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STUDY ON THE EFFECT OF FLOCCULATION PRETREATMENT WITH A SINGLE FLOCCULANT ON WASTEWATER FROM MUNICIPAL WASTE TRANSFER STATIONS

The authors investigated efficient flocculation methods for the treatment of effluents from municipal waste transfer stations. First, the fluctuation of effluent quality parameters from samples collected at municipal waste transfer stations was analyzed to deeper understand the characteristics of this type of wastewater. Eight flocculants were employed to treat the effluent samples. By controlling variables, the turbidity (Tur), chemical oxygen demand (COD), total nitrogen (TN), and ammonium nitrogen NH_4^+-N levels of the supernatant were measured to determine the optimal concentration, dosage, and settling time of the flocculation. The results indicated that inorganic flocculants exhibited a certain flocculation effect on municipal waste transfer station sewage. However, due to the formation of small flocs, extended flocculation times, and changes in effluent color, they were not suitable for direct application in industrial wastewater.

1. INTRODUCTION

Municipal waste transfer station wastewater primarily comprises a mixture of refuse leachate, cleaning effluent, and rainwater [1]. Refuse leachate is generated during the stacking of waste at the transfer station due to water evaporation from the refuse, natural

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factors such as rainfall and surface runoff, as well as water infiltration during mechanical operations like compaction and crushing [2]. Cleaning effluent results from the use of water guns, high-pressure washers, and other equipment by station operators to clean waste and vehicles during waste handling, transferring, and compacting activities. Rainwater mixing occurs when refuse accumulation and operational activities interfere with drainage systems, leading to the combination of rainwater with refuse leachate, thereby increasing both the volume of effluent produced and the level of pollution.

The amount of effluent generated at a municipal waste transfer station is influenced by factors such as the type and composition of waste, ambient temperature, humidity, precipitation, air temperature, and the degree of waste compaction. Typically, the amount of effluent increases with the quantity of waste processed. Moreover, since municipal waste transfer stations predominantly operate during daylight hours, the generation of effluent exhibits both seasonal and diurnal patterns.

Currently, the three common methods for treating waste transfer station effluent are recharge, evaporation, and non-hazardous treatment [3]. Although numerous methods exist for treating refuse effluent [4], few of them can effectively remove pollutants, and some of them are relatively expensive [5, 6]. The high concentration of recalcitrant pollutants and salt-containing compounds in refuse effluent makes it poorly biodegradable. Therefore, physicochemical treatment is often preferred [7]. Flocculation is a simple and cost-effective technique for treating leachate membrane concentrates, as it promises to remove dissolved organic pollutants [8], and coagulation-sedimentation was suitable for organic matter removal. When the solution pH was 6 and the PAC (polymeric aluminum chloride) dosage was 8 mg/dm^3, the COD removal could exceed 50% and polyacrylamide was beneficial to such a process. After Fenton oxidation, it was suitable for subsequent biochemical treatment [9]. Given the advantages of coagulation and sedimentation in pretreating wastewater, this paper focuses on coagulation as the primary method for treating refuse transfer station effluent.

Coagulation pretreatment technology is a physicochemical method extensively utilized in wastewater treatment. By introducing coagulants into wastewater, it enables the aggregation of suspended solids, colloids, and other pollutants into larger particles, which can subsequently be removed through sedimentation and flotation. Consequently, this reduces pollutant concentrations in wastewater and enhances water quality [10]. Coagulation pretreatment technology offers several advantages, including low capital investment, minimal operating costs, and consistent treatment performance, making it highly promising for application in urban waste transfer station wastewater treatment.

2. MATERIALS AND METHODS

Samples, reagents, and instruments. The samples were collected from the intersection of Ningwu Avenue and Zhonghuan Avenue in Jiangning District, Nanjing City, Jiangsu

Province, approximately 240 m west of the Binjiang Development Zone Sanitation Service Center. As shown in Fig. 1, the raw wastewater exhibits a yellowish-brown color, contains numerous solid residues, and has an oil film, foam, or low-density debris floating on its surface, accompanied by a strong, pungent odor.

