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Original Article

Optimal Treatment of Ceramic Industrial Wastewater

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Abstract *- This study aimed to determine the most efficient method to treat and reuse wastewater from the Ceramica Cleopatra factory in the 10th of Ramadan City, Egypt. A lab-scale pilot was designed and tested through four experimental runs. The system included three parallel treatment lines: the first combined chemical sedimentation with filtration, the second paired flotation with filtration, and the third consisted of cyclone separation followed by filtration. The wastewater used in the experiments had an initial concentration of 20,800 ppm. In the absence of coagulants, the sedimentation line achieved a removal efficiency of 99.51% (102 ppm effluent), the cyclone line reached 99.83% (34 ppm), and the flotation line recorded 99.70% (63 ppm). However, these results were inadequate for reuse in the ceramic industry. When ferric chloride was introduced as a coagulant, the sedimentation line's efficiency increased to 99.95% (10 ppm), the cyclone line to 99.93% (16 ppm), and the flotation line to 99.94% (14 ppm). Despite the improvement, these results were still insufficient for industry requirements. The addition of coal filters significantly enhanced performance. The sedimentation line reached 99.95% efficiency (10 ppm effluent), the cyclone line achieved 99.97% (5 ppm), and the flotation line attained 99.96% (7 ppm). The cyclone line, combined with the coal filter, produced results that met the ceramic industry's standards, marking it as the most optimal and effective wastewater treatment method for this application.*

Keywords *- Cyclone, Filtration, Flotation, Sedimentation, Wastewater treatment.*

1. Introduction

The ceramic industry depends on water in all stages of production. Ceramic manufacturing can be made by taking mixtures of earthen elements, clay, powders, and water and then shaping them into required forms. After the ceramic is shaped in the required forms, it can be fired at high temperatures using an oven known as a kiln. Often, ceramics are covered in waterproof, decorative, paint-like materials known as glazes [1].

A lot of waste is produced during the ceramic manufacturing process. It must be treated before disposing or using it to protect the environment [2]. Wastewater from the ceramics industry contains large amounts of organic and inorganic pollutants, Chemical Oxygen Demand (COD) and it also may include heavy metals such as lead, boron, iron, aluminium, copper, manganese, cadmium, and zinc. Total Dissolved Solids (TDS) and Total Suspended Solids (TSS) also exist in ceramic industry wastewater because of the high mineral components of materials produced. Oil and grease may also exist from machining used for ceramic manufacturing [3]. Ceramic industrial wastewater treatment depends mainly on chemical and physical treatment. Physical methods of treatment are used to get rid of contaminants. It was one of the first treatment techniques used in industrial wastewater treatment. It is still used in most wastewater treatment processes. These methods depend on applying physical forces and are used when highly polluted water [4].

The most common methods in the physical treatment of industrial wastewater are flow equalization, screening, sedimentation, filtration, and floatation [4]. Chemical methods used in industrial wastewater treatment are designed to make changes through chemical reactions. These methods are consistently integrated with both physical and biological approaches.

Chemical methods, compared to physical methods, have inherent disadvantages, given that they are additive processes. That is, the dissolved elements in wastewater usually increase. This is an important factor if the wastewater is to be reused [5]. The most common methods in the chemical treatment of industrial wastewater are neutralization, chemical precipitation, adsorption, disinfection, and dechlorination [4].

Some studies worldwide, including those in Egypt, have been conducted to treat ceramic industrial wastewater. In Indonesia, Poly Aluminum Chloride (PAC) was used as a coagulant to reduce the concentration of COD, TSS, and lead metal (Pb).

In this study, the coagulant was placed in a glass beaker containing 1L of wastewater with a coagulant volume (5 ml, 7.5 ml, 10 ml, 12.5 ml, and 15 ml). Then, it is stirred using a flocculator with a speed of 100 rpm and varied times (2, 4, 6, 8, and 10 minutes) to form flocs. Then, the mixture formed was left for 30 minutes and filtered to analyse TSS, COD, and Pb. Based on the study results, it can be concluded that the best reduction efficiency for TSS levels was 99.9%, with a coagulant volume of 12.5 ml at a time of 6 minutes.

The best reduction efficiency of COD levels was 98.23% with a coagulant volume of 15 ml at a time of 6 minutes. The best efficiency of reducing Pb levels was 99.10% with a coagulant volume of 5ml at a time of 2 minutes; all of these values were below the quality standard of the ceramic industry [6].

