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Chemical coagulants and *Moringa oleifera* seed extract for treating concrete wastewater

Heber Martins de Paula[1], Marina Sangoi de Oliveira Ilha[2*] and Leonardo Santos Andrade[3]

*[1]Departamento de Engenharia Civil, Universidade Federal de Goiás, Catalão, Goiás, Brazil. [2]Departamento de Arquitetura e Construção, Faculdade de Engenharia Civil, Arquitetura e Urbanismo, Universidade Estadual de Campinas, Rua Saturnino de Brito, 224, 13083-889, Campinas, São Paulo, Brazil. [3]Departamento de Química, Universidade Federal de Goiás, Catalão, Goiás, Brazil. *Author for correspondence. E-mail: milha@fec.unicamp.br*

ABSTRACT. Wastewater from concrete plants has a high pH and a high concentration of suspended solids, necessitating treatment before reuse or discharge into the environment. The objective of this study is to evaluate the efficiency of two chemical coagulants, aluminum sulfate ($Al_2(SO_4)_3$) and iron chloride ($FeCl_3$), and a natural coagulant, *Moringa oleifera* (MO), all in their soluble forms, in the treatment of wastewater from concrete plants. To this end, the efficiencies of the three coagulants, in combinations with different proportions, were tested. The quality parameters of the wastewater obtained after the treatments were compared to the limit values for non-potable water. The use of coagulants in their soluble form potentiates their effect, especially when preparing the MO extract, i.e., greater amounts of the protein responsible for the coagulation is extracted. A mixture with MO and $Al_2(SO_4)_3$ in a 20:80 proportion showed the best results, with 97.5% of the turbidity removed at 60 min. of sedimentation, allowing the treated water to be used for washing vehicles and flushing toilets. The $FeCl_3$ treatment produced a high concentration of chlorides, which could cause corrosion problems, and is therefore not recommended for concrete wastewater treatment.

Keywords: coagulation, *Moringa oleifera*, combination treatment, chemical coagulants, natural coagulant.

Coagulantes químicos e o extrato de semente de *Moringa oleifera* para o tratamento da água residuária de concreto

RESUMO. Este artigo tem como objetivo avaliar a eficiência do uso de dois coagulantes químicos, o sulfato de Alumínio ($Al_2(SO_4)_3$) e o cloreto férrico ($FeCl_3$) e da Moringa oleifera (MO) no tratamento das águas residuárias de usinas de concreto. Para tanto, foram considerados o uso exclusivo dos três coagulantes e também o uso associado, em diferentes dosagens, em pó e solução. Os resultados obtidos para os parâmetros de qualidade da água residuária foram comparados com os valores limite para a água não potável para fins de abastecimento. Verificou-se que o uso dos coagulantes na forma solúvel potencializa o tratamento, principalmente no caso do preparo do extrato da MO em que ocorre melhor extração da proteína presente nas sementes e que é responsável pela ação coagulante. A proporção 20:80 MO e $Al_2(SO_4)_3$ solúvel apresentou os melhores resultados, com remoção de turbidez de 97,5% para o tempo de 60 min. de sedimentação, permitindo o uso da água tratada na lavagem de veículos e na descarga de bacias sanitárias. O tratamento efetuado com o $FeCl_3$ apresentou elevado teor de cloretos, o que pode acarretar problemas de corrosão, sendo este coagulante menos recomendado para o tratamento da água residuária do concreto.

Palavras-chave: coagulação, *Moringa oleifera*, tratamento associado, coagulantes químicos, coagulante natural.

Introduction

The construction industry has grown significantly in the last five years in Brazil. In 2012, the construction sector represented 5.7% of the gross domestic product (GDP), maintaining a growth rate of 1.4%, which was higher than the growth rate of the national GDP (0.9%).One indicator of this growth is the consumption of cement, which reached more than 64 million tons in 2012 (Departamento Intersindical de Estatística e Estudos Socioeconômicos [DIEESE, 2013]). The industries that produce concrete are connected to this growth; they expanded their installations without environmental procedures for the final disposal of their solid and liquid wastes.

One of the primary wastes from these factories is the wastewater from the concrete production process. This wastewater, primarily produced from washing the floors and the mixer trucks, has a high concentration of suspended solids, a high pH, high turbidity and high alkalinity, among other parameters (Chatveera & Lertwattanaruk, 2009). These characteristics have prompted environmental legislation prohibiting the disposal or discharge of untreated wastewater (Ekolu & Dawneerangen, 2010).

