Case Studies on Municipal Wastewater Reclamation and Reuse in China

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ABSTRACT

Water shortage and water environmental pollution have promoted the development of wastewater reclamation and reuse in China in recent yeas. Different treatment processes are employed for this purpose, such as pond-farmland systems using solar radiation as initial energy source treats wastewater at low costs and low energy consumption to realize wastewater reclamation and reuse for irrigation on farmland to provide both water and nutrients. Some full-scale projects on municipal wastewater reclamation mainly based on activated sludge and/or submerged biofilm processes followed by some advanced treatment processes such as filtration and disinfecting, from which the effluent is reused in agriculture, industry and domestic uses except for drinking purpose have been built and put into operation in some water shortage cities, which are described in this paper In some water scarce cities the domestic wastewater reclamation and reuse (dual water system) is employed for a building, a group of buildings or a sub-residential district, whose treatment system consists of Submerged biofilm process, dual-media filter and disinfecting.

Keywords: wastewater reclamation and reuse, Municipal wastewater, Eco-ponds, submerged biofilm process, Dual water pipeline system

INTRODUCTION

The increasing water shortage facing the whole world has promoted the increasing interest in and practice of wastewater reclamation and reuse worldwide, in severe water shortage countries or areas in particular, where the wastewater is treated, reclaimed and reused in industry [RIZA, 1999], agriculture [Pettygrove and Asano, 1985], municipal and domestic purposes [Asano and Levine, 1995 and Asano, et al., 1996]. In some acute water scarce areas or cities the reclaimed wastewater is reused as indirect drinking water through recharge into groundwater [Asano, 1985], or even as direct drinking water [Asano and Tchobanoglous, 1995]. The widespread practice of wastewater reclamation and reuse has alleviated the water resource scarcity and abated water environment pollution significantly.

China is among the most water scarce countries in the world, and the wastewater is regarded as a regenerated or reusable water resource. The wastewater is reclaimed either by conventional treatment technologies like activated sludge and biofilm processes followed by filtration and disinfecting, or by appropriate ones, mainly eco-pond-land systems [Wang, et al., 1999; Wang, et al., 1996 and Zhao and Wang, 1996].

Some eco-pond/land treatment and utilization projects for all the year round wastewater reclamation and reuse have been set up described as follows:

Preliminary treatment → Aerobic –facultative pond→ Storage pond→farmland irrigation project in Qiqihar, Heilongjiang with a treatment capacity of 250,000m^3/d [Wang, 1987; Wang, et. al. 1999];

Preliminary treatment→ anaerobic pond→facultative ponds I, II, III→ polishing/storage pond→farmland irrigation (200ha) with a treatment capacity of 30,000m^3/d in Jiaozhou, Shandong [Wang, et. al.1999].

Preliminary treatment→Advanced facultative ponds→aerated ponds→fish ponds→lotus pond→constructed wetland→reservoir→paddy field irrigation, with a treatment capacity of 100,000m^3/d in Dongying, Shandong [Wangs, 1997];

Preliminary treatment→Intensified Anaerobic ponds→Facultative ponds→Polishing/storage ponds→Farmland irrigation with a treatment capacity of 30,000m^3/d in Jining, Inner-Mongolia [Qi, et. al., 1996];

In two main oil production areas, such as in Shengli Oil Field and Daqing Oil Field, the water is recharged into the oil containing ground layers to improve oil production. However, these two areas are facing serious water shortage for they have not enough available water, therefore, they have to partially depend on wastewater reclamation and reuse as the recharging water after proper treatment.

The effluent from Chunliuhe municipal WWTP employing conventional activated sludge process in Dalian City after filtration is sent to a nearby chemicals factory with a capacity of 10000m^3/d as cooling water. The performance of the wastewater reclamation plant is quite good and well meets the standard of cooling water.

The effluent from the secondary municipal wastewater treatment plant after further treatment and the effluent from the lightly polluted domestic wastewaters or gray water treatment facilities serving a building, a group of buildings or a residential sub-district are sent into the dual water systems for multipurpose uses such as watering of gardens, parks and green belts, washing floor and car, and toilet flushing, which is described in this paper.