In the EGE Ceramic Factory in Turkey, an activated sludge in the second stage was applied after chemical sedimentation. The effluent wastewater from the chemical sedimentation stage had a high average COD of 720 ppm. Experiments were performed under varying hydraulic and solids retention times. Optimal results were achieved with a hydraulic retention time (θc) of 20 hours and a solids retention time (sludge age) of 20 days, yielding an effluent COD concentration of 40 mg/l from an initial wastewater feed containing 720 mg/l of COD. The suspended solids content of the activated sludge effluent was approximately 52 mg/l [7].

In India, a study made on the sample was taken from the Cosa ceramic factory at Morvi, Gujarat and used for laboratory scale tests using different concentrations of coagulants to enhance TSS, pH and turbidity. The main purpose of this study is to determine the optimum doses of Fecl3, Alum, Polyelectrolyte and Lime. Lime and Alum were diluted in 100ml distilled water with a concentration of 1gm. Fecl3 was diluted in 100ml distilled water with a concentration of 1ml.

Polyelectrolyte was diluted in 100ml distilled water with a concentration of 50mg jar tests were done in 1 L flask containing 500ml wastewater with pH (range from 7.5 to 7.7), and the coagulants (Lime, Alum, FeCl3, and Polyelectrolyte) were added to the sample in various doses and were mixed first for 2 minutes at 200 rpm, then mixed for 20 minutes at 20 rpm (flocculation phase). Finally, settling was allowed for 30 minutes to take place flock by precipitation. The results showed that all coagulants used have significantly removed TSS and turbidity.

The optimal pH was 7-8 achieved by adding Lime, Alum, Fecl3 and Polyelectrolyte dosages with a range of 10-60 mg/L, 4-48 mg/L, 0.2-1.2 mg/l and 0.1-0.6 mg/l respectively. All the coagulants used decreased the turbidity from 400NTU to below the allowable concentration, i.e. < 20NTU. From the results, it can be concluded that coagulation and flocculation may be useful primary wastewater treatment processes for the ceramic industry [8]. In the Royal Ceramic factory in the industrial zone of El-Obour City in Egypt, the wastewater was treated by plain sedimentation, but it was modified to a Dissolved Air Floatation (DAF) system preceded by a chemical feed to improve the quality of effluent treated wastewater to reuse it. In this study, the coagulants used are Aluminium sulphate and Ferric chloride. The modified DAF system showed higher removal efficiencies for all parameters monitored than the Plain sedimentation process.

The DAF efficiency for turbidity was 98.19%, while PS was 88.40%. As for TSS, the modified system improved the removal efficiency by about 34.87% with influent values of 269.17 mg/l compared to the original system with 3177.22 mg/l. The removal of Total Dissolved Solids (TDS) was minimal in both systems; however, the Dissolved Air Flotation (DAF) system demonstrated superior removal efficiency. The COD removal efficiency was increased from 43.49% to 69.89% by the modified system, while the pH values were almost the same in both cases [9].

A study was made to treat the wastewater in the El Gawharah Factory in El Fayoum, Egypt. The chemical treatment followed by a flotation-filtration treatment line achieved the highest removal efficiency for pH, TSS and turbidity so that the effluent wastewater could be disposed to an agricultural drain, but it wasn’t the lowest cost.

The wastewater effluent from the chemical sedimentation process of the ceramic industry was subjected to biological treatment in a laboratory-scale activated sludge unit. The experiments were carried out under different conditions and solids retention times. The best treatment results were obtained with mixed liquor suspended solids 3000 MLSS and 6 hrs. Solids retention times (sludge age) resulting in effluent COD and BOD concentration of zero mg/l from feed wastewater of 4000 mg/l COD and 150 mg/l BOD contents [10].

This study focuses on finding the most efficient and cost-effective solution for treating industrial wastewater generated by the ceramic industry. The research aims to promote more sustainable and economically viable wastewater management practices in the sector by achieving this goal. Ceramic industry wastewater is characterized by high Total Suspended Solids (TSS) levels, ranging from 15,000 to 30,000 ppm, and a pH level between 7.5 and 9.5. Therefore, this research is specifically designed to address and solve the challenges posed by these pollutants, ensuring cleaner and more manageable wastewater output.

2. Materials and Methods

The study was applied to the wastewater of the Ceramica Cleopatra factory for the ceramic industry, which is located on the 10th of Ramadan City. The experimental work was performed at the factory laboratory using a pilot scale. The lab-scale pilot consisted of 3 lines that work in parallel: the first line consists of chemical sedimentation followed by filtration, the second line consists of flotation followed by filtration and the last one consists of cyclone followed by filtration.

Figure 1 shows the schematic diagram of the pilot. Figure 2 shows the final shape of the lab-scale pilot. Wastewater was supplied into the pilot system from a feeding tank that stores wastewater with a capacity of 250 litres.

