Reclaimed municipal wastewater – a potential water resource in China

He Pinjing*, L. Phan, Gu Guowei* and G. Hervouet*****

*State Key Laboratory of Pollution Control and Reclamation, School of Environmental Science and Engineering, Tongji University, Shanghai, 200092 China

**Anjou Recherche, 1 place de Turenne, 94417 Saint Maurice Cedex, France

***Anjou Recherche, Chemin de la Digue, BP 76, 78603 Maisons Laffitte Cedex, France

Abstract Due to water resource shortage and socio-economic development within twenty years, China faces serious problems of water supply and water pollution. Several criteria and suitable reclamation processes related to water reuse have been created in China, which are helpful to improve the situation of water scarcity. In the future, reclaimed municipal wastewater reuse will mainly be developed for urban and industrial use. Potential supply quantity of reclaimed water, quality of reclaimed water, and reclamation cost are favorable to potential reuses. Based on further public environmental education, on a relevant development of national and local standards for reclaimed water quality, and on an increase of sanitary rate, more and more planned reclaimed water reuse projects would be expected in China.

Keywords Municipal wastewater; reclaimed municipal wastewater; water resource; water reuse in China; water shortage

Introduction

China is one of the countries in which water resources are lacking. Its mean annual water resource per person is only 2730 m^3/a (Huang, 1998). Moreover, the distribution of surface water resources is uneven in both spatial and temporal scale. More than 50% of runoff volume occurs in summer. The mean annual precipitation is 650 mm, areas with less than 400 mm of mean annual precipitation cover 45% of national territory (Yang, 1997). Due to uneven distribution and shortage of water resource, in some regions, especially the north of China, water resources are more limited and the gap between water demand and water supply is much greater than the average figure for the whole country.

According to statistics, 181 cities of China suffered water shortage in 1983. The amount of water shortage was 450 million tons per year. By 1995 the number of cities that were short of water reached 333 (about 50% of total Chinese cities) and the amount of water shortage increased to 600 million tons per year (Huang, 1998). In rural areas, about 70.0 million people are in a situation of drinking water shortage (Yang, 1997). At the same time, water pollution aggravates the water resource shortage. The investigation results in 1996 showed that the water quality of 33% of 242 surveyed groundwater aquifers and 37% of 329 surveyed surface water sources was not able to meet the requirements of water source standards (Lin, 1998). Monitored results also show that 39% of the main resources which are the great watercourses and the inner land rivers in China are not suitable as raw drinking water sources (Huang, 1998).

Table 1 shows the water resource situation of Hebei province located in the north of China in 1997 (Li, 1999). It appears that the province lacked water volume of 4.09×10^9 m^3/a, which was balanced by over-exploitation of ground water.

On the other hand, recent climatic variation negatively affected the amount and disparity of water resource in time and space in some regions of China. Table 2 shows the water resource changing of Shanxi province located in the north of China in various years (Liang,

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Table 1 Water resource of Hebei province in 1997

Source	Surface water		Groundwater	Total	Demand
	Total	Available	Available	Available	
Value (10^8, m^3/a)	152	80.6	100	180.6	221.5

Table 2 Water resource of Shanxi province in various years

Years		1950s	1970s	1980	1982	1988	1994
Runoff	(10^8, m^3/a)	109.0	117.0	116.8	114.0	108.6	97.9
Groundwater	(10^8, m^3/a)	–	–	–	27.8	29.5	31.1
Total	(10^8, m^3/a)	–	–	–	141.8	138.1	129.0

1998). It is clear that the water resource shortage has become a limiting factor for further development in China.

The reuse of reclaimed municipal wastewater has numerous benefits, such as saving fresh water resource, mitigating the conflict of water demand among agriculture, industry and city, alleviating the pollution of water bodies, etc (Tselentis *et al.*, 1996). It also has far-reaching significance in preventing environmental pollution (Shelef, 1991). The practice of planned water reuse will give a chance to improve the serious situation of water shortage in China.

Status of reclaimed municipal wastewater reuse in China

National and local standards concerning water reuse

"To prevent water pollution and to economize on water resources" has been declared as a national policy by the Chinese government. In 1986, the National EPA of China issued the Technical Policy of Water Pollution and Control (revised in 1996), that included recommendations concerning water reuse like:

- strengthening management of water resource and water use, pricing of the water resource exploitation;
- promoting the planned reuse of reclaimed municipal wastewater, especially in northern regions of China;
- considering the reuse of reclaimed municipal wastewater while the sewage system and treatment works are planed and designed;
- establishing stringent and systematic water quality standards for wastewater reuse.

