Desalination and Water Treatment
www.deswater.com
doi: 10.5004/dwt.2022.29117

280 (2022) 52–59
December

Impact of influent quality on the mixed liquor volatile suspended solids/mixed liquor suspended solids of mixed liquor from treatment plant

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Received 15 May 2022; Accepted 4 November 2022

ABSTRACT

In order to study the reason of mixed liquor volatile suspended solids/mixed liquor suspended solids (MLVSS/MLSS) decline in wastewater treatment plant (WWTP), a WWTP in Chongqing City was chosen as the object, and the relationship between influent quality and MLVSS/MLSS of mixed liquor was investigated. After tracking and monitoring the WWTP for 1 y, the average concentrations of influent for chemical oxygen demand (COD), suspended solid (SS), inorganic suspended solid (ISS), total nitrogen (TN) and total phosphorus (TP) were 635; 1,123.2; 809.2; 67.72 and 9.3 mg/L, respectively. After the pretreatment of grit chamber and primary settling tank, the average concentrations of influent for COD, SS, ISS, TN and TP were decreased to 277, 317.6, 231.9, 45.08, and 4.8 mg/L, respectively. And the volume average grain diameter was decreased from 60.93 to 49.56 μm. Besides, the concentrations of influent for SS, ISS, COD and MLSS were decreased in the dry season, while the concentrations of influent were higher concentration in rainy season. The annual variation rule of MLVSS/MLSS for mixed liquor was ranging from 0.24 to 0.57. According to the coefficient analysis obtained by Pearson correlation, the COD, ISS, TP and particle size for influence were the most important factor on MLVSS/MLSS of mixed liquor. The COD and particle size were positively correlated with MLVSS/MLSS, and the correlation coefficients were 0.525 and 0.25, respectively. While, ISS and TP were negatively correlated with MLVSS/MLSS, and the correlation coefficients were –0.635 and –0.557, respectively. Finally, a linear regression model between MLVSS/MLSS (Y) and COD (X_1), ISS (X_2), TP (X_3) and particle size (X_4) was established by a backwards method, that was $Y = 0.488X_1 - 0.521X_2 - 0.154X_3 + 0.165X_4$.

Keywords: Wastewater treatment; Activated sludge; Influent quality; Inorganic suspended solid/ Chemical oxygen demand; Mixed liquor volatile suspended solids/mixed liquor suspended solids

1. Introduction

The characteristics of influent water quality of urban sewage treatment plant are an important basis for the design and operation management of sewage treatment process. Accurately control the quality load of pollutants in sewage is a necessary condition for determining the treatment capacity and operation characteristics of treatment facilities and auxiliary equipment, ensuring the stable achievement of treatment objectives [1]. Therefore, the characteristics of influent water quality for urban sewage treatment plant is one of great significance to improve the operation effect of urban sewage treatment plant. The influences of the change of C, N, P load and flow rate for influent on the removal

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of phosphorus and nitrogen using biochemical treatment system have been carried out, and lots of experience about operation and regulation have been obtained [2–4]. However, less attention has been paid to suspended solids (SS) in influent.

As the drainage system is the combined sewer system in most cities of China, the water quality of sewage plants is characterized by high SS and low chemical oxygen demand (COD) [5]. It is reported that SS/biochemical oxygen demand (BOD_5) in sewage plant influent is higher than 2, much higher than the ratio of 1.1 in developed countries [6]. At the same time, the high concentration of inorganic solids entered sewage plants through sewage pipe network with the acceleration of urbanization in China, which seriously affected the operation of sewage plants. In recent years, a large number of inorganic solids were deposited at the bottom of structures in oxidation ditch and other sewage treatment systems [7,8], which reduced the hydraulic residence time of sewage and the effective volume of the reactor. This results seriously affected the effect of sewage treatment. Meanwhile, mixed liquor volatile suspended solids/mixed liquor suspended solids (MLVSS/MLSS) of activated sludge (as low as 0.3–0.5) was significantly affected by SS for influent, which was far lower than the normal level of 0.7 [9–11].

