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TECCIENCIA

Evaluation of Chemical Coagulants in the Removal of Suspended Solids, Chemical Oxygen and algae in the Salguero pond system.

Evaluación de Coagulantes Químicos en la Remoción de Sólidos Suspendidos, Demanda Química de Oxígeno y Algas en el Sistema Lagunar Salguero.

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Abstract

The present research establishes the coagulation process as an post-treatment alternative for the effluent polishing of the stabilization ponds of the Wastewater Treatment System El Salguero (municipality of Valledupar, Colombia). This study presents the possibility of removing nutrients and organic matter using chemical coagulants, for which it was necessary to estimate the optimal dose to achieve the removal of COD, TSS and algae; thus contributing to the decrease of agents causing eutrophication, depletion of dissolved oxygen and the development of septic conditions in the Cesar river.

Determining the optimum coagulant dosage for each parameter was performed using jar tests of water, testing different concentrations of coagulants and a blank or control. Essential optimal dosage for each coagulant was obtained, which was applied to achieve the removal of the study parameters; subsequently, assays were performed in a sedimentation column.

The coagulant that showed the best results regarding the studied parameters (COD, TSS and algae) was the ferric chloride (FeCl3) with removal rates of 77.13%, 91.03% and 96.22% respectively. Furthermore, a lower dosage with ferric chloride of 170 mg / L and greater doses to the use of PAC of 400 mg / L was obtained. In this research we can conclude that the use of chemical coagulants such as ferric chloride is a good option to remove high concentrations of algae, suspended and colloidal solids causing increased turbidity and color of the waste discharges, decreasing the concentration of COD, TSS and algae and therefore in the receiving bodies.

Keywords: Non-conventional materials, Acoustic and thermal Insulation, Sustainable Development.

Resumen

En la presente investigación se establece el proceso de coagulación como una alternativa de post tratamiento para el pulimiento del efluente de las lagunas de estabilización del Sistema de tratamiento de Aguas Residuales El Salguero (municipio de Valledupar-Colombia), este estudio presenta la posibilidad de remover nutrientes y materia orgánica, utilizando coagulantes químicos, para lo cual fue necesario la estimación de la dosis óptima para lograr la remoción de COD, TSS y Algas; contribuyendo de esta manera a la disminución de los agentes causantes de procesos de eutrofización, agotamiento de oxígeno disuelto y desarrollo de condiciones sépticas del río Cesar.

La determinación de la dosis óptima del coagulante para cada parámetro se realizó mediante pruebas de jarras, ensayando diferentes concentraciones de coagulantes más un blanco o control. Se obtuvo la dosis óptima essential para cada coagulante, la cual fue aplicada para lograr la remoción de los parámetros de estudio, posteriormente se realizaron ensayos en una columna de sedimentación.

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El coagulante que presento mejores resultados con relación a los parámetros estudiados COD, TSS y algas fue el Cloruro Férrico (FeCl3) con porcentajes de remoción de 77,13%, 91,03% y 96,22% respectivamente. Además se obtuvo una menor dosificación con el Cloruro férrico de 170 mg/Lt y una mayor dosis con la utilización del PAC de 400 mg/Lt. En esta investigación podemos concluir que el uso de coagulantes químicos como el cloruro férrico es una buena opción para remover altas concentraciones de algas, sólidos suspendidos y coloidales que causan aumento en la turbidez y el color de los vertidos residuales, disminuyendo la concentración de COD, TSS y algas en los vertimientos y por ende en los cuerpos receptores.

***Palabras clave*:** Coagulantes químicos, Efluente, Post-tratamiento, Pulimiento, Remoción.

1. Introduction

One of the most significant problems regarding environmental control is the contamination of water bodies. This occurs by the disposal of an element or compound, organic or inorganic, that dissolved, dispersed or suspended, reaches a concentration that exceeds the tolerance for a particular use. The discharges of wastes to water bodies, resulting of human activities: domestic, industrial and agricultural [1, 2, 3, 4]; produce harmful effects on water currents and on the community, due to the content of organic matter presented by these effluents.

