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Application of MBR for hospital wastewater treatment in China☆

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A B S T R A C T

In China, the number of hospitals has increased to 19,712 in 2008, with the production of hospital wastewater reaching 1.29×10⁶ m³/d. Membrane bioreactor (MBR) technology presents a more efficient system at removing pathological microorganism compared with existing wastewater treatment systems. In the past 8 yr, over 50 MBR plants have been successfully built for hospital wastewater treatments, with the capacity ranging from 20 to 2000 m³/d. MBR can effectively save disinfectant consumption (chlorine addition can decrease to 1.0 mg/L), shorten the reaction time (approximately 1.5 min, 2.5–5% of conventional wastewater treatment process), and attain a good effect of inactivation of microorganism. Higher disinfection efficacy is achieved in MBR effluents at lower dose of disinfectant with less disinfection by-products (DBPs). Moreover, when capacity of MBR plants increases from 20 to 1000 m³/d, their operating cost decreases sharply.

1. Introduction

In China, the total number of hospitals has raised from 14,377 in 1990 to 19,712 in 2008, which is also more than two times of that in 1986. In 2008, 1.29×10⁶ m³/d hospital wastewater was generated, corresponding to approximately 1% of municipal wastewater [1]. It has been identified that hospital wastewater, especially from those treating infectious patients, contains a wide variety of microbial pathogens and viruses [2], requiring proper treatment and management before being discharged into receiving water bodies. The presence of pathogenic microorganisms and viruses in hospital wastewater is a major environmental and public health concern, especially following the outbreak of severe acute respiratory syndrome (SARS) in 2003. Along with the implementation of Discharge standard of water pollutants for medical organization (GB 18466-2005) in 2006, it is becoming more and more important to develop a technique that has high efficiency, less secondary pollution, is easy to operate, and is effective for virus removal for the disinfection of hospital wastewater. Membrane technology is more efficient at removing pathological microorganism compared with other wastewater treatment systems.

Recently, more attention has been paid to the membrane bioreactor (MBR) technology for hospital wastewater treatment because of its higher efficiency in pollutant removal, excellent effluent quality, low/zero sludge production, compact size and lower energy consumption [3,49]. Previous researches on MBRs have shown that an MBR is extremely efficient in the removal of bacteria [4–6] and viruses [7,8]. In addition, with the help of a membrane filter, some suspended substances and big molecule matter can be eliminated, so the turbidity of effluent is reduced to below 0.2 NTU [9]. In the past, membranes have been considered unsuitable for wastewater treatment due to high operating costs caused by low resilience of the then available membranes, which were generally unreliable, and had only a short operation period between cleaning cycles. However, increasingly stringent standards and decreasing costs are making the use of MBR systems for hospital wastewater treatment more economically viable. Therefore, MBR technology has a large application potential in the field of public sensitive regional wastewater treatment in China.

2. The characteristics of hospital wastewater in China

Hospital wastewater has long been treated with the conventional wastewater treatment processes, which are designed for the removal of BOD (biological oxygen demand) and SS (suspended solids), but not for pathogens [10,11]. Markers of pathogenic microorganisms and viruses, such as Mycoplasma, Chlamydia, Enterovirus, have been identified in the hospital effluents [12]. The eligible rate of wastewater disinfection from medical institutions and hospitals in different city is low in China. The investigation results from 45 hospitals in 2004 in Kunmin city, which is the biggest city in southwest of China, showed that there were 36 hospitals with wastewater disinfection equipments, whereas the eligible rate of wastewater disinfection was only 55.6% [3]. At the same year, wastewater treatment facilities of 50 hospitals were investigated in Wuhan city, which is the biggest city in central south of China. It showed that there were 46 hospitals with wastewater treatment facilities, and only about 50% effluent quality from wastewater treatment facilities accorded with the national discharge standard [48]. Even in the economic developed Yangtse River Delta or...
Pearl River Delta areas, the low eligible disinfection rate were found [13]. In 2004, the total number of bacteria and E. coli in effluents, derived from 20 hospital wastewater outlets in Guangzhou city, the capital of Guangdong province, was high and ranged across 6 magnitude grades, which is summarized in Table 1. In particular, the number of Escherichia Coli Groups severely exceeded 500/L — the Hospital Wastewater Discharging Standard (GBJ48283). Moreover, the detection rates of two typical enteric pathogenic bacteria, Salmonella and Shigella, reached 10% and 5% in the effluents, respectively [14].

