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Enhancing Ceramic Industry Effluent Wastewater Quality for Reuse

Khalid H. Khalil[1], Olfat H. Ibrahim[1]
[1]*Department of Civil Engineering, Higher Institute of Engineering, Shorouk Academy, Egypt.*

Abstract:- An existing wastewater treatment unit treating ceramic industry wastewater by plain sedimentation (PS) was modified to a dissolved air floatation (DAF) system preceded by chemical feed for effluent reuse. Preliminary bench scale tests were conducted to select a suitable coagulant and to determine the optimum dose; Aluminium sulphate, Ferric chloride and Magnafloc 351 were tested and all gave good removal efficiencies. The later coagulant was selected for large scale field application with a dose of 400 mg/l as it yielded removal efficiencies exceeding 98%. The modified DAF system demonstrated higher removal efficiencies for all the parameters monitored compared with the original PS system. With regards turbidity the DAF gave 98.19% compared with 88.40% for the PS system. As for TSS the modified system improved the removal efficiency by about 34.87% with influent values of 269.17 mg/l compared with the original system with 3177.22 mg/l. TDS removal was negligible in both systems although the DAF system gave higher removal efficiency. COD removal efficiency was increased from 43.49% to 69.89% by the modified system while the pH values were almost similar in both cases.

Keywords:- ceramic industry wastewater, total suspended solids, chemical oxygen demand, coagulation, plain sedimentation, dissolved air floatation.

I. INTRODUCTION

Ceramic industry in Egypt showed tremendous development in the last two decades with more than 20 factories currently being operated across the country. Concurrently, water management has become an increasingly critical issue in most traditional industrial sectors, owing to the large quantities of water consumed and wastewater produced. With regards the ceramic tile industry, most of the wastewater arises in the washing operations of the facilities used for the preparation and application of glazes and other coatings. The composition of these ceramic industry wastewaters varies widely and includes high concentrations of both suspended & dissolved solids and electrolytes of very different nature, as well as significant amounts of organic substances that mostly come from the additives used in decorating the tiles [1].

With increasing environmental regulations, it is important to identify and adequately address environmental issues in the ceramic industry. Therefore, beyond just the conservation of the natural environment by reducing pollution (atmospheric emissions, solid waste, aqueous discharges, noise pollution, etc.), the problem can be considered from economic and strategic points of view. Financial savings can be brought about by reduction in energy and raw materials consumption, reduction in the cost of waste disposal or even, in many countries, reduction in the taxes for pollution reduction activities. One possibility is to use recycled water and recycled sludge in production operations.

However, the treatment methods that are currently used (generally physico-chemical treatment) are not highly efficient, in particular with regards to non-biodegradable organic compounds that increase the water COD, certain ions such as alkaline and alkaline-earth cations, boron compounds, chlorides, sulphates, etc. This insufficient wastewater treatment makes it impossible to reuse this water in the same production process and may even impede water discharge. Consequently, this water needs external handling or further treatment, entailing high economic costs and/or environmental impact.

Pysico-chemical treatment of solids laden wastewaters like marble processing, ceramic tiles production and paper & pulp industries is fully documented in literature [2], [3], [4], [5]. Optimum coagulant-flocculant doses for turbidity removal in wastewater from the cutting, faience and equalization processes in marble processing were determined as 500, 200 and 100 ppm of $Al_2(SO_4)_3$; 600, 500 and 300 ppm of $FeCl_3$ and 600, 500 and 200 ppm of Agrofloc 100 respectively. It was found that the removal of total solids from cutting and equalization process wastewaters was highest for the 100 ppm dosage of all chemicals used. The amount of total solids removed from faience process wastewater by Agrofloc 100 was higher than that removed by the other chemicals. The removal of suspended solids from cutting, faience and equalization process wastewaters were similar for each of the chemicals [6].

Dissolved air floatation (DAF) is an extremely effective process used for the separation of suspended solids and oils from wastewater [7], [8]. The introduction of air bubbles to the influent wastewater causes suspended particles to float to the top for removal. The system consists of four major components: air supply, pressurizing pump, saturator (retention tank) and flotation chamber [9]. A pressurizing pump with a pressure range of (172-620) kPa and a vertical rise rate of air bubbles in the range of (0.152-0.061) m/min is proposed to achieve the required treatment efficiency [9], [10].

Dissolved air flotation (DAF) is generally considered more effective than sedimentation in the treatment of algal-rich water. However, the type and dose of coagulant, as well as the coagulation, flocculation and DAF operating conditions are key parameters for particle removal [11].

Dissolved air floatation increased the efficiency of grease and oil removal from biodiesel wastewater by about 10% compared with other conventional processes [12]. Dissolved air flotation has gained widespread usage for the removal of contaminants and recovery of by-products from wastewater and other industrial process streams over the last 20 years. While considered a relatively simple technology, there have been significant improvements in the technology including operating parameters, bubble generation systems and process design. There has also been an expansion of applications using DAF over the last several years in traditional and non-traditional areas of water and industrial effluent treatment [10], [13].

Bubble size plays a key role in particle separation; microbubbles (10-100) µm give very promising results in large scale operation [10], [8], [14]. Pilot studies conducted on the treatment of marble wastewater using DAF gave a removal efficiency of 98.5% of the total suspended solids with a chemical dose of 20 mg/l, this removal efficiency dropped to 94.5% when the pretreatment chemical dose was omitted [15].

Recent studies by [16] for the comparison between two wastewater treatment plants treating marble wastewater by both using conventional coagulation/sedimentation (C/S) and dissolved air floatation (DAF) treatment techniques. In the first treatment unit polyacrylamide (PAM) coagulant was used with a dose of 50 mg/l and this yielded an average total suspended solids (TSS) removal efficiency of 97.28%. In the second DAF treatment unit no any chemical used for pre-treatment the overall resulting average removal efficiency achieved was 95.41%.

