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RESEARCH ARTICLE

Classification of contaminants and treatability evaluation of domestic wastewater

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Abstract Long-term sampling and analysis were conducted in a domestic wastewater treatment plant for the investigation on the characteristics of the representative contaminants in raw sewage such as SS, COD, BOD_5, TP, and TN. All these constituents were classified into dissolved and suspended groups by using a 0.45-μm membrane filter, and the concentration of each constituent in each group was analyzed. As a result, almost 100% of the SS was found to be suspended matter, as well as about 65% of COD, 60% of BOD_5, 50% of P, and 20% of N. All these could be easily removed by sedimentation or coagulation/sedimentation. A treatability evaluation diagram was proposed for a rational selection of wastewater treatment process in accordance with raw water quality.

Keywords domestic wastewater, dissolved matter, suspended matter, treatability evaluation

1 Introduction

The contaminants in domestic sewage can be divided into three categories: suspended solids (SS), organic matter (chemical oxygen demand or biochemical oxygen demand), and nutrients (nitrogen and phosphorus), which are the substances to be removed by conventional and/or advanced treatment for the purposes of discharge or treated water reuse. A conventional treatment processes often consist of primary treatment (physical process) and secondary treatment (biological process). In recent years, enhanced primary treatment that utilizes a chemical coagulant to assist the removal of suspended and dissolved contaminants, has drawn wide attention for wastewaters that are not amenable to conventional biological treatment [1], especially in developing countries [2,3]. Many studies have been conducted on the optimization of particle separation [4], utilization of inorganic coagulants and polymers [5], post filtration [6], and post disinfection [7] in the enhanced primary treatment process. Chemically enhanced primary treatment is also recommendable as the first step of wastewater treatment prior to biological treatment to achieve higher removal of organics and nutrients [8,9].

In general, organic and inorganic substances in the domestic sewage may include both suspended and dissolved fractions, and the suspended fraction can be easily removed by physical and/or physiochemical processes under most conditions. However, some dissolved substances may attach on to the suspended particles. Therefore, as long as the suspended particles can be effectively removed, the originally dissolved matter may also be removed substantially [1,10]. Regarding a selection of treatment technology, especially when primary or enhanced primary treatment is considered as the sole process for achieving certain water quality goals, there is often a dispute on the evaluation of the treatment effect due to discrepancies of past experiences of different people dealing with different wastewaters. The lack of a theoretic base for contaminant classification and treatability evaluation has influenced a rational selection and optimization of the wastewater treatment process [11].

In this paper, the authors used the domestic sewage at the Beishiqiao Wastewater Purification Center, Xi'an, China as an example, and through long-term water quality analysis, investigated the distribution of contaminants of different categories and different fractions. On this basis, a water quality matrix was formulated and the treatability of contaminants by primary, enhanced primary, and secondary treatments was evaluated.

2 Materials and methods

2.1 Raw domestic sewage

Raw domestic sewage used for this study was from the inlet of the Beishiqiao Wastewater Purification Center, Xi'an,

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China. During the experimental period, the average values of the main water quality items were as follows: the concentrations of SS, COD, BOD_5, TN, NH_3^+–N, NO_3^-–N, and TP were 162.3 mg/L, 275.8 mg/L, 134.7 mg/L, 38.8 mg/L, 26.2 mg/L, 0.48 mg/L, and 8.16 mg/L, respectively; pH was 7.6.

2.2 Classification of suspended and dissolved substances

In this study, each substance in the raw sewage as well as in the treated water was roughly classified into suspended and dissolved fractions using a 0.45-μm membrane filter. Those that could pass through the 0.45 μm filter were taken as dissolved substances, and those that were retained by the 0.45 μm filter were taken as suspended substances.

2.3 Chemical analysis

Chemical analysis in this study was conducted regarding SS, COD, BOD_5, TN, NH_3^+–N, NO_3^-–N, NO_2^-–N, and TP of the raw sewage and treated water. Methods utilized are shown in Table 1 (the numbers in the brackets are the codes of Chinese National Standards).

