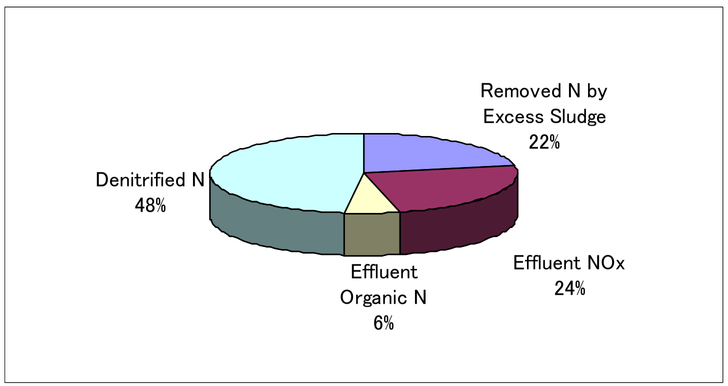
Operational Condition
(monthly average in fiscal year 2005)

	STEP			AO	Conventional
	Average	Max	Min		
Influent Volume (m^3/D)	49,230	53,140	40,010	66,980	62,330
Return Sludge Ratio (%)	49	51	43	24	35
HRT in Reaction Tank (hr)	12.6	14.0	11.8	9.1	9.7
MLSS (mg/L)	1,210	1,400	1,050	1,120	1,180
BOD-SS Loading (kg/kg D)	0.08	0.10	0.05	0.11	0.10
A-SRT (Day)	7.2	11.0	5.9	9.7	11.6
Air Volume Ratio (m^3/m^3)	1.9	2.2	1.6	2.9	2.3

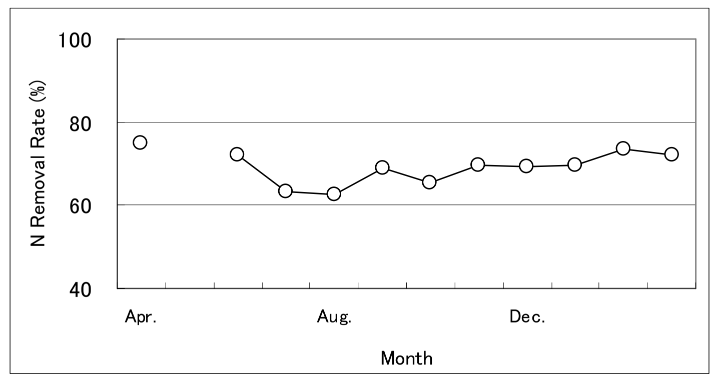
Water Quality and Removal Rate
(from Apr. 2005 to Mar. 2006)

	Influent	STEP	AO	Conventional
C−BOD (mg/L)	47	1.0	1.6	1.9
SS (mg/L)	37	1.1	1.3	2.3
T−N (mg/L)	14	4.1	8.4	8.4
NH_4−N (mg/L)	8.8	0.0	0.3	0.2
N Removal Rate (%)	−	70.0	39.0	39.0
T−P (mg/L)	1.4	0.58	0.22	0.67
PO_4−P (mg/L)	0.60	0.52	0.13	0.57
P Removal Rate (%)	−	57.6	83.6	50.6

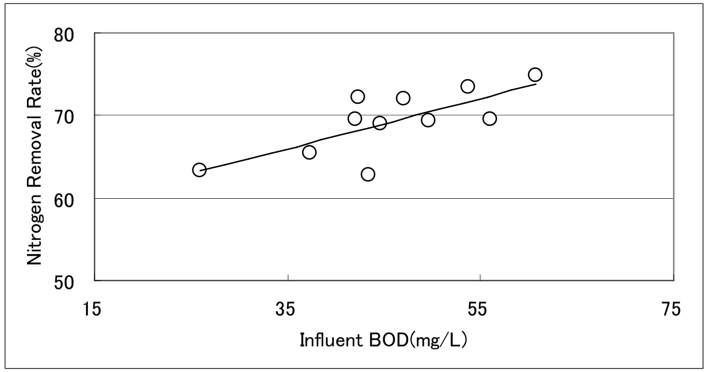
Breakdown of Nitrogen Removal Rate



Variation of Nitrogen Removal Rate



Influent BOD and Nitrogen Removal Rate



Power Consumption in Reaction Tank

		STEP	Conventional
Power for Mixer	(kWh/D)	1,633	-
Power for Blower	(kWh/D)	1,755	2,689
Total Power	(kWh/D)	3,388	2,689
Influent Volume	(m^3/D)	49,230	62,330
Power for Blower/Influent Volume	(kWh/m^3)	0.036	0.043
Total Power/Influent Volume	(kWh/m^3)	0.069	0.043

