한국습지학회지 제9권 제1호, 2007년 4월 (47 - 60)

Status, Trend and Strategy on Municipal Wastewater Management in China

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Abstrcat : The rapid development of economy in China at the expense of consuming huge amount of energy and resources, water resource in particular, which has resulted in the production and discharge of increasing amount of wastewater to the water environment. In order to effectively control the increasing water pollution trend, the State Council has stipulated that all the cities with population over 500,000 should reach wastewater treatment rate of 60% by 2005, and all the cities should reach the rate of 60% by 2010, of which Capital Beijing and all the province capital cities and important tourism cities should reach 70% then. By the end of 2005, of the 661 cities in China, 393 have built and operated municipal wastewater treatments with a total number of 790 sets, total treatment capacity of $80.91\times106\ m^3/d$ and total treatment rate of > 48%. Other 73 cities have started the construction of municipal wastewater treatment plants, and other 168 cities have started to prepare, planning and design of wastewater treatment plants. Most of municipal wastewater treatment plants in big cities in China operate normally and perform well with good quality of effluent in terms of wastewater treatment train, but the sewage sludge treatment is usually poor with big problems. It has been found that the small scale WWTPs using activated sludge process in the towns are usually operated and maintained abnormally because of lack of fund, skilled operators and energy. It is therefore suggested that the small scale MWWTPs in small cities and towns adopt appropriate technologies, of which the most available ones are multi-stage ponds, constructed wetlands and the combination of them for further purification and reuse of treated wastewater.

Keywords : Activated sludge, Appropriate technology, China, Ponds, Wetland, Wastewater treatment, WWTP

Status and trend of water pollution and control in China

The rapid development of economy in China at the expense of consuming huge amount of energy and resources, water resource in particular, which has resulted in the production and discharge of increasing amount of wastewater to the water environment, which has in turn caused deterioration of water environment and water resource. According to the Bulletin on Environment in China in 2004 published by China National Environmental Protection Administration in 2005, of the 412 monitored sections of the 7 large water systems, the 1-3 grade, 4-5grade and worse than 5 grade surface fresh water areas account for 41.8%, 30.3% and 27.9% respectively. In general, the water quality is comparable to 2003, of which both Pearl and Yangze Rivers are better, while liaohe, Huaihe, Yellow and Songhua Rivers are worse and haihe is the worst, with ammonia nitrogen, BOD_5, COD_{Mn} and petroleum as main pollutants.

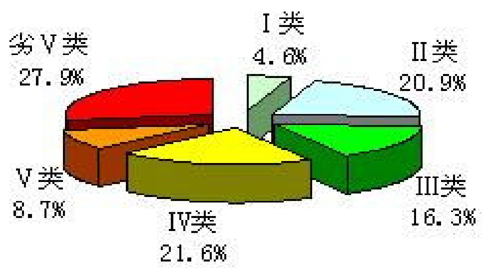

Fig. 1. Water Quality grade distribution of 7 Water Systems

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According to statistics of the 246 monitoring stations in the coastal sea areas in 2004, 1st-2nd grade sea water area accounted for 49.6%, 3rd grade-15.4%, lower than that in 2003 by 4.4%; 4th grade and worse than 4th grade~35.6%, higher than 2003 by 5%. Both Yellow sea and South Sea had better quality, with 1st-2nd grade sea water area percentage of 83.4% and 77.8% respectively.

In order to effectively control the increasing water pollution trend, the State Council has stipulated that all the cities with population over 500,000 should reach wastewater treatment rate of 60% by 2005, and all the cities should reach the rate of 60% by 2010, of which Capital Beijing and all the province capital cities and important tourism cities should reach 70% then. In most priority places, like Beijing to host Olympic 2008, South four-lakes Watershed as a major water resource trans- portation project of East Line Water Diversion Project from South to North, and Three Gorges Reservoir, for the purpose of guarantee good water quality of their respective water systems, the wastewater treatment rate should reach as high as 90% or more.. Besides, as integrated pollution control

