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Research Article

Technical and Economic Comparison between two Marble Industry Wastewater Treatment Systems

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Abstract

Marble wastewater slurry was treated at two different industrial sites at Shaq Al-Thoaban region 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/lit and this reduced the average total suspended solids (TSS) influent from 6521.25 mg/lit to 177.50 mg/lit yielding an average removal efficiency of 97.28%. In the second DAF treatment unit no any chemical was used for pretreatment and the resulting average removal efficiency achieved was 95.41%. The pH and EC values of the treated wastewater were negligible and in the neutral range. The average turbidity values recorded were 34.25 NTU and 50.75 NTU respectively. Furthermore, economic & technical comparison with regards initial costs, operation & maintenance requirements, environmental impact and settled sludge reuse favored the use of the DAF treatment unit although it recorded a 1.87% drop in TSS removal compared with the C/S treatment unit. The cost of the coagulant used in the first treatment system amounted to a 70% increase in the O & M costs compared to the second system.

Keywords:*Wastewater treatment, industrial wastewater, marble industry wastewater, dissolved air floatation, coagulation and sedimentation.*

1. Introduction

In the last two decades, the marble industry in Egypt showed a tremendous development. There are around 500 big enterprises in this industry and at least 3000 workshops (A. Rania *et al,* 2011). About 70% of the industry is located in Shaq Al-Thoaban located in Katameyya near Maadi suburb of Cairo with a total investment in this place of around 6 billion EGP (I. Azza *et al,* 2013) while the remaining 30% is distributed within Egypt. Egypt occupies the fifth position among the stone producing countries and Shaq Al-Thoaban is ranked the world fourth marble & granite industrial zone (A. Mashaly *et al,* 2012).

Marble factories use plenty of water in the process of cutting, washing and polishing. This requires a large volume of fresh water and the resulting wastewater leads to environmental problems. The high water consumption in production increases the costs and subsequent wastewater flow (S. Osman *et al,* 2010; S. Alves *et al,* 2008). Recovering the water from wastewater treatment is a vital need to reduce cost and wastewater flow but, however, the poor quality of the treated wastewater and associated high treatment costs makes this need inconvenient for application. Actual figures about the quantity of wastewater produced in Egypt from the marble and the granite industry are inaccessible since it is not calculated or monitored by the government or any other party (A. Rania *et al,* 2011).

Pysico-chemical treatment of marble processing wastewater was documented in (E. Arslan *et al,* 2005) and optimum coagulant-flocculant doses for turbidity removal in wastewater from the cutting, faience and equalization processes were determined as 500, 200 and 500 ppm of $Al_2(SO_4)_3$; 300, 500 and 300 ppm of $FeCl_3$ and 600, 400 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 used.

The removals of suspended solids from cutting, faience and equalization process wastewaters were similar to each other for each of the chemicals. The pH values after treatment by Agrofloc 100 were higher than the values determined after treatment by other chemicals for all process wastewater. Electrical conductivity values, however, were lower for Agrofloc 100 than for the others. Settled sludge volume experiments showed that settled sludge volumes decreased with time. The results of the quiescent settling experiment showed that the settling type could be termed flocculent settling (E. Arslan *et al,* 2005).

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Table 1 DAF design parameters values ranges (J. Haarhoff *et al,* 1993)

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/lit	6-8	
Cross flow velocity	m/hr	20-100	50-200
Flotation zone surface loading	m/hr	5-11	
Flotation zone solids loading	kg/m²/hr		2-6*, 6-12ˣ
Flotation zone side wall depth	m	1.5-3.0	2.0-4.0

*without coagulation; ˣwith coagulation

Marble wastewater treatment by direct filtration using glassy ceramic membrane filters provided highly clear filtrate of 0.2 NTU turbidity and high filterability of 9 tons of filtrate per m^2 of filter area through filtration conducted for one hour operation (S. Osman *et al,* 2010). Filtration is a major solid liquid separation process in mineral, chemical and ceramic production industries and their wastewater treatment. The wastewater commonly has dilute slurries and contains varying sizes of solid particles without and with polymeric species due to the water used in the processes.

