Technical and Economic Analysis of Wastewater Treatment Plants in China

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Keywords: Biological technologies; Distance function; WWTPs in China

Summary of key findings
Technical and economic performances of 1104 WWTPs in China were analyzed. A detailed comparison was made among 10 biological WWTP technologies. Technical index was removal rate of pollutants (including COD, SS, TN and TP). Economic index was represented by quadratic parametric form of distance function. Input was cost of WWTPs. Desirable output was treated wastewater. Undesirable outputs were pollutants discharged into environment. Distance function approach was applied in calculating how much desirable outputs could increase and undesirable outputs could decrease with fixed inputs. The results show that:

1. Average TI of COD, SS, TN, and TP were 0.81, 0.90, 0.52 and 0.69. It suggested lower efficiency of nutrients removal, especially total nitrogen.
2. Average EI was 0.25, suggesting 25% increase in desirable outputs and 25% decrease in undesirable outputs under same inputs if all plants worked economically.
3. A/O2 had the highest TI (COD, SS, TP). BCO had the highest TI (TN). OD had lowest EI.
4. Kruskal-Wallis test showed the differences among technologies were statistically significant.
5. Large-scale WWTPs had best economic efficiency. Medium-scale WWTPs had best TI of COD, SS and TN.
6. WWTPs in East had the highest TI of COD, TN and TP, accordingly economic efficiency was low.

Background and relevance
Wastewater treatment plants (WWTPs) have been widely recognized as an efficient way to protect environment and support sustainable development. Although different technologies of WWTPs provided adequate options to decrease effluent concentration, high costs in treatment process also become a huge concern for policy makers and practical operators. Over last three decades, over 3000 urban WWTPs were built in China. New treatment capacity of WWTPs will increase 42 million m³/day in the next 5 years. Biological technologies were the most widely used in China. However different technologies had their own properties. Thus, it is urgent to identify best practices WWTPs, especially from both technical and economic perspectives.

Despite the widespread presence in literatures of different WWTP technologies, contributions in systematic analysis of WWTPs remain scarce. First, in most WWTP technology studies, firm-level with limited samples was impossible to obtain general property. Second, although a few attempts were made to achieve an integrated picture of WWTPs, economic information was missing. Third, traditional research methods, such as Life Cycle Analysis and Multiple-objective evaluation, required detailed inventory data and were technically complicated. To our knowledge, there has been no integrated analysis of both technical and economic performances of WWTPs in China.

In this paper, an integrated analysis was applied among 1104 WWTPs in China using distance function approach. Distance function approach provided an alternative way to systematically assess WWTPs, only requiring quantitative input/output data. The aim of this work was to determine the economic index and technical index of each WWTP and to obtain characteristics of best practice WWTPs. Other factors that affected WWTPs performance will be discussed in depth, including technology, region, and scale.

(1) Data
Statistical information for 2011 was supplied by authority (Ministry of Housing and Urban-Rural Development of China). All WWTPs of biological process and secondary treatment level with non-null data in China was analyzed. The sample included 1104 WWTPs in 30 provinces. 10 biological technologies analyzed were: Conventional Activated Sludge (CAS), High Concentration Activated Sludge (HCAS), Anoxic-Oxic (A/O2), Anaerobic-Oxic (A/O), Anaerobic-Anoxic-Oxic (A2/O), Oxidation Ditch (OD); Sequencing Batch Reactor (SBR), Bacteria Bed (BB), Biological Contact Oxidation (BCO) and Membrane Bioreactor (MBR). 4 pollutants were considered, chemical oxygen demand (COD), suspended solids (SS), total nitrogen (TN) and total phosphorus.

(2) Technical Index and Economic Index

This paper sought to assess performance of biological WWTP technologies in both technical and economic perspective. Technical Index (TI) was associated with certain biological wastewater treatment technology itself that what percentage of pollutants would be removed. Economic Index (EI) was associated with minimum use of resources (costs) to reach a determined output set which the volume of treated wastewater was large and discharged pollutants were small.

TI was measured by pollutant removal rate for each pollutant, as TI= (Influence – Effluence) / Influence. Pollutants measured in this paper were COD, SS, TP, and TN. EI was estimated based on the concept of distance function. [13] For each technology, P(x) represented feasible output set with fixed input vector x, cost of WWTP, that P(x)=\{(y,b): x can produce (y,b)\}. Vectors y and x were treated water and pollutants discharged into environment respectively. EI was defined as directional output distance function that EI =max\{ \beta : (y+\beta , b-\beta )\in P(x) \}. The value of EI was achieved by quadratic parametric form of distance function.[14,15] Restrictions were made to solve linear programing problem. EI provided the maximum expansion of treated wastewater and the maximum reduction of pollutants discharged that was feasible given the technology P(x). Specifically, if EI=0, it meant cost of WWTP was efficiently used and current technology supported this WWTP performed at best practice frontier. Accordingly, efficient but inefficient WWTPs would take values greater than zero, reflecting the increase in treated wastewater and decrease in pollutants with additional unit cost.