On the basis of this major drawback, the need to apply proper treatments to the wastewater to decrease their impact on the environment and give them other uses arises. Wastewater treatment dates back to very ancient times, but it is only in the 1990s, as a result of technological advances, that the wastewater treatment focuses mainly on solving public health problems caused by toxic substances and pathogens present in the wastewaters, and on developing practices that allow to fix the problem from the source [5, 6].

The stabilization ponds are economic and efficient methods of wastewater treatment, particularly in regions where there is enough land available and they are low-cost in tropical countries [7]. They are intended to remove organic matter and eliminate pathogenic microorganisms, thus decreasing the concentration of contaminants in water. However, the STAR (wastewater treatment system, by the Spanish acronym) - Salguero generates algae waste that alters relevant parameters such as COD and TSS in the receiving water body causing significant eutrophication processes. In consequence to the above, it is necessary to implement a post-treatment system that ensures an effluent with permissible value of disposal in accordance with applicable laws and national competent regulations.

The use of coagulants to polish the effluent of stabilization ponds is presented today as a solution for fast, cost-effective implementation that can produce excellent quality effluents [8]. The post-treatment of effluents via physico-chemical processes, which includes the stages of rapid mix, flocculation and sedimentation or flotation, is a treatment alternative to remove algae and nutrients [9, 10].

The use of coagulants such as aluminum sulfate, ferric chloride, and other polyelectrolytes, allows to cancel the surface charges of the algae and destabilize the colloidal suspension formed by them, so as with the removal of algae in the effluent not only provides a better aesthetic appearance, but also reduces BOD and COD, decreasing the risk of consumption of oxygen and therefore, the contamination of water sources [11]. This alternative has been implemented in several countries, which has shown excellent results, as the case of Colombia, where investigations to laboratory scale are performed using different coagulants to improve the quality of the effluent.

Therefore, the main objective of this research is to evaluate the removal of suspended solids, chemical oxygen demand, and algae in the pond system El Salguero in the city of Valledupar from the use of chemical coagulants, jar tests will be performed with three types of coagulants to find the optimal coagulant dose of the more efficient coagulant for the removal of COD, TSS and Algae and subsequently make an assay in a Batch type sedimentation column with depth of 2.20 m, its efficiency and percentages of removal obtained to establish the feasibility of its use as an alternative post-treatment for the polishing of the effluent from the system of stabilization ponds

2. Methodology

2.1 Population

The population to carry out this work corresponds to the effluent of the wastewater treatment plant Salguero Station, property of the Public Services Company S.A. of Valledupar (Emdupar). To perform the experiment a volume of approximately 40 liters was taken from the effluent of the pond system. The experimental phase of the research was carried out in the laboratories of Environmental and Health Engineering of the Popular University of Cesar.

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2.2 Materials of thermal insulation

Two pre-tests were conducted to know the behavior of the variables in order to find the ranges of optimal doses of the coagulants

2.3 Determination of the optimal dose of each coagulant for each parameter analyzed.

The coagulants that were used in the experiment are aluminum polychloride (PAC), aluminum sulfate (Al2(SO4)3) and ferric chloride. The optimal dose of each coagulant to remove COD, TSS, and algae in the samples analyzed was determined. The optimal coagulant dose for each parameter was determined through jar tests, rehearsing different concentrations of coagulants and a blank or control. The fast system of 110 rpm mixing was provided for one minute, slow mix of 40 rpm, letting the water flocculate for 15 minutes and a period of sedimentation of 30 minutes. In all the jar tests, the samples analyzed in each container were observed in detail, to then determinate which one presented best removal for each parameter of interest

2.3.1 Choice of optimal essential dose for each coagulant.

A comprehensive optimal dose that could guarantee an approximate value of 80% of removal for each parameter of the study was selected

2.4 Control parameters.

They were evaluated based on the use of coagulants following the next parameters: pH, temperature and turbidity through direct reading, total suspended solids (TSS), chemical oxygen demand (COD) and algae following Standard Methods [12]

2.5 Removal efficiency

To determine the efficiencies of algae removal, TSS and COD of the wastewater from the STAR (Wastewater treatment system) "El Salguero", through the use of coagulants, percentages of removal of contaminants from the water treatments were compared with the coagulants versus a control without coagulants.