A constant head tank is used after the feeding tank to ensure flow stability and distribution on each line. The flow is controlled for each treatment line by valves.

The pilot was designed to work continuously for three parallel treatment lines, each with a flow of 25 l/d, and the working period was 6hrs/day. The dimensions of the chemical sedimentation tank (tube settler) were 10 cm in diameter and 10 cm in depth, the dimensions of the flotation tank were 10 cm in diameter and 13 cm in depth, The dimensions of the cyclone were 10 cm in diameter and 15 cm in depth, The dimensions of filtration tank were 10 cm in diameter and 70 cm in depth.

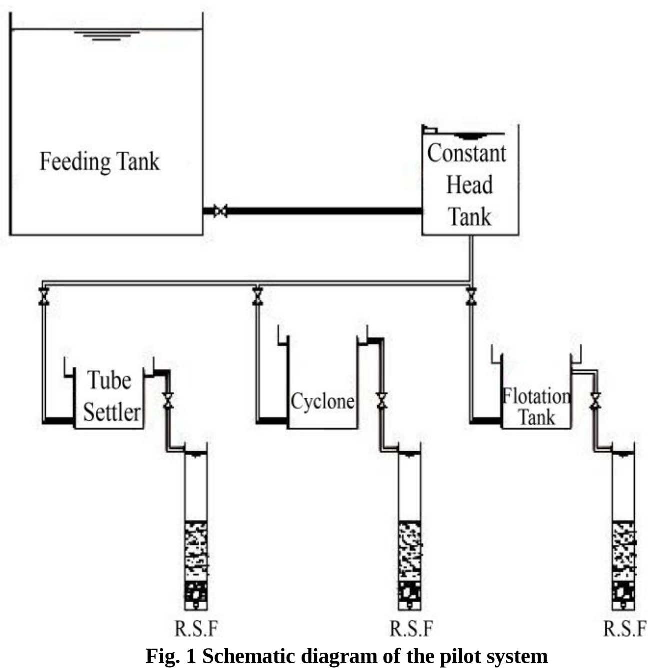

Fig. 1 Schematic diagram of the pilot system

The program is designed in three stages: the first stage, which is two weeks without using any chemicals, and the second stage, which is two weeks with ferric chloride as a coagulant. This is because it is cheap, widely available and has achieved good results before the third stage for two weeks by using an anthracite coal filter instead of a sand filter; using a coal filter is cheaper than using chemicals and is expected to produce better results.

Samples were taken at each treatment line's inlet and outlet to measure the change in TSS, pH and turbidity. The first samples were taken at the inlet before running the pilot, and the second was taken after 6 hours at the outlet to ensure the treatment had been successfully done.