Conclusion

- Approximately 70% of nitrogen removal rate is achieved.
- Construction cost and operational cost of the STEP process per influent volume are higher than those of conventional process by 65% and 60% respectively.
- In order to reduce the operational cost, some measures have been investigated.

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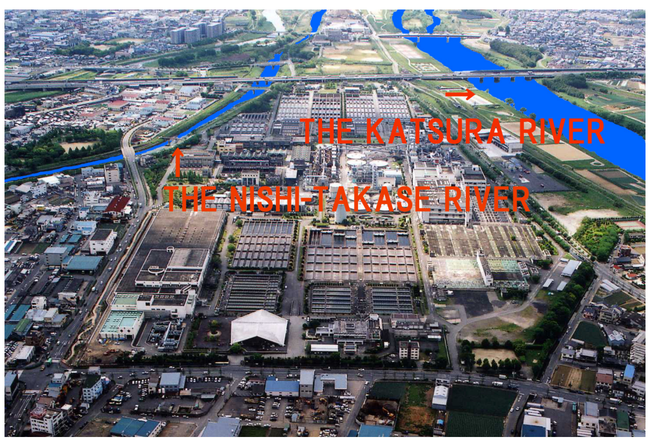
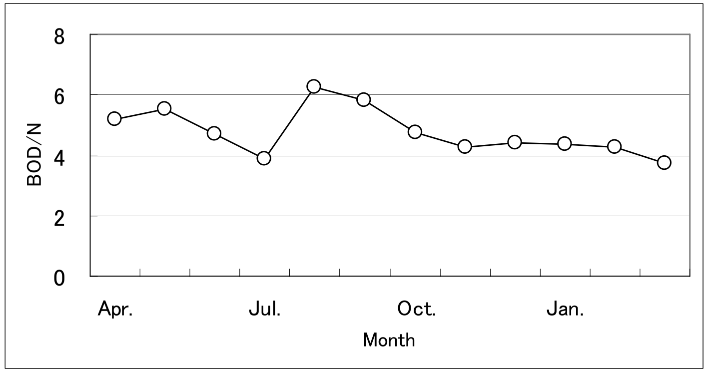
END

