The effect of ecological restoration based artificial reoxygenation on water quality Improvement of urban river water

Nan Luo1,2, Changying Hu2, Weiyu Li2, Tao Xie2,3, HuiLi Gong1* and Rui Liu2*

1College of Resource Environment and Tourism, Capital Normal University, Beijing, 100037, China; 2China Sciences MapUniverse Technology Co., Ltd (MAPUNI), Beijing, 100101, China; 3Beijing Zhongkeyaqing Environmental Protection Technology Co., Ltd, Beijing, 100101, China

Abstract. Urban river pollution sources such as Combined Sewer Overflows (CSOs) or Illegally Discharging of Industrial Waste (IDIW) are generally hard to control on-site and cause serious water quality degradation problems across the nation. Therefore developing effective in-situ remediation techniques for urban rivers is of great interest. In this research we combined river reoxygenation, artificial floating island and microbial agents technologies (O-AFI-MA) to developed a comprehensive in-situ remediation technique and obtained water quality data from Sunhe River case study to evaluate its effectiveness. Our discovery indicates that the O-AFI-MA technique effectively improves water quality by reducing chemical oxygen demand (COD), total phosphorous (TP), ammonium nitrogen (NH4-N) level by 45.9%, 61.31, 7.66% respectively and our technique enhances the natural degradation rate by raising the dissolved oxygen (DO) level from 2.8mg/L to 10mg/L upstream. The case study suggests that the sediment accumulation from CSOs and the subsequent internal source release causes great water quality degradation for Sunhe River. We also tested combinatory microbial agents, physical adsorption and multimedia bio-filter bed technologies independently on site to improve the ammonium nitrogen and total phosphorous removal rate of our technique, and the multimedia bio-filter bed is found to be most effective.

1 Introduction

The treatment of Black and odorous water body has become an important part of improving urban living environment for local people. In order to quickly eliminate the black and odorous problems, traditional engineering methods such as sediment dredging, water diversion dilution, enhanced flocculation and other technologies are often used [1-5]. However the lack of complete sewage interception often renders the treatment process fruitless even with a great amount of manpower, resources and government funds invested. Sewage problems are prone to rebound after treatment and flooding increasingly becomes a threat [6-8]. The downside of "engineering water control" is becoming more severe in the new era.

Sunhe River is a typical Black-odor River Water Body located in Beijing. It is a beheaded stream with domestic sewage replacing its source. The water of Sunhe River appears black with violent odor emitting all the year round and the aquatic lifeforms in the river have all deceased, leaving the water untreated poses a threat to health condition of all people living in the vicinity of the river. In this study, Sunhe River was selected as the research subject for urban river ecological restoration. Through the comprehensive technology of artificial aeration [9], artificial floating island [10, 11] and microbial agents [12] (O-AFI-MA), the effect and influence of the O-AFI-MA on Black and odorous Water Body treatment were investigated.

2 The general situation of Sunhe River

Sunhe River is a tributary of Wenyu River that originates from the town of Sunhe at Chaoyang District, Beijing. The river connects Sunhe Community Health Center (upstream) with Beidian sewage treatment plant (downstream) from southwest to northeast along Jinmi Road. Sunhe river stream is converged with sewage collected from Kangying community at Beidian sewage treatment plant near the west side of Binhe Road and discharged into Wenyu River after being treated. The overall river course of Sunhe River is shown in Figure 1.

The source of the Sunhe River is the sewage originated from the sewage culvert under the bridge across the junction between Xidian Middle Street and Huangkang Road in the town of Sunhe. The volumetric flow rate is

*Corresponding author. Tel.: +886 01068901196; E-mail address: gonghl@263.net.