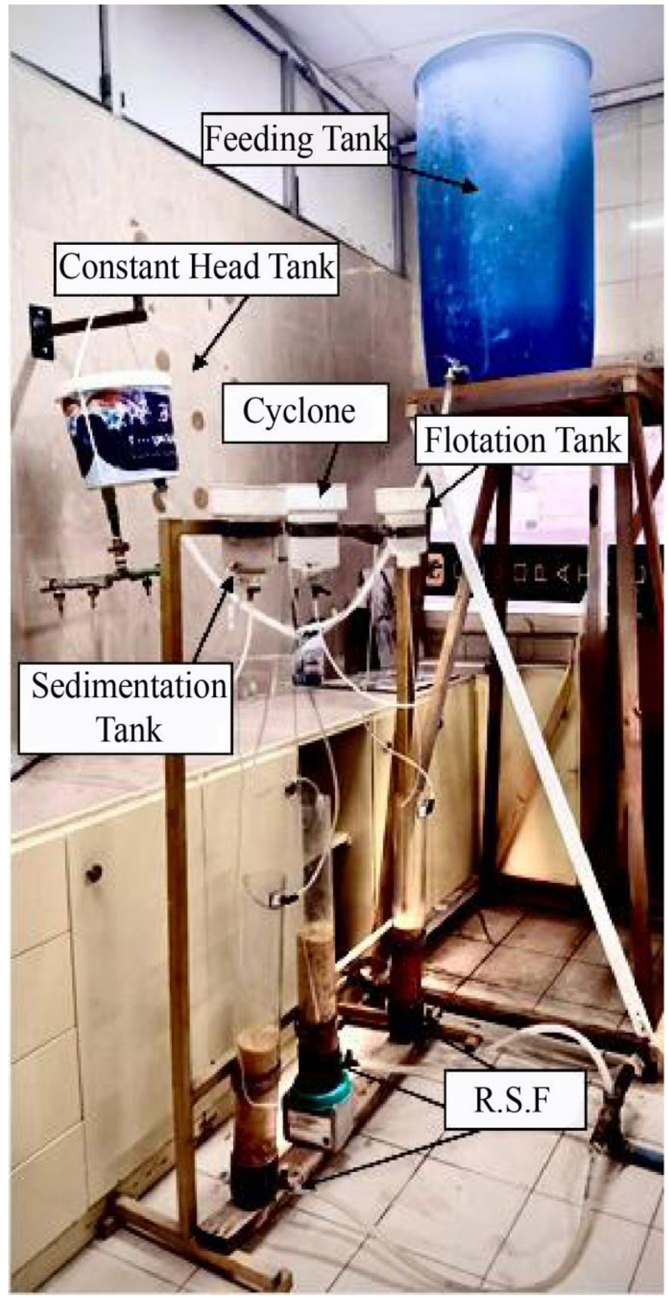

Fig. 2 The ultimate design of the lab-scale pilot

3. Results

Each stage was done for two weeks. Tables 1 to 4 illustrate all the sample analyses made during the study.

Table 1. Applied wastewater

	DATE	pH	TSS (mg/l)	DATE	pH	TSS (mg/l)
Stage 1	**Day 1**	8.57	20800	**Day 7**	8.56	20700
	Day 2	8.58	21500	**Day 8**	8.59	21400
	Day 3	8.57	20900	**Day 9**	8.55	20900
	Day 4	8.60	23600	**Day 10**	8.61	23500
	Day 5	8.60	22800	**Day 11**	8.62	22600
	Day 6	8.58	23100	**Day 12**	8.58	23000
Stage 2	**Day 1**	8.55	18675	**Day 7**	8.54	18550
	Day 2	8.57	19120	**Day 8**	8.58	19000
	Day 3	8.55	18900	**Day 9**	8.53	18950
	Day 4	8.62	21800	**Day 10**	8.63	21700
	Day 5	8.62	22150	**Day 11**	8.64	22050
	Day 6	8.66	21570	**Day 12**	8.65	21450
Stage 3	**Day 1**	8.52	18475	**Day 7**	8.51	18350
	Day 2	8.54	19000	**Day 8**	8.55	18800
	Day 3	8.52	18700	**Day 9**	8.50	18750
	Day 4	8.59	21600	**Day 10**	8.60	21400
	Day 5	8.60	22050	**Day 11**	8.61	21950
	Day 6	8.63	21370	**Day 12**	8.62	`21250

Table 2. Sedimentation line results

	DATE	pH	TSS (mg/l)	DATE	pH	TSS (mg/l)
Stage 1	**Day 1**	8.38	103	**Day 7**	8.37	102
	Day 2	8.36	110	**Day 8**	8.37	108
	Day 3	8.38	105	**Day 9**	8.36	103
	Day 4	8.40	120	**Day 10**	8.41	119
	Day 5	8.40	112	**Day 11**	8.42	110
	Day 6	8.38	117	**Day 12**	8.37	115
Stage 2	**Day 1**	7.17	10	**Day 7**	7.16	10
	Day 2	7.19	12	**Day 8**	7.20	11
	Day 3	7.10	14	**Day 9**	7.11	12
	Day 4	7.22	12	**Day 10**	7.23	11
	Day 5	7.20	15	**Day 11**	7.22	14
	Day 6	7.25	14	**Day 12**	7.24	12
Stage 3	**Day 1**	8.35	10	**Day 7**	8.34	11
	Day 2	8.33	12	**Day 8**	8.34	13
	Day 3	8.35	11	**Day 9**	8.33	10
	Day 4	8.37	14	**Day 10**	8.38	15
	Day 5	8.38	15	**Day 11**	8.40	14
	Day 6	8.35	13	**Day 12**	8.34	12

Table 3. Cyclone line results

	DATE	pH	TSS (mg/l)	DATE	pH	TSS (mg/l)
Stage 1	**Day 1**	8.52	35	**Day 7**	8.51	34
	Day 2	8.53	42	**Day 8**	8.54	40
	Day 3	8.53	39	**Day 9**	8.51	37
	Day 4	8.52	54	**Day 10**	8.53	53
	Day 5	8.55	42	**Day 11**	8.56	40
	Day 6	8.52	50	**Day 12**	8.54	48
Stage 2	**Day 1**	7.42	17	**Day 7**	7.41	16
	Day 2	7.45	17	**Day 8**	7.46	17
	Day 3	7.40	18	**Day 9**	7.42	17
	Day 4	7.50	20	**Day 10**	7.48	19
	Day 5	7.48	22	**Day 11**	7.50	20
	Day 6	7.48	18	**Day 12**	7.49	16
Stage 3	**Day 1**	8.49	5	**Day 7**	8.48	6
	Day 2	8.50	7	**Day 8**	8.51	8
	Day 3	8.50	6	**Day 9**	8.48	5
	Day 4	8.49	9	**Day 10**	8.50	9
	Day 5	8.51	9	**Day 11**	8.53	8
	Day 6	8.50	8	**Day 12**	8.51	7