So far, direct chlorination or primary treatment followed by chlorination is the most widely used method for disinfecting hospital wastewater in order to prevent the spread of pathogenic microorganisms, causal agents of nosocomial infectious diseases. of the 94 hospitals in Beijing, 89.6% use chlorine-containing disinfectant for sewage treatment, in which liquid chlorine disinfection accounted for 56.3% (Fig. 1); 84.6% of the 36 hospitals in Kunming use sodium hypochlorite disinfectant in 2004 [5]; and 63% use liquid chlorine and 35.8% use chlorine dioxide disinfection of the 106 hospitals in Hangzhou in 2004 [15]. The widespread medical use of chlorine disinfection is due to its very broad spectrum of biocide activity against bacteria, virus and fungi and simple operation. However, this method is capable of producing undesirable disinfection by-products (DBPs), its efficacy depends much upon the quality of the feed water and in particular low efficiency of virus removal. There is an increasing concern about the formation of mutagenic/carcinogenic and toxic disinfection by-products that are potentially harmful to humans and aquatic organisms [16]. Chlorine-containing disinfectant for virus removal depends much upon the quality of the feed water. The results of study indicate that viruses still can be detected despite the lower than 50 PFU/100 ml number of E. coli, which accorded with the hospital wastewater discharging standard [9,18,19] because of their much higher tolerance compared to coliform or enteric pathogenic bacteria [20,21]. Moreover, the presence of suspended solids and organic compounds in wastewater often makes disinfectants’ efficiency to decrease drastically [41–44]. Therefore, many hospitals use excessive disinfectants to ensure thorough sterilization. In our investigation, the highest residual chloride level in effluent was 128 mg/L and the second highest value was 103.50 mg/L (Table 2) [17,22]. Statistical study showed that the overall emission of residual chlorine of these hospitals was about 14,400 kg/yr in Jinan city, the capital of Shandong province [17]. Excessive residual chlorine not only increased the treatment costs of hospital wastewater, but also caused the serious second pollution to aquatic environment.

3. MBR application in hospital wastewater treatments in China

Many researches and practices have proved that MBR technology has a good capability to degrade organic compounds in wastewater and remove a wide range of microorganisms, resulting in an effluent free from pathogenic microorganisms [4–8]. Therefore, MBR holds great promise to provide an alternative wastewater treatment technique for better protection of public health and the environment. Moreover, increasingly stringent standards and the requirement for lower cost processing are making the use of MBR systems more interesting for hospital wastewater treatment. Typical, capacities of commercial MBR plants for hospital wastewater treatment are small, ranging from 20 to 200 m³/d. However, over 50 MBR plants, mostly employing the submerged technology, have been successfully applied in hospital wastewater treatment with the capacity ranging from 20 to 2000 m³/d in China (Table 3).

The operating conditions and the MBR’s efficiency resulted from our investigation for hospital wastewater treatment in removing COD, BOD, NH₃–N, TSS and the total coliform are presented in Tables 3 and 4. It is clear that after membrane biological reactor treatment, more than 80% COD, BOD, TSS, and NH₃–N were removed. BOD concentration in the effluent varied from non-detectable level to 20.6 mg/L. The effluent TSS concentration in all cases was less than or equal to 19 mg/L. The fecal coliform of effluent was lower than 760 PFU/100 ml.

According to previously studies [7,8], there exists two synergistic mechanisms for the MBR technique to achieve phage removal — virus rejection depended on the dynamic layer on the membrane surface and viral inactivation of the activated sludge. Furthermore, pathogenic bacteria and viruses are usually adsorbed onto the surfaces of suspended solids regardless of the surface properties, which make these microorganisms, especially viruses, more stable [45–47]. Therefore, MBR technique demonstrates obvious advantage to remove viruses and bacteria. The effluent without disinfectant can meet Discharge standard of water pollutants for medical organization, which makes MBR high potential for applications in hospital wastewater treatment in China. MBR technique benefits the disinfection process due to its capacity making the quantity of the bacteria and viruses decreased to a

Table 1

| Microorganisms situation of effluent in different hospitals in Guangzhou (2004) [5]. |
|---------------------------------|---------------|------------------|------------------|
|                                | Minimum       | Maximum          | Geometric mean   | The number of sample |
| Total bacteria /ml             | 2.40×10⁶      | 1.19×10¹²        | 2.00×10⁴         | 20              |
| Coliform group /L              | 9.00×10⁴      | 2.38×10¹⁰        | 1.01×10⁴         | 20              |