Fig 1. Raw sewage from the refuse transfer station site

Table 1

Reagents

Chemical	Norm	Manufacturer
Sodium hydroxide (NaOH)	analytically purity	SCR, China
Polymeric aluminum ferric chloride (PAFC)	chemically pure	
Polymeric ferrous sulfate (PFS)		
Polymeric aluminum silicate ferric (PSAF)		
Polymeric aluminum chloride (PAC)		
COD determination reagent	HR 200–15 000 mg/dm^3	HACH, China
TN determination reagent	HR 2–150 mg/dm^3	
NH_4^+-N determination reagent	0.4–50.0 mg/dm^3	

Table 2

Instruments

Instrument	Model	Manufacturer
pH meter	Raycom PHS-3C	SYSI
Analytical balance	EX2242H	OHAUS, USA
COD reactor	DRB 200	HACH, China
Portable turbidimeter	2100Q	
Portable spectrophotometer	DR 1900	
Brushless mixer (digital display)	QW-WS60-SH	HQI, China
Pipette gun	TopPette Manual Adjustable Pipettes	DXEI, China

Chemical reagents used in this experiment are presented in Table 1; deionized water was also used. Ca^{2+}, Mg^{2+} determination was done with ultrapure water. The main instruments are shown in Table 2.

Experimental methods. Through the experiments of single coagulant, the wastewater quality indexes including pH, turbidity (Tur), chemical oxygen demand (COD), total nitrogen (TN) and ammonium nitrogen $(NH_4^+\text{-N})$ of the raw and treated wastewater were determined to evaluate the optimal concentration and dosage of the flocculants as well as the settling time and obtain the optimal coagulation pretreatment of municipal waste transfer station wastewater. Specifically, 500 cm^3 of wastewater sample was taken, and the pH value was adjusted to 7 with NaOH solution. The sample was stirred at a constant speed of 300 r/min for 10 minutes and then precipitated. Under different concentration gradient conditions, the optimal concentration of single inorganic or single organic coagulant was determined. The state of the supernatant was observed, and then the Tur, COD, TN, and $NH_4^+\text{-N}$ of the supernatant were analyzed. Through data processing and comparative analysis, the best dosage and precipitation time of a single inorganic coagulant or a single organic coagulant were determined.

Methods of analysis. pH was determined by the electrode method, Tur was determined using a portable turbidimeter, and data processing was analyzed by means of Origin 2018 64 Bit. COD was determined by the Hach colorimetric rapid test method with a range of 200–15 000 mg/dm^3 (U.S. Environmental Protection Agency, USEPA). TN was determined by the high-range persulfate oxidation method (Test'N Tube™ tube) of the Hach rapid test method, with a selected range of 2–150 mg/dm^3. $NH_4^+\text{-N}$ was determined by the high-range salicylic acid method (Test'N Tube™ tube) of the Hach rapid test method, with a selected range of 0.4–50.0 mg/dm^3. The removal rate η of pollutants (Tur, COD, TN, and $NH_4^+\text{-N}$) was calculated using the following equation

$$\eta = \frac{C_1 - C_0}{C_0} \times 100\%$$

where C_0, C_1 are the concentration of pollutants in the raw emulsified wastewater, and after addition of the agent, respectively, NTU, mg/dm^3.

3. RESULTS AND DISCUSSION

3.1. QUALITY OF WASTEWATER FROM THE MUNICIPAL WASTE TRANSFER STATION

The wastewater samples were collected at 8:00 am from March 13, 2024, to March 19, 2024, at the Riverside Development Zone Sanitation Service Center. The raw sewage was analyzed for pH, Tur, COD, TN, and $NH_4^+\text{-N}$. The obtained data are summarized in Table 3.

pH of the raw wastewater ranged from 4.66 to 6.81. Due to the difference in quality and amount of incoming effluents, pH fluctuated. Tur also exhibited substantial variability, with the minimum value of 136.1 NTU and the maximum of 833.6 NTU. This may be influenced not only by the amount of waste, but also by the amount of generated leachate. Although the amount of garbage remained constant, road wash wastewater was mixed at the waste transfer station, introducing additional variability.