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about 4000-6000 m³/d. The total length of the open channel of Sunhe River is about 2.3km, with a width ranging from 2.5m to 4m, and water depth from about 20cm to 40cm. For the middle reaches of Sunhe River, both side of riverbanks are covered with natural vegetation with only a few rain vents scattered along the river, and the point source pollution inflow here is less severe comparing to other parts of the river. For lower reaches of Sunhe River, under the bridge across Shun Huang Road, another stream of sewage discharges directly into the river. The overall water quality of the river drastically exceeds the Environmental Quality Standards for Surface Water (BG3838/2002) issued by the government. Almost all parts of the river is contaminated by dense domestic sewage. This makes Sunhe River a typical black and odorous water body with milky white appearance and pungent odor.

Table 1. Raw water quality of Sunhe River

| NO. | Sampling location                     | COD(mg/L) | NH₄⁺-N (mg/L) | TP (mg/L) | DO (mg/L) |
|-----|--------------------------------------|-----------|---------------|-----------|-----------|
| 1   | Upper reaches sewage culvert         | 104.02    | 13.99         | 1.32      | 0.69      |
| 2   | Package sewage treatment plant outlet | 97.71     | 12.51         | 0.42      | 0.65      |

3 Experimental materials and methods

3.1 Construction plan of Sunhe River Ecological Restoration Project

3.1.1 Overall design of Sunhe River Ecological Restoration Project

The project focuses on improving the water quality of over a 1849 meters length of the river between the flocculation package treatment plant (Point 0+078) to the bridge across Shunhuang Road (Point 1+927), and ultimately improve water quality of the Wenyu River.

For this project a water treatment station was set at Point 0+078 (50m north from the flocculation package treatment plant) based on the overall water quality, pollution-load and reoxygenation equipment’s processing capacity. The treatment station is equipped with a set of reoxygenation equipment that is capable of processing over 2400m³ of sewage water per day by utilizing oxygen (93% pure) generated on-site. A supplementary cofferdam was also built between point 0+078 and 0+300 to form the water distribution area with an average depth of 1.4m. The water distribution area was designed with a retention time of around 2 hours to provide sufficient time for O-AFI-MA treatment process to take effect.

Between points 0+300 to 0+781, a 500 meters long artificial floating island (AFI) reaction zone was to be set up, and a subsequent combinatory microbial agents were “seeded” at point 0+300. The seeding process rapidly set up water-purifying microbiome beneath AFIs by embedding carbon fiber-biofilm-media with selectively cultured bacteria. The layout of the project design is shown in Figure 3.

To set up the correct microbiome for water purification, the water treatment station was installed and operated for one full month to revert the original anaerobic environment via reoxygenation. This reversion was followed by the introducing of AFIs that are packed with fresh carbon nanofiber contact media to grow both anaerobic and aerobic bio-film. To further enhance the purification capabilities of AFIs, several dosage of electively cultured microbial agents were added one week...
3.1.2 Restoration technique

This project adopts the O-AFI-MA technology provided by Beijing Zhongkeyuqing Environmental Protection Technology Co., Ltd. The main components of O-AFI-MA includes artificial reoxygenation equipment, carbon-nanofiber artificial floating island, and microbial agents (as shown in Figure 4). A national patent was also granted for O-AFI-MA technique (patent: ZL201620509104.X).

3.1.2.1 Artificial reoxygenation technology (O)

In this project, the high-efficiency reoxygenation equipment (model: ZKYQ-100) is used as the artificial reoxygenation equipment. A set of submersible pumps are used to transfer water from downstream of the river to high-efficiency reoxygenation equipment and evenly diffused into upstream of the river after being treated with a perforated piping apparatus. The high-efficiency reoxygenation equipment was designed with capability of injecting 20~30mg/L dissolved oxygen for every cubic meter water treated. This is achieved by adopting 93% pure oxygen source (PSA generator) in combining with an oxygen-water mixing chamber specifically designed to break down bulky water cluster at molecular level. The schematic design is shown in Figure 5.