Table 3 to Table 5 summarize some typical reclaimed municipal wastewater quality standards for different uses (Zhou, 1996a).

These regulations cover the main potential non-potable uses of reclaimed water. Direct or indirect potable reuses are not recommended in China now. The relevant criteria are much more stringent than the related recommended guidelines for wastewater reuse published by the World Health Organization (WHO) in 1989 (WHO, 1989) but comparable to the related guidelines published by the U.S. Environmental Protection Agency (EPA) in 1992 (U.S. EPA, 1992).

Amount of municipal wastewater resource

The output of municipal wastewater was 3.6×10^{10} m^3/a and the related treatment capacity was 3.2×10^9 m^3/a in China in 1995 (Zhou, 1996b). Therefore about 8.5% municipal wastewater had been treated and about 64% of the treated wastewater were undergoing a secondary treatment process. Table 6 shows the secondary treatment processes now available in China and their treatment capacity in details.

Table 3 Water quality criteria for irrigation of agriculture.[1](mg/L unless specified otherwise)

pH	Salinity	Chloride	Sulfide	Hg	Cd[2]	As[2]
5.5–8.5	1000–2000	200	1	0.001	0.002–0.005	0.005–0.1
Cr^{6+}	**Pb**	**Cu**	**Zn**	**Se**	**CN[2]**	**F[2]**
0.1	0.5	1.0	2.0	0.002	0.5–1.0	2.0–3.0
Oil	**Volatile phenol[2]**	**Benzene[2]**	**Trichloridealdehyde[3]**	**Allyl aldehyde**	**Ba[3]**	**Total coliform**
5.0–10.0	1.0–3.0	2.5–5.0	0.5–1.0	0.5	1.0–2.0	1000 (count/L)

(1) China national regulations (GB5084-85, issued in 1985), except vegetables whether eaten raw or cooked
(2) According to soil condition
(3) According to crop type

Table 4 Reclaimed water quality criteria for industry.[1](mg/L unless specified otherwise)

Item	CFCS-93[2] (1993)	Dalian city[3] (1992)	Taiyuan city[3] (1993)	Xian City[3] (1995)
Turbidity (NTU)	5	3–4	–	5
SS	10	6	15	5
BOD_5	10	5	20	5
COD	75	60	50	40
Chloride	300	220	–	300
NH_4-N	10–20[4]	–	5	5
TDS	1000	900	–	1000
Alkalinity	350	260	–	350
pH	6.5–9.0	7–8	–	6–8
Color(units)	–	36–46	–	30
Chlorine residual	0.1–0.2	0.4	–	0.2
Mn	0.2	0.1	–	0.1
LAS	–	–	–	0.5
Hardness	450	280	–	450
Conductivity	–	–	–	3000
Bacteria (count/ml)	1.0×10^6	5.0×10^5	–	5.0×10^5
Total coliform(count/L)	10,000	–	–	3,000

(1) For industrial cooling water & general process water uses
(2) China national suggested regulations
(3) Cities in north region of China, local regulations
(4) According to season

It is demonstrated that the potential municipal wastewater resource that could be reclaimed for reuse was 3.6×10^{10} m^3/a, which reached 20% of the total amount of industrial and urban water consumption in China in 1995 (Huang, 1998). The amount of secondary effluent, which is suitable for selected reuses, is 2.0×10^9 m^3/a. Compared with the amount of potential municipal wastewater resource, two results can be concluded. One is that with the increase of sanitary rate in China, more and more reclaimed municipal wastewater resource will be realized. The other is that the secondary effluent now available is equal to 9.2% of urban drinking water supply, which will make up for 35% of the gap between water demand and water supply in the cities of China (Yang, 1997).

Uses of reclaimed water and relevant processes

Agricultural irrigation. Agricultural irrigation practices with municipal wastewater have existed in China since years 1950. But agricultural use of municipal wastewater was often

Table 5 Reclaimed water quality criteria for urban use.(1)(mg/Lunless specified otherwise)

Item	Min. of Construction(2) (1991) Toilet flushing	Min. of Construction(2) (1991) Car washing and road flushing	Taian city(3) (1994)	Tianjin city(3) (1989)
Turbidity (NTU)	10	5	10	10
TDS	1200	1000	–	–
SS	10	5	10	10
Color(units)	30	30	30	30
pH	6.5–9.0	5.0–9.0	5.8–8.0	6.5–8.5
BOD_5	10	10	10	10
COD	50	50	–	50
NH_4-N	20	10	3	10–20(4)
Hardness	450	450	–	450
Chloride	350	300	–	350
LAS	1.0	0.5	–	0.5
Fe	0.4	0.4	–	0.4
Mn	0.1	0.1	–	0.1
Chlorine residual	0.2	0.2	0.4	0.2
Total coliform (count/L)	3	3	3	3