Fine quartz particles (dp < 100 µm) ranging from 6% to 53% (by mass) were obtained from DAF experiments [17]. Design ranges that have been used in practical applications of DAF for wastewater treatment and sludge thickening were documented by [18] and are given in Table 1.

Table. 1: DAF design parameters values ranges [18]

Parameter	Units	Clarification applications	Thickening applications
Reaction zone surface loading	**m/hr**	**40-100**	**100-200**
Reaction zone Residence time	**min**	**1-4**	**0.5-2.0**
Air/solids ratio			**0.02-0.04**
Air release	**mg/l**	**6-8**	
Cross flow velocity	**m/hr**	**20-100**	**50-200**
Flotation zone surface loading	**m/hr**	**5-11**	
Flotation zone solids loading	**$kg/m^2/hr$**		**2-6*, 6-12$^{\times}$**
Flotation zone side wall depth	**m**	**1.5-3.0**	**2.0-4.0**

***without coagulation; $^{\times}$ with coagulation**

Accordingly, the main objective of this research work is to modify the existing wastewater treatment plant of a ceramics production factory to reduce its environmental impact. Environmentally, can be brought benefits are not only to equalize the effluent for discharge, but also for recycling and reuse of process water and residual solids.

II. MATERIALS AND METHODS

II.A. Goal and scope definition

This research work was conducted to improve the quality of effluent treated wastewater for the purpose of reuse. The research was conducted on effluent wastewater of Royal Ceramics Production Factory situated in the industrial zone of El-Obour City 10 kms north-east of Cairo City. The factory has an existing plain sedimentation tank that gives a poor effluent quality prior to disposal to the city drainage network. Modifications were made to the existing treatment system to improve the quality of the treated effluent for reuse in the factory production units. All experimental work and sample analyses were conducted in the laboratories of the Higher Institute of Engineering at Shorouk City and Shobra El Khaima wastewater treatment plant. The experimental procedure both on the bench and field scales is described as follows:-

II.B. Influent Wastewater Characteristics

Industrial wastewater in the factory is separated from the domestic wastewater; the domestic wastewater is directly discharged to the sewage collection network while the industrial wastewater is pretreated prior to disposal to the same network. This wastewater is mainly produced in the tiles production stages of body preparation, atomization and decoration. The factory works 12 hours per day producing 1000 cubic meters and five parameters were monitored as shown in Table 2 for the proximate analysis of the raw wastewater.

Table 2. Proximate analysis of raw wastewater

Parameter		Units	Concentration
pH	**pH**		**7 - 9**
Turbidity		**NTU**	**4100 - 5220**
Total Suspended Solids	**TSS**	**mg/l**	**7930 - 8700**
Total Dissolved Solids	**TDS**	**mg/l**	**11500 - 12350**
Chemical Oxygen Demand	**COD**	**mg/l**	**500 - 1300**

II.C. Existing Treatment Setup

The existing treatment unit consisted of a holding tank for collecting the influent wastewater and followed by a rectangular plain sedimentation tank as in the schematic diagram in figure 1. The unit was operated for a period of 12 hours coinciding with the factory operating hours. The whole setup is constructed from steel plates and sections and coated with epoxy. Figure 2 shows a cross section in the existing treatment system and the details of the units were as follows:-

Holding Tank:-

Depth = 4.00 meters
Length = 3.00 meters
Width = 5.00 meters
Volume = 60.0 cubic meters
Retention Time = 0.72 hours
Mixer : For keeping the solids is suspension

Plain Sedimentation Tank:-

Depth = 4.00 meters
Length = 12.50 meters
Width = 5.00 meters
Volume = 250.00 cubic meters
Retention Time = 3.00 hours
Surface Loading Rate = 50 $m^3/m^2/day$

Treated effluent from the existing setup was discharged to the drainage collection network of the Obour industrial city after being mixed with the domestic sewage of the factory.