3.1.2.2 Carbon nanofiber AFI

A 500m long carbon nanofiber artificial floating island arrays were installed downstream of the artificial reoxygenation equipment. Since the impact of storm water discharged during summer might cause major damage, AFIs are equipped with high density PVC floating frames anchored by stainless steel wires. The length of carbon nanofiber bio-film media was carefully measured to avoid rapture damage caused by dragging (Figure 6). The carbon nanofiber used in this project was developed by the Water Treatment Engineering Center of Beijing University of Chemical Technology as high-performance bio film growth media [13]. Mechanical and biological properties of carbon nanofiber are shown in Table 2.

| Tensile strength (GPa) | Tensile modulus (GPa) | Elongation at break (%) | Diameter (μm) | Body density (g/cm³) | Line density (g/Km) | Carbon content (%) | Specific surface area (㎡/m³) |
|-----------------------|-----------------------|------------------------|---------------|----------------------|---------------------|------------------|--------------------------|
| 4.92                  | 240                   | 2.1                    | 7             | 1.80                 | 880                 | 93.2             | 54000                    |

3.1.2.3 Microbial agents (MA)

The microbial agents were used to reconstruct the river microbiome for the purposes of nitrification, phosphate removal and general water purification. This purpose is achieved by immobilizing microorganisms via thick layer
of biofilm on surface of carbon nanofiber. The microbial agents used in the project are BZT type nitrification, water purification as well as Biquing microbial agents provided by Shandong Bio-form Co., Ltd.

3.2 Mechanism study

To achieve ammonium nitrogen removal goal of this project, a pilot study was carried out before the project study and a water purification mechanism was purposed based on experimental facts. The pilot study includes several aspects which are the effect of endogenous release from river sediment on the water quality of Sunhe River, the effect of different microbial agent dosage on the improvement of river water quality, and compared several methods to efficiently remove ammonium nitrogen from Sunhe River.

3.2.1 Experiment effect of river protists and sediments on Sunhe water quality

The Sediment Releasing Experiment is conducted under a semi-enclosed environment where only compressed air is introduced to avoid external-source microbe contamination. Two 18-liter plastic buckets were used to extract 15L of water near the submerged pump within reoxygenation reaction zone. 2L of river sediment was added only to the second bucket. Both buckets were stored under shade near the river to maintain a steady temperature (as shown in Figure 7). The dissolved oxygen concentration was kept above 5mg/L by air-diffuser aeration without disrupting the sediments added to simulate a dissolved oxygen concentration that is similar to what was found in oxygenated Sunhe River. We sample each sites first at 5:00 and then at around 15:00 during summer season on daily basis to study the effect of temperature variation. We evaluate each sample’s CODCr, NH4+-N, TP by employing the National standard techniques. Based on evaluation results, we examine samples microscopically for Protozoa and microbial activities and conduct correlated Sediment Releasing Capacity Experiments to detect endogenous pollution.

Figure 7. Schematic diagram of river water and sediment test

3.2.2 Pilot study of NH4+-N removal in Sunhe River

3.2.2.1 Nitrification microbial agents

About 15L of the river water is placed in a plastic bucket and an air-diffuser aeration apparatus was introduced to maintain a 5-9mg/L dissolved oxygen level. Nitrobacteria and ammonia nitrogen agents (BZT type) are added to the bucket in batches. We collect water samples every day to test each sample’s CODCr, NH4+-N and TP. The experimental design of NH4+-N removal study is shown in Table 3.

Table 3. Microbial inoculum for removal of ammonium nitrogen

| Time  | Nitrifying bacteria (gram) | Ammonia nitrogen bacteria (gram) | Sampling time |
|-------|---------------------------|---------------------------------|---------------|
| Day 1 | 2.5                       | 2.5                             | 15:30         |
| Day 2 | 2.5                       | 2.5                             | 15:30         |
| Day 3 | 0                         | 0                               | 15:00         |
| Day 4 | 1                         | 1                               | 15:00         |
| Day 5 | 0                         | 0                               | 15:30         |
| Day 6 | 0                         | 0                               | 15:30         |
| Day 7 | 0                         | 0                               | 15:00         |

3.2.2.2 NH4+-N absorption experiment

Clinoptilolite, Montmorillonite, pearl dust and activated carbon were selected as ammonium-nitrogen adsorption materials [14]. The powder was weighed 2g, 5g and 10g and placed in a sterilized conical bottle. Then the powder was added into 250 mL NH4Cl solution (conc. 30mg/L). The reaction mixture was evenly mixed by using an electric shaker setting up at 25°C 100 rpm. The supernatant was sampled every half an hour to detect any change of ammonium-nitrogen.