Dissolved air floatation (DAF) is an extremely effective process used for the separation of suspended solids and oils from wastewater (C. Oliveira *et al,* 2012; L. Feris *et al,* 2001). The introduction of air bubbles to the influent 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 (A. Srinivasan *et al,* 2013). 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 (A. Srinivasan *et al,* 2013; R. Rodrigues *et al,* 2007).

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 (M. Teixeira *et al,* 2013).

Dissolved air floatation increased the efficiency of grease and oil removal from biodiesel wastewater by about 10% compared with other conventional processes (C. Rattanapan *et al,* 2011). 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 (R. Rodrigues *et al,* 2007; F. Capponi *et al,* 2006).

Fine quartz particles (d_p< 100 μm) ranging from 6% to 53% (by mass) were obtained from DAF experiments (A. Englert *et al,* 2009). Design ranges that have been used in practical applications of DAF for wastewater treatment and sludge thickening were documented by (J. Haarhoff *et al,* 1993) and are given in Table 1.

Bubble size plays a key role in particle separation; microbubbles (10-100 μm) give very promising results in large scale operation (R. Rodrigues *et al,* 2007; L. Feris *et al,* 2001; Alves *et al,* 2008). Recent 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/lit, this removal efficiency dropped to 94.5% when the pretreatment chemical dose was omitted (M. El Nadi *et al,* 2013).

The main objective of this research work is to technically and economically compare the full scale treatment of marble industry wastewater using two systems – conventional coagulation and sedimentation process and dissolved air floatation process; aiming at comparing its processing and treatment. 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.

Materials and Methods

This research work was conducted on two separate nearby wastewater treatment plants operating in Shaq Al-Thoaban region on the outskirts of Cairo city. Both treatment units were monitored for a 16 weeks period and the operation of the treatment units during this period was conducted by each factory technicians. Twelve samples were collected and analyzed for pH, total suspended solids (TSS), electric conductivity, and turbidity. All samples were analyzed in the laboratory of Shobra El Khaima wastewater treatment plant and the sanitary engineering laboratory of the Higher Institute of Engineering at Shorouk City. Tests were conducted according to Standard Methods 2002. The operating conditions and description of both treatment units is as follows:-

Coagulation/Sedimentation (C/S) Treatment Unit

A schematic diagram of the system is as shown in Fig. (1) and it consists of an equalization tank followed by