Table 3

Raw wastewater quality from the municipal waste transfer station

Date	Tur [NTU]	COD [mg/dm^3]	TN [mg/dm^3]	NH_4^+-N [mg/dm^3]	pH
March 13	500	3576	60.2	28.04	4.66
March 14	320.6	4576	73.6	14.72	5.09
March 15	535	5294	53.6	16.58	4.82
March 16	136.2	3346	65	16.12	5.87
March 17	833.6	11988	233.2	27.54	4.93
March 18	657.2	10248	167.8	29.3	5.09
March 19	448.8	922	30	4.8	6.81

For instance, heavy road wash or rainfall significantly impacted Tur levels. The data collected on March 19 indicated pH 6, which demonstrated an upward trend compared to the pH levels observed at other times. Conversely, the values for COD, Tur, TN, and NH_4^+-N showed a decrease. This could potentially be attributed to significant dilution of the effluent sample, leading to lower measured concentrations. The volume of effluents discharged from the refuse transfer station varied considerably, with trends in NH_4^+-N, and COD being similar. Nitrogen in the waste transfer station primarily exists as organic nitrogen, which can reduce into NH_4^+-N under both aerobic and anaerobic conditions over time. If the waste is not treated in time, nitrogen will be transformed into each other, resulting in a large difference in the concentration of TN, and NH_4^+-N. In general, the contaminant concentrations of wastewater are affected by the volume of waste, water, weather and season, which are complex, variable and difficult to treat.

3.2. FLOCCULATION PRETREATMENT STUDY WITH SINGLE INORGANIC FLOCCULANT

3.2.1. FLOCCULATION PRETREATMENT STUDY WITH POLYMERIC ALUMINUM IRON CHLORIDE (PAFC)

The supernatant was taken sequentially to determine the Tur, COD, TN, and NH_4^+-N. The quality of wastewater treated by PAFC (30 wt %) is given in Table 4, whereas the removal efficiencies and the amount of precipitation are shown in Fig. 2. After 2 hours, the overall removal rates of Tur, TN, COD and NH_4^+-N were 94.52–98.10, 68.60–75.69, 72.34–77.13, and 7.44–64.88%, respectively. The removal efficiencies increased with the increasing dosage of PAFC. The removal rates of NH_4^+-N was relatively low at dosages of 2 cm³/500 cm³ and 4 cm³/500 cm³. However, as the PAFC dosage increased from 6 cm³/500 cm³ to 8 cm³/500 cm³, the removal rates of NH_4^+-N significantly improved and the removal rates began to stabilize when the PAFC dosage reached 8 cm³/500 cm³. When the dosage exceeded 8 cm³/500 cm³, the removal rate of NH_4^+-N remained unchanged. Therefore, without considering the impact of settling time, 8 cm³/500 cm³ was determined to be the optimal dosage of PAFC (30 wt %).

Table 4

Flocculation effect of different dosages of PAFC (30 wt %)

Dosage [cm³/500 cm³]	Tur [NTU]	COD [mg/dm³]	TN [mg/dm³]	NH_4^+-N [mg/dm³]
0	–	10285	188	33.6
2	7.44	3230	52	31.1
4	6.15	3000	49	29.6
6	4.92	2650	45	29
8	2.85	2530	44	12
10	2.58	2500	43	11.8