(3) Inputs and Outputs

The differences in pollution level between the influent and effluent were compared by TI. EI was to calculate negative impacts on environment with certain inputs. Due to limitation of our data, unit cost of wastewater treatment was input (x). Desirable output was the volume of wastewater treated (y). And undesirable outputs were effluent of pollutants, COD(b1), SS(b2), TN(b3) and TP(b4).

**Results**

In this work, Technical Index (TI) and Economic Index (EI) of 10 biological technologies were quantified. We normalized data by the mean of each variable to avoid convergence problems as customarily when estimating EI. The results are shown in Table 1.

<table>
<thead>
<tr>
<th>Bio-Technology</th>
<th>Number of WWTPs</th>
<th>TI-COD</th>
<th>TI-SS</th>
<th>TI-TN</th>
<th>TI-TP</th>
<th>EI</th>
</tr>
</thead>
<tbody>
<tr>
<td>A/O2</td>
<td>8</td>
<td>0.87</td>
<td>0.92</td>
<td>0.55</td>
<td>0.80</td>
<td>0.32</td>
</tr>
<tr>
<td>A/O</td>
<td>57</td>
<td>0.78</td>
<td>0.88</td>
<td>0.55</td>
<td>0.67</td>
<td>0.24</td>
</tr>
<tr>
<td>A2/O</td>
<td>277</td>
<td>0.83</td>
<td>0.91</td>
<td>0.54</td>
<td>0.73</td>
<td>0.27</td>
</tr>
<tr>
<td>SBR</td>
<td>152</td>
<td>0.81</td>
<td>0.90</td>
<td>0.52</td>
<td>0.71</td>
<td>0.25</td>
</tr>
<tr>
<td>CAS</td>
<td>139</td>
<td>0.80</td>
<td>0.90</td>
<td>0.52</td>
<td>0.67</td>
<td>0.25</td>
</tr>
<tr>
<td>HCAS</td>
<td>10</td>
<td>0.76</td>
<td>0.89</td>
<td>0.53</td>
<td>0.75</td>
<td>0.26</td>
</tr>
<tr>
<td>BB</td>
<td>21</td>
<td>0.79</td>
<td>0.87</td>
<td>0.52</td>
<td>0.68</td>
<td>0.23</td>
</tr>
<tr>
<td>BCO</td>
<td>32</td>
<td>0.82</td>
<td>0.91</td>
<td>0.57</td>
<td>0.69</td>
<td>0.27</td>
</tr>
<tr>
<td>MBR</td>
<td>38</td>
<td>0.83</td>
<td>0.91</td>
<td>0.55</td>
<td>0.71</td>
<td>0.29</td>
</tr>
<tr>
<td>OD</td>
<td>370</td>
<td>0.80</td>
<td>0.90</td>
<td>0.50</td>
<td>0.66</td>
<td>0.23</td>
</tr>
<tr>
<td>mean</td>
<td>1104</td>
<td>0.81</td>
<td>0.90</td>
<td>0.52</td>
<td>0.69</td>
<td>0.25</td>
</tr>
</tbody>
</table>
Discussion

(1) EI and TI

Average TI of COD, SS, TN, and TP were 0.81, 0.90, 0.52 and 0.69. It suggested lower efficiency of nutrients removal, especially total nitrogen. Average EI was 0.25, suggesting 25% increase in desirable outputs and 25% decrease in undesirable outputs under same inputs if all plants worked economically efficiently. Technology A/O2 had the highest TI (COD, SS, TP). Technology BCO had the highest TI (TN). OD had lowest EI.

(2) Kruskal-Wallis Test

Among literatures, Kruskal-Wallis test has been proved as a useful method to validate statistically significant of multiple groups. In order to test distribution of 10 biological WWTP technologies, 5 independent Kruskal-Wallis tests were applied for TI (COD, SS, TN, and TP) and EI. The results showed with 5% significance, the differences in all the variables among the 10 groups were statistically significant.

(3) Scale and Region

Other factors might also affect the performance of WWTPs. Categorizing all WWTPs with designed capacity as 3 groups: small-scale (not larger than 1 $10^4$m$^3$/d), medium-scale (1-10 $10^4$m$^3$/d), and large-scale (larger than 10 $10^4$m$^3$/d), EI were 0.28, 0.25, and 0.22 respectively. It implied larger scale of WWTPs had better economic efficiency. Medium-scale WWTPs had highest TI of COD, SS and TN. Regional distributions of EI were East (0.26), Middle (0.23) and West (0.24). WWTPs in East had the highest TI of COD, TN and TP. This suggested WWTPs in East had the best pollutant removal efficiency but economic efficiency was low accordingly. Regional distribution was showed in Figure 1.

![Image of regional distribution](image.png)

**Figure 1 Regional distribution of TI-COD, TI-SS, TI-TN, TI-TP and EI**

References