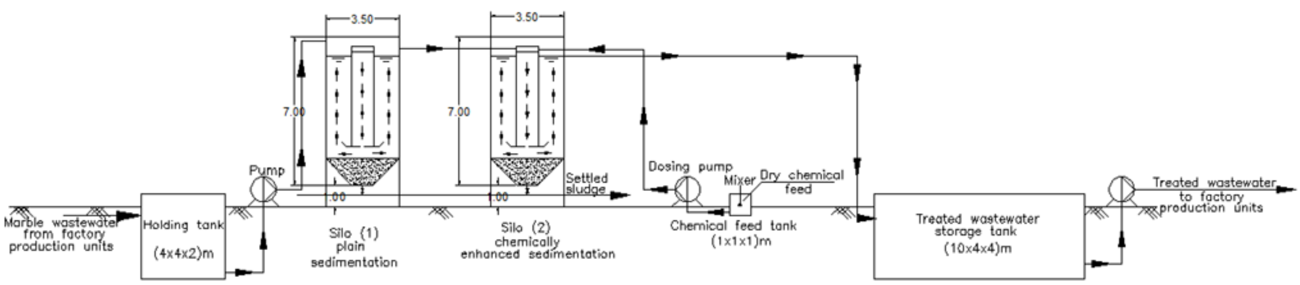

Fig.1 Schematic diagram of the (Coagulation/Sedimentation) Treatment Plant

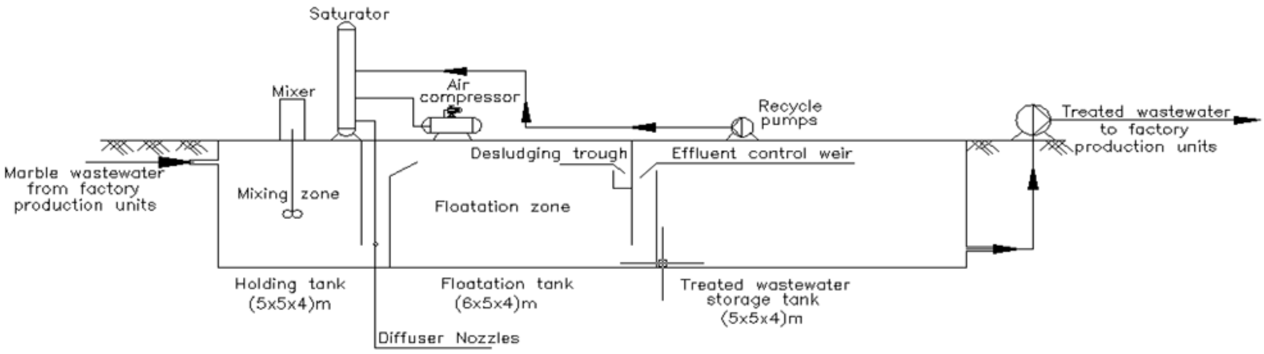

Fig.2 Schematic diagram of the DAF Treatment Plant

two silos; a plain sedimentation silo followed by a chemically enhanced sedimentation silo and, finally, a treated water storage tank. The treatment unit also has a chemical feed tank, sludge holding tank and a series of pumps. The silos are constructed from steel while the remaining units are from reinforced concrete. The details of the treatment unit are follows:-

Discharge= 301.00 m^3/day
Name of Chemical = Polyacrylamide
Chemical Dose= 50 mg/lit
Equalization Tank:-
Depth = 2.00 meters
Length = 4.00 meters
Width = 4.00 meters
Volume = 32.0 cubic meters
Plain Sedimentation Tank (1st Silo):-
Depth = 7.00 meters
Diameter = 3.50 meters
Volume = 68.00 cubic meters
Chemical Sedimentation Tank (2nd Silo) :-
Depth = 7.00 meters
Diameter = 3.50 meters
Volume = 68.00 cubic meters
Treated Water Storage Tank:-
Depth = 4.0 meters
Length = 10.00 meters
Width = 4.00 meters
Volume = 160.00 cubic meters

Dissolved Air Floatation (DAF) Treatment Unit

A schematic diagram of the system is as shown in Fig. (2) and it consists of an equalization/holding tank followed by an aeration/floatation tank, treated water tank and a sludge holding tank. The treatment unit is operated without chemical pretreatment and full flow dissolved air floatation, air compressor units and a series of pumps. All the units of the treatment system are constructed from reinforced concrete. The details of the treatment unit are as follows:-

Discharge= 280.00 m^3/day
Holding Tank:-
Depth = 4.00 meters
Length = 5.00 meters
Width = 5.00 meters
Volume = 100.0 cubic meters
Floatation Tank:-
Depth = 4.00 meters
Length = 6.00 meters
Width = 5.00 meters
Volume = 120.0 cubic meters
Treated Water Storage Tank:-
Depth = 4.00 meters
Length = 5.00 meters
Width = 5.00 meters
Volume = 100.0 cubic meters

The pH, electrical conductivity (EC) and turbidity were measured using a pH 211 microprocessor pH meter (Hanna Instruments), WTW LF 330 EC meter and Velp Scientifica turbidimeter 115, respectively. Whatman 934-AH glass fiber filters were used to filter samples for suspended solids analysis and dried at 105°C in a Hangzhou Sumer dry oven BPG-7032Cr. All suspended solids samples were weighed using a Contech electromagnetic force compensation balance CA-503 with an accuracy of 0.01 g.