Ammonium iron-exchange affinity is directly evaluated by parallel absorption tests, where the absorbent capacity of Clinoptilolite, Montmorillonite, pearl dust, activated carbon, etc. as ammonium (NH4+-N) absorbent are measured under standard experimental procedures. After an initial screening, testing candidates with promising capabilities are further tested under a progressively increasing ammonium concentration.

3.2.2.3 Multi-media biological filter

Based on the previous experimental results, the multi-media biological filter technology is selected to achieve intended NH4+-N removal rate. Multimedia biofilter technology utilizes polyurethane (PU) carrier with microscopic porous embedded with selectively cultured microbial agents. When the PU carrier is suspended in water, microorganisms can rapidly exchange oxygen and other substances with the surrounding environment. This process effectively lowers the CODCr, NH4+-N and TP concentration of water surrounding the PU carrier. This can achieved by a combination effect of organic media adsorption, microbial oxidation, fixation and biological extraction. The effluent with different hydraulic retention time (HRT) and aeration time was collected and tested. The water quality and DOM characterization data were obtained to determine NH4+-N removal rate. Schematic design of multi-media biological filter is shown in Figure 8.
3.3 Testing instruments

The testing instruments and methods used in this experiment for water quality analysis are shown in the Table

| index | Methods                        | Instrumentation                  | manufacture |
|-------|--------------------------------|----------------------------------|-------------|
| NH₄⁺-N | Nessler’s reagent spectrophotometry | Lianhua 5B-3 (B) multiple speed measuring instrument | Lianhua     |
|       | Potassium dichromate method     | Lianhua 5B-3 (B) multiple speed measuring instrument | Lianhua     |
| COD   | Molybdenum antimony photometer | Lianhua 5B-3 (B) multiple speed measuring instrument | Lianhua     |
| TP    | Microorganism spectrophotometric method | BD-SW4001 biometer microscope | Boschda     |
| DO    | Spectrophotometric method       | AZ8403 portable dissolved oxygen instrument | AZ          |

4 Results and discussion

4.1 Water Quality Improvement Results of Sunhe River Ecological Restoration Project

The ecological restoration project was first started on January 17, 2018. After two months of trial operation on March 15, 2018, it was officially put into operation. After more than six months of ecosystem reconstruction, the water quality of Sunhe River has been significantly improved. A significant improvement of water quality was observed. The transparency was increased from 10cm to an average of 60cm and peaking at 80cm, and the growth of benthic plants were observed. Water quality data of samples collected from upper to lower reaches of Sunhe River shows a solid removal of Organic, phosphoric and ammonic pollutant. The ecological restoration project effectively lowered COD₄₅ by an average of 45.9% over six months period. The average removal rate of TP over the last six months was 61.31%, and the average removal rate of NH₄⁺-N over the last six months was 7.66% (as is shown in Figures 9 to 10).