Table 4. Flotation line results

	DATE	pH	TSS (mg/l)	DATE	pH	TSS (mg/l)
Stage 1	**Day 1**	8.22	64	**Day 7**	8.21	63
	Day 2	8.25	72	**Day 8**	8.26	70
	Day 3	8.25	69	**Day 9**	8.23	67
	Day 4	8.23	87	**Day 10**	8.24	86
	Day 5	8.23	80	**Day 11**	8.25	78
	Day 6	8.25	71	**Day 12**	8.24	70
Stage 2	**Day 1**	7	14	**Day 7**	7.02	15
	Day 2	7.10	15	**Day 8**	7.11	14
	Day 3	7.11	14	**Day 9**	7.12	15
	Day 4	7.15	18	**Day 10**	7.16	17
	Day 5	7.05	16	**Day 11**	7.06	14
	Day 6	7.12	15	**Day 12**	7.11	16
Stage 3	**Day 1**	8.19	7	**Day 7**	8.18	8
	Day 2	8.22	9	**Day 8**	8.23	10
	Day 3	8.22	8	**Day 9**	8.20	7
	Day 4	8.21	11	**Day 10**	8.21	12
	Day 5	8.20	12	**Day 11**	8.22	11
	Day 6	8.22	10	**Day 12**	8.21	9