Table 2 Influent and effluent TSS values

Samples	C/S Treatment Plant		DAF Treatment Plant	
	Influent (mg/lit)	Effluent (mg/lit)	Influent (mg/lit)	Effluent (mg/lit)
1	6620	175	6250	330
2	6350	185	6275	260
3	6450	165	6300	280
4	6500	220	6220	275
5	6690	170	6450	295
6	6660	200	6225	280
7	6570	170	6300	300
8	6375	140	6450	325
9	6490	155	6300	280
10	6750	210	6350	290
11	6600	180	6500	270
12	6200	160	6270	300
Average	**6521.25**	**177.50**	**6324.17**	**290.42**
% removal	**97.28**		**95.41**	

Results and Discussion

Samples from both treatment plants were collected tested during the monitoring period for the parameters stated in the previous section. Analysis of the data obtained during the monitoring period is demonstrated as follows:-

Total suspended solids

TSS values recorded for wastewater from the effluent streams of both factories was almost similar with a average influent value of 6521.25 mg/lit for the C/S treatment plant and 6324.17 mg/lit for the DAF treatment plant. The operation periods of both treatment plants ranged from (8 to 12) hours per day depending on the work load of both factories. Summary of the influent and effluent TSS values for both treatment plants are shown in Table 2.

The influent TSS values recorded for the C/S treatment system ranged from 6350 mg/lit to 6750 mg/lit compared with those of the DAF treatment system with a range of 6220 mg/lit to 6500 mg/lit, figure 3. The effluent values ranged from 140 mg/lit to 220 mg/lit and 260 mg/lit to 330 mg/lit for the C/S and DAF treatment systems respectively, figure 4.