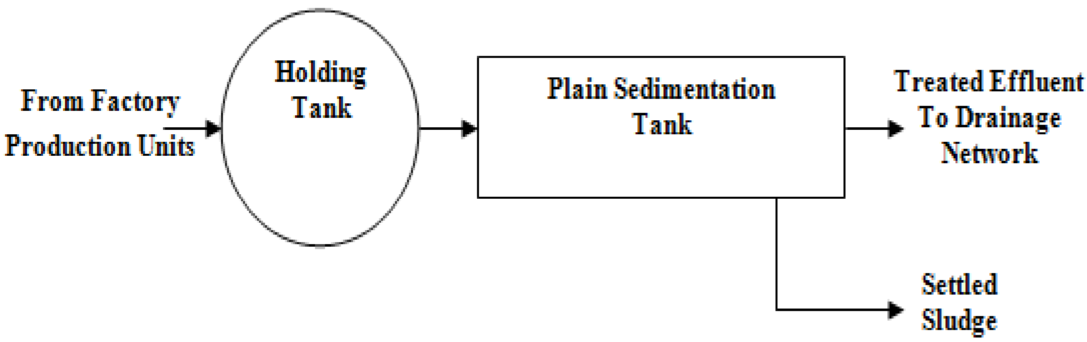

Figure 1. Schematic Diagram of Existing Treatment Plant

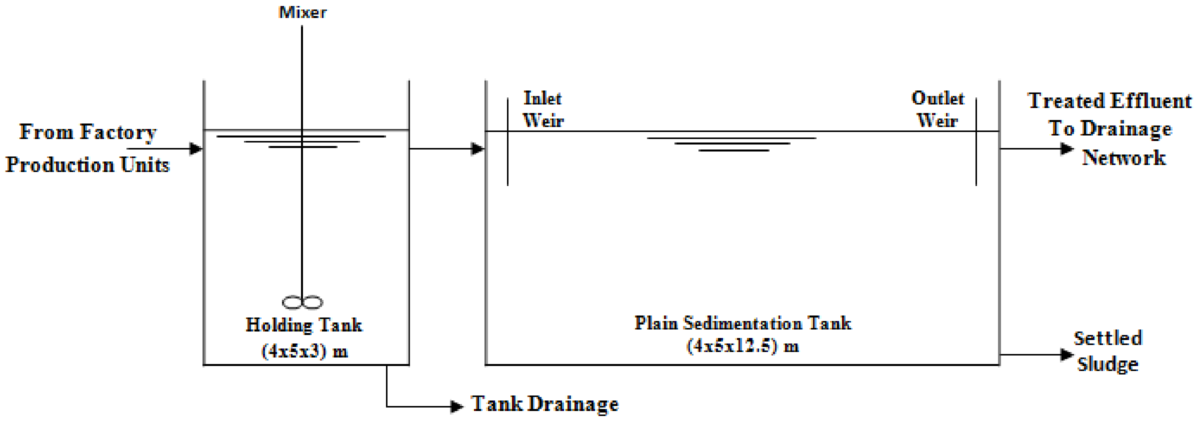

Figure 2. Cross-Section in Existing Treatment Plant

II.D. Experimental Jar Test Analysis

Prior to factory onsite application, the physico-chemical treatability of the wastewater was investigated by using jar tests conducted at room temperature 25°C. Aluminium sulphate, Ferric chloride and Magnafloc 351 were used as coagulants. The coagulant doses selected were 100, 200, 300, 400, 500 and 600 mg/l. The coagulant and wastewater were mixed rapidly and then slowly at 100 rpm for 90 seconds and at 40 rpm for 25 minutes respectively. The sedimentation time was 30 minutes and supernatants were then analyzed accordingly. The pH and turbidity were measured using a pH 211 microprocessor pH meter (Hanna Instruments) and Velp Scientifica turbidimeter 115, respectively. The total suspended solids (TSS), total dissolved solids (TDS) and chemical oxygen demand (COD) were determined according to standard methods [19]. Whatman 934-AH glass fiber filters were used to filter samples for solids analysis and dried at 105°C in a Hangzhou Sumer dry oven BPG-7032Cr. All samples were weighed using a Contech electromagnetic force compensation balance CA-503 with an accuracy of 0.01 g.

II.E. Modified Treatment Setup

A schematic diagram of the modified treatment system is as shown in Figure. 3 and it consists of changing the holding tank to a flash mixing by adding a chemical feed pipe and increasing mixer capacity. The plain sedimentation tank was modified to a flocculation tank and a dissolved air floatation (DAF) system for solids separation using turbulent floatation. Figure 4 shows a cross section in the modified treatment system and the details of the units are as follows:-

Holding/Flash Mixing Tank:-
- Depth = 4.00 meters
- Length = 3.00 meters
- Width = 5.00 meters
- Volume = 60.0 cubic meters
- Retention Time = 0.72 hours
- Coagulant = Magnafloc 351
- Coagulant dose = 400 mg/l

Flocculation Tank:-
- Depth = 4.00 meters
- Length = 3.00 meters
- Width = 5.00 meters
- Volume = 60.0 cubic meters
- Retention Time = 0.72 hours

Dissolved Air Floatation Tank:-
Reaction Zone:-
- Depth = 4.00 meters
- Length = 1.00 meters
- Width = 5.00 meters
- Surface Area = 5.00 square meters
- Volume = 20.00 cubic meters

Separation Zone:-

Depth = 4.00 meters
Length = 8.50 meters
Width = 5.00 meters
Surface Area = 42.50 square meters
Volume = 170.00 cubic meters