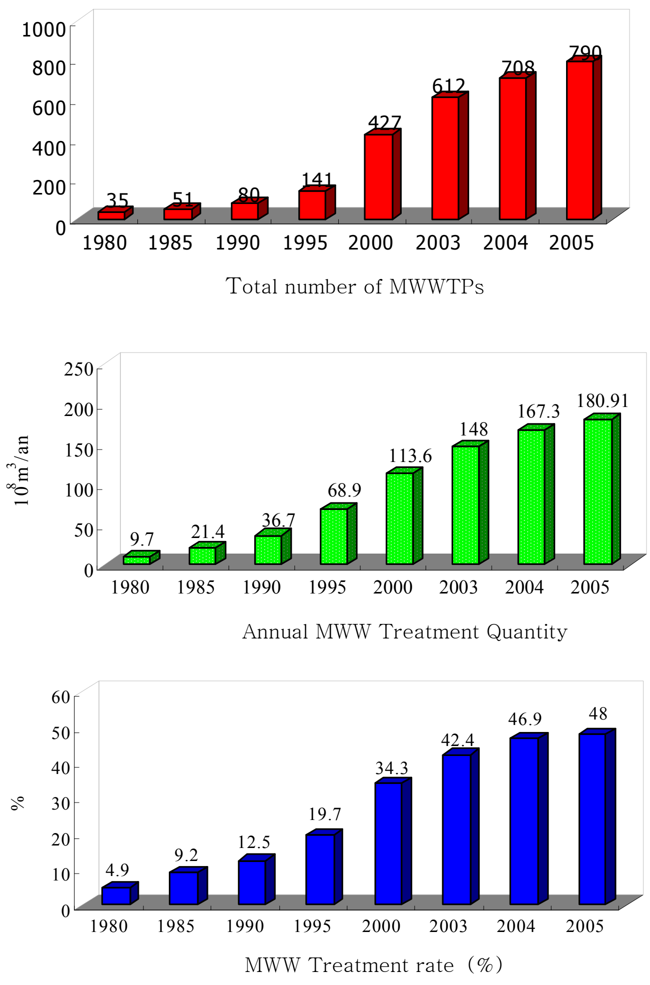


Fig. 2. Development trend of MWW in China

Table 1. Summary of wastewater treatment in China and its main Cities and provinces

Location	Total Waste water. amount ($10^4\times$ m^3/y)	Total Numb. of M-WWTP	Treatment. Capacity, ($10^4\times m^3$/d)	Total number of second. .-tertiary MWWTP	Treatment. Capacity Of other treat. plants, ($10^4\times m^3$/d)	Total Treat. Capacity ($10^4\times m^3$/d)	Total treat. Quantity ($10^4\times m^3$/yr)	Treat. Rate (%)
China	3564600	708	4912..2	598	2475.07	7387.2	1672966	46.9
Beijing	102018	31	272.3	25	-	-	55019	53.9
Tianjin	55222.6	12	93.2	12	-	-	29639	53.7
Shanghai	205400	28	442.6	36	10	452.6	154193.4	75.1
Jiangsu Provoince	318074	99	414.5	97	603.2	1017.7	241965	76.1
Zhejiang Province	176804	35	289.8	30	213.7	503.5	94479	53.4
Shandong Province	190559	75	422.3	64	87.8	510.1	98698	51.8
Guangdong Province	469777	66	543.1	61	-	543.1	158337	33.7*

* Industrial wastewater treatment is not included, and the datum is low.

measures, the pollution sources should be controlled more strictly and effectively by means of using cleaner production processes instead of original processes with heavy pollution, abandoning some enterprises with heavy pollution to environment, such as small pulp and paper mills, chemical fertilizer and metal processing factories, and ecological remediation and improvement of the polluted and deteriorated lakes, reservoirs and rivers with the help of various measures such as pond, constructed wetland, pre-positioned reservoirs, on-site purification by the addition of special high-efficiency bacterial strains, aeration and package of biofilm carriers (WANG Baozhen *et al.*, 2004).

However, of various water pollution control measures, the most important and most effective one is the construction and put into operation of wastewater treatment plants as many as possible, which play the most important and decisive role in pollution load abatement. Therefore, the governments at different levels have attached major importance to them. The variation of total number of municipal wastewater treatment plants, total treatment capacity and treatment rate with year in China is shown in Figure 3, and the summary of wastewater treatment in China and her main municipalities and provinces is shown in Table 1.

By the end of 2005, of the 661 cities in China, 393 have built and operated municipal wastewater treatments with a total number of 790 sets, total treatment capacity of 80.91×10^6 m^3/d and total treatment rate of > 48%. Other 73 cities have started the construction of municipal wastewater treatment plants, and other 168 cities have started to prepare, planning and design of wastewater treatment plants.

Main problems on wastewater treatment in China

* The abated total pollution load by the existing wastewater treatment plants is a far cry from the increased total pollution load resulted from the rapid development of economy, thus causing a net pollution load augment to the water environment.