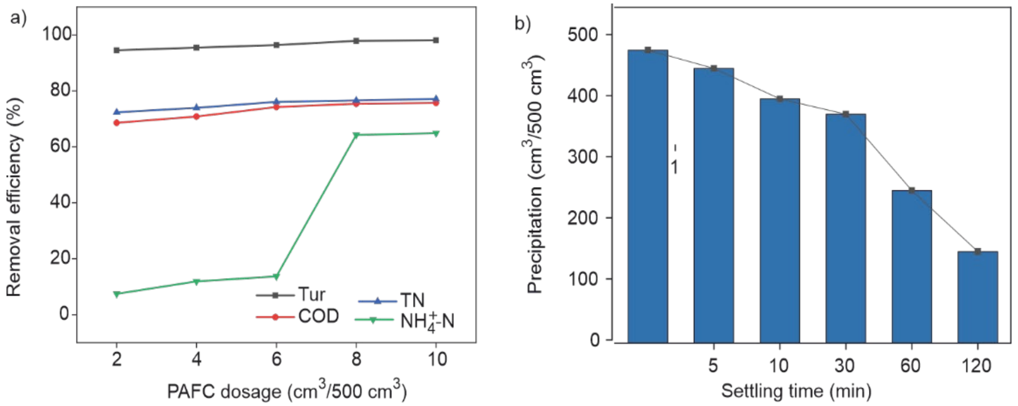

Fig. 2. The removal efficiencies of Tur, COD, TN, and NH_4^+-N under various dosages of PAFC (30 wt %) (a), and the precipitation produced at the settling time of 1 min, 5–120 min (b)

Based on the aforementioned results, 8 cm³ dosage of PAFC was applied to 500 cm³ of wastewater, and the samples were subjected to sedimentation for 1–120 min. The solid volume was 480, 450, 400, 375, 250, and 150 cm³. The proportion of solid phase volume decreased as the resting time increased with identical stirring times. After 2 hours, the settling rate of flocs changed very slowly. Under this condition, the removal efficiencies of Tur, COD, TN, and NH_4^+-N were 97.9, 75.4, 76.6, and 64.3%, respectively. When the dosage of PAFC was 8 cm^3/500 dm^3 and the optimal settling time was 2 hours, the removal efficiencies were highest.

PAFC demonstrated a significant effect on the pretreatment of sewage from municipal refuse transfer stations, effectively for the pollution parameters. However, from a practical application perspective, PAFC flocculants form small flocs that require extended settling times, leading to reduced equipment efficiency or significantly increased operating costs. It is essential to explore new, more efficient flocculant option.

3.2.2. FLOCCULATION PRETREATMENT STUDY WITH POLYMERIZED FERRIC SULFATE (PFS)

The treatment effect of different dosages of PFS on wastewater of municipal refuse transfer station is shown in Fig. 3. The supernatant after reaction was taken successively to measure Tur, COD, TN, and NH_4^+-N . The effluent value and removal rates are shown in Table 5 and Fig. 3a, respectively.

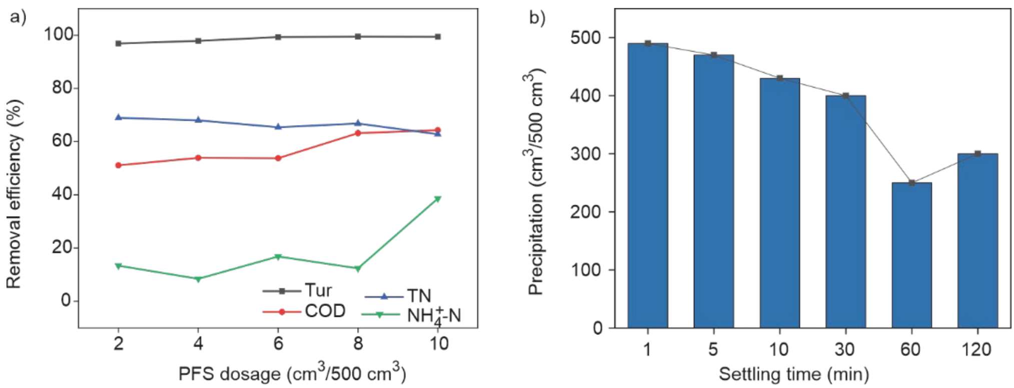

Fig. 3. The removal efficiencies of Tur, COD, TN, and NH_4^+-N under various dosages of PFS (a) and the precipitation at the settling times of 1–120 min (b)