Table 1 Chemical analysis for the raw sewage and treated water

Items	Methods
SS	Gravimetric method (GB 11901-89)
COD	Dichromate method (GB 11914-89)
BOD_5	5-day BOD test
TN	Alkaline potassium per-sulfate digestion—UV spectrophotometric method (GB11894-89)
NH_3^+–N	Nessler's reagent colormetric method (GB7974-87)
NO_3^-–N	phenoldisulfonic acid spectrophotometric method (GB 7480-87)
NO_2^-–N	EDTA spectrophotometric method (GB7973-87)
TP	Ammonium molybdate spectrophotometric method (GB 11893-89)

2.4 Experimental methods

In order to evaluate the treatability of various contaminants in the raw sewage, experiments of primary treatment and enhanced primary treatment were conducted. The results were compared with that of the secondary treatment in the wastewater treatment plant where Kruger Oxidation Ditch (BioDenipho Process) was applied.

2.4.1 Primary treatment

The primary treatment experiment was conducted using a 1-L measuring cylinder where the raw sewage sample was placed to settle for 1 h, and then the supernatant was collected for analysis.

2.4.2 Enhanced primary treatment

The enhanced primary treatment was conducted using a standard jar-tester with polyaluminium chloride (PAC, 23% as Al_2O_3) as coagulant. The optimum PAC dose was pre-determined by comparing the residual COD in the coagulated and settled water as 70 mg/L (dry weight) or 8.5 mg/L (aluminum ion). The operational condition was set as: rapid mixing (120 r/min) for 1 min, slow mixing (45 r/min) for 15 min, and settling for 30 min.

3 Classification of contaminants in the raw sewage

3.1 Suspended solids

After filtration using the 0.45-μm filter, the SS concentration of the filtrate was almost zero, indicating that all the solid particles in the raw sewage were above 0.45 μm in size.

3.2 COD and BOD

Figures 1 and 2 show the fractions of dissolved and suspended substances in the raw sewage regarding COD and BOD, respectively. From the variations of the concentrations of the total, dissolved and suspended parts and their average values, it is understood that of the organic substances represented by COD and BOD_5, 66% and 62% were retainable by the 0.45-μm filter either due to their own size distribution or their attaching to the filterable suspended particles.