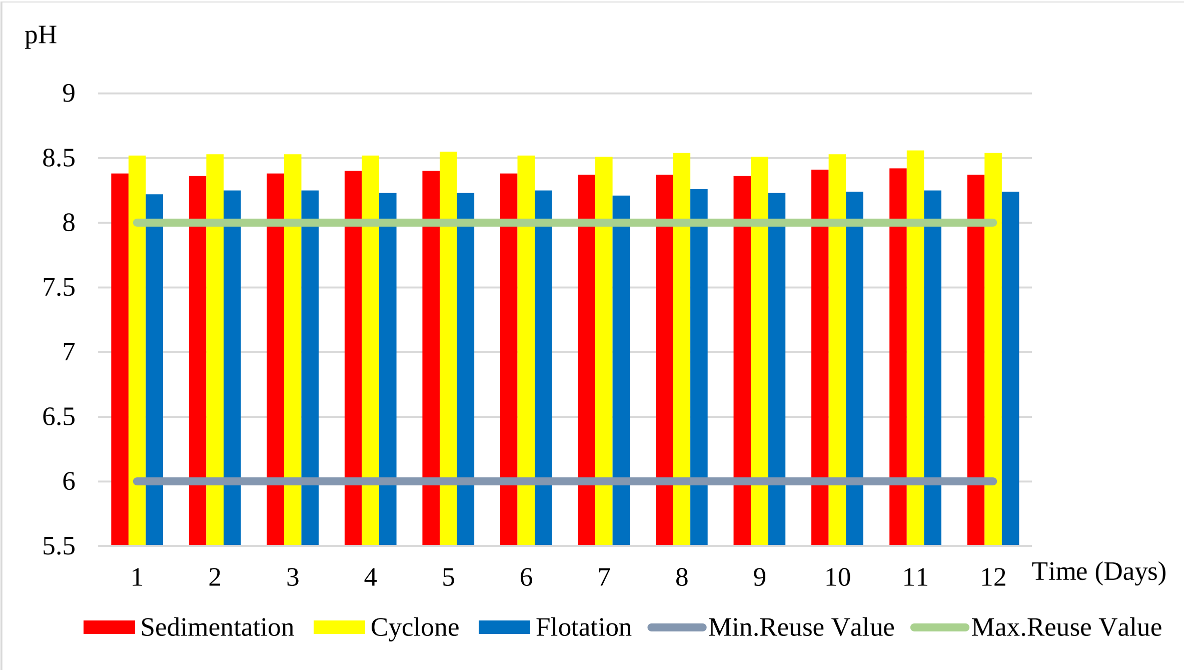

Fig. 3 pH results for first stage versus reuse limit

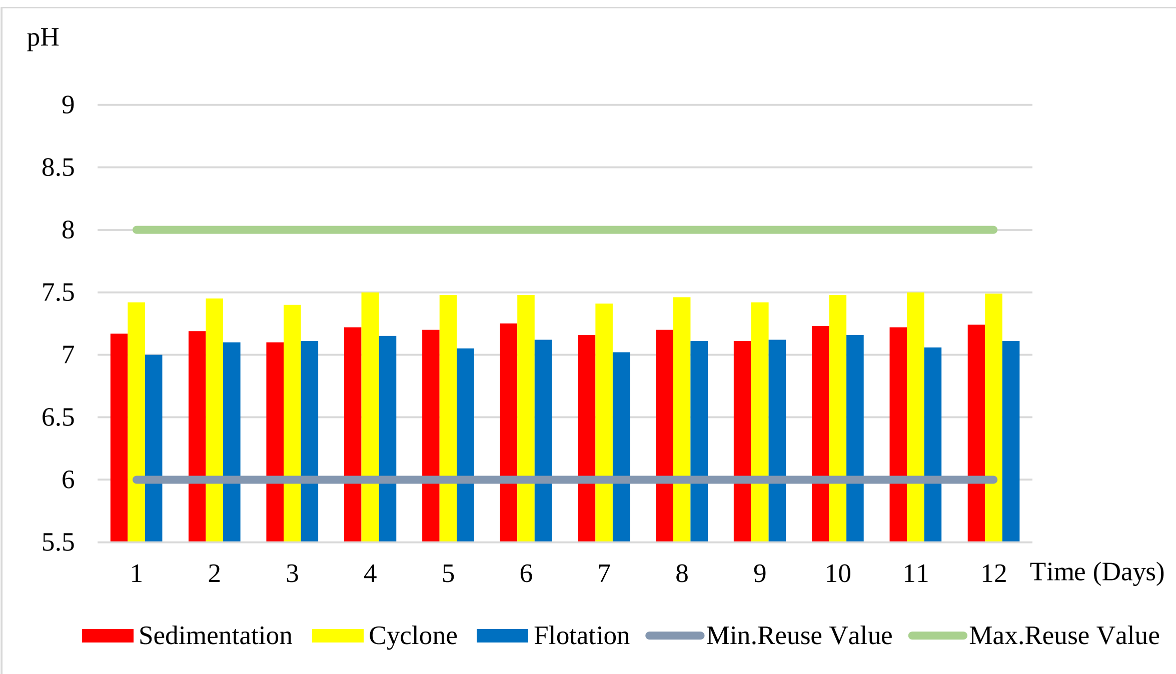

Fig. 4 pH results for second stage versus reuse limit

4. Discussions

4.1. Discussion of pH Results

According to the results illustrated, the pH values for the effluent of the three applied lines of treatment for each stage were discussed, as shown in Figures 3, 4, and 5. From Figure 3, all pH values are outside the permissible limits for reuse because the physical treatment standing alone without using any chemicals does not treat the high pH value, so it needs pH adjustment to decrease the pH to 8 (max permissible limit for reuse). From Figure 4, all pH values are between the permissible limits for reuse because this stage was done using ferric chloride as a coagulant so that it can be reused again.