The removal rates of Tur, COD, TN, and NH_4^+-N in wastewater after adding 2 cm^3/500 cm^3 PFS were 96.88, 68.96 and 51.10%, respectively. With the increase of the amount of PFS, the removal rates of Tur, COD, TN, and NH_4^+-N increased slowly, but the removal rates of NH_4^+-N showed a large fluctuation. When the dosage of PFS increased from 8 cm^3/500 cm^3 to 10 cm^3/500 cm^3, the removal rates of NH_4^+-N increased from 15.35% to 38.61%. However, the removal rates of TN, and NH_4^+-N fluctuated. This may be due to differences in pH and mixing rates in water samples due to differences in the dosage of PFS. Flocculant sedimentation mainly removes organic nitrogen in the form of macromolecules. When the concentration of organic nitrogen decreased, the removal rate of TN showed a downward trend, but the removal of NH_4^+-N was not necessarily proportional to TN due to the differences in external conditions. Therefore, the optimal dosage of PFS was 8 cm^3/500 cm^3.

Table 5

Flocculation effect of different dosages of PFS

Dosage [cm^3/500 cm^3]	Tur [NTU]	COD [mg/dm^3]	TN [mg/dm^3]	NH_4^+-N [mg/dm^3]
0	178.3	15294	422	20.2
2	5.55	7480	131	17.5
4	3.79	7050	135	18.5
6	1.26	7070	146	16.8
8	0.94	5628	140	17.7
10	1.07	5460	157	12.4

Then, 8 cm^3 of PFS was applied into 500 cm^3 wastewater and wastewater was subjected to settlement for 1–20 min. The precipitation volume produced is shown in Fig. 3b. With the increase of settling time, the volume of precipitation gradually decreased. After 2 h, the precipitation achieved the smallest volume of 300 cm^3. However, the amount of precipitation was still too large, so exploring new flocculants is still essential.

3.2.3. FLOCCULATION PRETREATMENT STUDY WITH POLYMERIC ALUMINUM FERRIC SILICATE (PAFS)

The dosages of PSAF (10 wt %) of 2–10 cm^3 were added to 500 cm^3 wastewater samples. The supernatant was analyzed for Tur, COD, TN, and NH_4^+-N. The effluent values and removal rates are presented in Fig. 4 and Table 6.

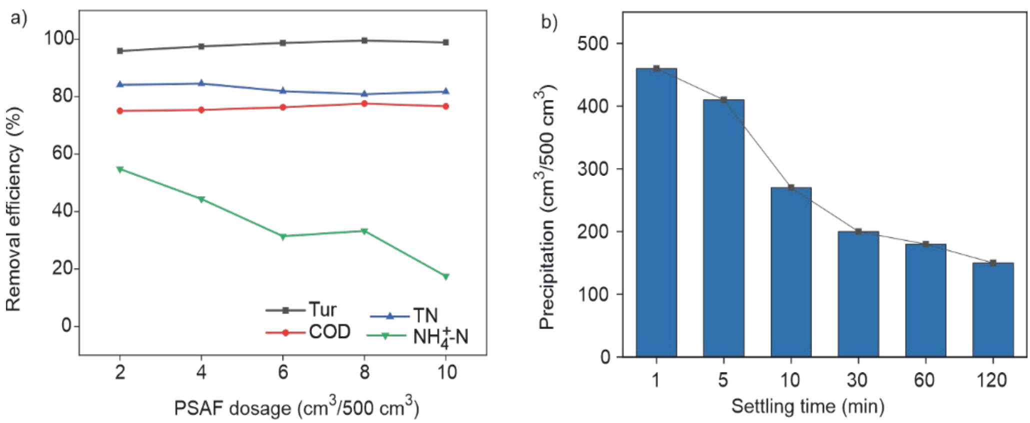

Fig. 4. The removal efficiencies of Tur, COD, TN, and NH_4^+-N under various dosages of PSAF (10 wt %) (a) and the precipitation produced at the settling time of 1–120 min (b)