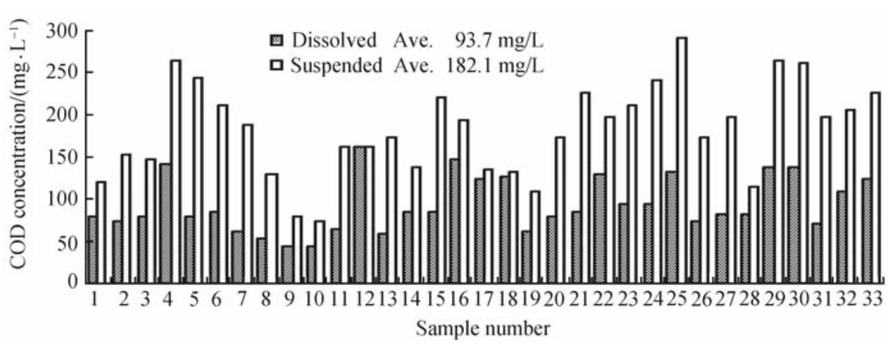

Fig. 1 Suspended and dissolved fractions of COD in the raw sewage

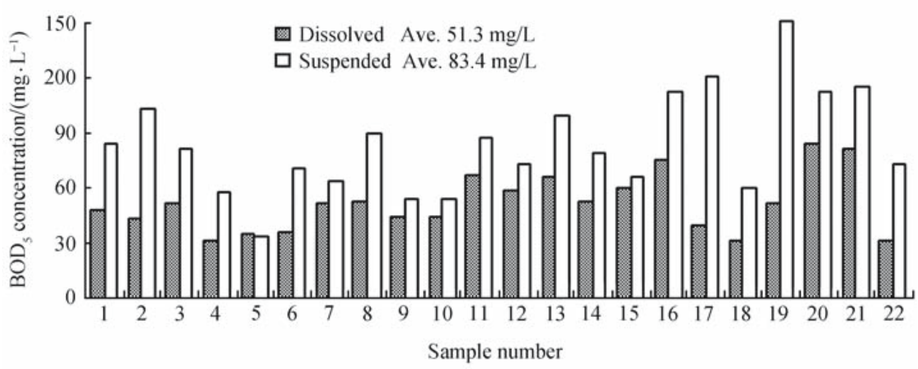

Fig. 2 Suspended and dissolved fractions of BOD_5 in the raw sewage

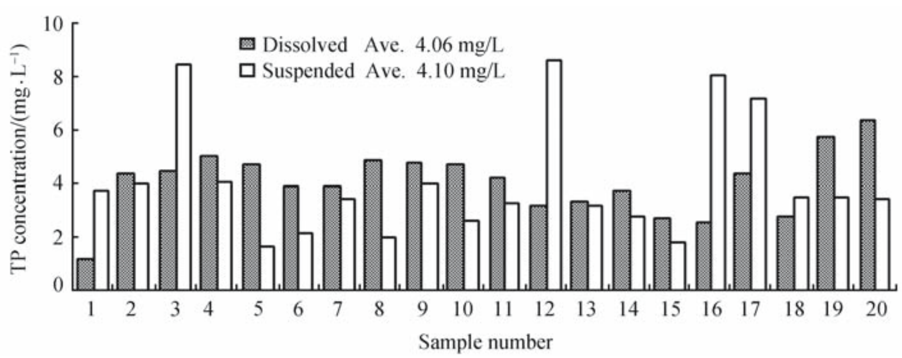

Fig. 3 Suspended and dissolved fractions of total phosphorus in the raw sewage

3.3 Total phosphorus and total nitrogen

Figure 3 shows the fractions of dissolved and suspended phosphorus in the raw sewage. In most measurements, the concentration of the suspended fraction was higher than that of the dissolved fraction, while they were about the same on average (50.2% and 49.8%, respectively). Regarding total nitrogen (TN), the dissolved fraction was much larger than the suspended fraction in each water sample (Fig. 4), while on average, the percentage of the dissolved fraction and that of the suspended fraction were 79.6% and 20.4%, respectively.

3.4 Composition of nitrogen

Figure 5 shows the composition of nitrogen in the raw sewage. Inorganic nitrogen took 68.8% of the TN while organic nitrogen took 31.2%. Of the inorganic nitrogen, the dissolved and suspended fractions were 87.8% and 12.2%, respectively. And of the organic nitrogen, the dissolved and suspended fractions were 59.6% and 40.4%, respectively. The inorganic nitrogen mostly took the form of NH_3^+–N (about 98%) with the other as NO_3^-–N. There was no NO_2^-–N detected from the raw sewage.