2.6 Column of sedimentation

The synthetic insulation materials originate with the For this test a column of sedimentation was used, of cylindrical shape built in acrylic with a diameter of 6 inches and a height of 2.20 meters, with their respective outlets located throughout this every 40 centimeters. The sedimentation test was performed using the respective essential optimal dose. 500 mL samples were taken every 20 minutes at depths of 0.60 m, 1 m, 1.40 m and 1.80 m, measured from the top of the column to the point of sampling, to complete a period of sedimentation of 80 minutes.

For study parameters algae, COD, TSS and turbidity, the retention times that guarantee a percentage of clearance equal to or greater than 80% in the column of sedimentation were determined with the following formula:

$$\% R = \sum_{h=1}^{n} \left(\frac{\Delta h_n}{H}\right) \left(\frac{R_n + R_{n+1}}{2}\right) \quad Equation\ 1$$

Where:

R = removal of the parameter %.
n = Number of curves with the same percentage of removal.
$\Delta H1$ = Distance between curves of equal percentage of removal (m).
H= Total height of the sedimentation column (m).
Rn= Equal Percentage of removal of curve number n.
$Rn+1$= Equal percentage of removal of curve number n

3. Results and Discussion.

3.1 Characterization of the pond effluent samples

According to the data obtained in the characterization of the effluent (see table 1), we could infer that in all cases a green coloration in different shades (light or dark) is presented, caused basically by the high concentrations of cells and pigments of algae, thus affecting the aesthetic appearance of the effluent. Concentrations of turbidity in the samples reflect the presence of organic particles mostly, and suspended or dissolved inorganic particles, that at the same time give color to water: From there, the relationship that is presented between TSS with the turbidity in the analysis. In this case, the higher was the concentration of the total suspended solids in the water, the higher was the concentration of the turbidity. The above is confirmed as provided by Torres et al. [13] who in 2005 remarked that the measurements of turbidity in situ can be used to estimate concentrations in real-time of Total Suspended Solids (TSS) in hydro-systems.

Table 1: Characterization of study samples. Authors: 2014.

PARAMETER	UNIT	SAMPLING		
		M1	M2	M3
		(17-07-2014)	(28-07-2014)	30-07-2014)
Temperature	°C	25	25	25
pH		7.33	7.55	7.54
Turbidity	unt	77.67	70.05	68.03
COD	mg /L	205.44	189.25	192.345
TSS	mg /L	100	80	78.08
Algae	(µg/mL)	2.0823	1.6348	1.5805

3.2 Choice of optimal essential dose for each coagulant

After having identified which was the best dose for the removal of each parameter, COD, TSS and Algae in the 3 study samples, we proceeded to choose an essential optimal dose (See table 2) that could ensure a value close to the 80% of removal for each parameter, percentage of removal close to the requirements established in Decree 3930 [14] of 2010 and Decree 1594 [15] in 1984. The choice of an essential dose for each coagulant allows making a comparative analysis between the same and, at the same time facilitates the overdose of the coagulant and the reduction of the costs of operation

Although with other doses greater removals of TSS and algae were presented, the choice of the essential dose was adjusted to the dose that shows a bigger removal with regard to the COD, because this was the parameter most critical for this research, the only one that did not reach an efficiency of 80% removal with none of the coagulants and one of the most exceeded by the STAR El Salguero in its concentration at the moment of assessing the disposal carried out on the Cesar river.

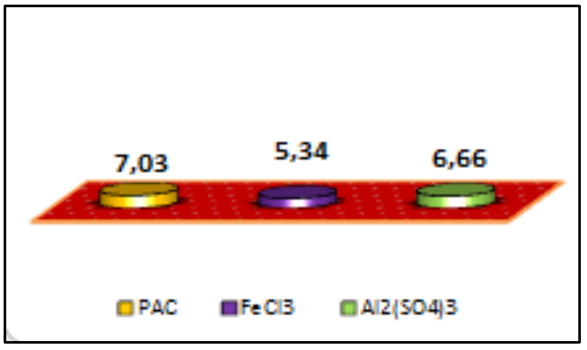
Table 2: Essential optimal dose for each chemical coagulant.