* The operation of wastewater treatment plants is only capable of abating point source pollution, but not effective to remove non-point source pollution, such as those from run-off of farmland and atmosphere precipitation, which usually contain organic pollutants, synthetic fertilizers (nutrients), pesticide, herbicides and volatile heavy metals, which are more difficult to deal with. For instance, in the United States, the municipal wastewater treatment rate is over 80%, and industrial wastewater have adopted best available technologies (BAT) and some have even reached zero discharge. However, the water environment is still polluted to some extent, of which the pollution load from non-point sources accounts for 70% of the total. In the South four-lakes watershed as the main hydraulic project of East Line Water Diversion Project from South to North, the various pollutant loads from non-point sources such as farmland runoff, scattered living points, piggeries, potteries and cattle breeding houses are described as follows: COD accounting for 15% of the total; TN and TP 48%, from which it is evident that in this watershed even though the wastewater treatment plants remove nitrogen and phosphorus at 100%, the TN and TP remain in the watershed is still about 50% of the total nutrient load. In some water systems like water net regions in Jiangsu and Zhejiang Provinces, the total N and P loads from non-point sources are even higher than those from point sources. For example, the ammonia nitrogen concentration is usually in the range of 5-10 mg/L, and in some cases exceeded 10 mg/L, which is mainly resulted from runoff of farmland with over-fertilization.

* Of the existing wastewater treatment plants, a part of them are not in normal operation and maintenance. As regards industrial wastewater treatment plants, although the total treatment capacity has reached 90% of the total wastewater production and discharge quantity, unfortunately, of which only 1/3 are in normal operation, another 1/3 in abnormal operation and the last 1/3 not in operation, which aremainly caused by financial or technical reasons. Some factories have to spend a huge fund to maintain normal operation of their respective wastewater treatment plants, i.e. millions or even dozen millions Yuan (RMB), which will compensate a major part or even the whole of their annual financial income, which hardly make the plants operate sustainable. Besides, some kinds of industrial wastewaters are very difficult to treat, and some adopted processes are not effective to treat them, which make the built and operated wastewater treatment plants perform poor with final effluent exceeding discharge standards concerned.

* Of the existing municipal wastewater treatment plants, those built and commissioned in recent five years in big cities, most are operated normally and perform well with good quality of final effluent, which well meets the newly implemented effluent pollutants emission standards 1A, 1B or 2nd class of municipal wastewater treatment plants (GB18918-2002). However, in the small cities and towns, only few can operate normally with effluent meeting discharge standards, which are mainly caused by the lack of fund to maintain normal operation.

Some counties and small cities located in the regions of Huaihe River pollution control region, pollution control region of East Line Water Diversion Project and pollution control belt along Bohai Sea (so called Clean Waters and Blue Sky Project), have the right to get financial support from the central government for the construction of their municipal wastewater-treatment plants. However, they can not get financial support for operation of the built wastewater treatment plants. As a result, most of the them are not put into operation or not in normal operation just because of the shortage of operation fund, and the local wastewater treatment charge from the residents is too low (0.2-0.3 Yuan/m^3) to maintain normal operation of the MWWTPs that in fact need operation fee of 0.6-0.8 Yuan/m^3 treated wastewater.

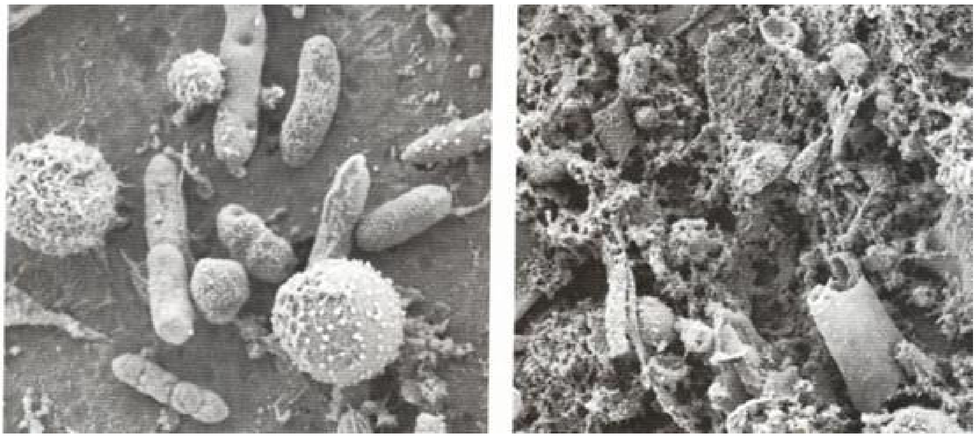
Improvement of municipal wastewater treatment in big cities in China