The concentration of MLSS for active sludge included active component (MLVSS) and inorganic suspended solid s (MLISS). Researchers have been focused on active component (MLVSS) of sludge at home and abroad. According to the design program [12] and simulation model [13,14], the water quality of influent, biological growth and metabolic process influencing MLVSS were only reported, and little attention was paid to MLISS. Some researches concluded that the proportion of inorganic suspended solid (ISS) and COD in influent water had a great influence on MLVSS/MLSS of sludge [15–17]. As the rate of ISS/COD for influent was increased from 0 to 0.1, the values of MLVSS/MLSS for nitrification system, anoxic phosphorus and nitrogen removal system and anaerobic system for phosphorus and nitrogen removal were decreased from 0.95, 0.9 and 0.8 to 0.7, 0.65 and 0.6, respectively. This indicated that the MLVSS/MLSS of the mixture showed a strong sensitivity to the influent water for ISS/COD, and this sensitivity become more and more obvious with the gradual increase of ISS/COD. Impact of ISS produced by biological phosphorus removal in activated sludge process on MLVSS/MLSS was analyzed. ISS in the influent was also at a very low level below 0.1, which was far from the existing water quality of the sewage plant. However, this study was only focused on the theoretical research without verification of practical engineering cases.

At present, the qualities of influent water for urban sewage plants were mainly focused on concentration of harmful substance for influent water [18,19], low carbon ratio [20,21], and operation regulation of technology [22], lacking the status of influent COD, SS, ISS and other comprehensive influences. The MLVSS/MLSS of activated sludge was obviously affected by SS and ISS for influent water, but the data tracking of actual engineering cases was not available. This work was focused on the influence of influent COD, SS and ISS on the mixed MLVSS/MLSS based on a 1-y continuous sampling study of a sewage treatment plant in Chongqing. It was intended to provide engineering basis for operation regulation of urban sewage plants with high influent concentration of SS and ISS.

2. Materials and methods

2.1. Introduction of the sewage treatment plant

The sewage treatment plant is located in the main urban area of Chongqing, using combined sewer system and with a service area of 125 km^2. The treatment capacity of sewage treatment plant is 60,000 t/d in dry season and 100,000 t/d in rainy season with adopted inverted AAO process and is shown in Fig. 1. In this work, 27 samples were taken from May 2020 to June 2021 and the layout of sampling points are shown in Fig. 1. During the sampling process, a professional bottom inlet water quality sampler was used to extend into the middle of the structure and take mixed samples to ensure the representativeness of samples.

2.2. Analysis

Indicators of SS, total phosphorus (TP), MLSS, total nitrogen (TN) and TP were measured according to water and wastewater monitoring method (4th edition). SS was calcined at 600°C in muffle furnace for 1 h and obtained constant weight, and the remaining residue was ISS. The difference between the weight of SS and ISS was volatile suspended solids. The COD was measured using DR1010 at test range was 0.1~1,000 μm (Hach Company in the United States). The volume and particle size were analyzed by BT-9300HT laser particle size testing system (Dandong Better Technology Co., Ltd., China).

3. Results and discussion

3.1. Variation trend and average statistics of water quality

The annual variation of various pollutants in the sewage treatment plant is shown in Fig. 2. The concentrations of SS and ISS were the lowest from November to March, while it was higher in other months. The results were consistent with existing reports [23,24]. The reason for this result was that lots of rain from April to October, and the initial scouring effect of rain led to a large number of SS and ISS entering the sewage plant, resulting in the increase of concentration of SS and ISS. The concentration of COD from November to March was slightly higher than that from June to October. Besides, COD showed the maximum value from April to May when there was the most rain. Although the concentration of SS was the lowest from January to March, the concentration of COD was higher. The result indicated that the main component of SS in sewage was organic matter during this period. The influent flow of the sewage treatment plant was increased while the pollutant mass load was increased, so the concentrations of COD, TN and TP for the sewage treatment plant still maintained a high level in the rainy season.