Reuse of the water, in combination with rationing, is an alternative that can minimize the wastewater discharged from the plant (Sealey, Phillips, & Hill, 2001), possibly to the point where none is discharged, in which case the plant is known as a zero-discharge plant (Lobo & Mullings, 2003). For the wastewater to be reused, however, it must be treated for uses other than concrete production. This concept is related to urban metabolism, i.e., cities should not only consume raw materials but also provide them. The word 'metabolism' refers to the set of physiological processes that occur within living beings that provide the necessary energy and nutrients for their existence (Agudelo-Vera, Leduc, Mels, & Rijnaarts, 2012).

There are different treatment systems that have been proposed in the literature to improve concrete wastewater quality. All of them, however, are based on the principle of sedimentation (Tsimas & Zervaki, 2011), which produces an effluent that does not always meet water reuse requirements. Additionally, the treatment system should have the smallest possible environmental impact; therefore, the use of systems and natural treatment techniques, such as *Moringa oleifera* (MO) as a natural coagulant, is an important alternative (Rico, Santos, Reis, Silva, & Zonetti, 2013).

MO has been used as a natural coagulant in the treatment of different types of wastewater, such as tannery effluents (Kazi & Virupakshi, 2013) and palm oil mill effluents (POME) (Bhatia, Othman, & Ahmad, 2007a), and has consistently demonstrated excellent results, especially for the removal of turbidity (greater than 80% removed).

Bhatia, Othman, and Ahmad (2007b) conducted a study to optimize the treatment of POME. To obtain the best ratio between the associated extract of MO and flocculants, they adopted a full factorial composite experimental design and response surface methodology (RSM). Their results indicated a 99% removal of suspended solids (SS) at a dosage of 3469 mg L^{-1} MO and 6736 mg L^{-1} flocculants. The authors note that the results compare well to treatment with chemical coagulants, and they emphasize the advantages of the natural treatment.

Nwaiwu and Bello (2011) studied combinations of aluminum sulfate ($Al_2(SO_4)_3$) and MO at different concentrations for the treatment of surface water to be used in the public water supply. The combination of 40% $Al_2(SO_4)_3$ and 60% MO resulted in the highest rate of turbidity removal (> 90%), demonstrating the potential for MO use in wastewater treatment.

The authors of the present study have previously investigated the treatment of wastewater from a concrete plant using a combination of MO and $Al_2(SO_4)_3$ and found the best mixture to be a 20:80 (m/m) mix of both coagulants in their insoluble, i.e., powder, form. These results showed that the removal of turbidity by the combination of the coagulants was more efficient than the removal with $Al_2(SO_4)_3$ alone. Additionally, after treatment, the water satisfied the reuse requirements for washing vehicles and flushing toilets (De Paula, Ilha, & Andrade, 2014).

Thus, the objective of this study is to evaluate the efficiency of the combined $Al_2(SO_4)_3$/MO and $FeCl_3$/MO, both in their soluble form, and compare the results with those obtained from the previous study by De Paula et al. (2014), which used the same combination of coagulants for treating wastewater from concrete plants in their insoluble form.

Material and methods

For this study, wastewater samples were collected from the treatment system of a concrete plant with a monthly production of 2,000 m^3 (Figure 1). The treatment system is composed of eight chambers: one for the wastewater from the washing of the mixing trucks and for the surface runoff from the production patio; six for the treatment itself (sedimentation); and one that serves as an outlet. The sample was collected from the fourth sedimentation chamber, located at point (2) in the figure.

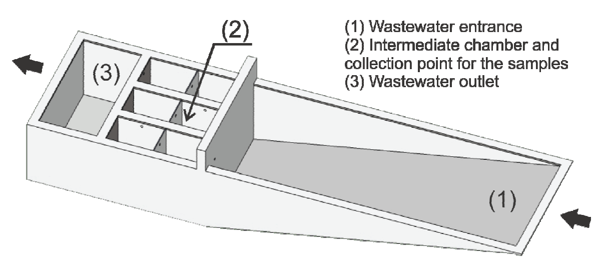


Figure 1. Existing treatment system in the concrete plant.

Three concrete wastewater samples were collected, and the following parameters were obtained to evaluate water quality: a) parameters from the U.S. Environmental Protection Agency (USEPA, 2012) requirements for urban reuse water, including pH (pH meter, PG 1800 Gehaka), turbidity (Model DLT-WV, Del Lab), residual chlorine (DR 890, Hach) and alkalinity (water potability kit, Alfakit), and b) other parameters of interest, including chlorides and hardness (water potability kit, Alfakit).

The tests were developed according to the American Public Health Association (APHA, 2012) specifications and performed in triplicate, with the exception of turbidity, for which six readings were performed. The average of the values was used for the subsequent analyses.

The results obtained were compared with the limit values for the non-potable water supply quality parameters described by Sautchuk et al. (2005), NBR 15527 (Associação Brasileira de Normas Técnicas [ABNT], 2007) and USEPA (2012), which are shown in Table 1.