Table 2

| City and hospital               | Total residual chloride (mg/L) | City and hospital               | Total residual chloride (mg/L) |
|---------------------------------|-------------------------------|---------------------------------|-------------------------------|
| Nanshan district hospital in Shenzhen | 0.064–26.9  | Chongqing                     | 0.0825                        |
| Jinan                           | 9.1–77.7³ | Certain large hospital in Guilin | 0.27                          |
|                                 | 3.7–128³  | Certain general hospital in Dongyang | 0.96–3.71                     |
| Tianjin General hospital of Medical university | 0–81.9³ | Taian                          | 0–12.5                        |
| Tianjin Heping district hospital | 3.1–5.6  | Certain hospital of Baiyun district in Guangzhou | 2.4  |
|                                 | 3.1–86.9  | Xishan district hospital in Kunmin | 1.77–103.50                 |

Investigation results in Jinan ① 43 hospitals in 2001; ② 16 hospitals in 2002; ③ 12 hospitals in 2003.
of 20, 140, 500 and 1000 m³/d, respectively. Since the startup, these facilities have worked well and the treated water meet the requirements of the wastewater reuse standard (Table 4). When capacity of MBR increases from 20 m³/d to 1000 m³/d, unit capital costs are decreasing from 3.86 RMB/m³ to 1.395 RMB/m³ because of the decreased energy consumption in these cases study. Such reductions have come about as a result of the process design improvements, the economies of scale derived from a growing demand of membrane productions, improved schedules, and longer membrane life.

### 4. Case studies

Table 5 shows four cases study. MBR systems was installed in Haidian community hospital, Huludao hospital, Tianjin first center hospital, and Tianjin medical university general hospital, with capacity of 20, 140, 500 and 1000 m³/d, respectively. Since the startup, these facilities have worked well and the treated water meet the requirements of the wastewater reuse standard (Table 4). When capacity of MBR increases from 20 m³/d to 1000 m³/d, unit capital costs are reduced from 3795 RMB/m³ to 3380 RMB/m³, and the unit operating cost are decreasing from 3.86 RMB/m³ to 1.395 RMB/m³ because of the decreased energy consumption in these cases study. Such reductions have come about as a result of the process design improvements, the economies of scale derived from a growing demand of membrane productions, improved schedules, and longer membrane life.

### Table 3

Applications of MBRs in hospital wastewater treatments in China[31–39].

| Program                  | Membrane area (m²) | Membrane material            | Membrane pore (μm) | Capacity (m³/d) | HRT (h) | Comissioned |
|--------------------------|--------------------|------------------------------|---------------------|-----------------|---------|-------------|
| MBR                      | 96                 | Hollow fiber membrane (PE)   | 0.4                 | 20              |         | 2000        |
| MBR + NaClO             | 96                 | Organic membrane            | 1.3                 | 140             | 6       | 2004        |
| MBR                     | 200                | PVC                          | 0.22                | 400             | 7.5     | 2005        |
| MBR + NaClO             | 900                | PVDF                         | 0.22                | 500             | 7       | 2003        |
| MBR + ClO₂              | 8000               | Hollow fiber membrane (PVDF) | 0.4                 | 1000            | 5       | 2005        |

PVDF: poly vinylene fluoride; PE: polyethylene.

### Table 4

Performances of MBRs in hospital wastewater treatments in China[30–40].

