APPLICATION OF COMPACT PIPING SEDIMENTATION UNIT AS PRETREATMENT FOR ULTRAFILTRATION PLANT

Amira Mohamed NAGY^{1,*}, Mohamed ElHosseiny El-NADI¹, Nany Ali Hassan NASR¹, Hossam Mostafa HUSSEIN¹

¹ Department of Civil Engineering, Faculty of Engineering, Ain Shams University, Egypt.
^{*} corresponding author: amiranagy1290@yahoo.com

Abstract

The study aimed to create a compact pretreatment unit before the ultrafiltration modules. This unit targeted to improve the inlet water quality to meet the average values of the feed water quality required for the ultrafiltration plants according to the manufacturer. The used unit in this study was a pipe worked as a sedimentation unit with inclined plates to apply the plate settler technology. The suitability of using this unit was determined by using varied water sources with different Total Suspended Solids (TSS) concentrations and different retention times. The removal efficiencies for the low TSS water source reached 96.47 %, 82.94 %, 64.80 % & 30.59 % with retention time 30 minutes, 15 minutes, 5 minutes & 20 seconds respectively. For the medium TSS water source at the same retention times, the removal efficiencies reached 97.33 %, 92.87 %, 86.10 % & 63.89 %. For the high TSS water source, the removal efficiencies reached 98.64 %, 93.86 %, 87.51 % & 76.23 %. These results make the sedimentation unit able to work as an effective pretreatment unit for the ultrafiltration units for all water sources.

Keywords:

Water treatment;
 Sedimentation;
 Plate settler;
 Pretreatment;
 Ultrafiltration.

1 Introduction

Water is an important element to human survival [1]. Raw water purification is a necessary process to can produce potable water able to be consumed by humans. Membrane technology appears to be an attractive alternative to conventional plants, because of the major advantages that can be offered. A membrane plant needs a small area with almost no time to construct, it can produce the required quality regardless of the incoming water quality, and also it does not need high costs when compared with the conventional plants.

Recently in Egypt, several plants were applied using ultrafiltration modules. Unfortunately, many of these plants do not work with their optimum capacity. This is due to the poor feed water quality caused by the disposal of domestic and industrial wastes to the water canals in most of the rural areas. Also, chemical fertilizers and pesticides used during irrigation lead to an increase in the loads on the membranes. All of this affects the membrane performance and increases the rate of backwashing and chemical cleaning which reduces the plant productivity, increases the operating costs, and causes a reduction in a membrane lifetime. All of these reasons make the application of ultrafiltration with no benefit. This raises the need for pretreatment associated with the membrane plants to be suitable for our needs for this type of treatment. More researches needed for the pretreatment to be able to apply this technology with maximum efficiency and minimum costs.

The major drawback of the membrane process is fouling, which acts as a limiting factor to increase the use of membrane processes. Fouling is the accumulation of particles on the membrane surface or inside the membrane pores [2]. Fouling leads to reduce the flux which affects the capacity, increases the required trans-membrane pressure (TMP), required more frequent backwashing processes, required more chemical cleaning, and shortens the membrane lifetime, all of these cause increase in the operational cost [3, 4]. Improving the feed water quality to ultrafiltration units may

reduce these negative effects. Table 1 shows the average and the maximum feed water quality required to enter the ultrafiltration modules according to the manufacturer.

Table 1: Ultrafiltration feed water quality required.

Parameter	Unit	Value average	Value max.
Turbidity	NTU	<50	300
TOC	mg/l	<10	40
Particle size	Micron	<150	300
COD	mg/l	<20	60
pH	-	6-9	2-11
Temperature	°C	25	40
CL ₂	mg/l	0.5	200
TSS	mg/l	50	100

The pretreatment processes can be done by physical, chemical, or biological actions [5]. The selection of the suitable pretreatment strategy dependent on many factors such as the feed water quality, membrane properties, and operation conditions [6].

Coagulation-sedimentation (conventional), oxidation, adsorption, and bio-filtration are the most common pretreatment techniques before the ultrafiltration process [7, 8]. This study discusses the use of the sedimentation process without using coagulants as a pretreatment technique.