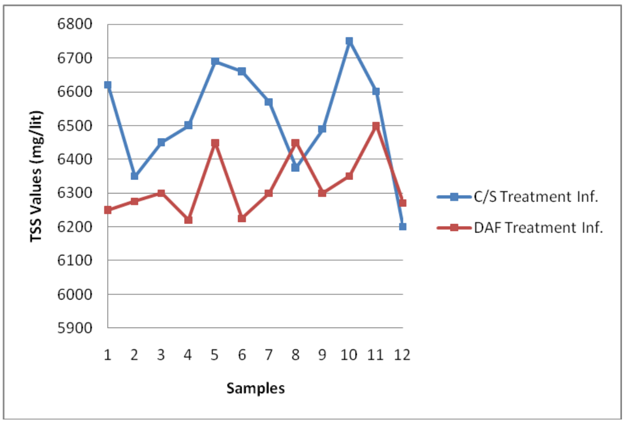

Fig. 3 Influent TSS values for the C/S & DAF treatment systems

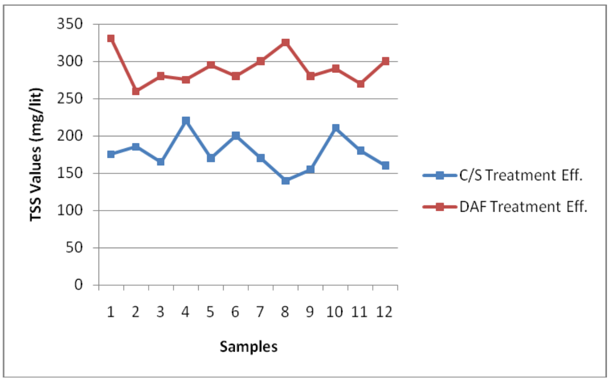

Fig. 4 Effluent TSS values for the C/S & DAF treatment systems

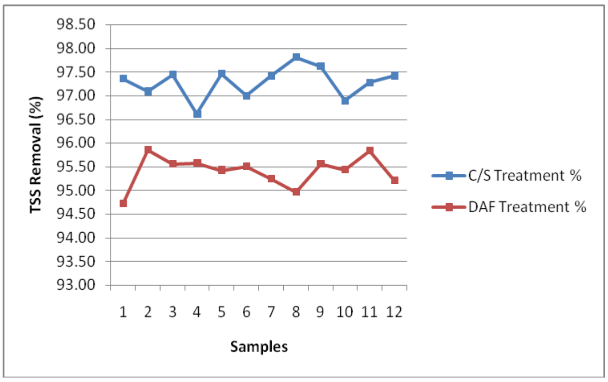

Fig. 5 TSS removal efficiency for the C/S & DAF treatment systems

In the case of the C/S treatment system, process removal efficiency was between 96.62% and 97.80% with an average value of 97.28%. While for the DAF treatment system, process removal efficiency was between 94.72% and 95.86% with an average value of 95.41%, figure 5. In similar pilot studied conducted by (E. Arslan *et al,* 2005; M. El Nadi *et al,* 2013; M. Fahiminia *et al,* 2013), different coagulants were used with different doses. Also pre-treatment was experimented prior to the floatation zone. In these studies, the maximum removal efficiency was 98.50% for the DAF treatment with chemical pretreatment while the lowest value recorded was 94.35% for the DAF treatment without chemical pretreatment. The use of lime doses of up to 100 mg/lit increases the removal efficiency to 99.10% as reported by (M. Fahiminia *et al,* 2013). The removal efficiency obtained from the large scale operation is almost similar to those available in literature and the C/S system was more efficient than the DAF system by about 1.87%.

pH and Electrical conductivity

The conductivity values of the treated wastewater by polyacrylamide (C/S system) were slightly higher than that of the DAF system, and similarly the pH values were higher, figures 6 & 7.

The anionic and non-ionic polyelectrolytes used by the C/S system helped the system to achieve high removal efficiencies because a small amount can increase the floc size several times and does not require monitoring of the pH values compared with metallic coagulants. However, no any significant variances or effects were noticed with regards the pH and EC values between both treatment systems.

Turbidity

The turbidity value was monitored as a quick reference for the quality of the treated effluent for its reuse in the production process; comparing the required time and effort for the turbidity and suspended solids tests. The turbidity values recorded for the C/S treatment system ranged from 25 to 45 NTU with an overall average value of 34.25 NTU, figure 8.

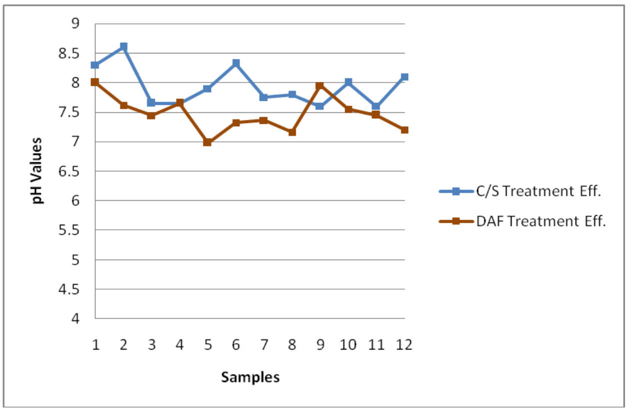

Fig. 6 pH values recorded for the effluent wastewater for both systems

While the turbidity values recorded for the DAF treatment system ranged from 35 to 67 NTU with an overall average value of 50.75 NTU, figure 7. The turbidity/suspended solids ratio for both systems showed a very close correlation with values of 0.193 and 0.175 respectively. This can be further studied for obtaining a relationship between turbidity and suspended solids.