GRAY WATER RECLAMATION AND REUSE

In some water scarce cities like Beijing, Shenzhen, Qingdao and Dalian, the gray water reclamation and reuse facilities have been built and operated, which serve a building, a group of buildings or a residential sub-district. The authors have consulted 12 gray water reclamation and reuse projects with a treatment capacity in the range of 100-1500m^3/d, which adopt the following flowchart and processes:

Grey water (light polluted domestic wastewater from washing and bathing)→

Equalizing basin HRT 8-10H → A/O two stage submerged biofilm aeration basin /lamella settler→

↓ClO_2

Dual media filter → Clean water storage basin HRT 8-10 → Reclamation water used for toilet

flushing, green belt watering and car washing.

The gray water treatment facilities installed in Futai Building, Qingdao, shown in Figure 1 and 2.

Figure 1 Integrated treatment tank

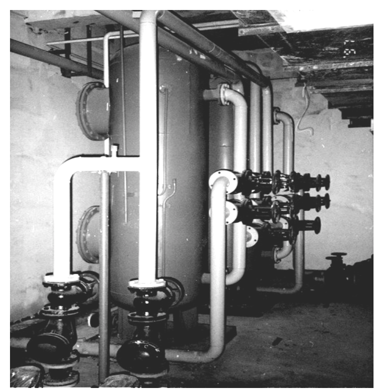

Figure 2 Dual medium filters

The performance of the gray water reclamation facilities is shown in Table 1

Table 1 The performance of the gray water reclamation facilities

Parameters	Raw water	Final effluent	Standard for MDW* use	
			1st Class	2nd Class
Turbidity (NTU)	17.5-38.0	0.3-2.8	5	10
Color (PCU)	28-40	12-15	20	20
SS (mg/l)	15.8-41.3	0.3-3.1	5	10
BOD_5 (mg/l)	15.1-36.3	2.1-5.6	10	10
COD (mg/l)	38.2-82.6	11.2-25.6	50	50
NH_3-N (mg/l)	3.6-12.8	0.3-0.8	10	20
Total hardness (mg$CaCO_3$/l)	115-245	110-210	450	450
DBS (mg/l)	1.6-3.5	0.01-0.1	0.04	0.04
Fe (mg/l)	0.1-0.2	0.01-0.05	0.4	0.4
Mn (mg/l)	0.05-0.1	0.3-0.4	0.1	0.1
Residual Cl_2 (mg/l)		1-3	0.2	0.2
Total coliform (MNP/ml)		3	3	3

* Multipurpose domestic-use water(MDW)

MUNICIPAL WASTEWATER RECLAMATION AND REUSE IN INDUSTRY

Chengfengzhuang Municipal Wastewater Reclamation Plant (WWPR) is situated in Daqing City, Heilongjiang, designed by the authors in 1992, and put into operation in October 1993 with a treatment capacity of 30,000m^3/d, which is the first WWPR in northeast of China, the most cold climate area in China. The average annual temperature is 3.3^oC, the lowest temperature –37.4^oC. The raw water is domestic wastewater from Chengfengzhuang residential area, and mixing with a small amount of industrial wastewater from industries nearby. There is no groundwater and surface water available for domestic use, and hence the long distance diversion project was implemented for solving the water source shortage problem. However, this is only enough for domestic use, but not for industries use, especially for oil exploitation. Therefore, the municipal wastewater is reused for oil exploitation as the only practical and affordable methods. The treatment flowchart is shown as follows:

Raw water→Screens→Aerated grit chambers→Primary settling basins→Equalizing basin→

Anoxic/oxic aeration basins→Secondary settling basins→Micro-flocculation contact filtration by

pressurized fibrous filters→ Filtrate injection into oil bearing ground layers for oil exploitation. The A/O aeration basin and pressurized fibrous filter are shown in Figure 3 and Figure 4.