As shown in Fig. 4, both the Tur and COD removal rates initially increased and then decreased, reaching their peak at a dosage of 8 cm^3/500 cm^3. Under the dosage of 8 cm^3/500 cm^3, the removal rates were highest. In contrast, the removal rates for TN and NH_4^+-N exhibited a decreasing trend. This can be attributed to the same mechanism observed with PFS flocculant, where the conversion between different forms of nitrogen played a significant role. Considering the factors that most influence biochemical effects, particularly Tur as well as economic considerations, it is concluded that 8 cm^3/500 cm^3 is the optimal dosage for PSAF. As shown in Fig. 4b, it is evident that the precipitation volume gradually increased after dosing, stirring, and settling, while the sedimentation rate progressively decreased. After 1 h, the change in sedimentation became minimal, indicating that 1 h was the optimal settling time with a sedimentation ratio of approximately 23%.

Table 6

Flocculation effect with different dosages of PSAF (10 wt %)

Dosage [cm^3/500 cm^3]	Tur [NTU]	COD [mg/dm^3]	TN [mg/dm^3]	NH_4^+-N [mg/dm^3]
0	260.77	25401	674	43.15
2	10.7	6340	107	19.5
4	6.5	6250	104	24
6	3.39	6020	122	29.6
8	1.22	5690	129	28.8
10	2.89	5930	123	35.6

In summary, PSAF showed a notable treatment effect on municipal refuse transfer station wastewater. When the PSAF concentration was 10%, the dosage 8 cm^3/500 cm^3, and the settling time 1 h, the removal rates of Tur, COD, TN, and NH_4^+-N were 99.75, 77.6, 80.9, and 33.2%, respectively. However, the efficiency of PSAF in removing chromaticity was limited, resulting in a yellowish supernatant after treatment. From a practical application standpoint, the settling time after adding PSAF was only half of adding PAFC or PFS, but the chromaticity treatment performance was inferior to both PAFC and PFS.

3.2.4. FLOCCULATION PRETREATMENT STUDY OF POLYMERIC ALUMINUM CHLORIDE (PAC)

PAC (30 wt %) (2– 10 cm^3) was added to the wastewater samples. After the reaction, the supernatant was analyzed sequentially for Tur, COD, TN, and NH_4^+-N. The results are presented in Table 7 and Fig. 5. The Tur removal rate exhibited continuous fluctuations, but the overall differences were minimal. The COD removal rate generally increased, peaking at a dosage of 8 cm^3/500 cm^3. However, with the increasing addition of PAC, the removal rates of TN, and NH_4^+-N showed fluctuating trends. Unlike flocculants PFS and PSAF, the fluctuations in TN decreased after treatment, although the reasons for these fluctuations were similar (Fig. 5a). Considering the significant impact of Tur on biochemical effects and from an economic perspective, 8 cm^3/500 cm^3 PAC was the optimal dosage. As illustrated in Fig. 5b, following dosing, stirring, and settling, the sedimentation ratio gradually increased, while the settling rate decreased. After 2 h, the changes in precipitation became very slow, with no significant changes observed over longer periods. Therefore, the optimal settling time was 2 h. Therefore, PAC as a flocculant demonstrated effective treatment of municipal waste transfer station wastewater. At a PAC concentration of 30 wt %, a dosage of 8 cm^3/500 cm^3 and settling for 2 h, the removal rates of Tur, COD, TN, and NH_4^+-N were 99.2, 78.6, 77.5, and 30.7%, respectively. From the post-treatment chromacity perspective, the treatment effect was comparable to PAFC but superior to PSAF and PFS.