.COAGULANTS.	OPTIMAL DOSE	PARAMETERS.				
		pH	TURBIDITY	ALGAE	TSS	COD
$FeCl_3$	170 mg/L	5.34	98.96 %	96.22%	91.03%	77.13%
$Al_2(SO_4)_3$	175 mg/L	6.66	96.55%	90.34%	88.47%	76.36%
PAC	400 mg/L	7.03	97.43%	90.70%	89.75%	76.06%

3.2.1 Comparative analysis of the essential optiamla doses in the study parameters.

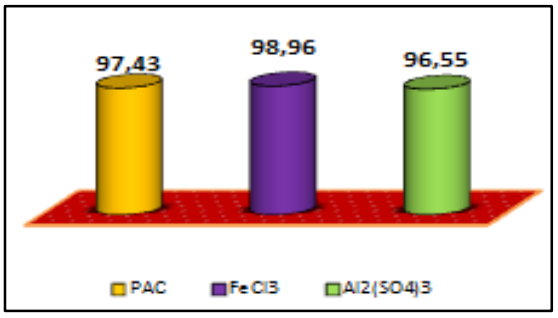
Of the three coagulants applied to treat the pond effluent, the aluminum polychloride (PAC) kept the pH range despite the high dosage that was used in this research, which was at 7.03 (conforms to Decree 3930/2010 Art.72. pH of 5 to 9 units). This behavior can be attributed to the high percentage of basicity of the coagulants belonging to the family of pre-hydrolyzed or pre-polymerized coagulants, such as the case of the PAC [16]. The pH obtained with the treatment of aluminum sulfate Al2(SO4)3 was 6.6, a value that conforms to the Decree 3930/2010. On the other hand, the pH value of FeCl3 was 5.34, which although it is in the value range of the environmental regulations for this type of disposal, it is not recommended to ensure adequate health for the receiving ecosystem, since the decrease in pH in water bodies prevents the free development of the life conditions of the resource, as well as limits the use of the same (See graph 1)

Figure 1. pH-value with the optimal dose.



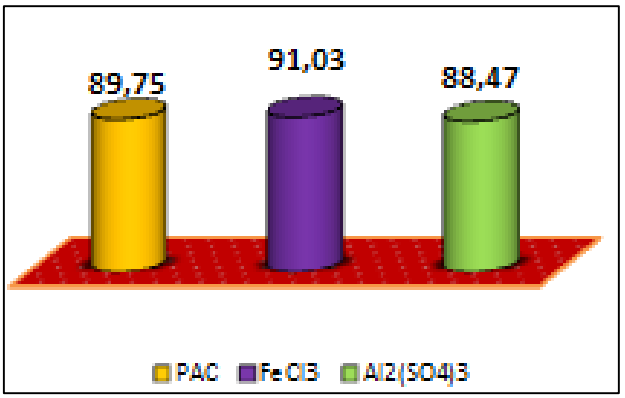
The coagulant that presented better efficiency for the removal of turbidity with respect to the essential optimal dose was FeCl3 with 0.70 NTU, reaching a removal percentage of 98.96%, then aluminum polychloride with 97.43%, and finally the aluminum sulfate with 96.55%, demonstrating that the doses selected allow to successfully meet the Colombian Environmental Regulations (Decree 3930/2010, Article N°72Turbidez ≥ 5 NTU); these results of removal are similar to those obtained by Moncada et al. [17] who found removals of turbidity increased to 92%, for the coagulants of study; Llano et al. [18] who obtained removal percentages higher than 90% using aluminum sulfate; but they differ with those obtained by Manjarrez et al [19] who reached in their studies the greatest removal with PAC. The efficiency of FeCl3 on the turbidity removal is due to the ability to form larger more compact and numerous flocs, which is due to an increase in the probability of collisions and sedimentation of the colloids formed during the coagulation of aluminum sulfate. On the other hand, the efficiency of PAC lies in the fact that this forms flocculates in the form of spheres of string type which makes them strong and always together making the descent of the particles that cause turbidity to be reduced (See Figure 2).