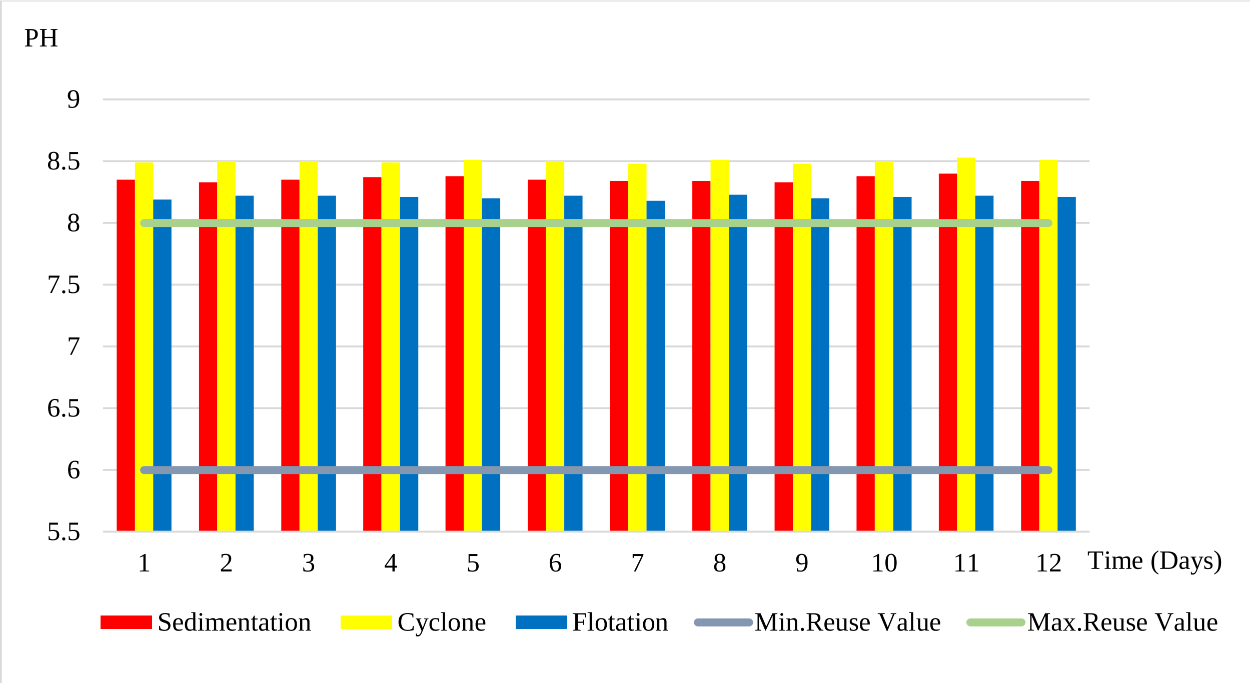

Fig. 5 pH results for third stage versus reuse limit

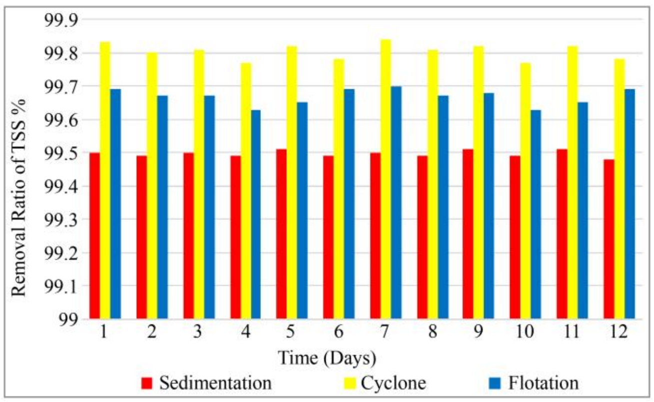

Fig. 6 Removal Ratio of TSS for First Stage

From Figure 5, all pH values are outside the permissible limits for reuse because the physical treatment standing alone without using any chemicals does not treat the high pH value, so it needs pH adjustment to decrease the pH to 8 (max permissible limit for reuse).

It was noticed that the pH value in effluent with flotation is less than that of sedimentation, which is also less than that of cyclone in all stages. This could be explained by the fact that diffused air with flotation could oxidize some dissolved solids as a by-product, which may be the reason for the decrease in pH value compared to the other two procedures. In all cases, if no chemical addition for coagulation needs to be used, it is better to have a pH adjustment to decrease the pH value between (0.5 – 1) using any acidic salt such as hypochlorite sodium or potassium with a low dose (20 – 40) ppm which is less than the coagulant dose applied (120 ppm ferric chloride).

4.2. Discussion of TSS Results

According to the results illustrated, the removal efficiency for the effluent of the three applied lines of treatment for each stage was calculated and discussed, as shown in Figures 6, 7, and 8.

From Figure 6, the best value of removal efficiency is for the cyclone line, with an average of 99.80%, and the minimum average value with the sedimentation line is 99.50%. In this stage, the cyclone line is the best treatment line. Because it not only depends on the weight of the particles but also centrifugation and the effect of centrifugation in separating particles from water is stronger than sedimentation and flotation.

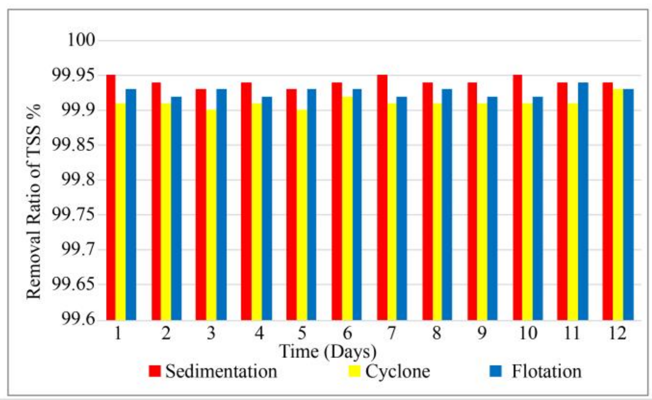

Fig. 7 Removal ratio of TSS for second stage

From Figure 7, the removal ratio of TSS is over 99.9% in all lines, with very little variation for each line between 1 and 4 ppm (± 0.03%). The best value is for the sedimentation line with an average of 99.94%, and the minimum average value with cyclone is 99.91%. In all cases, the effluent TSS could be accepted for recycling in the industry for its value varied between (10-18) ppm with minimal effect on the product line that, could save the high-water consumption in the factory and decrease the required cost for water supply.