Generally, the particle size of the influent for sewage plant was generally low, ranging from 50 to 80 μm. Because the service area of the sewage plant was large and the length of sewage pipe network was too long, so large suspended

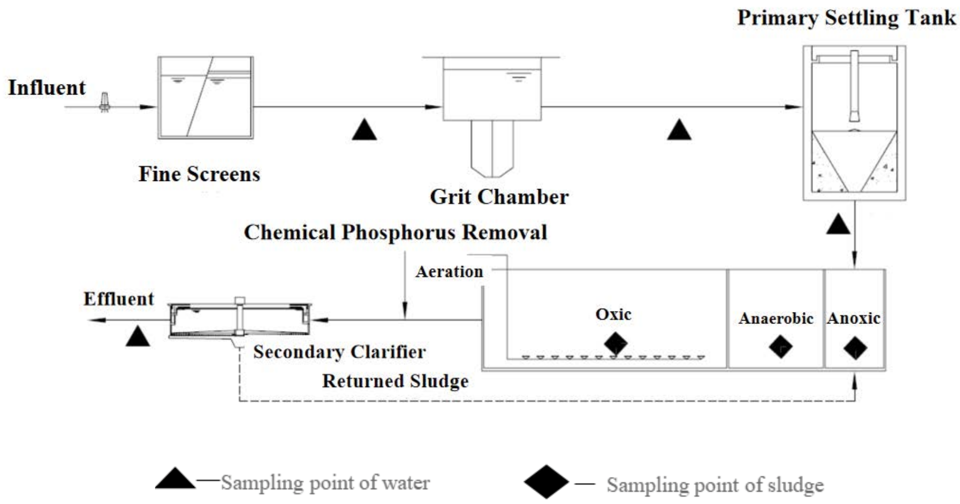

Fig. 1. Schematic of wastewater treatment plant.

solid particles with more than 100 μm were deposited in the pipeline [25]. The concentration of pollutant and particle size of sewage tended to be stable after treatment of primary sedimentation tank, indicating the primary sedimentation tank had a positive impact on regulating water quality.

The mean values of water quality parameters of 27 samples are shown in Table 1. The grit chamber showed a good removal efficiency of suspended solids with particle size greater than 200 μm. As the particle size of SS in the influent water of the grit chamber was about 60.93 μm, which was far less than 200 μm, so the removal efficiency of SS and ISS in grit chamber was lower.

3.2. Annual variation properties of mixed liquor

As shown in Fig. 3, the concentrations of MLVSS and MLSS for this sewage treatment plant was the lowest between January and March, maintaining between 3,000 and 5,000 mg/L. While, the concentrations of MLVSS and MLSS in the other months was between 4,000 and 8,000 mg/L, which was similar to the variation of ISS for influent water. However, the ratio of MLVSS/MLSS for mixed liquid showed an opposite trend with the variation of sludge concentration. The ratio of MLVSS/MLSS was between 0.4 and 0.6 from January to March, and reached the maximum value of 0.57 in February and the lowest value of 0.24 in September.

3.3. Correlation analysis between influent water quality and MLVSS/MLSS

Sewage entering the biological treatment structure was the direct factor affecting the properties of activated sludge. So the Pearson correlation coefficient analysis on the water quality index of primary sedimentation tank effluent and MLVSS/MLSS of mixed liquid was conducted using SPSS software, and the obtained results were shown as following.

Correlation analysis results in Table 2 show that the MLVSS/MLSS of activated sludge was significantly correlated with COD, ISS, TP and TN of effluent from primary sedimentation tank. The above factors were further analyzed by linear regression with backward screening method to determine the main factors affecting MLVSS/MLSS of activated sludge and establish the regression model.