We compared the average water quality data collected from upper reaches sewage culvert (the culvert), reoxygenation equipment diffusing pipe (water distribution pipe), submerged pump (water pump) and downstream of cofferdam for over six months. The results clearly showed that reoxygenation equipment has effectively raised dissolved oxygen level. The dissolved oxygen concentration of the culvert raise from 2.8 mg/L to 10 mg/L, and the dissolved oxygen for 2km downstream is stabilized at about 4mg/L (as is shown in Figure 11). Because the water quality of distribution pipe is of minor difference compare to that of flocculation package treatment plant effluent, the water sample at the distribution pipe is treated as if it was taken form the culvert. From the figure 12, it can be seen that the flocculation-sedimentation process contributed the most to TP removal, with an average rate of 68.5%. Flocculation-sedimentation process has limited effect on COD₄₅ and NH₄⁺-N removal, with a removal rate of 6.05% and 11.64% respectively. It can also be seen from the trendline of diagram that TP and NH₄⁺-N first rise than fall as we move from the water distribution pipe to the Sunhe River downstream. This result appeared intriguing since the middle reaches of Sunhe river is mostly surrounded by natural environment where little to none human activities including the drainage of rain and sewage can be found nearby. This result suggested a possibility that endogenous release form river sediment might be related
to the fall and rise of TP and NH$_4^+$-N from upstream to 
downstream. Please refer to 4.2 to see the detailed analysis.

The COD$_{cr}$ removal rate for each individual process of 
O-AFIs-MA technique can be deducted using our 
experimental data. Flocculation-sedimentation process 
has limited effect on COD$_{cr}$ reduction, which accounts 
for only 12% of the total decrease. The carbon nanofiber AFIs 
also has limited effect to COD$_{cr}$ reduction, which accounts 
for 9% of the total decrease. The reoxygenation equipment 
contributed the most to the COD$_{cr}$ reduction, which 
accounts for 79% of the total decrease. By excluding the 
effect of flocculation-sedimentation process the net 
reduction rate of Sunhe River ecological restoration 
process is equal to 88% of the total COD$_{cr}$ reduction rate. 

Literature review of similar projects shows a 20 to 30% 
reduction for both COD$_{cr}$ and NH$_4^+$-N [15] while our 
project data, in comparison, showed a much-lower 4.6% 
COD$_{cr}$ removal rate and little to none NH$_4^+$-N removal. 
We observed that the effluent of flocculation-sedimentation 
process contains considerable amount of 
flocs (≥ 5% in volume) because of inappropriate operation 
such as filter press failure. This leaking problem enabled 
high molecular weight PAC and PAM to form a dense 
coating over the natural sediments causing long-term 
detrimental effects to various aquatic lifeforms. This 
significantly limited the oxygen exchange between water 
and sediments therefore drastically decreases the 
population of benthic and water-born microorganisms in 
Sunhe River and with decreased microorganisms 
population the net weight of biofilm grew in carbon 
nanofiber AFIs was also decreased significantly. The 
viscosity of biofilm is very low and has an iconic black 
color. The results of microscopic examination of fibrous 
fillers can be seen (as shown in Figure 14) that the 
bacterial micelles are loosely packed with almost no 
filamentous bacteria present. Chlorella and nematodes in 
the bacterial micelles also indicates that the self-
purification capability under the effect of leaking flocs is 
significantly reduced. Such environment in river can lead 
to low microbial activity and decrease of self-purification 
capability for carbon fiber carriers [16].

4.2 Effect of endogenous release of river 
sediment on water quality

The static sediment release experiment suggested that the 
river sediment has a continuous endogenous releasing 
effect. As shown in Figure 15, the endogenous release of 
COD$_{cr}$, NH$_4^+$-N and TP are severe over the first 58 hours. 
It can be seen from the diagram that after 106 hours of 
static intermittent aeration, NH$_4^+$-N and TP in the raw 
water with no sediments added were reduced over time. The 
COD$_{cr}$ level was slightly increased, but eventually 
stabilized. This result suggests that the ecological 
restoration project has successfully recovered the self-
purification capabilities of Sunhe River. The second 
experiment was conducted with sediments and the 
experimental result suggested that COD$_{cr}$, NH$_4^+$-N and TP 
increased significantly in comparison to first experiment 
which involved little sediments. After 106 hours of 
experiment, the final COD$_{cr}$ level reached 400% of the 
starting value. The final NH$_4^+$-N level also reached 230% 
of the starting value after the experiment with a net 
increase of 7.011mg/L. The final TP level reached 115% 
of the starting value after the experiment, with a net
increase of 0.378mg/L.