Table 7

Flocculation effect of different dosages of PAC (30 wt %)

Dosage [cm^3/500 cm^3]	Tur [NTU]	COD [mg/dm^3]	TN [mg/dm^3]	NH_4^+-N – [mg/dm^3]
0	107.65	8084	404	14.7
2	3.12	2140	35	9.9
4	2.76	1970	28	10.8
6	1.16	1950	59	9.8
8	0.86	1730	91	10.2
10	0.75	1770	45	9.9

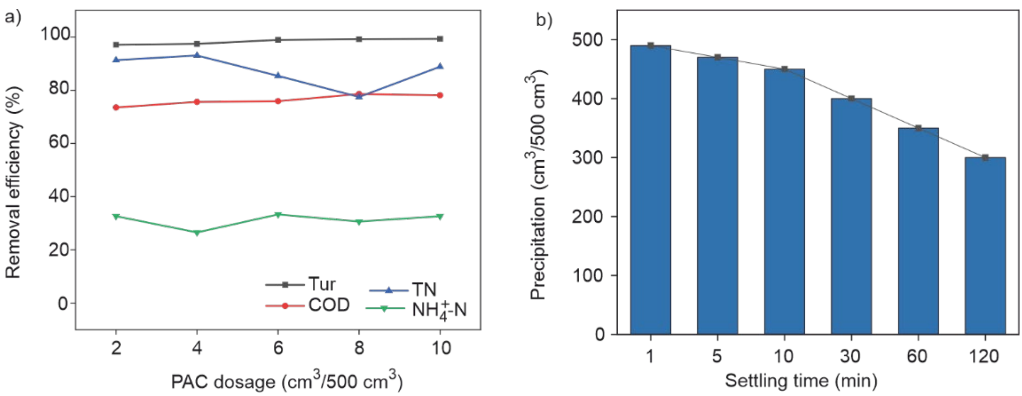

Fig. 5. The removal efficiencies of Tur, COD, TN, and NH_4^+-N under various dosages of PAC (30 wt %) (a) and the precipitation produced at the settling time of 1–120 min (b)

3.2.5. DISCUSSION OF THE RESULTS OBTAINED FOR SINGLE INORGANIC FLOCCULANT

When using PAFC as the flocculant at a concentration of 30 wt % and dosage of 8 cm^3/500 cm^3 at a settling time of 2 h, the removal rates of Tur, COD, TN, and NH_4^+-N could reach 97.9, 75.4, 76.6 and 64.3%, respectively. When PFS was used as the flocculant at a dosage of 10 cm^3/500 cm^3 at a settling time of 2 h, the removal rates of Tur, COD, TN, and NH_4^+-N were 99.4, 64.3, 62.8, and 38.5%, respectively. At the flocculant concentration of 10 wt % and dosage of 6 cm^3/500 cm and a settling time of 1 h, the removal rates of Tur, COD, TN, and NH_4^+-N reached 99.75, 77.6, 80.9, and 33.2%, respectively. When PAC was used as the flocculant at a concentration of 30 wt % and dosage of 8 cm^3/500 cm^3 at a settling time of 2 h, the removal rates reached 99.2, 78.6, 77.5, and 30.7%, but the supernatant had poor coloration.

All four inorganic flocculants have flocculation effects on wastewater. The choice of a flocculant should be made based on effluent requirements, economic costs, and operating efficiency before being applied in engineering practice.

4. SUMMARY

The pretreatment of sewage from municipal waste transfer stations with different single inorganic flocculants has been investigated. The composition of the sewage from the municipal waste transfer station was complex. The fluctuation of the effluent quality was affected by factors such as the type, composition, and total amount of the compressed garbage on that day, as well as the weather. Four inorganic flocculants, such as PAFC, PFS, PSAF, and PAC had good removal rates for Tur, COD, TN, and NH_4^+-N. However, the flocs formed by inorganic flocculants were too small, and the settling time was too long, resulting in low efficiency and limitations in practical applications. The overall results of the study showed that a single inorganic flocculant influenced sewage, but improving efficiency was the key to better application. Therefore, it is necessary to explore new or combined flocculants to further improve the efficiency of flocculation pretreatment. In future research and practice, we will continue to optimize the treatment process. We hope that through these efforts, we can better protect water resources and the ecological environment, and achieve the goal of a green and sustainable society.

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