It was determined that the COD, ISS, TP and particle size were the important factors affecting MLVSS/MLSS after screening, among which the concentration of ISS for influent water was the most important factor, followed by the

Table 1
Average concentration of pollutants at each sampling point

Sampling point	Inflow of grit chamber	Inflow of primary settling tank	Effluent of primary settling tank	Effluent of secondary sedimentation tank
Particle size (μm)	60.93 ± 7.17	57.58 ± 8.15	49.56 ± 7.73	Negative
COD (mg/L)	635 ± 203	620 ± 177	277 ± 91	35 ± 24
SS (mg/L)	1,123.2 ± 272.7	1,048.7 ± 335.7	317.6 ± 125.0	56.7 ± 35.2
ISS (mg/L)	809.2 ± 234.5	769.5 ± 261.3	231.9 ± 86.9	15.1 ± 8.5
TN (mg/L)	67.72 ± 8.23	64.24 ± 9.13	45.08 ± 8.22	18.12 ± 4.92
TP (mg/L)	9.3 ± 1.4	8.7 ± 1.4	4.8 ± 1.1	0.5 ± 0.3
ISS/COD	1.34 ± 0.40	1.30 ± 0.51	0.93 ± 0.89	/
COD/TN	9.30 ± 2.29	9.61 ± 2.24	6.11 ± 1.59	/