Sewage sludge treatment, utilization and disposal

Most of municipal wastewater treatment plants in big cities in China operate normally and perform well with good quality of effluent in terms of wastewater treatment train, but the sewage sludge treatment is usually poor with big problems. For example, most digesters perform poor, and the disposal and utilization of dewatered sludge are also problematic and unreasonable. Therefore, it is suggested that :in all the wastewater treatment plants employing such processes as A/A/O (A^2/O), A/O, modified A^2/O like UCT, modified UCT, Johnnesburg process with pre-anoxic zone, SBR and its various modified processes like CAST, UNITANK, ICCEAS, MSBR(CSBR) (Wang B.Z *et al.*, 2003; Wang Baozhen *et al.*, 2000), or other activated sludge and biofilm processes with anaerobic and anoxiczones, remove sludge digesters, because the active sludge or/and biofilm have conducted acidification, hydrolysis and gasification through methane fermentation while flowing through the anaerobic and anoxic zones of the bioreactors, which result in the digestion and stabilization of sludge and biofilm, thus making the discharged excess active sludge exhibit good settling and dewatering characteristics, which can be thickened and dewatered directly with no problems. For examples, in Ruhleben Municipal Wastewater Treatment Plant in Berlin, Germany, in Shatian and Liede Municipal Wastewater Treatment Plants in Guangzhou (Canton), Guangdong, in Luofang, Yantian, Henggang and Huawei (Banxuegang) Municipal WWTPs in Shenzhen City, Guangdong, and in Zhen'an MWWTP in Foshan, Guangdong, there are no digesters at all, and the thickening and dewatering of their wasted excess sludge perform very well.

Adopt novel processes with much less excess sludge production in the newly designed WWTPs. For the WWTPS using active sludge process, among the available novel processes with less excess sludge production are Biologic process developed in U.K. (Pujor., 2000) and the MicroSludge Process developed in Canada. The former process uses a specially designed venture injector that makes complete mixing between the micro-air-bubbles and fine sludge particles caused by serious turbulence in it, which results in the effective degradation of suspended organic sludge particles with sharp sludge reduction.

In the Canadian MicroSludge Process, the microbial cells present in the sludge are destroyed and liquefied by means of alkaline and high pressure, and the such processed sludge is sent into digesters to conduct anaerobic



Sludge before treatment (left) Sludge after treatment

Fig. 3. Different micro-structure of the sludge before and after MicroSludge Treatment

digestion. The original sludge and that after MicroSludge treatment have complete different micro-structures as shown by electro-micro-scopic scanning in Figure 4.

A full scale experiment was carried out in Chilliwack MWWTP in Vancouver, Canada, in which the mixed sludge of raw sludge (65%) and activated sludge (35%) was used. As a result, the average volatile biomass reduced 78%, and that of activated sludge reduced 95%.

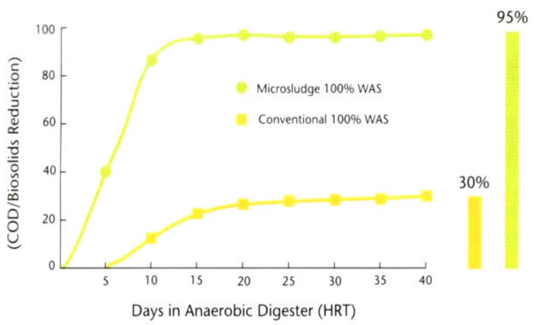


Fig. 4. Variation of volatile biosolid reduction with operation time

* A WWTP using biofilm process usually produces much less biosolid or excess sludge, i.e. 0.1-0.2 g excess biosolid/g removed BOD_5 compared to 0.5-0.6 g excess AS/g removed BOD_5. The WWTPs using submerged fixed biofilm process developed by the authors produce only 1/10 or even less excess biosolid that of activated sludge process. For example, the MWWTP in Clifford Residential Sub-district in Panyu District, Guangzhou City consulted by the authors has operated for 9 years without discharge of any excess sludge from the system. The MWWTPs using hybrid SBF-AS process developed by the authors like those in Dong'e and Guangrao Counties, Shandong Province has operated for 3-4 years with good performance and much less excess sludge discharge, only 1-2 times a month with less quantity, which are mainly applied on the green belts in the WWTP sites as organic fertilizer.