Figure 2. Percentage of turbidity removal with the optimal dose.



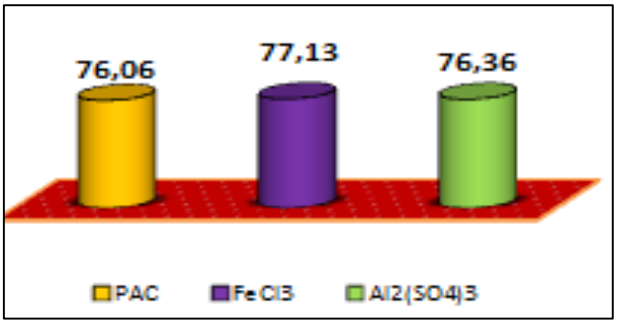
The greater removal in TSS was obtained with the ferric chloride in a 91,03% followed by the treatment with aluminum polychloride (PAC) in a 89.75%, and subsequently with aluminum sulfate, with a removal of 88.47% (See graph 4) complying in all cases with competent environmental regulations (Decree 3930/2010 Art.72.SS≥ 50% in load for the existing user). The removal efficiency of TSS of the ferric chloride is due to its ability to rapidly form heavier flocculates and with greater speed of settlement that the aluminum salts.

Figure 4. Removal percentages of TSS with the optimal dose.



The removal of COD with different doses of chemical coagulants chosen did not meet the expectation set out in the alternative hypothesis in which it was expected, with the application of the different treatments, to obtain a removal of the 80% of this parameter. Despite this, the values of removal were close to the goal and very similar between them, the higher removal of COD was obtained with the ferric chloride in a 77.13% followed by the treatment with aluminum sulfate, with the removal of the 76.36% and finally aluminum polychloride (PAC) with 70.06% (See graph 5), where it was possible to appreciate the difficulty presented by some pre-polymerized coagulants for the removal of organic matter, situation that does not occur when surface water for human consumption is treated which presented basically high content of inorganic matter in the form of colloidal such as flax and clay. The three essential optimal doses complied fully with the Decree 39307/2010 art 72 COD ≥30% load for existing user. In terms of the removal efficiency of COD with chemical coagulants such as $FeCl_3$ and $Al_2(SO_4)_3$ the literature has pointed out, in relation to, greater efficiency for $FeCl_3$ (Núñez et al.,[23], Ebeling et al.,[24], Al-Mutairi et al., [25], Mittal [26], Ghandy [27]).

Figure 5. Removal percentages of COD with the optimal dose.



3.3 Tests of columsn

The initial conditions of the pond effluent before being subjected to the different treatments of a coagulant, with the optimal essential doses found in stage I. In the column of sedimentation two assays were conducted with two samples at different dates, in which the different parameters as measured in their characterization were determined; the samples were captured on 28 August and 1 September, 2014 at 9:00 am. The results for each parameter are recorded below (See table 3).

Table 3. Characterization of the sample.

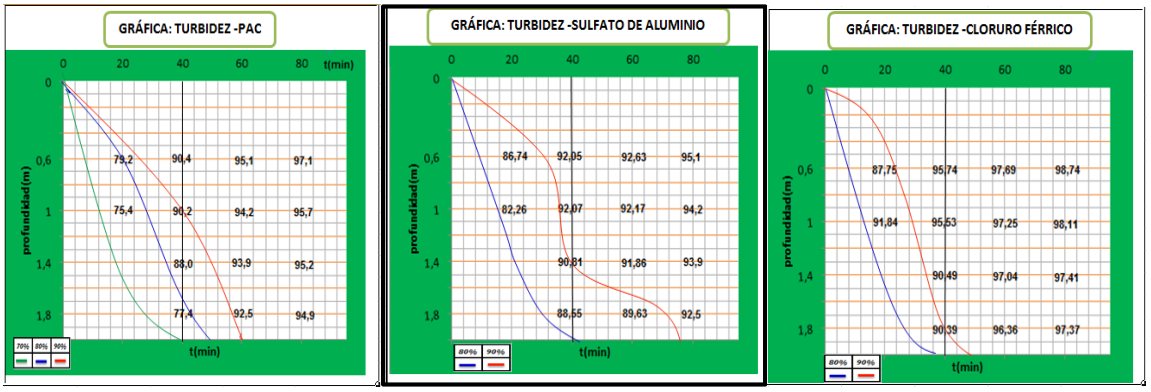
PARAMETERS	UNIT	SAMPLING		
		C1:PAC	$Al_2(SO_4)_3$	C3: $FeCl_3$
		(1-09-2014)	(28-08-2014)	(1-09-2014)
DOSE	mg /L	400	175	170
Temperature	°C	31	27.09	31
pH		7.31	7.33	7.31
Turbidity	UNT	69.2	69.32	69.2
COD	mg /L	172.8	157.9	172.8
TSS	mg /L	70	80	70
Algae	(µg/mL)	1.732	1.489	1.732