Figure 15. Results of endogenous release experiment

Significant traces of algae growth in all test samples can be discovered from the 58th on-going hour of experiment where sediments were added. With this active algae growth-decay cycle observed. We reasoned that trace of Hormospores present in the tested sediment eventually caused that blue and green algae to thrive in an enclosed environment. In-situ studies also shows an increasing trend of algae colonies density peaking at 15:00 of a day and minimizing at 5:00 of a day. This trend is discovered by mapping the water quality trend line over a whole day period. We discovered that the total nitrogen and total phosphorous increases via hypoxia digestion in sediments shortly after algae decaying when the surroundings environment thermally plummets. However, the total nitrogen and total phosphorous decreases sharply when the surrounding is best suited for algae growth. This "rapid growth-and-decay cycle of algae", in addition to heavy endogenous releasing significantly deteriorates the water quality in such a way that releasing rate of pollutants eventually surpasses the degradation rate. This evidently makes the downstream pollutant concentrations stands above the upstream concentrations despite the fact that water was treated upstream with ex-situ remediation techniques followed by an in-situ remediation in the river [17].

4.3 Discussion of different NH₄⁺-N removal technologies for Sunhe River

4.3.1 NH₄⁺-N removal effect by Microbial inoculum

A small-scale ammonium nitrogen removal test with microbial inoculum was conducted with a significant NH₄⁺-N removal effect (Figure 16). However microbial inoculum agent only works on static water body. Under normal circumstances with flowing water, this method has a very limited effect. This is mainly due to the fact that microbial agents, after applying to river, requires long time to take effect. Microbial inoculum eventually becomes relevant after those microorganisms become the dominant species after competing with wild type. For carbon nanofiber carrier microbial inoculum gradually takes occupancy from the wild type.

4.3.2 NH₄⁺-N removal effect by adsorption

As can be seen from Figure 17, Clinoptilolite has the best removal effect on NH₄⁺-N, followed by montmorillonite, and pearl dust has the worst adsorption. The ammonia adsorption efficiency of these four materials increased with the increase of the dosage. The adsorption rate was the highest in the first 5 minutes of the reaction. The adsorption reached saturation after 1 h, and the adsorption effect tended to be gentle. It can be concluded from Figure 18 that the removal rate of NH₄⁺-N increases gradually with the increase of Clinoptilolite dosage. The removal rate of NH₄⁺-N increases from 45% to 73% with the increase of Clinoptilolite dosage from 2g to 10g.
It can be seen from Figure 19 that between the dosage of 0.5g and 5g Clinoptilolite used, the removal rate of NH$_4^+$-N increases significantly as the dosage increases. When the dosage is more than 5g, the removal rate of NH$_4^+$-N increases slowly as the dosage increases. The removal rate peaked at 0.1 g of Clinoptilolite added but sharply decreased after it reaches its maximum capacity. The maximum adsorption capacity reached 0.164 mg/g. When the dosage exceeded 1 g, the adsorption capacity decreased sharply.

**Figure 19. Effect of Clinoptilolite on NH$_4^+$-N removal in Sunhe River**

4.3.3 NH$_4^+$-N removal by Multi-media Biological Filter

Through the treatment of the raw water of Sunhe River, it is found that the removal efficiency of TP and TN by multi-media biological filter is remarkable (Figure 20). The removal rate of total phosphorus and total nitrogen can reach up to 80%, 56% respectively with only 2 hours of hydraulic retention time. The NH$_4^+$-N removal rate decreased at first but then raised, while the TN removal rate varied little over time. We reasoned that this trend is due to the high level of organic nitrogen presents in domestic sewage that contaminated Sunhe River and automatically generates ammonium nitrogen after being digested by microorganisms. Ammonium nitrogen underwent nitrification nitrate nitrogen to produce nitric salt. At beginning of the experiment the conversion rate between organic ammonia to ammonium nitrogen is greater than the nitrification rate as the concentration of NH$_4^+$-N in the water will increase. This is likely caused by cellular uptake of ammonium nitrogen during bacteria growth period. However after the bacteria population become steady this conversion rate will decrease, which causes the rises and fall of NH$_4^+$-N. This is another reason why NH$_4^+$-N form downstream Sunhe river is higher than upstream.