Coagulation-flocculation-sedimentation is the most common treatment to surface water purification by removing turbidity and Non-Organic Matter (NOM). Alum and Ferric base salts are the most common coagulants used in the coagulation process. Aluminium sulphate is the most used coagulant in water treatment [9]. The coagulant is added to the feed water to form flocs which heavy enough to settle in the sedimentation tank leaving the feed water. To reduce the formation of the disinfection by-products (DBPs), it is a must to use a higher dosage from the coagulant to target the NOM removal rather than just turbidity [10].

Coagulation as a pretreatment to ultrafiltration is an attractive process used all over the world [11]. There are two types for applying the coagulation prior to the ultrafiltration, the first is coagulation followed by the sedimentation process which allows using a higher dosage of the coagulant and giving more efficiency [9]. The second is in-line coagulation when a small coagulant dosage is added to the feed water just before the entrance of the ultrafiltration unit without sedimentation [12].

In coagulation followed by sedimentation processes, aquatic colloids and other contaminants attached to the coagulant and forming flocs that settled in the sedimentation stage prior to the membrane filtration, which improves the membrane performance and causes less fouling [13].

In in-line coagulation, it is common to use a low dosage of coagulant directly prior to the membrane filtration without any sedimentation process [12], to change the colloids and NOM characteristics [13]. The main advantages of the in-line coagulation process that it is a small process compared to the conventional processes and uses low coagulant dosage which reduces the operating costs. The main disadvantage is the difficulty of determining the proper dose. Jar testing is very helpful in predict coagulant dose and its performance in conventional coagulation, but unfortunately, it is may not be beneficial in in-line coagulation [14].

Park compared using coagulation followed by sedimentation and in-line coagulation to treat surface water, the results showed that in-line coagulation was more effective in improving the membrane performance [15].

Liang compared three pretreatment techniques (in-line coagulation – coagulation followed by sedimentation – coagulation followed by sedimentation followed by filtration) to treat surface water with high algae content, the result found that coagulation followed by sedimentation was the best for improving the membrane performance and reducing the membrane fouling [16].

Moon compared the coagulation followed by sedimentation with the direct ultrafiltration and found that the coagulation followed by the sedimentation process gave higher production efficiency and reduce the fouling [17].

Some studies were made to investigate the effects of the in-line coagulation prior to ultrafiltration process to treat secondary wastewater effluent, the results showed that using in-line coagulation increased the removal efficiency and improved the fouling resistance due to preventing the pore blocking and reducing the cake formation [12, 17].

Finally, using coagulation with or without sedimentation as a pretreatment for the ultrafiltration process is an effective method, and its efficiency dependent on some factors such as coagulant type, coagulant dose, mixing time, and feed water characteristic. In this study, the target was to determine the suitability of using the sedimentation process only without coagulation in the pretreatment process.

2 Materials and methods

The pilot was located at the sanitary & environmental engineering laboratory at engineering faculty at Ain Shams University. The pilot unit consists of an Unplasticized Polyvinyl Chloride (UPVC) pipe with 10 cm diameter and 100 cm length. This pipe material suitable to use with the water type treated in this study also this material has excellent chemical resistance to many acids, alkalis, bases, and salts which can be a very important advantage in the case of using coagulants. There were three valves connected to the pipe, one for the water inlet, one for the water outlet, and the other one for the sludge outlet. This pipe contains 47 inclined smooth plastic plates fixed on an axis by an angle of 45° with the horizontal line and spacing between every two plates equal 2 cm. This axis was fixed at the ends of the pipe. Fig. 1 shows a schematic diagram of the sedimentation unit. Fig. 2 shows the axis and the inclined plates. Fig. 3 shows the final shape of the sedimentation unit. This unit is connected by a tank with a capacity of 200 liters as the water source for the unit. The water flow enters the pipe and passes through the spacing between the plates to the top zone of the pipe then to the water outlet opening. The particles crashed with the inclined plates and settle down in the bottom zone of the pipe then pass through the sludge outlet opening periodically. The smooth plastic material offered an easier sedimentation process for the particles to settle in the bottom zone of the pipe as there was no rough surface to settle on it. This can be an advantage in the long term as the plates didn't need to clean.