It is therefore suggested that the new WWTPs adopt the newest generation of biofilm processes, such as BAF(Biological aerated filters) like Biofor (Payraudeau *et al.*, 2001) and Biostyr (OTV., 2001) developed by France, Linpor developed by Germany and fixed biofilm processes like aqualution developed in German y, and the hybrid SBF－AS process developed by the authors, which have numerous advantages over activated sludge process, such as much shorter HRT, some only 3~4 h vs. 8~10 h for activated sludge process for organic and nutrients removal, which resulting in sharp reduction of needed footprint of the WWTP, only 1/2-1/3 that of WWTP using AS process.. Much less excess sludge production and wastage save both the capital and operation /maintenance costs in sludge treatment and disposal.

Omit primary Settling Basins while treating low strength wastewater

There are many municipal wastewater treatment plants in China treating influent with low organic concentration, i.e. $BOD_5 \leq 100mg/L$ or even less in the range of 50-80mg/L, in contrast with influent BOD_5 of 200-350 of most MWWTPs abroad, which is mainly ascribed to the incompleteness of sewerage systems with serious infiltration of groundwater, and some municipal WWTPs receiveinfluent from streams rather than sewers, thus treating diluted wastewater with sharp variation of pollutants concentrations with flow rate of the stream, which impact the operational performance of the WWTPs seriously, for those using AS process and oxidation ditch in particular, in which it is hardly to maintain adequate activated sludge concentration (MLVSS) for normal operation.

The enforcement of the new and much stricter MWWTPs effluent pollutants emission standards(GB 18918-2002) since October 2004 have made all the existing municipal WWTPs designed according to the original standard (GB-8978-1996) facing new task of upgrading their treatment performance, particularly the N and P removals. And the new and to-be-expanded or -modified municipal WWTPs should be designed according to the new standard to make their effluent pollutants well meet the respective standard value.

In order to improve the performance of municipal WWTPs, it is necessary to take effective measures as follows:

- Complete sewerage system serving a municipal WWTP to make it receive real wastewater rather than mixed wastewater diluted by groundwater or/and surface water;

- For the MWWTPs receiving influent with BOD_5 less than 200mg/L, for the purpose of efficient removal of TN and TP that need sufficient amount of carbon source to carry out dentrification and enhanced biological P removal, it is preferable to omit primary settling basin that usually remove 30-40% COD and BOD_5, which will result in the shortage of carbon source fordenitrification and EBPR in the post-positioned bioreactors. Many MWWTPs receiving low BOD strength influent have to stop the operation of primary settling basins and send the effluent from grit chambers directly into the bioreactors through a bypass line, to supply sufficient amount of carbon source for TN and TP removal. And many newly built MWWTPs have omitted primary settling basins in their treatment flowsheets and systems, such as Zhen'an MWWTP in Foshan City, Henggang MWWTP, Huawei MWWTP, Luofang MWWTP and Yantian MWWTP in Shenzhen City, Guangdong, and MWWTPs in Dong'e, Guangrao and Kenli Counties, Shandong, using combined SBF-AS process consulted by the authors, which perform quite well in terms of TN and TP removal because of adequate carbon source supply.

Of course, to guarantee normal operation, in the WWTPs using BAF (Biostyr or /and Biofor) it is necessary to build advanced primary treatment facilities like ACTIFLO (enhanced chemical primary settling basins with micro-sand recirculation) to make BAFs receive low TSS (≤30mg/L)of influent. In the case of using combined system of high rate AS process followed by BAF, it is no need for enhanced primary settling basins in the system.

UV disinfection instead of chlorination

Although in most municipal WWTPs in Europe (especially in Germany) and Canada the disinfection of effluent by chlorination have been abandoned for many years for the protection of water environment, the aquatic eco-systems in particular, most of MWWTPs even newly built ones in China still follow the American practice to use chlorination for disinfection, whose main drawbacks are described as follows:

- The chlorination in the presence of free chlorine and hypochlorous acid is only capable of killing pathogenic bacteria, but incapable of deactivating pathogenic viruses and protozoa like giardium cysts and cryptosporidium oocysts.

- For the secondary effluent with BOD_5≥ 20mgt/L, COD≥50mg/L and TSS≥20mg/L, chlorination will form significant amount of mutagenic and carcinogenic by-products like THMs, which will pollute the receiving waters, and make the aquatic food chains concentrate the toxic and harmful by-products step by step from lower tropic level to higher ones. According to the surveys in the United States, of the chlorinated organic compounds present in drinking source water, about 80% are from chlorination of secondary effluent, which will be harmful to human health through drinking and/or consumption of aquatic produces through food chains concentration. The residual free chlorine and chlorinated by-products once discharged to the receiving waters with effluent will also harmful and toxic to aquatic lives like fish, shrimp and clam.