**Figure 20. Time-variation of NH$_4^+$-N, TN and TP of Sunhe raw water treated by Multi-media biological filter**

5 Conclusion and Prospect

For the typical urban river with continuous sewage discharge, the O-AFI-MA has obvious effect on the improvement of water quality. The dissolved oxygen concentration of the culvert rises from 2.8 mg/L to 10 mg/L, and the dissolved oxygen 2km downstream can be maintained at about 4mg/L. The water transparency also increased significantly from less than 25cm to up to 80cm. The ex-situ flocculation-sedimentation process is a effective way to reduce TP level with a average removal rate of 68.5%, but the effect of COD reduction is limited. The O-AFI-MA technique is effective for COD reduction. Both of the these two technology has not significant effect on NH$_4^+$-N removal. Through the comparison of microbial agents, physical adsorption and multi-media biological filter, we found that multi-media biofilter bed is the most suitable technology for nitrogen and phosphorus removal.

Base on the results above we concluded that O-AFI-MA technique coupled with ex-situ multi-media biological filter technology is an effective measure to
improve the river water quality under low pollution load. This combined technology provides a novel way to improve water quality before a complete sewage interception can be achieved.

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References

1. G. Zhou, *Water & Wastewater Engineering*, 6, 56-58 (2016).
2. L. Zhang, H. Wang, G. Li and Y. Xiong, *Environmental Protection*, 5, 62-65 (2017).
3. Y. Zhao, R. Yao, M. Xu and L. Song, *Environmental Protection*, 13, 27-29 (2015).
4. M. Xu, R. Yao, L. Song, Y. Wu, Y. Xie and D. Wang, *Chinese Journal of Environmental Management*, 2, 74-78(2015).
5. W. Liao, J. Huang, J. Ding, M. Liu, T. Chen, Q. Tong, Y. Yao and S. Lv, 2017 the ninth Forum on river lake management and water ecological civilization development, Xi’an, Shanxi province, China, 8(2017).
6. H. Hu, Y. Sun, J. Xi and T. Zhao, *Environmental Protection*, 13, 24-26(2015).
7. S. Wang, T. Zhang, Y. Gao, F. Zhao and P. Zhuang, *Resources and Environment in the Yangtze Basin*, 1, 215-224(2018).
8. S. Chang, *Green Environmental Protection Building Materials*, 2, 74(2018).
9. Z. Hu, C. Liu, Q. Zhou, C. Wu, W. Tu and Y. Liang, *Chinese Journal of Environmental Engineering*, 12, 4281-4288(2012).
10. P. Yeh, and Y. Chang, *Renewable and Sustainable Energy Reviews*, 47, 616-622(2015).
11. Y. Chang, C. Ku, and N. Yeh, *ECOL ENG*, 69, 8-16(2014).
12. J. Guo, W. Chen, F. Ma, L. Wei and L. Zhao, *China Water & Wastewater*, 15, 76-80(2013).
13. L. Yang, R. Hai, M. Li, Y. Li and X. Wang, *Environmental Science & Technology*, 11, 136-141(2013).
14. H. Li, *Hebei University of Engineering*, 65(2018).
15. F. Zhao, S. Xi, X. Yang, W. Yang, J. Li, B. Gu, and Z. He, *ECOL ENG*, 40, 53-60(2012).
16. H. Fu, *Environmental Protection & Circular Economy*, 8, 62-63(2013).
17. L. Cai, G. Zhu, J. Liu, S. Xiang, J. Liu, B. Chang, X. Dai and Y. Guo, *China Environmental Science*, 8, 3087-3093(2018).