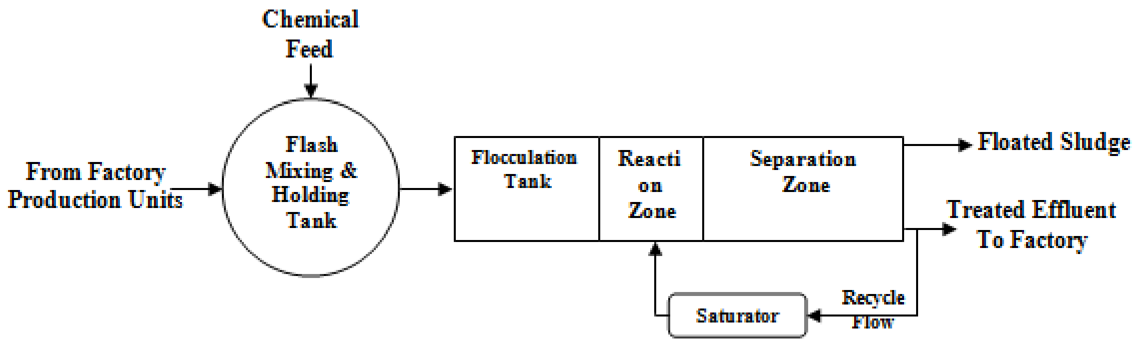

Figure 3. Schematic Diagram of Modified Treatment Plant

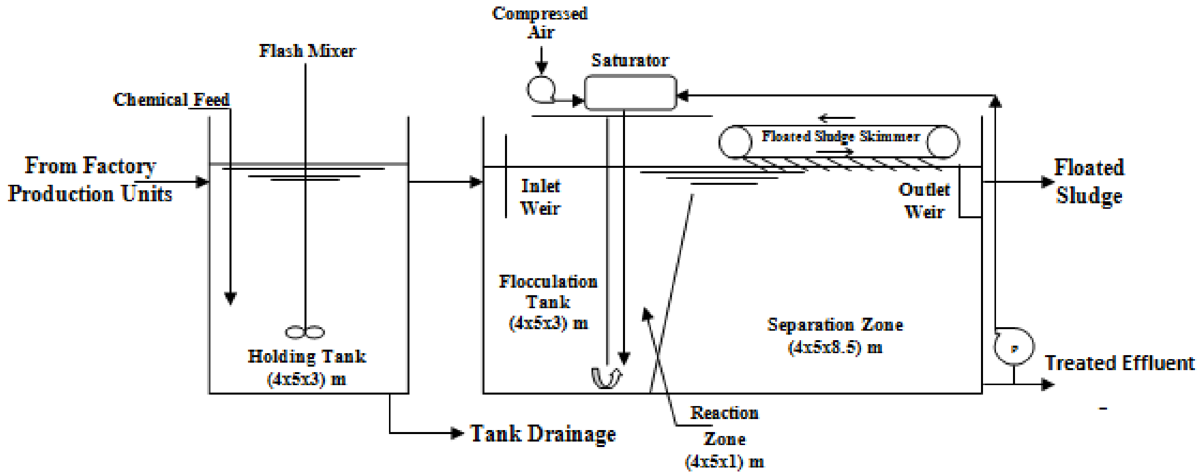

Figure 4. Cross-Section in Modified Treatment Plant

The air source is from an air compressor and the flow rate is varied as shown in Table 2. Air is introduced into the slurry through a Mazzei air injector (Model 784-PVDF) connected to the circulation piping. The suction capacity of the air injector was controlled by the differential pressure drop between the inlet and downstream outlet pressures of the injectors. The air bubble size was not been monitored nor estimated. The design variables are shown in Table 3

Table 3. DAF Unit Design Ranges

Parameter	Units	Design Ranges
Average Air Pressure	kPa	450 - 550
Reaction Zone Retention Time	min	5 - 10
Reaction Zone Surface Loading	$m^3/m^2/hr$	15 - 40
Cross Flow Velocity	m/hr	5 - 20
Separation Zone Surface Loading	$m^3/m^2/hr$	2 - 8
Separation Zone Solids Loading	$kg/m^2/hr$	8 - 15
Air Release Rate	m^3/hr	0.06 - 0.28
Air-to-Solids Ratio	mlAir/mgSolids	0.005 - 0.060
Recycle Ratio	%	50 - 100

III. RESULTS AND DISCUSSION

This section of the research work shows the results of the initial jar test results conducted in the laboratory followed by the factory field application both before and after plant modifications. Analysis of the data obtained is demonstrated as follows:-

III.A. Pysico-chemical Treatment

This section of the research work shows the results of the initial jar test analyses conducted in the laboratory in order to obtain the optimum coagulant dose together with the efficient coagulant. For the three chemicals tested, the results showed that all doses of ferric chloride were efficient as a coagulant for treatment of ceramic wastewater samples collected from the factory with turbidity removal range between (98.09-99.15)% and the removal range of TSS ranged between (96.39-98.93)%. In the case of aluminium sulphate for all doses used, process removal efficiency was between (98.62-99.15)% for turbidity removal and between (95.80-98.70)% for TSS removal figures 5 & 6.

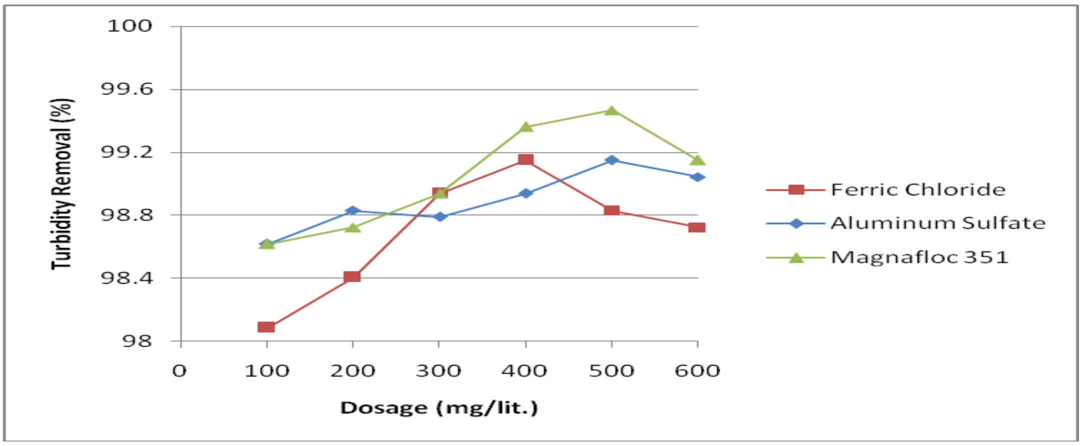

Figure 5. Turbidity removal percentage for the different coagulant doses used

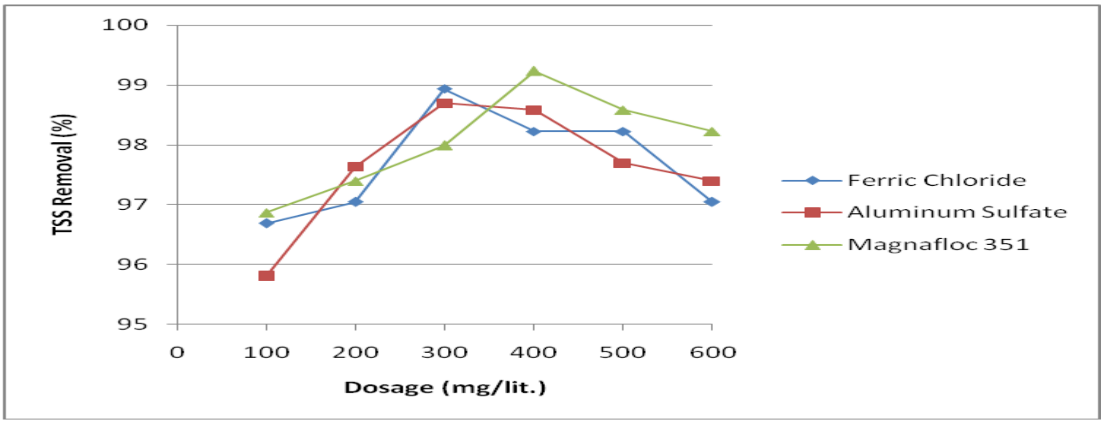

Figure 6. TSS removal percentage for the different coagulant doses used

III.B Treatment Using Existing & Modified Setup

Monitoring of the modified treatment plant was conducted for a period of 10 weeks after initial start-up. The results obtained by monitoring the modified setup were compared with those obtained from operating the old existing treatment plant. The recycle ratio was adjusted to 50% during the operation of the modified setup.