- It is therefore suggested for the MWWTPs discharging their effluents to the centralized water supply sources or waters for fish protection that UV disinfection be used instead of chlorination. For the advanced secondary WWTPs with very low TSS, COD and BOD5 concentrations, say less than 10mg/L, 40mg/L and 10 mg/L, it is very effective and efficient to disinfect the effluent due to deep penetration of UV light (H. Abdennaceur *et al.*, 2000).

- In the case of wastewater reclamation plants, as the effluent is reused for various purposes, it is preferable to disinfect it by UV first and then followed by chlorination to make the product water contain certain amount of residual free chlorine to prevent the regrowth of bacteria in the transporting and distribution systems.

Improvement of preliminary treatment facilities

There is a common drawback in most MWWTPs in China, i.e. the incompleteness of preliminary treatment units including screens and grit chambers, which makes them poor performance with large amount of coarse solid wastes and inorganic particles entering into the post-positioned units like primary settling basins or bioreactors without them, thus resulting in over-accumulation of sediment on their bottoms. A MWWTP using vertical rotary screens with insufficient capacity, which resulted in sediment accumulation depth in Stage A aeration basin of AB process reach 1-1.5m in its front part, which covered all the diffusers completely, and the aeration basin had to stop operation for removing and cleaning the sediment, as shown in Figure 7.

For complete removal of coarse solid wastes, it is preferable to use rotary drum type of fine screens with 1-2mm wide openings. It has been found that of various types of grit chambers the aerated grit chambers with horizontal rotary flow and scum removalzones are most effective, which can most efficiently remove inorganic particles and scum caused by grease, oil and suspended solids. Furthermore, the effluent from the aeration grit chambers contain certain DO, which is helpful to form pre-anoxic zone in front of the post-positioned bioreactors for more efficient enhanced biological phosphorus removal by denitrified PAOs (LI Jun *et al.*, 2001).

Fig. 7. Accumulation of sediment in aeration basin due to poor performance of grit chambers

High loading rate bio-processes dominate the trend of large scale MWWTPs

The land area available for the construction of large scalemunicipal WWTPs in municipalities and big cities has become less and less, and many planned to build MWWTPs facing the most headache problem is very difficult to find out adequate area of land to build a WWTP using conventional or modified AS process., which has forced the owners of the WWTP to find alternative process with much higher loading rates (including hydraulic, organic and nutrients ones) and much smaller footprint, which has promoted the development of intensified bio-processes with much higher hydraulic, organic and nutrient loading rate in comparison with AS processes, such as BAF including Biostyr, Biofor and Biobead which mostly have organic (BOD_5)loading rate of 2~5kg/m^3.d, or 4~10-fold that of CAS or MCA process, which means that the land area needed to build a WWTP using BAF process account for only 1/4~1/10 that of a WWTP using CAS or MAS process.

Therefore, the number of WWTPs using BAF process is on the increase in China in recent years. Among such municipal wastewater treatment plants are Malanhe MWWTP (Biofor process) with a treatment capacity of 120,000m^3/d in Dalian City, Xian'nvhe MWWTP (C-Biofor+N-Biofor process and 320,000m^3/d) in Shenyang City, Liaoning; Pingzhou MWWTP (Biostyr process and 100,000m^3/d) in Foshan City, East Suburb MWWTP (C-Biofor+N-Biofor process and 40,000m^3/d) in Xinhui City, Guangdong; Maidao MWWTP (Biostyr process and 200,000m^3/d) in Qingdao, Shandong; and Handan MWWTP (biostyr process and 100,00m^3/d) in Handan City, Hebei. In addition, there are about ten industrial WWTPs using BAF process (either Bioform or Bio carbon process) have been built and in operation.

Another high loading rate bio-process is MBBR including Linpor developed by Dr Morper, Linde AG. Germany and Caldnes developed by Caldnes Co. Norway, which are the combined or hybrid BF-AS processes with different types of biofilm carriers, i.e. small cubes of plastic foam for Linpor and various forms (multi-surface hollow ball, cylinder and gear) PE carriers for Caldnes process (SHI, L *et al.*, 2004). Both the MBBR processes have much higher biomass measured as equivalent MLSS and MLVSS that is the sum of real MLSS and MLVSS in suspension form and biofilm attached to the surface of carriers, which usually have the equivalent MLSS concentration of 10-20g/L, or 4-~8- fold that of CAS or MAS process. Therefore, the MBBR process is most helpful to the increase of treatment capacity and/or upgrading treatment performance, or to the improvement of performance with higher quality effluent to meet the increasing and stricter new standards or regulations. Many existing MWWTPs and IWWTPs in Europe and North America operating at over loads with poor quality of effluent have improved operational performance substantially with an increase in treatment capacity by 1~2 times, and/or much better quality of effluent that well meets the new and stricter standards for various effluent pollutants.