With respect to the iron concentration, the limit values for Class 3 water from the CONAMA 430 resolution (Conselho Nacional do Meio Ambiente [CONAMA], 2011) were used (maximum iron concentration of 5.0 mg L^{-1}).

With respect to water hardness, soft water contains less than 50 mg L^{-1} calcium carbonate ($CaCO_3$), moderately hard water contains between 50 and 150 mg L^{-1} $CaCO_3$, hard water contains between 150 and 300 mg L^{-1} $CaCO_3$, and very hard water contains more than 300 mg L^{-1} $CaCO_3$ (Von Sperling, 2006).

The treatment of the collected water was performed using the coagulation-flocculation process with two chemical coagulants generally used in water treatment systems, $Al_2(SO_4)_3$ and $FeCl_3$, in combination with a solution prepared from the seeds of MO at different concentrations.

The performances of the different concentrations of the chemical coagulants were evaluated by the volume necessary to correct the pH of the wastewater, using the limits established by Sautchuk et al. (2005) and USEPA (2012). For this purpose, 500 mL of wastewater was agitated and monitored using a bench-top pH meter, while increments of 50 g L^{-1} (5% by mass) coagulant concentration solution were added. For $Al_2(SO_4)_3$, 50 mL was added in 5 mL increments. For $FeCl_3$, 17 mL was added in 1.0 mL increments. The pH value after each addition was measured after allowing 2 min. for the solution to stabilize.

The pH was plotted as a function of the final concentration of each coagulant. From the concentration curves, the volumes of $Al_2(SO_4)_3$ and $FeCl_3$ necessary to yield a pH near 7.5, corresponding to the average of the minimum and maximum values required in Sautchuk et al. (2005) and USEPA (2012), were used as a reference. The dosages of the coagulants to be tested were made following the proportions suggested by Nwaiwu and Bello (2011), which are shown in Table 2. Additionally, a reference sample with no added coagulants was evaluated.

The MO seeds were collected near Viçosa, Minas Gerais State, Brazil, in the spring of 2012 and remained in their pods until testing. The seeds were then peeled, crushed in a food processor, and stored in a closed container at room temperature for one day prior to the preparation of the extract.

The MO, the $Al_2(SO_4)_3$ (P.A., Quimidrol), and the $FeCl_3$ (38%, Quimidrol) coagulants were prepared at a 5% by mass concentration in the three solutions (50 g L^{-1} for MO and $Al_2(SO_4)$ and 131.60 mL L^{-1} for $FeCl_3$ 38%). The solutions were agitated for 30 min. in a jar-test procedure with a controlled rotational velocity of 100 rpm. Then, the MO extract was gravity-filtered and stored at 4°C for 24 hours before use.

For the coagulation-flocculation test, the jar test used six beakers, with a volume of one liter for each sample. There is no established standard for the mixing cycles during a jar test; thus, the rotational velocities of the mixture were selected according to the capacity of the equipment and as suggested by Ndabigengesere, Narasiah, and Talbot (1995). The rotational velocities used in the experiment were 1 min. of rapid rotation at 100 rpm, followed by 20 min. of slow mixing at 40 rpm. The coagulants were simultaneously added to the wastewater immediately before turning on the equipment.

Table 1. Limit values for non-potable water quality parameters for recovery/reuse.

Parameter	I	II	III	IV
pH	6 - 9	6 – 9	6 - 9	6 – 8
Turbidity	≤ 2 NTU	< 5 NTU	≤ 2 NTU	< 2 NTU*, < 5 NTU
Residual chlorine	--	Max. 1 mg L^{-1} (a)	> 1 mg L^{-1}	0.5 - 3 mg L^{-1}
Chloride	--	< 350 mg L^{-1} (a) / < 100 mg L^{-1} (b)	--	--
Alkalinity	--	--	50 - 150 mg L^{-1} (c)	--

* for less restrictive uses. I – Sautchuk et al. (2005) water quality standard recommended for Class 1 reuse water (washing of vehicles and flushing of toilets). II – Sautchuk et al. (2005) water quality standard recommended for Class 3 reuse water (irrigation of green areas and watering gardens). III – USEPA (2012) water quality standard for urban reuse (for all types of irrigation, washing vehicles, flushing toilets, firefighting systems, commercial air conditioning systems and similar uses, accesses and exposures). IV – NBR 15527 (ABNT, 2007). (a) for surface irrigation (b) for irrigation with sprinklers (c) for reuse.

Table 2. Coagulant concentrations used in the simulations.