Figure 3 A/O aeration basin

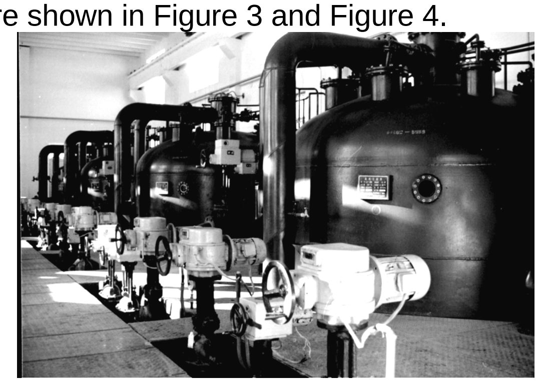

Figure 4 Pressurized fibrous filters for micro-flocculation contact filtration

The design parameters are 0.24kgBOD_5/kgMLSS of sludge load, 8h of hydraulic retention time and 50% of recycling rate. The raw wastewater quality is shown in Table 2.

Table 2 The raw wastewater quality

Parameters	BOD_5	COD_{cr}	NH_3-N	NO_2-N	NO_3-N	TN	TP	SS	pH
Range	36.5-189	52.8-225	3.3-20.5	0-0.178	0-0.176	10.9-39.4	0.99-3.25	145-200	6.6-7.0
Mean	74.4	144.5	13.15	0.020	0.062	20.3	1.89	189	6.8

The WWRP performs very well with a high quality of final filtrate, as shown in Table 3, SS<3mg/l, BOD_5<5mg/l, COD<30mg/l, TN<10mg/l, NH_3-N<2mg/l, and total bacterial number <2X10^3MPN/ml, which is well qualified as injection water for oil exploitation.

Table 3 Performance of Chengfengzhuang WWRP in Secondary and tertiary treatment

Parameters	Raw wastewater	Secondary Effluent	Tertiary Effluent(Filtrate)
pH	7.2-7.5		
SS (mg/l)	43.2-89.5 (68.4)	8.3-28.6 (18.9)	0.5-3.0 (1.6)
BOD_5 (mg/l)	46.8-86.9 (71.2)	2.6-15.3 (11.2)	1.3-6.9 (4.2)
COD (mg/l)	108.5-240.3 (172.5)	25.6-68.4 (45.6)	11.8-31.5 (24.3)
TN (mg/l)	18.4-24.6 (21.5)	11.2-15.6 (13.2)	8.6-10.2 (9.8)
NH_3-N (mg/l)	12.7-18.9 (15.5)	1.8-3.2 (2.6)	1.2-2.3 (1.8)
NO_3-N (mg/l)	0.3-1.5 (0.8)	2.1-4.8 (3.6)	2.2-4.5 (3.2)
TP (mg/l)	3.5-5.8 (4.7)	2.1-4.3 (3.6)	1.0-2.1 (1.6)
Total Bacterial (MPN/ml)	$(2.2\text{-}8.3)\times10^8$	$(1.2\text{-}2.6)\times10^4$	$(1.2\text{-}2.0)\times10^3$

DOMESTIC WASTEWATER RECLAMATION AND REUSE FOR RECREATION

Panyu City is situated in the southeast part of Guangdong Province and in the central area of Pearl River Delta, and located in the East longitude of 113°14'-113°42' and North latitude of 22°26'-23°05'. The annual average atmospheric temperature was 23.5°C, with extremely high temperature of 36.5°C, and extremely low temperature of 5.2°C. The temperature of raw wastewater of the Clifford Villa WWTP was 12-15°C in winter, 23-26°C in summer, and 16-22°C in other seasons, which favors the microbial growth with higher activity in metabolism.

Wastewater Characteristics

The raw wastewater of Clifford Villa WWTP is predominantly domestic, which was monitored by 24h and 4h composite samplings carried out by the on-line automatically sampling devices. The raw water quality adopted in design and the actually analytical data are shown in Table 4 in different columns.