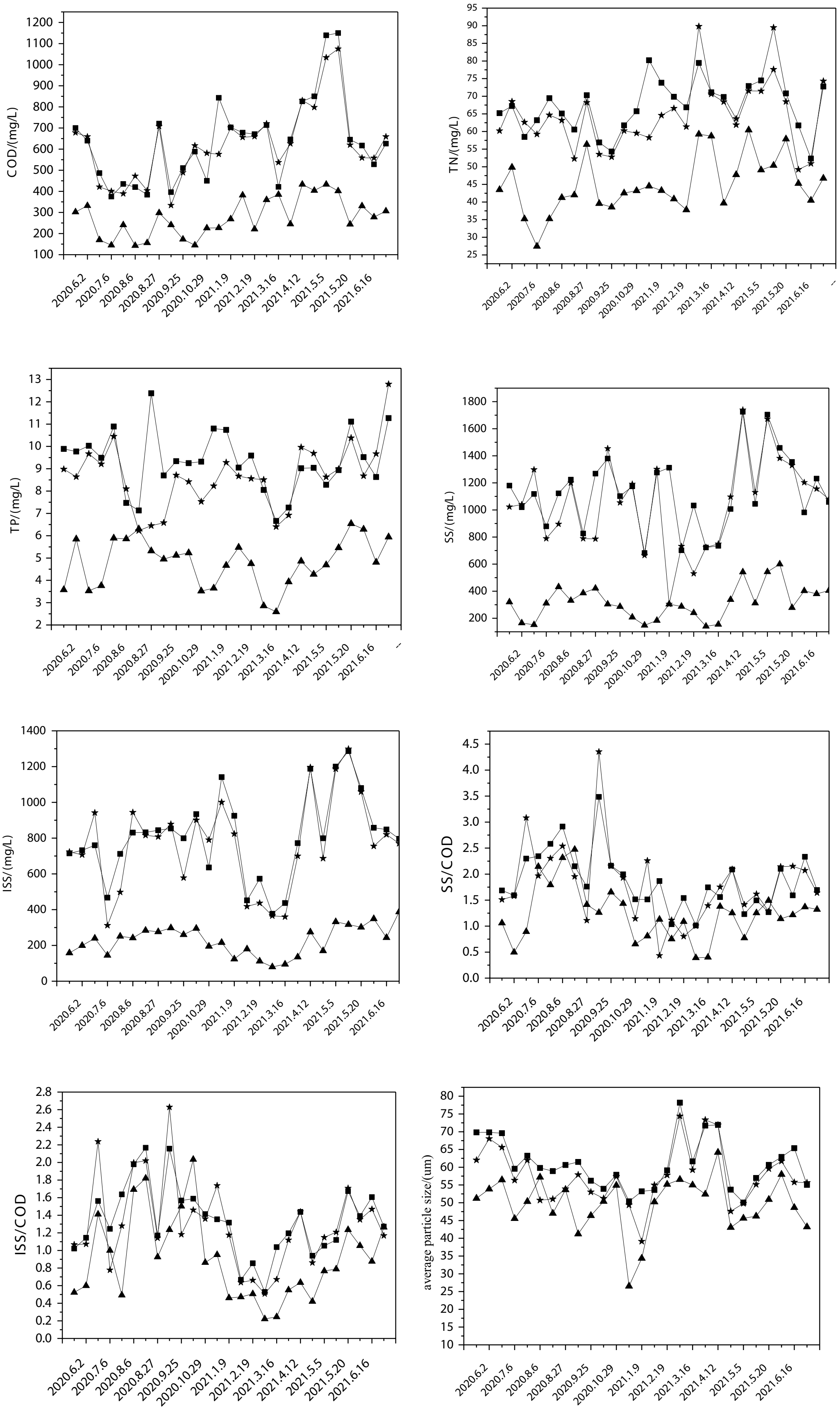

Fig. 2. Annual variation of influent quality.

Table 2
Pearson correlation coefficient analysis

	COD	SS	ISS	TP	Particle size	TN	Rate of MLVSS/MLSS
COD	1	0.379*	0.001	–0.099	0.131	0.640**	0.525**
SS	0.379*	1	0.570**	0.474**	0.009	–0.003	–0.183
ISS	0.001	0.570**	1	0.691**	–0.051	–0.010	–0.635**
TP	–0.099	0.474**	0.691**	1	0.034	–0.054	–0.557**
Particle size	0.131	0.009	–0.051	0.034	1	0.101	0.250
TN	0.640**	–0.003	–0.010	–0.054	0.101	1	0.380*
Rate of MLVSS/MLSS	0.525**	–0.183	–0.635**	–0.557**	0.250	0.380*	1

*Correlation is significant at the 0.05 level (1-tailed);
**Correlation is significant at the 0.01 level (1-tailed).

Table 3
Regression analysis

Model	Unstandardized coefficients		Standardized coefficients	t	Sig.	R^2	Adjust R^2
	B	Std. error	Beta				
(Constant)	0.315	0.086		3.650	0.001		
COD	0.000	0.000	0.488	4.199	0.000		
ISS	0.000	0.000	–0.521	–3.262	0.004	0.845	0.714
TP	–0.013	0.014	–0.154	–0.961	0.347		
Particle size	0.002	0.001	0.165	1.421	0.169		

Dependent variable: rate of MLVSS/MLSS.

concentration of COD. The regression equation was $Y = 0.4881X_1 - 0.521X_2 - 0.154X_3 + 0.165X_4$.
where Y was the MLVSS/MLSS of activated sludge; X_1 was the concentration of COD for influent, mg/L; X_2 was the concentration of ISS for influent, mg/L; X_3 was the concentration of TP for influent, mg/L; X_4 was the particle size for influent, mg/L.

Residual diagram analysis of the above regression models showed that the standardized predicted values did not increase or decrease, which indicated that the established MLVSS regression model did not show heteroscedasticity, and the explanatory variables (X_1, X_2, X_3 and X_4) in the regression model fully explain the explained variable (Y).

3.4. Influence of the primary treatment on SS/COD and ISS/COD

The removal efficiency of pollutants in the primary settling tank was a significant index, the average removal efficiencies of COD, SS, ISS, TN and TP were 55.3%, 69.7%, 69.7%, 29.8% and 44.7%, respectively. The removal efficiencies of SS and COD in ordinary horizontal sedimentation tank were about 50% and 30%, and the removal efficiencies of pollution were increased proportionally with the increase of influent concentration [26]. During the removal of SS in primary sedimentation tank, organic and inorganic components in suspended solids were precipitated together. Meanwhile, the excessive removal of organic matter and removal of suspended inorganic matter were occurred at the same time. The synergistic effect on the removal of COD and ISS was more obvious whenon the removal of COD and ISS was more obvious when the concentration of SS for influent water was too high. As a result, the wastewater treatment plant showed a high removal performance of COD, SS and ISS.