Fig. 1: Schematic diagram of the sedimentation unit.

Fig. 2: The axis and the inclined plates.

Fig. 3: The final shape for the sedimentation unit.

The experimental works are divided into four runs. Each run had a different retention time. 30 minutes, 15 minutes, 5 minutes & 20 seconds were the different retention times used in this study for each run with flow rates 0.38, 0.75, 2.26, and 40.38 m³/day respectively. Each run was repeated three times with different water sources that had different inlet TSS concentrations as the TSS is the main parameter in this study. The pilot was washed and emptied of water before each run to can measure the actual efficiency for each run at the same conditions. Average TSS concentration for the first water source equal 34 mg/l, for the second water source equal 146 mg/l, and for the third water source equal 468 mg/l.

Samples were taken twice a day from the inlet and the outlet of the unit. Water samples were routinely collected each day after the first retention time for each unit and at the end of the operation and then analyzed to investigate water quality during the examination period. Time and TSS concentration were the measured parameters in this study.

Time measured using a digital stopwatch and TSS was measured according to the standard method for examination of water and wastewater at the central laboratory of sciences faculty at Ain Shams University. The water sample was filtered with pre-weighed filter paper. The filter paper was dried in a drying oven at 100 - 105 °C for 1 hour. The dried filter paper cooled at desiccator for 30 minutes to reach room temperature then filter paper weighted using sensitive balance. TSS then calculated using the following equation;

$$\text{TSS}[\text{mg/l}] = \frac{(\text{weight final} [\text{mg}] - \text{weight initial} [\text{mg}]) \times 1000000}{\text{sample volume [l]}} \quad (1)$$

3 Results

Each run was applied for 3 days for each water source. The experimental results for each run illustrated in Tables 2 – 5.

Table 2: The TSS concentration during the experimental works for RT = 30 min.

Samples	First quality		Second quality		Third quality	
	TSS [mg/l]	Removal efficiency [%]	TSS [mg/l]	Removal efficiency [%]	TSS [mg/l]	Removal efficiency [%]
1	1.2	96.47	4.8	96.71	5.5	98.82
2	1.8	94.71	4.4	96.99	7.5	98.40
3	1.2	96.47	3.5	97.60	6.8	98.55
4	0.6	98.24	3.5	97.60	4.8	98.97
5	1.2	96.47	4.8	96.71	6	98.72
6	1.2	96.47	2.4	98.36	7.5	98.40
Average	1.2	96.47	3.9	97.33	6.35	98.64

Table 3: The TSS concentration during the experimental works for RT = 15 min.

Samples	First quality		Second quality		Third quality	
	TSS [mg/l]	Removal efficiency [%]	TSS [mg/l]	Removal efficiency [%]	TSS [mg/l]	Removal efficiency [%]
1	5.4	84.12	10	93.15	27.5	94.12
2	4.2	87.65	11.5	92.12	29	93.80
3	7.2	78.82	9.5	93.49	23.5	94.98
4	6	82.35	11	92.47	30.5	93.48
5	6	82.35	12	91.78	31	93.38
6	6	82.35	8.5	94.18	31	93.38
Average	5.8	82.94	10.41	92.87	28.75	93.86

Table 4: The TSS concentration during the experimental works for RT = 5 min.

Samples	First quality		Second quality		Third quality	
	TSS [mg/l]	Removal efficiency [%]	TSS [mg/l]	Removal efficiency [%]	TSS [mg/l]	Removal efficiency [%]
1	14.2	58.24	18.5	87.33	59	87.39
2	12	64.71	21.5	85.27	60.1	87.16
3	8.4	75.29	19.4	86.71	56.8	87.86
4	9	73.53	22.8	84.38	57.9	87.63
5	15.6	54.12	21.2	85.48	59	87.39
6	12.6	62.94	18.4	87.40	57.8	87.65
Average	11.96	64.80	20.30	86.10	58.43	87.51

Table 5: The TSS concentration during the experimental works for RT = 20 sec.