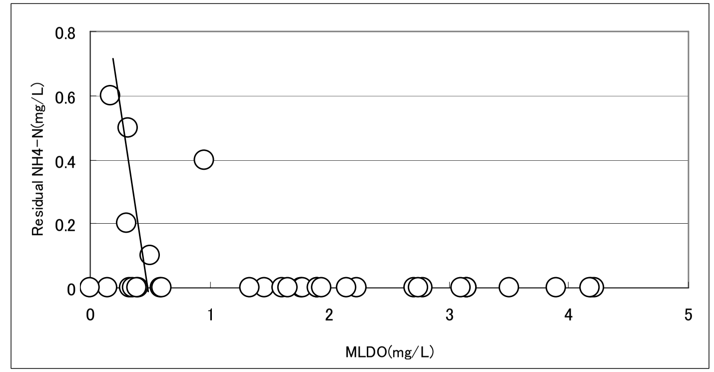
Discharging Rivers



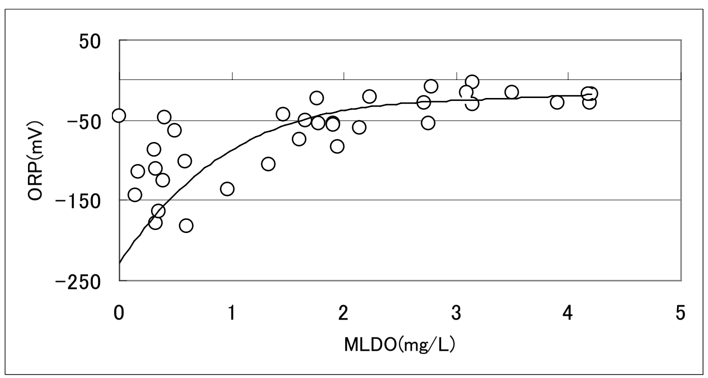
Variation of BOD/N Ratio



MLDO and Residual NH_4-N in the 1st Nitrification Tank



MLDO in the 1st nitrification tank and ORP in the 2nd denitrification tank



Outflow Quality to the River

	1995～1997		2000～2002		2005	
	E : conventional F : conventional G : conventional H : conventional I : conventional		E : AO F : AO G : conventional H : conventional I : conventional		E : AO F : AO G : STEP H : STEP I : conventional	
	inflow to reactor	outflow to river	inflow to reactor	outflow to river	inflow to reactor	Outflow to river
BOD (mg/L)	61	2.0	51	1.8	46	1.6
T-N (mg/L)	16	9.2	15	9.0	14	7.4
N removal rate (%)	**42.5**		**40.0**		**47.1**	
T-P (mg/L)	1.8	0.87	1.6	0.61	1.4	0.38
P removal rate (%)	**51.7**		**61.9**		**72.9**	

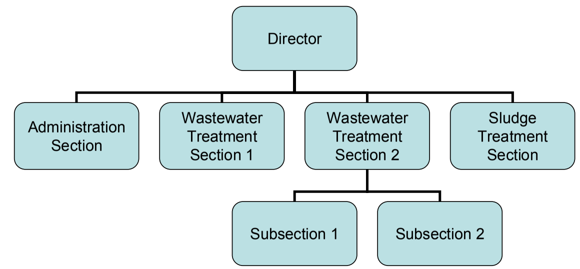
Target Effluent Water Quality

	Basin-wide planning(*1)	Master Plan (*2)
BOD (mg/L)	5	3
T-N (mg/L)	7.8	5.7
T-P (mg/L)	1.1	0.6

(*1) Osaka bay, the Yodo river comprehensive basin-wide planning of sewerage systems

(*2) Master Plan of Kyoto City up to 2025, treatment by nitrogen and phosphorus removal, sand filtration and ozonation

Organization of Toba Plant



Recycle Flow Quality

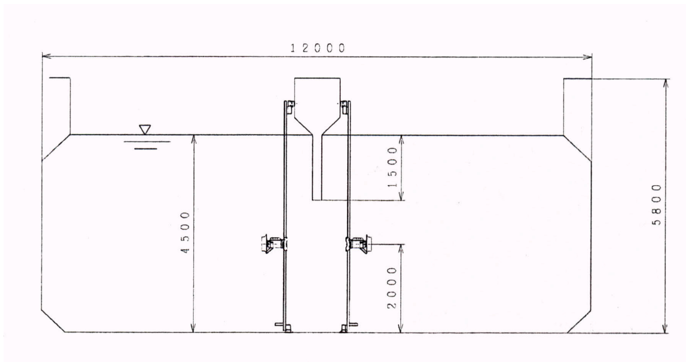
Recycle Flow from Sludge Treatment	Main Source	Volume	Water Quality	
1st Recycle Flow	Sludge Thickener Digestion Tank	35,300m³/D	BOD (mg/L)	610
			S S (mg/L)	967
			T-N (mg/L)	70
			T-P (mg/L)	17
2nd Recycle Flow	Dewatering Incinerator	60,200m³/D	BOD (mg/L)	450
			S S (mg/L)	602
			T-N (mg/L)	39
			T-P (mg/L)	11

The master plan of sewerage works of Kyoto City

- Target year : 2025

1 sewered population of 100%
2 storm water management
3 improvement of CSO
4 advanced treatment
5 sludge treatment
6 renovation and earthquake proof
7 multi-use of facilities and resources

Installation of Mixers



Effect of Installing Blower with Inlet-Vanes

	Power Consumption by Blower (May to August)
2005 (before installation)	17,100 kWh/Day
2006 (after installation)	12,300 kWh/Day
Benefit	28%

Breakdown of Nitrogen Removal

Influent-N (mg/L)	14	Nitrifiable-N	10.1	10.1
		Unnitrifiable-N	0.8	
		Excess sludge-N	3.1	
Effluent-N (mg/L)	4.1	Nitrifiable-N	3.3	3.3
		Unnitrifiable-N	0.8	
Removal Rate	70%			67%