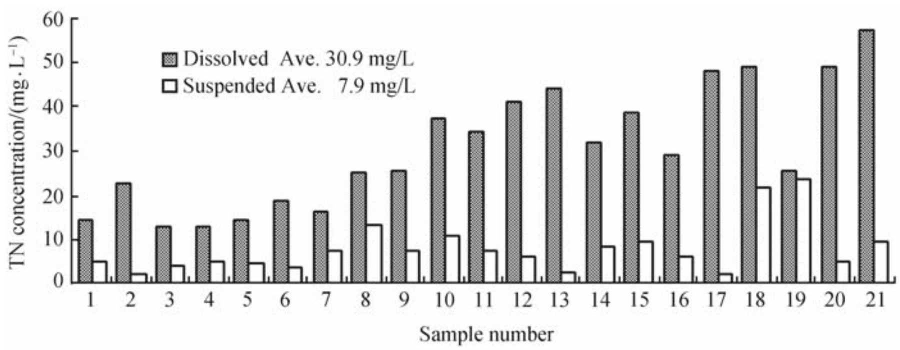

Fig. 4 Suspended and dissolved fractions of total nitrogen in the raw sewage

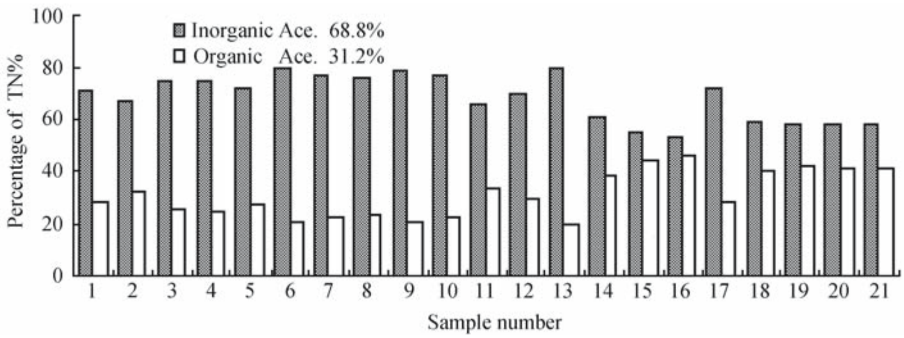

Fig. 5 Inorganic and organic fractions of total nitrogen in the raw sewage

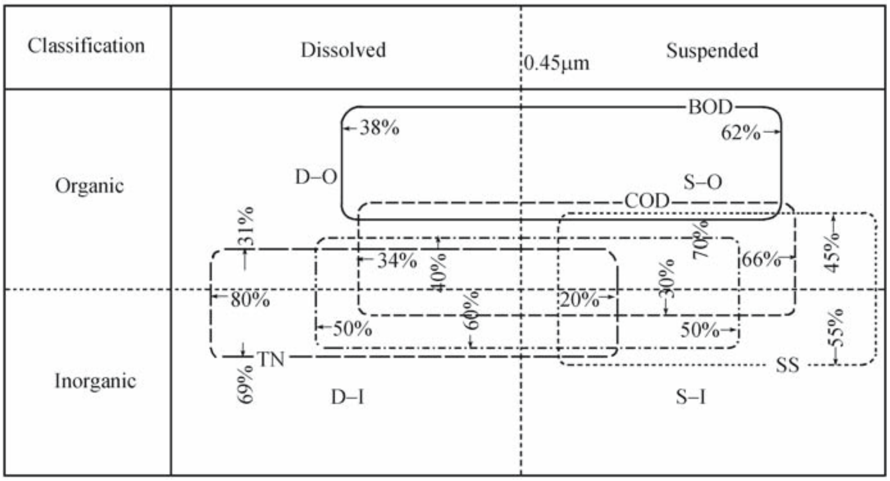

Fig. 6 Classification of pollutants by a 2 × 2 water quality matrix

4 Treatability evaluation of contaminants in domestic sewage

4.1 Formulation of a water quality matrix

Based on the results mentioned above, a water quality matrix was formulated as shown in Fig. 6. The figure is a 2×2 matrix and can thus classify each of the contaminants into 4 groups, namely dissolved-organic (D-O), suspended-organic (S-O), dissolved-inorganic (D-I) and suspended-inorganic (S-I) substances. The differences of organic SS, COD, and total phosphorus (TP) from inorganic ones were conducted principally by ignition method.

As shown in Fig. 6, in the raw sewage investigated, SS included both organic and inorganic fractions at about 45% and 55%, respectively. BOD_5 represented biodegradable organics of which 62% belonged to the suspended fraction and of which the remaining 38% belonged to the dissolved fraction. COD was composed of both organic substances and reductive inorganic substances that consumed oxygen. The percentages of the suspended and dissolved fractions of COD were 66% and 34%, respectively, which are very similar to that of BOD_5. Regarding TP, about 60% was inorganic, and its suspended and dissolved fractions were almost equal. Of the TN, the inorganic and dissolved fraction took most parts.

Because a 0.45-μm filter was used for the classification of suspended and dissolved substances, the existence of suspended solid particles in the raw sewage might have much influenced the fractions of BOD_5, COD, TP, and TN, as shown in Fig. 6, if we consider that even dissolved substances might be attached to the surface of the suspended particles [9]. Therefore, Fig. 6 might not represent the real state of the individual substance existing in the sewage. However, from the viewpoint of treatment, such a water quality matrix was still useful to assist the selection of suitable wastewater treatment processes.