The rate of SS/COD for the influent in the sedimentation tank of the sewage plant was about 1.78, and the rate of BOD_5/COD for the typical domestic sewage was 0.45 [27], and the rate of SS/BOD_5 was 3.96. Comparing with the ratio of 1.1 in developed countries, the ratio of SS/COD for the influent in this sewage treatment plant was high [6]. The rate of SS/COD was reduced to 1.14 after the primary sedimentation treatment, and the rate of ISS/COD for sewage was reduced from 1.3 to 0.93 after the primary sedimentation treatment [10]. The results indicated that a large amount of inorganic solids entered the biological treatment structure, which was the reason for the decrease of MLVSS/MLSS in the wastewater treatment plant. The COD/TN was decreased from 9.3 to 6.11 after primary sedimentation tank treatment, becoming a typical low-carbon source wastewater [28–30].

3.5. Influence of MLVSS/MLSS on treatment performance of sewage treatment plant

Recently, the discharge of excess sludge was mainly controlled by maintaining sludge concentration and the stable operation of the system for domestic sewage plants. According to outdoor drainage design specifications

(GB50014-2006), the sludge concentration should be controlled between 2,500–4,500 mg/L with A^2/O system when the MLVSS/MLSS of the mixture stabilized at the normal level (about 0.7) [31]. The sewage plant should obtain a higher concentration of sludge to maintain the MLVSS at the normal level when MLVSS/MLSS was much lower than 0.7. During the rainy season, the sludge in this sewage plant showed a high concentration of inorganic substances and it must be maintained at a high sludge concentration. The value of MLVSS/MLSS was increased from January to March, so the sludge concentration was appropriately reduced. Meanwhile, the average concentration of sludge was about 4,811 mg/L, and MLVSS/MLSS was about 0.49, so the concentration of MLVSS was about 2,357 mg/L. Similarly, the concentration of MLVSS was 1,900 mg/L in rainy season. After increasing the concentration of sludge, the concentration of organic matter for sludge in the sewage plant met the requirements of "Code for design of outdoor drainage". Although the sewage plant maintained the normal operation of the sewage treatment system by increasing the concentration of sludge, the inorganic solids in the influent should be accumulated in the sewage treatment system. The inorganic solid suspended in the mixture increased the density of sludge, causing the difficulty of mechanical mixing or aeration, blockage of sludge pipes, aggravation of mechanical wear of pipes and dehydration equipment. Therefore, it increased energy consumption and operating costs [32–34].

3.6. Relationship between influent water quality and MLVSS/MLSS

The above results show that COD, ISS, TP and particle size in influent had a great influence on MLVSS/MLSS. The concentration of organic matter for influent determined the growth rate of sludge, that was the amount of MLVSS of sludge. The ISS of influent determined the concentration of inorganic matter entering the biological treatment system, that was the amount of MLISS of sludge. Therefore, COD and ISS of influent were the most important factors affecting MLVSS/MLSS of activated sludge. Influent with high concentration of TP entering the biological treatment system could not be transformed into gas like Nitrogen by microorganisms and leave the system. Part of the phosphorus was absorbed by phospho-accumulating bacteria and stored as polyphosphate, and the productive rate of ISS was 3.19 gISS/gP [17]. Most of the excess phosphorus was removed by chemical phosphorus removal, and the chemical sludge also increased the amount of MLISS in the sludge [35–37]. According to the formula of Stocks, the sedimentation rate of suspended particles was positively correlated with the square of particle size, so the particle size would affect the distribution form of ISS for influent in the biological treatment system [38]. Inorganic solids with large particle size were more likely deposited at the bottom of the structure and those with small particle size were suspended in the mixture, reducing the rate of MLVSS/MLSS. Therefore, particle size was positively correlated with MLVSS/MLSS [39].