Turbidity Removal

Influent turbidity values recorded during the monitoring of the modified treatment unit using dissolved air floatation (DAF) were almost similar to those recorded previously during the plain sedimentation (PS) operation of the treatment plant with average values 4625.00 NTU. and 4586.67 NTU respectively, figure 7.

The removal efficiency of the DAF system ranged from (97.44-98.80)% with an average value of 98.19% compared with the PS system with removal efficiency values ranging from (86.72-89.50)% and averaging 88.40%, figure 8. The average effluent value recorded by the DAF system is 83.75 NTU compared with that of the PS system with 532.22 NTU, figure 9. The DAF system showed enhanced removal efficiency by about 9.79% yielding 448.47 NTU drop in turbidity effluent values.

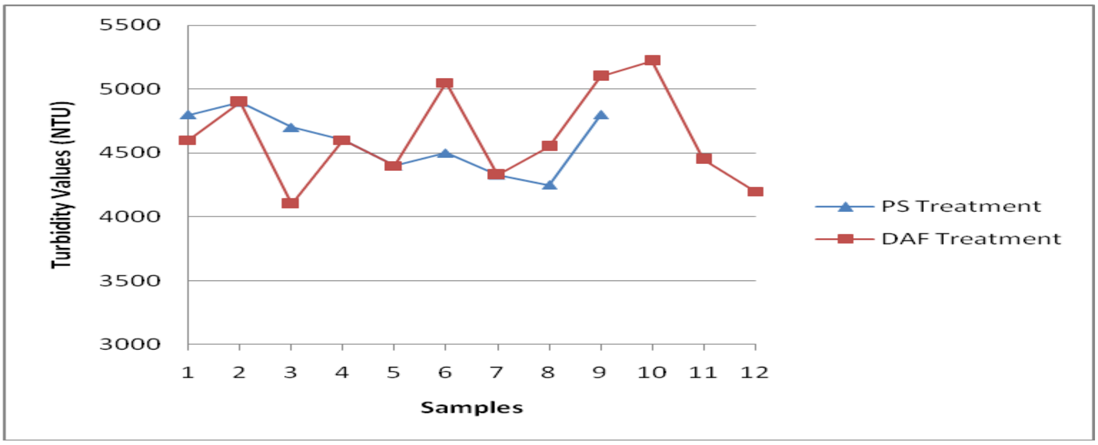

Figure 7. Influent turbidity values recorded for both treatment systems

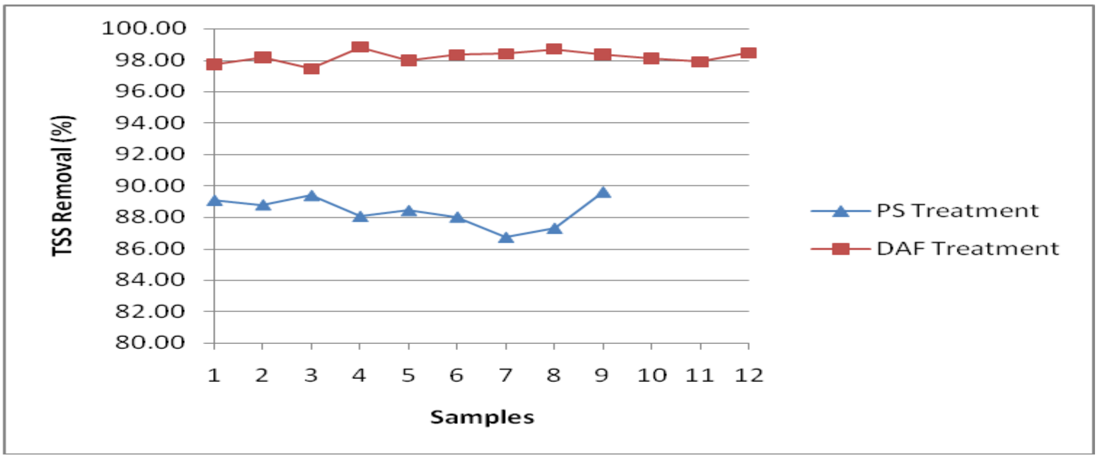

Figure 8. Turbidity removal efficiencies for both treatment systems

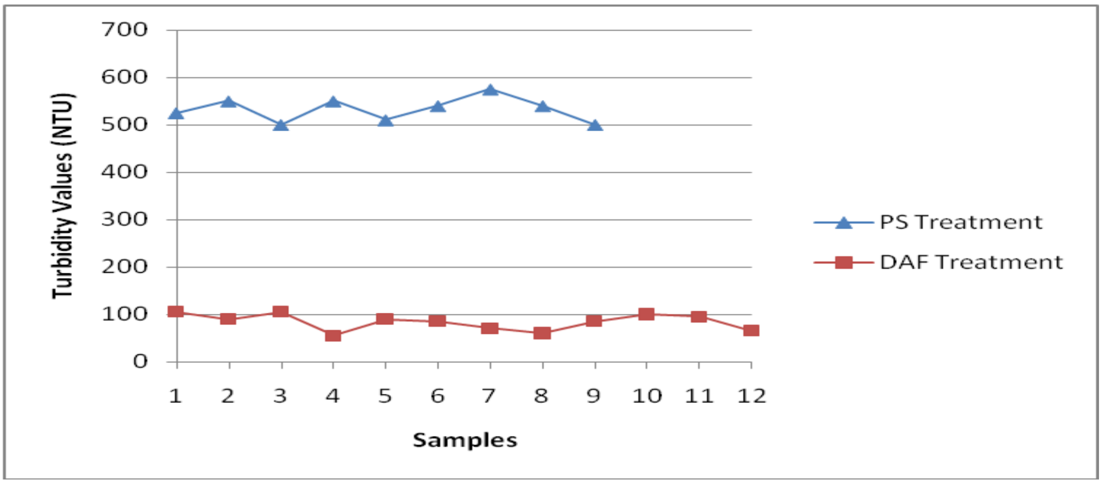

Figure 9. Effluent turbidity values recorded for both treatment systems

Total Suspended Solids Removal

Similar to turbidity, the TSS removal efficiency values showed by the DAF system are higher than those recorded by the PS system. The removal efficiency using the DAF system ranged from (93.37-97.51)% with an average value of 96.77%. While the PS system recorded a range of (52.25-65.09)% with an average of 61.90%, figure 10. The average influent TSS values recorded for the DAF and PS systems were 8338.33 mg/l and 8328.33 mg/l respectively, figure 11.