(1) Urban green field, recreational waters, car & street clean, etc
(2) Regulations issued by Ministry of Construction of China
(3) Cities in north region of China, local regulations
(4) According to season

Table 6 Processes of municipal sewage treatment work in China (1995)

Process type	Number of treatment works	Treatment volume 10^4, m^3/d
Air blow aeration	54	340.5
Biological attached aeration	4	5.7
Biological filter	1	0.44
Jet aeration	11	29.5
Surface aeration	11	25.6
Oxidation ditch	11	45.7
Oxidation pond	11	25.0
A/O	5	9.8
A^2/O	4	27.4
Hydrolysis aeration	2	4.5
A-B	4	32.5
Biological disc	2	0.8
SBR	1	2.5
Advanced treatment	6	6.3
Total 1	27	556.3

perceived as a method of wastewater disposal. Most of the sewage used for agricultural irrigation was lacking necessary treatment, which resulted in serious pollution of irrigated agricultural land. The investigated results showed in 1994 that the quality of 85% of sewage used for agricultural irrigation cannot meet the requirements of the criteria listed in Table 3 and 7000 km^2 irrigated agricultural land are polluted in China (Li, 1998).

Agricultural irrigation has constituted more than 65% of water resource usage in China (Huang, 1998). Agricultural irrigation with reclaimed water will greatly improve the situation of the water shortage in China. Chinese water supply board encourages irrigating with secondary effluent (most of the secondary effluent's quality can meet the requirements of the criteria listed in Table 3.) instead of raw municipal wastewater. At the same time, a sewage reclamation process as shown in Figure 1 is recommended, which combines ecosystem treatment of municipal wastewater and reclaimed water agricultural reuse together (Wang, 1985).

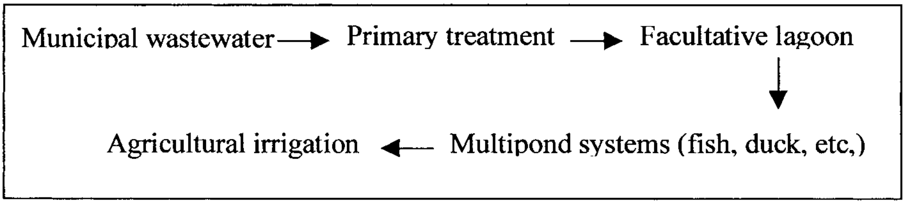

Figure 1 Recommended process of sewage eco-system treatment and agricultural irrigation with reclaimed water

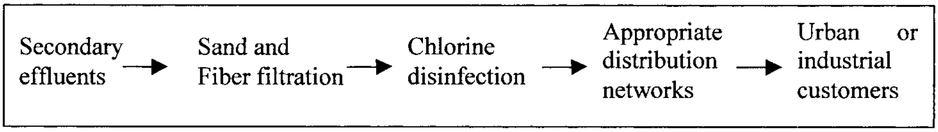

Figure 2 Typical process for municipal wastewater reclamation

Industrial and urban reuse. Reclaimed municipal wastewater has been used by industry for the following in China (Ma, 1997): indirect cooling water, water-washing process, wet-scrubber, etc. The guidelines related to those uses are listed in Table 4.

With the development of urbanization, urban uses (such as urban irrigation of land-scaped areas, road flushing, impoundments, fire demand, car washing, construction sites, and toilet flushing) of reclaimed water represent the fastest growing reuse options in China (Wei, 1995). The guidelines related to those uses are listed in Table 5.

Some projects of industrial and urban reuse of reclaimed municipal wastewater have been realized or planned, which are summarized in Table 7 (Zhou, 1996a). The typical reclamation process is shown in Figure 2 in which the reclaimed water is pumped through appropriate distribution networks to customers. The wastewater reclamation process shown in Figure 2 is basically consistent with the available reclamation processes developed internationally (Odendaal, 1991). The quality of reclaimed water can meet the requirements of non-potable reuses (Okun, 1991), which provides a sound technical support for the developing of reclaimed municipal wastewater reuse in China.

More than 90% of the projects showed in Table 7 were realized after 1995 and about 90% of them were located in the north regions of China. Although the scales of those projects are small relatively, the driving force of developing reclaimed water reuse is active and impressive.

In general, the quality of reclaimed water through the reclamation process can meet the requirements showed in Table 4 and 5. In summer, $N\text{-}NH_4$ values of some projects' effluents cannot meet the requirements (Zou, 1997), which is related to no denitrification process of secondary treatment processes in China. With the improving of wastewater treatment level, the problem can be solved.