Table 4. Raw wastewater quality of Clifford WWTP

Parameters	Design Concentration (mg/l)	Actual Concentration (mg/l)
COD	200mg/l	57-195 (89)
BOD	100mg/l	29-80 (43)
TP	5	1.3-2.5 (2.2)
TKN	20	11.0-15.0 (13)
SS	120	140-537 (318)

The data obtained in operation are generally lower than that adopted for the design except the TSS concentration, which is significantly higher than that used in design.

The WWRP was commissioned in 1998, the treatment flowchart is described as follows: Fine screen→ Aerated grit chambers→ Submerged biofilm aeration basin→ settling basins with perforated pipe→ adjustable overflow weirs→ effluent to artificial lake for recreational purpose. The pictures of the plant are shown in Figure 5 and 6.


Fig. 5 Overview of the Panyu WWRP **Fig. 6 Submerged biofilm aeration basin**

The novel process of submerged biofilm process developed by the authors and employed in Clifford WWTP has performed very well in the first year-round operation with a mean BOD_5 removal of 97%, COD 84.6% , SS 92 , NH_3-N 98%, and TP 46%, with average effluent BOD_5 1.1mg/l, COD 13.6mg/l, TSS 25mg/l, NH_3-N 0.2mg/l and TP 1.1 mg/l under normal operation conditions, in which the air/water ratio was 2.5:1 and DO in aeration basin 3-5mg/l.[Wang, et.al., 2000]

MUNICIPAL WASTEWATER RECLAMATION AND REUSE FOR AGRICULTURE IRRIGATION

Raw Wastewater Treated by the IIPS

The municipal wastewater to be treated by the integrated intensive pond system in Jining, Inner-Mongolia is a mixed domestic and wastewaters from industries, such as pulp and paper mills, distiller, wool textile factory, tannery, slaughter and combined meat processing factory. The raw mixed wastewater has been sampled 21 times until February 2000 at the inlet of the settling anaerobic pond or at the head of the IIPS and the main pollutants were analyzed by standard methods recommended by Ministry of Construction [Construction standard (Jian bio), 1992]. The analytical results and the analytical method are shown in Table 5.

Table 5 Analytical results of raw wastewater

Parameter	Concentration		Analytical method
	Range	Mean	
pH	7.80-7.85	7.82	pH-meter
SS (mg/L)	121.1-242.3	206.8	Weighing
COD (mg/L)	176.2-289.2	245.4	Dichromate method
BOD_5 (mg/L)	75.2-112.4	84.6	Dilution-seeding method
TN (mg N /L)	35.1-46.8	41.2	Distillation-titration
NH_3-N (mg N /L)	21.8-30.4	25.9	Spectrophotometry
TP (mg P /L)	3.5-6.7	4.8	Spectrophotometry
Total bacteria (MPN/ml)	5.1×10^8-2.3×10^9	1.5×10^9	Plate counting

It was found from the analytical results shown in Table 5 that the raw wastewater is a typical mixed industrial/domestic wastewater with lower BOD_5/COD radio of 0.293-0.355 (mean 0.345), whose biodegradability is lower than that of domestic wastewater usually with a BOD_5/COD radio of 0.5-0.6. Besides, the suspended solids content in the raw wastewater was quite high due to industrial discharges.

In consideration of the above characteristics, the settling and anaerobic ponds were added in the IIPS for the settlement of suspended solids and the improvement of biodegradability of the raw wastewater.

Jining City is situated in mid-southern part of Inner-Mongolian Autonomous Region at East Longitude of 113°03' and north latitude of 40°58' with an average elevation of 1425m. Its mean annual atmospheric temperature is 3.5°C with the highest monthly temperature in July (31.4°C) and lowest in January (-25.6°C). Its annual average wind velocity is 3.7m/s, with higher wind speed of 4.1 - 4.8 m/s in spring and lowers one of 2.5m/s in summer. Annual average precipitation is 298mm. The annual average solar radiation time is 2983 hours, which is favorable for pond performance for more solar energy can be obtained from long time solar radiation.