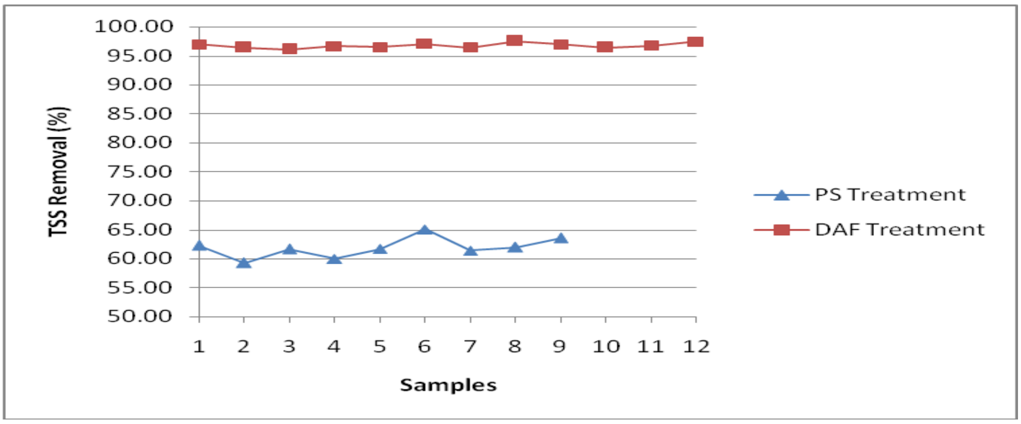

Figure 10. TSS removal efficiencies recorded for both treatment systems

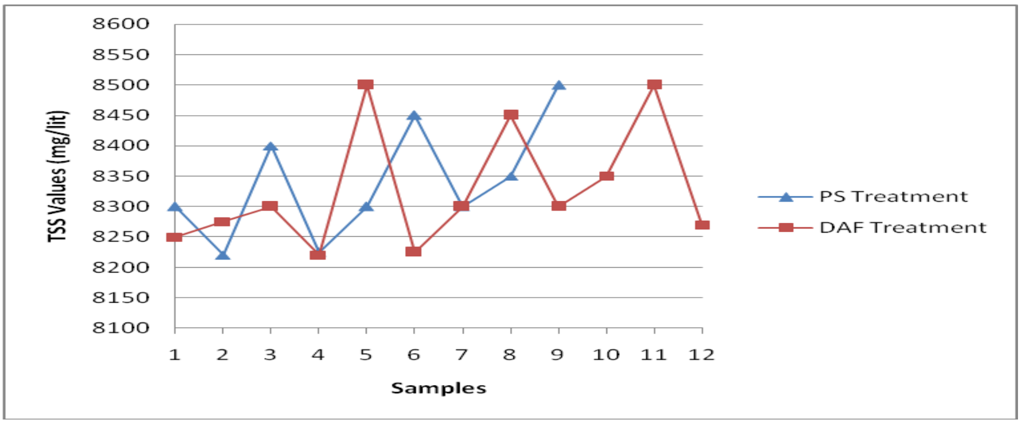

Figure 11. Influent TSS values recorded for both treatment systems

While the average effluent TSS values recorded for the DAF and PS systems were 3177.22 mg/l and 269.17 mg/l respectively, figure 12. The use of the DAF system increased the TSS removal efficiency by about 34.87% giving a drop of 2908.05 mg/l in TSS effluent values.

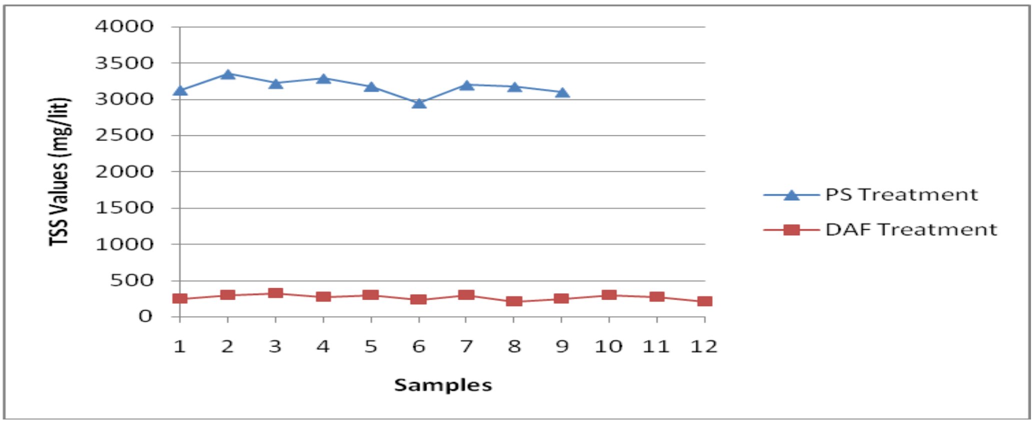

Figure 12. Effluent TSS values recorded for both treatment systems

Total Dissolved Solids Removal

Total dissolved solids removal efficiencies were negligible in both cases with average values of 29.79% for the PS system and increasing to 50.79% for the DAF system, figure 13. The average effluent value recorded for the PS system was 8465.56 mg/l and 5938.75 mg/l for the DAF system. Both systems showed poor removal efficiencies for TDS removal.