4. Conclusion

The concentration of pollutants for the influent water in sewage plant was high, and the treatment performance of pollutants in the primary sedimentation tank was obvious. The ratio of COD/TN became a typical low-carbon source wastewater after treatment, but the ratio of ISS/COD was still kept at a high level. The annual variation of influent for water quality and MLVSS/MLSS for mixed liquid was obvious. The concentrations of SS and ISS in influent water were the lowest in dry season from January to March, and showed the highest in rainy season from April to May. However, the variation of MLVSS/MLSS in mixed liquid was opposite. During the rainy season, the flow rate of influent in the sewage treatment plant was increased, and the mass load of pollutant was increased. Therefore, the concentrations of COD, TN and TP for the sewage treatment plant were still maintained a higher level in the rainy season. Finally, it was determined that COD, ISS, TP and particle

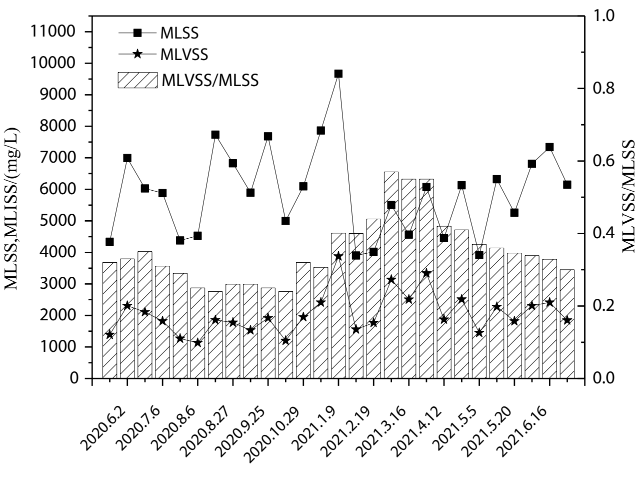

Fig. 3. Annual variation of sludge concentration and MLVSS/MLSS.

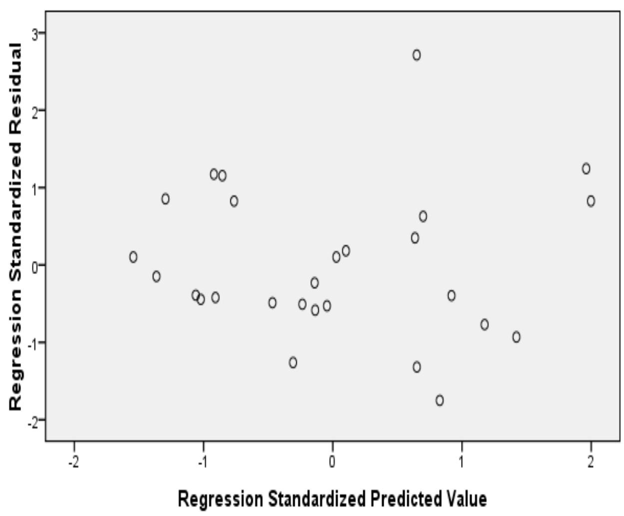

Fig. 4. Regression standardized residual of MLVSS/MLSS.

size for the influent were the important factors affecting the mixed liquid MLVSS/MLSS through Pearson correlation coefficient analysis and linear regression model test.

Author contributions

Conceptualization, T.T.; methodology, G.Z.X.; investigation, T.T.; data curation, G.W.; writing—original draft preparation, H.L.; writing—review and editing, G.Z.X.; project administration, Z.B.P. All authors have read and agreed to the published version of the manuscript.

Funding

This research was funded by Talents of Guizhou Science and Technology Cooperation Platform [2018]5784-04, Zunyi Science and technology projects (2021) 197 and Talent base for environmental protection and mountain agricultural in Chishui River Basin.

Conflicts of interest

The authors declare no conflict of interest.

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