Source: Authors, 2014

For a time of sedimentation of 40 minutes, and a depth of the column of sedimentation of 1.8 m, PAC presented a removal of 89.94%, aluminum sulfate of 92.83%, and the ferric chloride of 95% for the parameter of turbidity, the ferric chloride displaying an increased percentage of removal (See graph 6). These results are similar to those reported by Gutierrez et al. [27], in tests of sedimentation capacity, achieving removals of 90%.

The behavior of the turbidity in the three sedimentation columns at different depths of study, demonstrates how, with time passing, the best removals are located in the top of the column, which indicates that with time, after applying a dose of coagulant, the particles were precipitated by their force of gravity and the weight increases when forming the flocs, clarifying the water in the column at different depths.

Figure 6. Percentages of removal of turbidity in the batch type sedimentation column for the various coagulants.

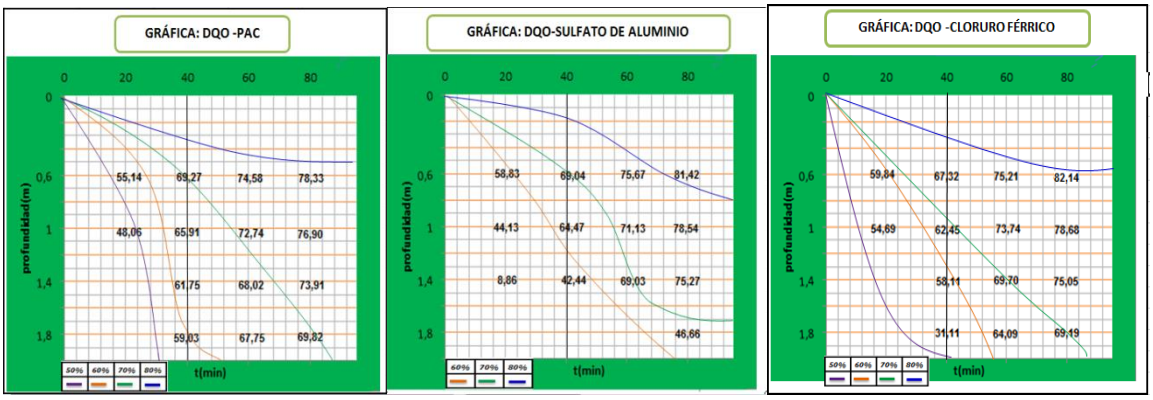


For a time of sedimentation of 40 minutes, and a depth of the column of sedimentation of 1.8 m, PAC presented a removal of 90%, aluminum sulfate of 83.6%, and ferric chloride of 94.38% for the parameter of algae, showing a percentage of removal increased the ferric chloride (See graph 7). Because the algae have the same dynamic of destabilizing the colloids, it can be seen that at 40 minutes, removals greater than 80% of the algae biomass in the different columns of sedimentation are presented.