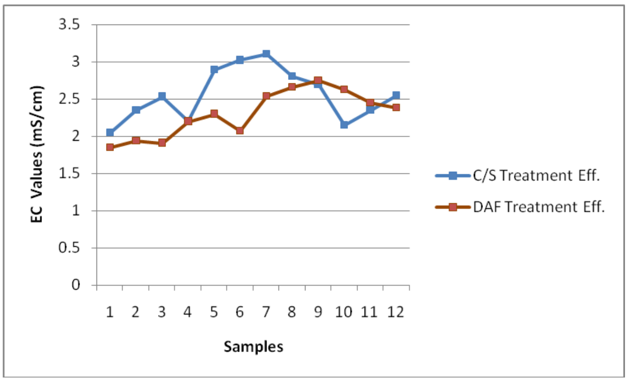

Fig. 7 EC values recorded for the effluent wastewater for both systems

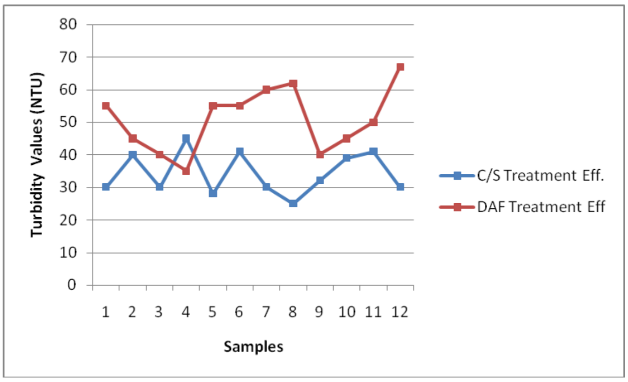

Fig. 8 Turbidity values recorded for the effluent wastewater for both systems

Economic comparison

The quick rough economic comparison made between both systems was based on the financial breakdown of both the initial costs and running costs. Data was obtained directly from the owners of both factories and from field survey with an accuracy degree of ±10%. The initial costs include the civil works and the equipment expenses. While the running costs comprise power, labor, chemical and operation & maintenance costs. The running costs were calculated on an annual basis and for a ten years operation period. Land costs were not taken into consideration in this economic study, while other parameters that were not taken in consideration in the economic comparison are the degree of the reuse of both the treated wastewater and produced sludge; although they have an indirect positive economic impact. Table 3 shows a summary of the financial breakdown of both systems under study.
From the financial breakdown shown in the above table it can be seen that the C/S treatment plant is expensive compared with the other system. With regards the initial costs the DAF treatment system was cost-effective by about 43.38% and by about 59.22% with regards the running costs. The overall cost of the C/S system was expensive by about 54.94% compared with the DAF system. The chemical cost has a very high impact on the running cost of the C/S system it amounts to about 70% of the running costs.

Table 3 Economic comparison between the two systems understudy*

Comparison Items	C/S Treatment Plant	DAF Treatment Plant
Civil works	**850000**	**350000**
Equipment	**95000**	**185000**
Sub-total(Initial Costs)	**945000**	**535000**
Power	25000	45000
Labor	**20000**	**12000**
Chemical	**175**000	---
O & M	**35000**	**47000**
Sub-total(Running Costs)Per annum	**255000**	**104000**
Sub-total(Running Costs)For 10 years	**2550000**	**1040000**
Total Costs	**3495000**	**1575000**

*all figures are in Egyptian pounds

Settled sludge

The settled sludge volume was not measured as there was no any provisions made for that onsite. For both treatment plants the settled sludge was collected in separate tanks and dumped by trucks to public dumping areas and, oftenly, it was dumped in the streets around the factories. Visual inspection of the settled sludge collected from both systems indicated that the sludge produced from the C/S system is gelatinous in nature due to the flocs produced by the coagulant added and the sludge produced from both silos is collected in one tank. The sludge from the DAF system is pure marble powder produced at the different stages of production in the factory and its environmental effect is low compared with that of the C/S system with added chemical. It was suggested that the DAF system sludge can be dewatered and the obtained sludge slurry can be used as a filler in the final marble finishing process.

Conclusions

This research work has considered the monitoring of two marble wastewater treatment plants adopting two different techniques; coagulation/sedimentation (C/S) and dissolved air floatation (DAF). Based on the study program executed in this research and the results obtained from the previous discussion, the following conclusions were recorded:-

- The C/S treatment system showed an average TSS removal of 97.28% compared with the DAF treatment system with 95.41%.
- The C/S treatment system yielded an average effluent TSS value of 177.50 mg/lit compared with the DAF treatment system with 290.42 mg/lit.
- The TSS removal efficiency in the C/S system was higher than that of the DAF system by about 1.87% yielding a drop of 112.92 mg/lit in the effluent values.
- The pH and EC values of the effluent treated wastewater recorded for both systems were negligible and the pH values were almost in the neutral range with the values of the C/S system slightly higher.
- The average turbidity values recorded for the effluent treated wastewater were 34.25 NTU and 50.75 NTU respectively.
- The economic comparison between both systems with regards both initial and running costs showed the DAF treatment system was cost-effective by about 43.38% with regards initial costs and by about 59.22% with regards the running costs.
- The overall cost of the C/S system was expensive by about 54.94% compared with the DAF system.
- The chemical cost has a very high impact on the running cost of the C/S system and it amounts to about 70% of the running costs.
- The settled sludge of the DAF system has a lower environmental impact and can be further dewatered and used as a filler in the marble finishing process compared with that of the C/S system.

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