Liuchunhe MWWTP in Dalian City took the lead to use Linpor process to expand treatment capacity of its existing treatment units (120,000m3/d), and more MWWTPs and IWWTP have adopted Caldnes MBBR process by using domestic PE multi-surface hollow balls (d50~100mm). For examples, The WWTP (40,000m^3/d)in Huangpu Economic Development Zone, Guangzhou City has used MBBR to treat municipal wastewater (mixed domestic and industrial waster); Binhe MWWTP in Shenzhen City is to start the construction for modification of the existing oxidation ditches (250,000m^3/d) with MBBR process by means of putting in them PE multi-surface hollow ballsas biofilm carrier, thus forming the combined or hybrid AS-moving bed (or fluidized) biofilm system, which will increase the treatment capacity and upgrade the treatment grade with much higher quality of effluent, especially in NH3-N, TN and TP removal, with the final effluent well meeting 1A or 1B standard of GB18918-2002 in contrast with that worse than 2ndclass standards at present. As a result, the receiving waters - Shenzhen River will be improved remarkably due to the significant abatement of discharged organic load resulted from such a modification in the future.

Appropriate technologies employed in WWTPs in small cities and towns

Since 90s last Century, there are numerous municipal WWTPs have been built, under construction or in design in small cities and towns with a treatment capacity of 20,000-50,000m^3/d in general, which employ various processes such as activated sludge, oxidation ditch, biofilm, ponds and constructed wetlands, or the combination of them according to the local conditions and specific requirements for effluent discharge. It has been found that the small scale WWTPs using activated sludge process in the towns are usually operated and maintained abnormally because of lack of fund, skilled operators and energy. In addition, the sharp fluctuation of influent flow rate and quality along with peak loading rates often make the performance unstable and unsatisfactory.

It is therefore suggested that the small scale MWWTPs in small cities and towns adopt appropriate technologies, of whichthe most available ones are multi-stage ponds, constructed wetlands and the combination of them for further purification and reuse of treated wastewater.

Multi-stage ponds and multi-stage ponds-C.W. systems

The typical multi-stage pond system generally consists of anaerobic ponds, facultative ponds, aeration ponds and polishing ponds(aerobic ponds) is very efficient to treat municipal wastewater with high removal efficiencies for various pollutants including organic substances, nutrients, refractory organic compounds, heavy metals and pathogenic microorganisms (Peng, J.F *et al.*, 2004; SHI, L *et al.*, 2004). If fish ponds, duck/geese ponds and/or aquatic vegetation ponds are added into the multi-stage ponds system, the eco-pond system is thus formed, in which the organic and nutrient substrates are removed through their transformation and transfer in the food chains present in the eco-ponds, in which the decomposers like bacteria and fungi degrade organic substances into CO_2, H_2O, NH_3-N and PO_4-P, which as inorganic nutrients promote the growth ofalgae and other aquatic plants through photosynthesis, which in turn serve foodstuffs for consumers at different trophic levels, such as zooplankton, fish, clam, shrimp, snail, duck and geese. As a result, the wastewater is well purified with high quality of final effluent that can be reused multi-purposely while the organics and nutrients being converted into valuable resources in forms of fish, duck/geese, aquatic vegetables, etc.

The so-called natural or ecological treatment systems have also the advantages of low capital and operation/maintenance cost, i.e. 300-500 Yuan/(m^3/d) in contrast with 1000-1200yuan/(m^3/d) for WWTP using AC process for capital cost, and 0.05-0.1Yuan/m^3versus 0.6-0.8 yuan/m^3 for WWTP with AS process for O/M costs (Osald, W.J., 1991; Osald, W.J., 1995).

The well designed and operated multi-stage pond systems and the combined multi-stage ponds-constructed wetland system can perform very well with high quality of final effluent well meeting the standards 1A or 1B of GB18918-2002 that can be reused multi-purposely, which, however, perform poor in cold seasons in northern areas of China, with final effluent only meeting 2nd or 3rd class standards. In order to upgrade the performance of eco-systems, it is necessary to intensify the unit ponds by means of packing biofilm carriers to increase biomass in them and thus improve their performance. As an alternative, in winter season the unqualified effluent is sent into storage ponds or lagoons for temperate storage and further purification in warm seasons next year, and then discharged to the receiving waters within their self-purification capacity.

Zero sludge discharge systems.