Table 7 Reclaimed municipal wastewater reuse practices in China (1996)

User	Plant number	Volume of reclaimed water 10^4, m^3/d
Industry	26	123.55*
Urban	3	5.0
Industry and urban**	5	9.5

*Some of the water reclaimed from industrial effluents
**Projects served for both industrial and urban customers

Whatever the intended use, bacteriological contamination must be limited, the acceptable level varying with the usage. Historically, gaseous chlorine has served as the principal disinfectant in wastewater reclamation plants. The low cost of gaseous chlorine coupled with its efficacy in pathogen destruction has represented major advantages versus alternate chemical disinfectants or techniques. However, in the last five years, safety concerns and restrictions regarding the storage and handling of hazardous materials as defined under the 1991 Uniform Fire Code have prompted a re-evaluation of gaseous chlorine use (Asano, 1998). As an alternative, the use of ultraviolet (UV) irradiation and ozonation for wastewater disinfection is receiving increased attention (Baron, 1997). The new options of disinfection would greatly improve the quality of reclaimed water.

The maintenance and operational cost of the reclamation process showed in Figure 2 is 0.25–0.40 yuan/m^3 (1.0 yuan = 0.12 U.S. $) and the price of the reclaimed water (including M&O cost, capital investment cost, and distribution management cost) is 0.60 yuan/m^3 (Ma, 1997; Zou, 1997).

Potentiality and feasibility of reclaimed water reuse in China

Demand for reclaimed water

According to the statistics investigated (Wei, 1995; Ma, 1997), 55% amount of industrial water consumption and 14% amount of urban water consumption can be supplied by reclaimed water. The investigated results from the drinking water customers of Chinese Cities show that the amount of industrial water consumption and urban water consumption is 46% and 54% of total drinking water supply respectively (Huang, 1998). It is concluded that more than 33% amount of total urban water consumption can be supplied by reclaimed municipal wastewater. It is estimated that total urban water consumption of China Cities in year 2000 is 8.6×10^{10} m^3/a (Nia, 1995) and therefore the potential demand of reclaimed water is 2.8×10^{10} m^3/a.

Possibility of reclaimed water supply

According to the planned statistics, the output of municipal wastewater is 4.0×10^{10} m^3/a and the wastewater treatment ratio is 20–30% in 2000 (Nia, 1995). If secondary treatment ratio keeps constant (64%), it can be expected that there will be $5.1–7.7 \times 10^9$ m^3/a of secondary effluents that are suitable for reuse. It can supply 18–28% of total urban water consumption in 2000. About 50% of China Cities are short of water and 16% of China Cities are in the serious situation of water shortage (most of them are located in the north regions of China. Huang, 1998). It can be concluded that the relation between the amount of potential reclaimed water demand and its supply is favorable.

Cost comparison

The price of drinking water is higher than 0.80 yn/m^3 now in China (subsided by government), which is higher than the price of reclaimed municipal wastewater. The price relation between reclaimed water and drinking water (price of reclaimed water/price of drinking water = 0.75) is not directly regulated by the actual costs of assets and operation in China. But it is similar to the price relation (price of reclaimed water/price of drinking water = 0.81) developed in some marketing countries (Maeda, *et al.*, 1996). The compared results show that there are favorable economic conditions for the development of reclaimed municipal wastewater reuse in China.

With the development of urbanization, the costs of intake works, manufacturing process of drinking water and wastewater disposal will increase gradually (Cui, 1998), which will make reclaimed water reuse more cost-effective.

Conclusion

Reclaimed municipal wastewater reuse, as a sustainable secondary urban water resource, is a cost-effective measure for solving water shortage and water pollution in China. Several criteria and suitable reclamation processes related to water reuses have been created. Reclaimed municipal wastewater could supply 18–28% amount of total urban water consumption in year 2000. The effluent quality of recommended reclamation process could meet the requirements of the criteria of selected uses. Reclaimed municipal wastewater reuse has become a cost-effective option comparing with other alternatives in China.

To develop planned practices of reclaimed water reuse, further systematic efforts should be focused on the following fields:

- public environment and water resource protection education should be intensified;
- on the basis of more and more reuse practices, relevant national/local guidelines should be systematically implemented;
- in the consideration of urbanization development, urban water supply networks, drainage works, wastewater disposal facilities and water reuse facilities should be planned at the same time, especially in north regions of China;
- more attention should be paid to increasing the wastewater treatment ratio (sanitary rate), and to the selection of wastewater treatment process that should meet the needs of planned water reuses.

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