In this stage, cyclones become less efficient because they are not greatly affected by the use of chemicals. This is because the centrifugation process gives high velocity, which prevents the chemical reaction from taking place. So, the efficiency of flotation and sedimentation increased above the efficiency of the cyclone.

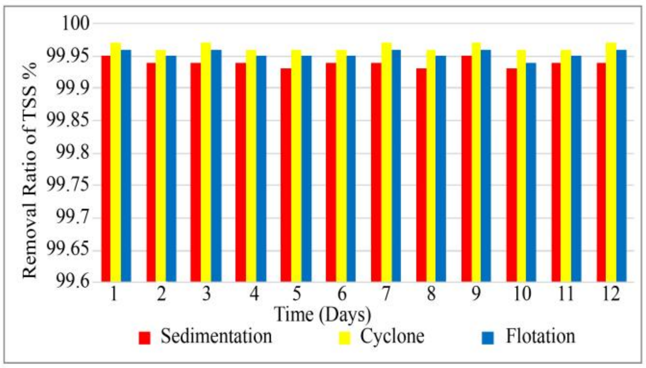

Fig. 8 Removal ratio of TSS for third stage

From Figure 8, the removal ratio of TSS is over 99.9% in all lines, with very little variation for each line between 1 and 5 ppm (± 0.02%). The best value is for the cyclone line, with an average of 99.96%, and the minimum average value with the sedimentation line is 99.94%.

In all cases, the effluent TSS could be accepted for recycling in the industry for its value varied between (10-15) ppm with minimal effect on the product line, which could save the high-water consumption in the factory and decrease the required cost for water supply.

It is clear that with the use of a coal filter, the removal efficiency increased. This is because the coal is extremely porous, and its grains are smaller. Therefore, its removal ratio is greater than that of the sand filter.

5. Conclusion

Based on the study results and collected data, the following conclusions could be drawn:

- In the case of an application without chemicals, the results show that the effluent efficiency is suitable only to be disposed of in the city sewer system, and it can't be reused for irrigation or returned to the industry.
- The cyclone line achieved the highest removal efficiency for TSS of 99.83%, and the effluent was 34 ppm without chemical assistant application, while the sedimentation line was the lowest with a removal efficiency of 99.51% and the effluent was 102 ppm.
- In the case of applying ferric chloride as a coagulant, the results show that the effluent efficiency is suitable to be disposed of in the city sewer system and to be reused for irrigation. It can't be returned to the industry.
- The sedimentation line achieved the highest removal efficiency for TSS of 99.95%, and the effluent was 10 ppm using ferric chloride as a coagulant, while the cyclone line was the lowest with a removal efficiency of 99.93% and the effluent was 16 ppm.
- In the case of using a coal filter instead of a sand filter, the results show that the effluent efficiency is suitable to be disposed of in the city sewer system and to be reused for irrigation.
- The cyclone line achieved the highest removal efficiency for TSS of 99.97%, and the effluent was 5 ppm in case of using a coal filter, while the sedimentation line was the lowest with removal efficiency of 99.95% and the effluent was 10 ppm.
- The sedimentation line and flotation line effluents can't be returned to the industry, while cyclone line effluent could be returned to the industry as its values varied between (5-10) ppm with minimal effect on the product line.
- In this case, the sedimentation tank existing in the factory should be followed by a dual filter system to reuse the treated wastewater again in the industry.

5.1. Recommendations

To minimize the wastewater from this industry to reuse it again to the industry, the following recommendations could be suggested:

- All existing systems that use physical treatment aided with chemicals should be provided with a dual filter system to ensure its effluent quality suitability for recycling purposes.
- The study recommended the application of cyclone followed by a dual filter system for the ceramic industry and other similar industries (bricks, tiles, marble, etc….) as the best treatment solution.

5.2. Further Work

In further work, the studying of the following is essential:

- Study the possibility of sludge reuse in the industry.
- Study the method of sludge disposal if it can't be reused in the industry.
- Study the cost-effectiveness of the cyclone line.

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