It should be noted that the multi-pond system consisting of preliminary treatment units like screens and grit chambers and anaerobic or facultative ponds with sludge fermentation pits on their bottoms as pre-positioned unit ponds, aeration ponds and polishing (or maturation ponds) is a zero sludge discharge system, in which all the organic sediments on the bottoms (mainly in the fermentation pits) of the anaerobic or/and facultative ponds are degraded into volatile organic acids, methane, CO_2, H_2, N_2, etc., or in other words, are converted into liquid and gaseous forms, i.e. liquefaction and gasification under anaerobic conditions. The gaseous products finally escape from the system to the atmosphere, while the liquid products are finally degraded into CO_2, H_2O, NH_3-N, NO_3-N and PO_4^{3-}, and some of them participate in the photosynthesis of algae and other aquatic plants as carbon source and inorganic nutrients, and then transformed and converted into protoplasm of new cells of algae and macro-aquatic plants. All of the municipal and industrial WWTPs using multi-stage ponds and the combined multi-stage ponds-constructed wetland systems consulted by the authors perform very well in terms of no sludge discharge from the systems for 5-10 years since their putting into operation, which makes the operation and maintenance of the eco-systems cost–effective, energy saving, simple and efficient (Osald, W.J., 1991; Osald, W.J., 1995).

Wastewater treatment and utilization eco-pond system, with the advantages such as low capital and O/M costs, easy to operate and maintain and high treatment efficiency, can not only effectively protect and improve the water environment but also achieve to waterresource recycle and utilization. Furthermore, if the wastewater treatment and utilization system combined with local agriculture, fish culture, forestry and stockbreeding, the water as well as the nutrient (such as nitrogen and phosphorus) recycle would be realized (Knight, R.L *et al.*, 2000).

High removal efficiency can be achieved in multistage pond system including treatment pond and utilization pond and multistage wetland system in which by initial solar energy initial driving force and food chain's transferring and transforming in eco-ponds system, the organic and nutrient substance contained in wastewater can be removed effectively, and by aquatic vegetable planting, fish farming, duck raising, etc., the wastewater can be resourced.

In north cold area, the eco-systems for wastewater treatment and utilization perform poor in cold seasons, and hence the storage pond is needed for the storage of effluent in winter season, or this can be solved by the addition of a simple secondary treatment units, preferably submerged biofilm process(either fixed biofilm- or moving bed biofilm reactors-MBBR) with shorter HRT of 4-6h., which in cooperation with the eco-system will guarantee the final effluent in cold climate to meet 1B or 2nd class standard of GB18918-2002.

Realization of integrated river basin management

China should learn the integrated river basin management from England, U.K., Germany and the U.S. which have rich and advanced experience in this respect, particularly Ruhr River Association (Ruhrverband) in Germany, which has the most successful and advanced experience in the integrated river basin management both in water quality and water quantity management by means of various available measures with the help of the water management power and right assigned by the Nordrhein-Westfahren State Government where River Ruhr is located to manage all the issues concerning water pollution control and water resources protection, utilization and sustainable development.

- Build and manage complete sewerage systems by the respective communities in the Ruhr river basin.

- The Ruhr River Association is responsible for the planning, design, construction and operation/maintenance of all the wastewater treatment plants including municipal and industrial wastewater treatment facilities in the river basin by the optimized wastewater and sludge treatment strategies and options in consideration of the local conditions. In most majority of its municipal wastewater treatment plants advanced secondary treatment processes are adopted with MAS process for biological nitrogen removal through nitrification and denitrification and chemical phosphorus removal by ferric chloride.

- About 40% MWWTPs using multi-cell polishing ponds for tertiary treatment or further purification of the secondary effluent with very high quality of final effluent such as TSS and $BOD_5 \leq 5mg/L$, $COD \leq 30mg/L$, $NH_3\text{-}N \leq 2mg/L$, $TP \leq 1mg/L$ and both the total bacterial number and total coliform number reached 6log removal.

- The Ruhr River association has built and operated a centralized sewage dewatering plant using completely automatically operatingcomprised plate-frame dewatering machines, which produce high solid content dewatered sludge (40%-50% solid content), which is much easier and cost-effectively to be disposed in the landfill in contrast with that by belt or centrifugal dewatering machines due to much less volume of dry solid waste.

- Some key or priority water pollution control projects in China like South Four-lake Watershed and three gorge Reservoir Basin should take the lead establish the water basin management associations or authorities having authorized power and right to manage all issues concerning water pollution control and water resource protection, utilization and sustainable development of their respective water basins.

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