Samples	First quality		Second quality		Third quality	
	TSS [mg/l]	Removal efficiency [%]	TSS [mg/l]	Removal efficiency [%]	TSS [mg/l]	Removal efficiency [%]
1	24	29.41	55	62.33	114.5	75.53
2	22.5	33.82	50	65.75	105	77.56
3	23.5	30.88	49.8	65.89	110	76.50
4	25	26.47	56	61.64	115.5	75.32
5	22.4	34.12	53	63.70	109	76.71
6	24.2	28.82	52.5	64.04	113.5	75.75
Average	23.60	30.59	52.72	63.89	111.25	76.23

4 Discussion

The data in Table 1 show that, for the first water source the average TSS removal efficiency using 30 minutes, 15 minutes, 5 minutes & 20 seconds as a retention time equal to 96.47 %, 82.94 %, 64.80 % and 30.59 % respectively. For the second water source the average TSS removal efficiency for the same retention times equal to 97.33 %, 92.87 %, 86.10 % & 63.89 %. For the third water source the average TSS removal efficiency for the same retention times equal to 98.64 %, 93.86 %, 87.51 % and 76.23 %.

Fig. 4 shows the average TSS removal efficiency with the different water sources according to retention time.

Fig. 4: Average TSS removal efficiency with different water sources.

As known from the previous studies concerned with sedimentation processes, the TSS removal efficiency increases with the increase of the sedimentation retention time which means that the relation between the TSS removal efficiency and the retention time for the sedimentation process is directly proportional. This is because of the effect of the retention time in the flow velocity, as when the retention time increased that causes a decrease in the flow velocity which makes the sedimentation process more effective and had a high TSS removal efficiency.

As the TSS concentration for the first water source equal 34 mg/l, so this type of water did not require pretreatment for the ultrafiltration modules because its TSS concentration was less than 50 mg/l, and this an acceptable value to enter the ultrafiltration modules as shown in Table 1. Despite that, the experimental results for this water quality recorded acceptable removal efficiencies for retention time above 5 minutes. This water source was used mainly to test the pilot unit and determine it is suitability to treat raw water. The removal efficiencies recorded proved that this unit can achieve high removal efficiencies for the inlet water.

From the experimental results, the behavior of the TSS removal efficiency for the second and the third water sources according to the retention time increase was similar but different from the first water source behavior. As with the first water source, the retention time affects highly in the removal ratio. But for the second and third water sources only retention time less than 5 minutes had a high effect on the efficiency. Retention time more than 5 minutes for the second and the third water sources had a slight effect on the removal efficiency. This is highly dependent on the particle size of the suspended solids. Usually, the high TSS water sources had a higher percentage of the large suspended solids particles than the low TSS water sources. This may be the reason for the higher removal ratio recorded with the second and the third water source as the large particles required less time to sediment.

Using small retention time with this pilot recorded low removal efficiencies compared with long retention times, but the reached removal ratio produce water with TSS concentration suitable to enter the ultrafiltration modules. Also, this small retention time allows creating the compact piping unit with small dimensions which an important factor in the required pretreatment unit.

The success of the TSS concentration reduction using this pilot unit with a very small retention time gives a very good indication to use this unit as a compact pretreatment unit. This small retention time allows using a small unit to treat high water capacity.

5 Conclusion

In general, the experimental works in this study approved that the developed sedimentation piping unit is succeeding unit to apply the plate settler technology and improve the TSS removal efficiencies with smaller time than usual which makes the unit size as small as it can and had a low cost to construct. These reasons make this unit suitable to use as a pretreatment unit for the ultrafiltration modules.

As known, the TSS removal efficiency increased with the increase of the retention time but the effect of increasing the retention time on the removal efficiency varied with each water source that had a different TSS concentration. The low TSS concentration water source had the maximum effect of the retention time increase while the medium and high TSS concentration water sources had a slight effect on the retention time increase especially for the retention time of more than 5 minutes.

The piping unit can be used as a treatment unit with retention time ranged between 15 to 30 minutes as their removal efficiency reached more than 90 % for all water types. Also, it is can be used as a pretreatment unit with a retention time smaller than 5 minutes according to the required removal efficiency.

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