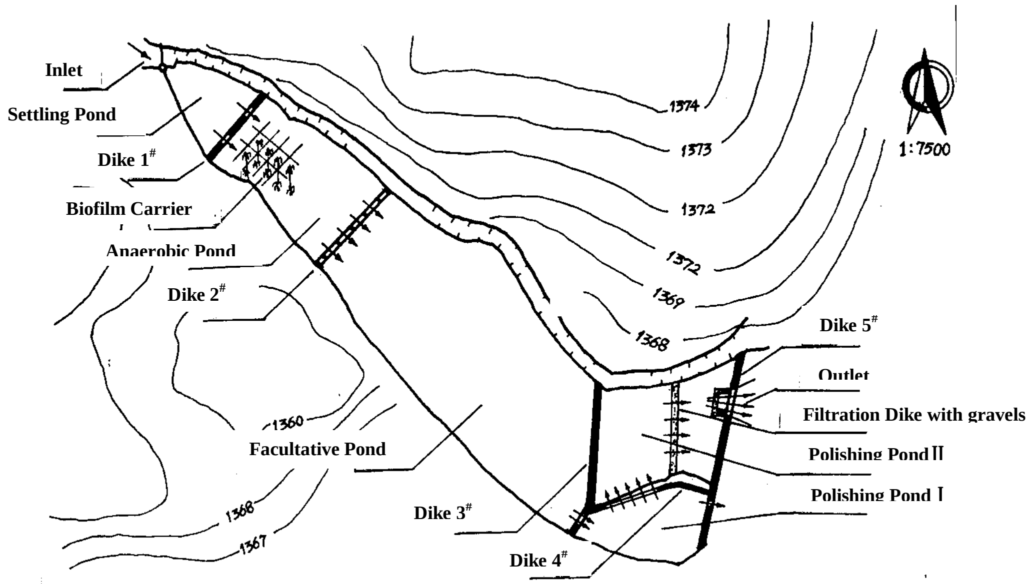

Figure 5 Layout of Integrated Pond System in Jining, Inner-Mongolia

Further Improvement of Effluent by Farmland Irrigation

The total farmland area irrigated with the effluent of the polishing ponds is 1200ha, on which the wheat, maize and vegetables are planted, and the soil of this farmland has inadequate fertility and thus has low yields of agricultural produces. During irrigation the effluent of the polishing ponds provides the farmland with organic substances, nutrients and water, which will improve the soil progressively. The farmland soil is mainly of sand clay and sand loam. The applied hydraulic load was in the range 3000-10000 m^3/ha/an. The removal efficiencies for main pollutants were considerably high due to various mechanisms, such as adsorption, chemical reaction, filtration in soil medium, metabolic degradation and assimilation by soil microorganisms, and uptake by plant root systems. The infiltrate of the irrigated farmland was sampled from monitoring wells (a total of ten wells were installed for sampling). The infiltrates from the wells on vegetable, wheat and maize planted farmlands one time a month (on 15^{th} of each month). The analytical results are shown in Table 6.

It is shown from Table 6, that the farmland irrigation with the effluent of polishing ponds of the integrated intensive pond system is very effective to the further improvement of the treated wastewater with high removal efficiencies for various pollutants, and all the main pollutants concentrations in the infiltrate or percolate of the irrigated farmland well meet the Chinese national standards for effluent of municipal wastewater treatment plant, i.e. SS and BOD_5 20 and 30 mg/L, COD 60 and 100 mg/L, NH_3-N 15 mg/L for 1st and 2nd class effluent quality standards of secondary wastewater treatment plants.