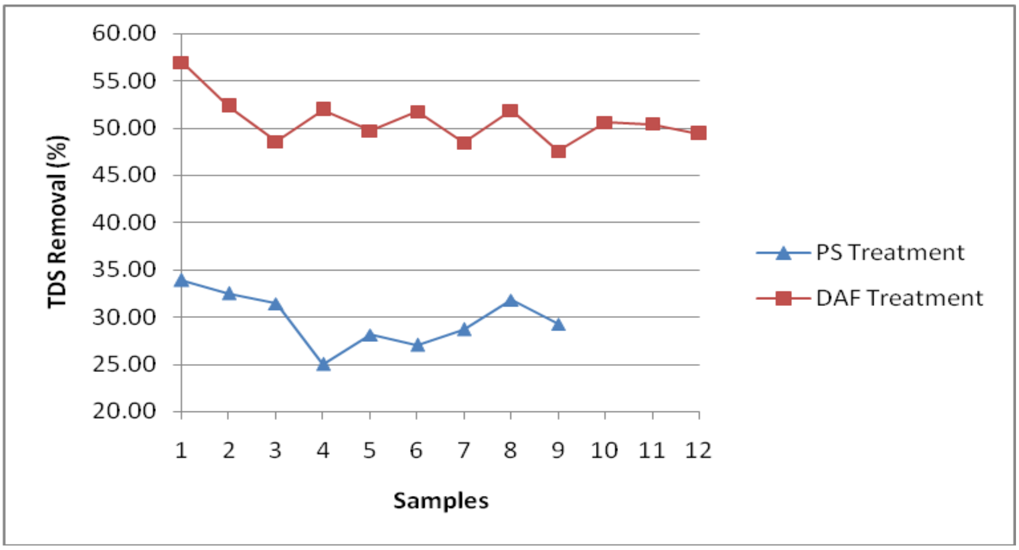

Figure 13. TDS removal efficiencies recorded for both treatment systems

Chemical Oxygen Demand Removal

The influent COD values for both system showed a wide range with values recorded ranging between (500-1300) mg/l. The average influent values recorded for both systems were 780.56 mg/l and 762.50 mg/l respectively, figure 14. For the PS system, removal efficiencies ranged between (31.82-59.00)% with an average value of 43.49%. The use of the DAF system increased the removal efficiency by about 26.40% with values recorded ranging between (50.00-84.62)% with an average value of 69.89%, figure 15. Although the chemical addition in the DAF system helped in improving the COD removal efficiency yet the effluent values are slightly higher. The effluent values for the DAF system ranged from (200 to 270) mg/l with an average value of 229.58 mg/l, figure 16. For similar wastewater [20] obtained effluent COD value of 52 mg/l using biological treatment while [21] with marble tiles wastewater and using coagulation/flocculation treatment obtained removal efficiencies exceeding 99%.