4.2 Treatability of contaminants of suspended and dissolved fractions

Table 2 compares the removals of the total, suspended, and dissolved fractions by the primary, enhanced primary, and secondary treatment processes based on this study. By the primary treatment experiment, i.e., plain sedimentation, the average removal of SS was 59.8%. Regarding COD and BOD_5, the overall removals were 39.6% and 38.9%, respectively, and all the removed contaminants were found to belong to the suspended fraction. Considering that the suspended COD and BOD_5 were about 66% and 62%, respectively, as shown in Fig. 6, the removal percentages

Table 2 Comparison of primary, enhanced primary, and secondary treatment processes for contaminants removal (%)

Item	Primary treatment			Enhanced primary treatment			Secondary treatment		
	Total*	Suspended**	Dissolved***	Total[a)]	Suspended[b)]	Dissolved[c)]	Total[a)]	Suspended[b)]	Dissolved[c)]
SS	59.8	59.8	—	98.0	98.0	—	96.0	96.0	—
COD	39.6	59.9	—	68.2	97.9	6.4	91.3	97.6	80.3
BOD_5	38.9	62.7	—	65.2	96.3	14.2	91.9	89.9	96.5
TP	12.6	25.2	—	95.1	98.8	91.6	88.2	93.0	81.9
TN	10.9	54.5	—	15.8	74.8	1.7	81.8	72.1	84.2

a) As the removal percentage from the total amount
b) As the removal percentage from the suspended fraction
c) As the removal percentage from the dissolved fraction

could be calculated as 59.9% and 62.7% from the suspended fractions of COD and BOD_5, respectively. These were about the same as the SS removal. Such a result indicated that the suspended fractions of COD and BOD_5 might be in coexistence with SS in the sewage. Regarding TP and TN, the overall removals by plain sedimentation were 12.6% and 10.9%, respectively, and the calculated removal percentages from the suspended fractions were much lower than SS removal, indicating a different relation between suspended phosphorus/nitrogen and suspended solids in the sewage.

By enhanced primary treatment, i.e., coagulation/sedimentation, it was interesting that the removal percentages of the suspended COD and suspended BOD_5 were also close to that of SS. This supported again the assumption of coexistence of the suspended fractions of COD and BOD_5 with SS in the sewage. The total removals of COD and BOD_5 were 68.2% and 65.2%, respectively, which include not only most of the suspended fractions but also part of the dissolved fractions. TP removal was high regarding both the suspended and dissolved fractions. It demonstrated that chemical precipitation played an important role in phosphorus removal. Regarding TN, about 75% of the suspended fraction was removed but the removal of the dissolved fraction was very low.

The secondary treatment process, i.e., the Kruger Oxidation Ditch performed well in the wastewater treatment plant. The dissolved fractions of COD and BOD_5, which were difficult to be coped with by the primary and enhanced primary treatment, were effectively removed. The process also achieved a high removal of TN, of which most was dissolved matter. Regarding suspended fractions of COD and BOD_5, as well as SS, their removal by the enhanced primary treatment seemed to be more effective than by the secondary treatment. Chemical phosphorus removal seemed to be more effective than biological phosphorus removal.

5 Conclusions

The domestic sewage at Beishiqiao Wastewater Purification Center, Xi'an was taken as an example, and the long-term water sampling and analysis regarding SS, COD, BOD_5, TP, and TN in the raw sewage were conducted. By using a 0.45-μm membrane filter, the contaminants were classified into suspended and dissolved fractions. According to the concentration of each constituent in each fraction and also their chemical compositions, i.e., organic or inorganic matter, a 2×2 water quality matrix was formulated to characterize the wastewater quality, which relates to the treatability of the contaminants. As a result, 65% of COD, 60% of BOD_5, 50% of TP, and 20% of TN were classified to the suspended fraction. We further analyzed the treatability of the contaminants in each fraction by conducting primary treatment (plain sedimentation), enhanced primary treatment (coagulation/sedimentation), and secondary treatment (Kruger Oxidation Ditch process). Almost all the contaminants belonging to the suspended fractions could be easily removed by sedimentation or coagulation/sedimentation. Therefore, the effect of the primary or enhanced primary treatment would depend on what percent of the contaminants in the raw sewage belonged to the suspended fractions. The dissolved contaminants were difficult to remove by sedimentation or coagulation/sedimentation. Therefore, biological treatment and other advanced treatment may have to be applied in accordance with the target water quality.

The amount of COD and BOD_5, which were classified to the suspended fraction, could be removed by a percentage, almost the same as SS, when sedimentation or coagulation/sedimentation was conducted. Therefore, it was assumable that the suspended COD and BOD_5 were in coexistence with the suspended solids in the domestic sewage.

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