| Program                  | COD (mg·L⁻¹) | BOD (mg·L⁻¹) | NH₃ (mg·L⁻¹) | TSS (mg·L⁻¹) | Turbidity (NTU) | Bacteria (PFU/L) | Facial coliform (PFU /100 ml) | pH | Reference |
|--------------------------|--------------|--------------|--------------|--------------|----------------|-----------------|-------------------------------|----|-----------|
| In                       | 48.278       | 20.55        | 10.1–23.7    | 6.1–27.9     | < 4            | 9.9 x 10³       |                               | 6.2–7.1 | [39]     |
| Out                      | < 30         | < 0.4        | 1            | < 23         | < 1            | 150 x 10⁶       |                               | 6–9   | [40]     |
| In                       | 2.3          | 150          | 30           | 30           | 170            | 10⁻⁵–10⁻⁶       |                               | 7.2    | [19]     |
| Out                      | 7.2–24.1     | 0–2.9        | 29           | 0.1–0.3      | 0–10⁻⁸         | 10⁻⁵–10⁻⁷       |                               | 7.1    | [35]     |
| In                       | 98.6–163.5   | 26.8–61.2    | 6.8–16.2     | 3.9–39.8     | 0.1–0.3        | 10⁻⁵–10⁻⁶       | 10⁻⁵–10⁻⁷                   | 5.4    | [33]     |
| Out                      | 16.1–42.0    | 3.1–4.9      | 20.6–99.5    | 14.8–190     | 150 x 10⁶      |                               |                               | 7.8    | [35]     |
| In                       | 350.8        | 82.4         | 18.4         | 0.1–0.3      | 0–10⁻⁸         |                               |                               | 8000–15000 | [35] |
| Out                      | 69.3         | 20.6         | 4.5          | 0.1–0.3      | 0–10⁻³         |                               |                               | 18–26  | [33]     |
| In                       | 90–130       | 47–68        | 20–29        | 15.2–25.5    | 0.1–0.3        |                               |                               | 2.5    | [33]     |
| Out                      | 8–11         | 1.5–25.5     | 0.8–18       | 0.1–0.3      | 0–10⁻⁷         |                               |                               | 23400  | [33]     |

Relative low level, and a drop in disinfectant consumption. However, in order to strictly control the pathogenic microorganisms in hospital effluent, it is necessary to further disinfect the MBfR effluent. The integration of membrane rejection for pathological microorganism in MBR and disinfection is satisfactory to enable the treated sewage to be available chlorine) is 1.0–2.0 mg/L. However, the same disinfection effect could not be achieved for the raw hospital wastewater, even if the dosage of sodium hypochlorite increase to 50 mg/L with 1.0 h of the contact[36]. Furthermore, the trichloromethane content in the disinfected MBR effluent and the raw hospital wastewater after disinfection till can all be tested, 5.14 and 19.70 μg/L, respectively [19,38]. MBR can produce a decrease in the concentration of trichloromethane, bromochloromethane, dibromochloromethane, halohydrocarbon and so on. These researches and practical applications show MBR can save consumption during the disinfectant process and prevent the formation of disinfection by-products (DBPs), enabling its universal applications in hospital wastewater.

### Table 5

Cost analysis of two cases study of MBR systems in hospital wastewater treatment [35–37–39].

| Hospital System              | Treatment capacity (m³/d) | Commissioned (RMB×10,000) | Capital costs (RMB×10,000) | Non-membrane costs (RMB×10,000) | Total capital costs (RMB×10,000) | Unit capital costs (RMB/m³) | Operating costs |
|-----------------------------|---------------------------|----------------------------|---------------------------|---------------------------------|---------------------------------|---------------------------|----------------|
| Haidian Community Hospital  | 20                        | 500                        | 140                       | 1000                            | 2000                            | 3795                      | 1.80           |
| Tianjin First Center Hospital| 2000                      | 2003                       | 2004                      | 2005                            | 3795                            | 3795                      | 1.80           |
| Huludao Hospital            | 2000                      | 2003                       | 2004                      | 2005                            | 3795                            | 3795                      | 1.80           |
| Tianjin Medical University General Hospital | 3795 | 4000 | 3500 | 3380 |

**Energy consumption** (RMB/m³) 1.80
**Membrane replacement** (RMB/m³) 1.05
**Depreciation of assets** (RMB/m³) 0.51
**Membrane life (year)** 5
**Others (RMB/m³)** 0.50
**Total operating cost** (RMB/m³) 3.86
life than that originally estimated. Further cost reductions are expected in the future, however, evidence shows that the membrane costs are unlikely to decrease significantly unless standardisation takes place in the same way as for reverse osmosis (RO).

5. Conclusion

Due to more stringent regulations and wastewater reuse strategies, it is expected that a significant increase in MBR plant capacity and a widening of application areas will occur in the future. Hospitals’ wastewater which contains a wide variety of microbial pathogens and viruses will be an important application area for this MBR technique. Existing practical application shows that MBR can effectively save disinfectant consumption (chlorine addition can decrease to 1.0 mg/L), shorten the contact time to 2.5–5% of conventional wastewater treatment process, and attain a good effect of microorganism inactivation. Additionally, higher disinfection effect, less disinfection by-products (DBPs) formation and lower acute toxicity are achieved in MBR effluent using lower dose of disinfectant.

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