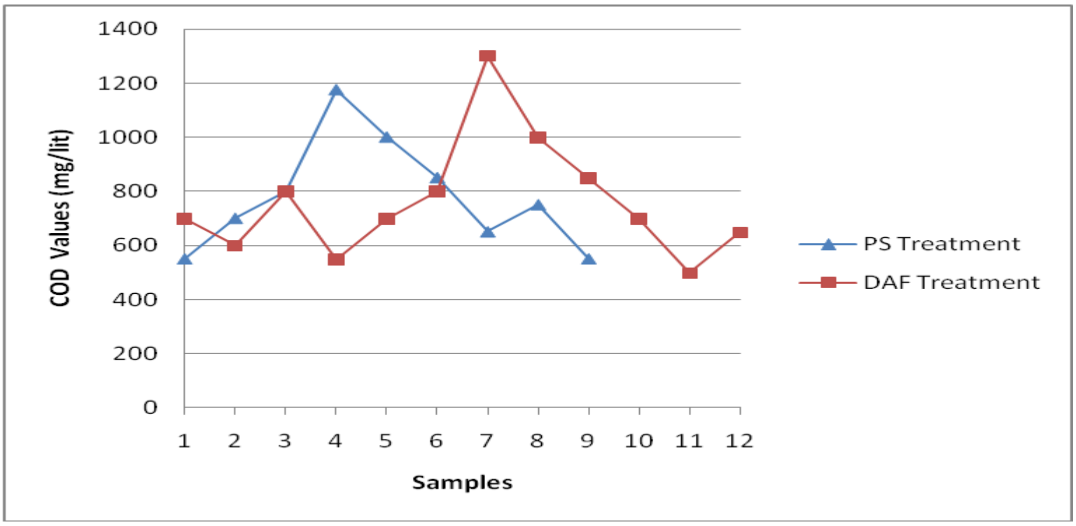

Figure 14. Influent COD values recorded for both treatment systems

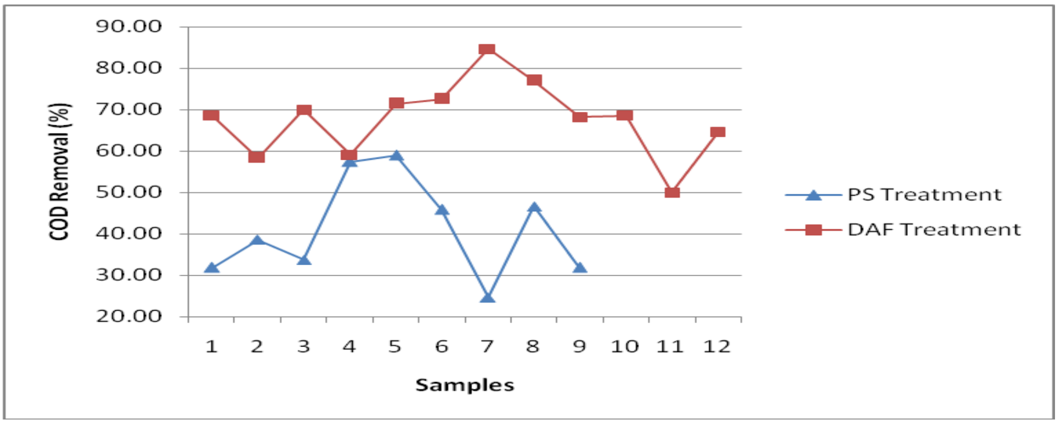

Figure 15. COD removal efficiencies recorded for both treatment systems

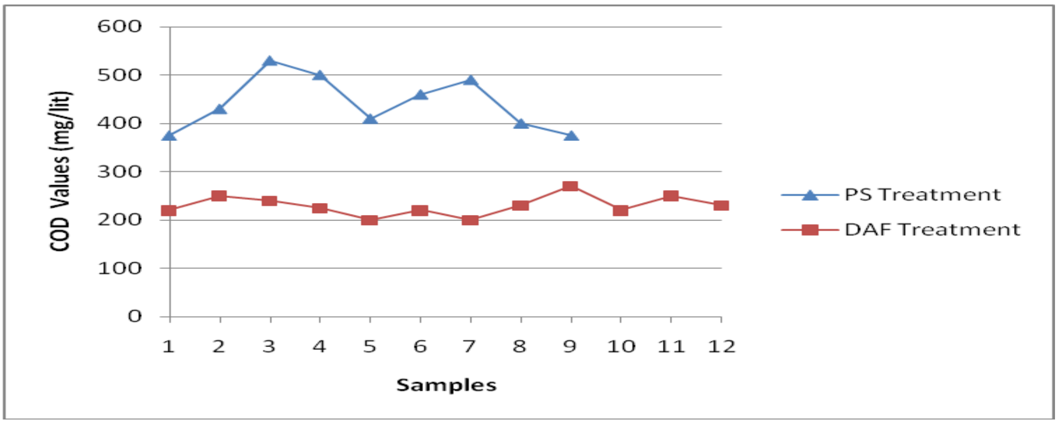

Figure 16. Effluent COD values recorded for both treatment systems

pH Monitoring

No significant changes in the pH values were recorded using both system although chemicals were used in the DAF system in contrast with the PS system. The average pH value recorded for the DAF system was 7.47 and for the PS system 7.95, figure 17.

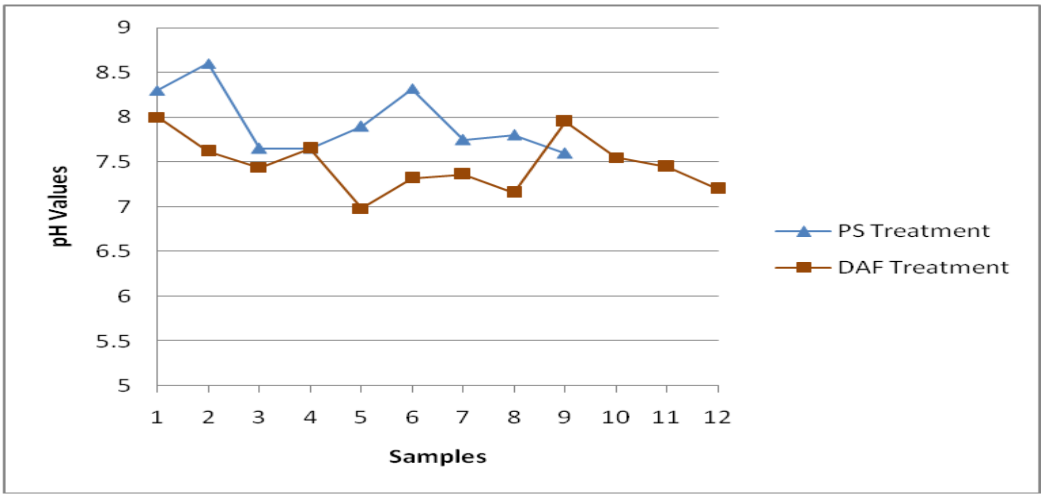

Figure 17. pH values recorded for both treatment systems

IV. CONCLUSIONS

This research work has considered the upgrading of an existing plain sedimentation (PS) treatment unit treating ceramic industry wastewater to a dissolved air floatation (DAF) system adopting chemical pretreatment. The main aim was to improve the quality of treated effluent for reuse in the factory production units and based on the study program executed in this research and the results obtained from the previous discussion, the following conclusions were recorded:-

1. The coagulants used in the jar test analysis in this study have both advantages and disadvantages. Aluminium sulphate and ferric chloride compounds are traditional coagulants used in both the water and wastewater industries. Metal coagulants offer the advantage of low cost per unit cubic meter treated while a distinct disadvantage is the large sludge volume produced. On the contrary Magnafloc 351 is expensive but small amounts increased the floc size several times with less sludge production.
2. In the jar test analysis Magnafloc 351 gave higher removal efficiencies for both turbidity and TSS with values above 98% and 96% respectively compared with the other two coagulants that were tested.
3. The modified DAF system gave 98.19% average turbidity removal efficiency compared with the PS system with 88.40%.
4. The modified DAF system gave 96.77% average TSS removal efficiency compared with the PS system with 61.90%. The average TSS effluent values recorded were 269.17 mg/l and 3177.22 mg/l respectively; the modified system increased the removal efficiency by about 34.87%.
5. The TDS removal efficiency was negligible in both systems. The modified system gave an average removal efficiency of 50.79% compared with the PS system with 29.79%.
6. COD removal efficiency for the modified system was 69.89% with an average effluent value of 229.58 mg/l. While the PS system gave a value of 43.49% with an average effluent value of 441.11 mg/l. The modified treatment system improved the COD removal by about 26.40%.
7. The pH values were similar for both systems with average values of 7.47 and 7.95 for the DAF and PS systems respectively.

DECLARATION OF CONFLICTING INTERESTS

The authors do not have any potential conflicts of interest to declare.

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