Table 6 Performance of farmland irrigation with effluent of the IIPS *

Plant (hydraulic load) $m^3/m^2 \cdot an$		Wheat (4000-5000)	Maize (3000-4000)	Vegetable (8000-10,000)
SS	Inf1	8.9-41.2 (25.2)		
	Eff1	2-16.2 (8.5)	1.5-5.4 (3.8)	2.5-21.3 (13.4)
BOD_5	Inf1	8.5-43.2 (25.1)		
	Eff1	2.5-18.3 (12.4)	1.8-15.4 (8.7)	2.4-21.6 (13.8)
COD	Inf1	45.6-110.3 (68.2)		
	Eff1	23.4-59.1 (43.2)	18.2-49.1 (36.8)	23.4-68.1 (52.6)
TN	Inf1	12.5-24.6 (18.4)		
	Eff1	5.3-24.6 (10.5)	4.6-12.5 (8.6)	6.8-18.9 (12.4)
NH_3-N	Inf1	1.5-14.6 (7.9)		
	Eff1	0.5-8.2 (4.6)	0.2-6.3 (3.7)	0.8-9.4 (5.2)
TP	Inf1	1.1-2.7		
	Eff1	0.01-0.2	0.01-0.05	0.02-0.08
Total bacteria (MPN/ml)	Inf1	$1.2{\cdot}10^3$-$2.6{\cdot}10^4$		
	Eff1	$2{\cdot}10^2$-$2{\cdot}10^3$	$1.5{\cdot}10^2$-$1{\cdot}10^3$	$0.6{\cdot}10^2$-$2{\cdot}10^3$

* Irrigation mode: spraying irrigation mainly applied on wheat and maize planted farmland, furrow and over/and flow irrigation mainly applied on vegetable farmland.

In plant growing season, the farmland is irrigated many times with a period of 3-30 day (for vegetable-for crops), and the applied irrigation load is 200-1000 m^3/ha.
In winter season the farmland is irrigated 1-3 times for water storage and soil and water conservation of farmland, and the applied hydraulic load is 1000-3000 m^3/ha.
In all the analytical data ranges, the lowest values were obtained in warmest and crop growing period, August or September, and the highest values were obtained in winter season without crop planting.

In addition, it was found that the infiltrate from vegetable planted farmland had worst effluent quality or highest concentrations of SS, BOD, COD, TN, TP and total bacterial number because of highest hydraulic load of 8000-10000 m^3/m^2an applied on this farmland,. The maize planted farmland had the best infiltrate quality, or lowest concentrations of the parameters mentioned above, because of the lowest hydraulic load of 3000-4000 m^3/m^2.an application. And the wheat planted farmland had medium infiltrate quality irrigated with hydraulic load of 4000-5000 m^3/m^2.an. The SS was very efficiently removed by filtration through the soil medium with the infiltrate concentration of 1.5-21.3 (mean 10.5) mg/L, BOD, COD and TN were removed by metabolic degradation and assimilation, adsorption, chemical oxidation, and filtration, and the infiltrate concentrations of BOD_5 were 1.8-21.0 (8.5) mg/L, COD 18.2-68.1 (44.1) mg/L, TN 4.6-18.9 (10.5) mg/L. The TP was removed very efficiently with the infiltrate concentration of 0.02-0.8 (0.2) mg/L, which was mainly due to the formation of hydroxy-apetite $Ca_2(OH)_5(PO_4)_3$ through chemical reaction between calcium present in the soil and the PO_4^{3-} present in the effluent of PPs. The total bacteria are also removed very efficiently through adsorption and filtration as well as predatory effect of organisms in soil. The infiltrate contained total bacterial number in the range of $1x10^2$-$2x10^3$ ($5x10^2$) MPN/ml.

CONCLUSION

As China is facing increasing water resource shortage, the wastewater reclamation and reuse have been being attached major importance for the wastewater has been becoming a regenerated and reusable water resource, and the wastewater reclamation and reuse projects have been increasing in number and expanding in scale in recent years in China, in water acute shortage cities in particular.

A portion of effluent from some municipal WWTPs after further treatment like filtration and disinfection has been reused in industries as cooling water, injection water for oil exploitation and recreation purpose.

In some water shortage cities, dual water system is employed, in which the gray water is collected, treated and the effluent after disinfection is sent for toilet flushing and green belt watering.

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