For a time of sedimentation of 40 minutes, and a depth of the column of sedimentation of 1.8 m, PAC presented a removal of 71.43%, aluminum sulfate 87.02% and ferric chloride 71.10% for TSS parameter, aluminum sulfate showing a greater percentage of removal (see graph 9),

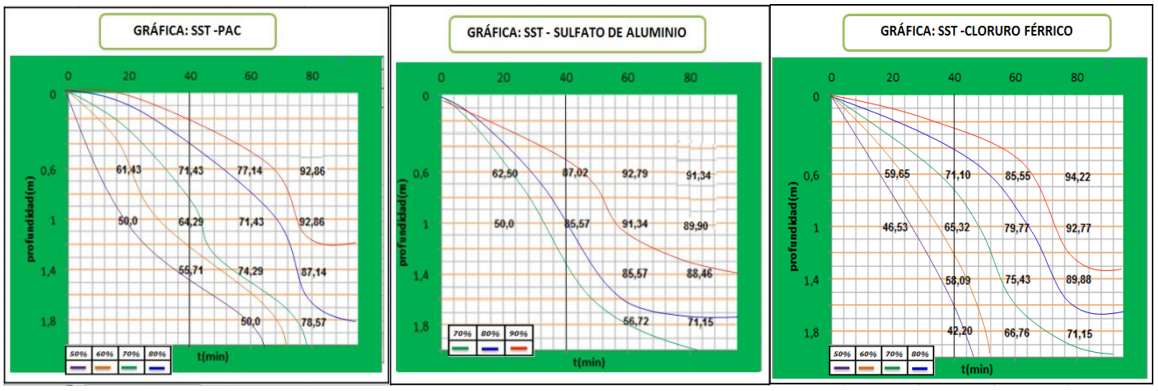
which shows that this chemical agent removes a significant proportion of the suspended solid [28]. However, at the end of the 80 minutes of sedimentation the percentages of removal found in the trials were of 91.34% for $Al_2(SO_4)_3$, 92.86% for PAC and 94.22% for $FeCl_3$, respectively. These values were higher than those obtained in the jar tests.

Figure 8. Percentages of Removal of COD in the batch type sedimentation column for the different coagulants



For a time of sedimentation of 40 minutes, and a depth of the column of sedimentation of 1.8 m, PAC presented a removal of 71.43%, aluminum sulfate 87.02% and ferric chloride 71.10% for TSS parameter, aluminum sulfate showing a greater percentage of removal (see graph 9), which shows that this chemical agent removes a significant proportion of the suspended solid [28]. However, at the end of the 80 minutes of sedimentation the percentages of removal found in the trials were of 91.34% for Al2(SO4)3, 92.86% for PAC and 94.22% for FeCl3, respectively. These values were higher than those obtained in the jar tests.

Figure 9. Percentages of Removal of TSS in the batch type sedimentation column for the different coagulants.



4. Conclusions

The use of coagulant chemicals is a good option for removing high concentrations of suspended solids and colloids that cause an increase in turbidity and the color of the waste discharges.

The dosage of coagulant is a critical parameter, since if this is added below the amount required, it does not perform a neutralization or total hydrolysis of particles, the formation of microflocs is scarce, and color and turbidity of the water are high as in the case of aluminum sulfate and aluminum polychloride; similarly, if excess of coagulant is added, an investment of colloidal particles occurs and the subsequent formation of microflocs with very small sizes, very low sedimentation and in some cases as which of the ferric salts very high turbidity.

Ferric chloride is a metallic coagulant salt, which can obtain very good results in wastewater with high content of organic matter.

The removal of the organic matter in the coagulant ferric salts is performed by mechanisms similar to those of the turbidity, but under conditions of pH lower than those required to remove it.

The use of dosing of ferric chloride as a coagulant causes a yellowing of the treated water, which can generate high amounts of residual iron, aesthetic problems.

In research a correlation between removal of turbidity, TSS and algae biomass was presented, indicating that in the majority of cases where there was more or less removal of one, it was similar in the other.

It can be stated that the samples without treatment i.e. control, achieved removal values of the study parameters, a situation that might be due to the reduction of TSS, COD, and Algae, is governed by unitary operations such as sedimentation, decantation and also filtration.

Finally, the process of clarification Coagulation/ Flocculation – Sedimentation can be a excellent post-treatment alternative to improve the quality of waste discharges and at the same time to comply with the requirements of environmental health on the disposal of these water bodies.

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