Dosage	% by volume $Al_2(SO_4)_3$	MO	Dosage	% by volume $FeCl_3$	MO
A	100	--	H	100	--
B	--	100	I	--	100
C	80	20	J	80	20
D	60	40	K	60	40
E	50	50	L	50	50
F	40	60	M	40	60
G	20	80	N	20	80
Reference	-		-		

The sedimentation of the flocking agents was evaluated by measuring the turbidity of the samples 15 min. (Matos, Cabanellas, Cecon, Brasil, & Mudado, 2007), 30 min. (Ndabigengesere & Narasiah, 1998) and 60 min. (Okuda, Baes, Nishijima, & Okada, 1999) after the end of the jar test by removing water from the center of each beaker. The other parameters were analyzed 60 min. after the end of the jar test, also from the center of the jar.

The turbidity results were analyzed with a multiple comparison of means method using a Scott-Knott test with a significance value equal to 0.05. This method has the advantage of separating the averages into discrete groups without superposition (Canteri, Althaus, Virgens Filho, Giglioti, & Godoy, 2001). In this analysis, the data were compared within each dosage and between two dosages at 15, 30, and 60 min. to determine whether there were significant differences in sedimentation over time.

Finally, the results for the turbidity removal for the treatment with MO and $Al_2(SO_4)_3$ were compared with the results from a similar study by De Paula et al. (2014) that used both coagulants in insoluble (powder) form.

Results and discussion

Table 3 shows the quality parameters of the wastewater collected from the concrete plant treatment system.

Table 3. Average values for the quality parameters of the concrete wastewater.

Parameter	Average value *
pH	12.5
Turbidity (NTU)	132
Chlorides (mg L^{-1})	170
Alkalinity (mg L^{-1} $CaCO_3$)	1000
Hardness (mg L^{-1} $CaCO_3$)	1200
Iron (mg L^{-1})	0.11

*calculated from the results obtained using the average of three collections performed at point 2 of the existing treatment system in the plant illustrated in Figure 1.

Most of the measured parameters exceed the limiting values found in the reference documents for non-potable water; therefore, treatment is necessary for the water to be reused as non-potable water in the factory. For this treatment, a coagulation-flocculation process is proposed with the concentrations of chemical coagulants and MO extract in their soluble forms evaluated in this study.

Figure 2 shows the pH values obtained with the different concentrations of chemical coagulants. A starting value of 38 mL L^{-1} $Al_2(SO_4)_3$ was used for the combinations of coagulants, which corresponds to the volume of aluminum sulfate necessary to produce a pH of 7.5. The mass of $Al_2(SO_4)_3$ to be added to the wastewater was determined as a function of the volume of wastewater to be treated. For example, 1.90 g of $Al_2(SO_4)_3$ must be added to 1.0 L of wastewater for a desired pH of 7.5, assuming that the $Al_2(SO_4)_3$ solution (with a concentration of 50 g L^{-1}) used in these tests has a 38 mL L^{-1} volume, which is approximately the same mass used in the study of De Paula et al. (2014). However, because the amount of $Al_2(SO_4)_3$ varies with the dosage (see Table 2), there is less mass of $Al_2(SO_4)_3$ added to the system and therefore a lower concentration. A similar procedure was used to determine a starting value of 15.5 mL L^{-1} $FeCl_3$ (Figure 2b), again corresponding to a desired pH of 7.5. As in the case of $Al_2(SO_4)_3$, this was the starting value for the dosages of the coagulants (Figure 2a).

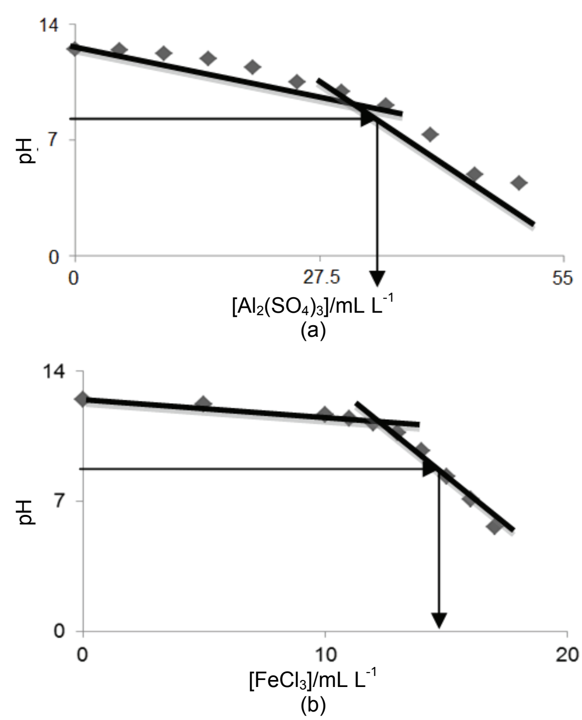
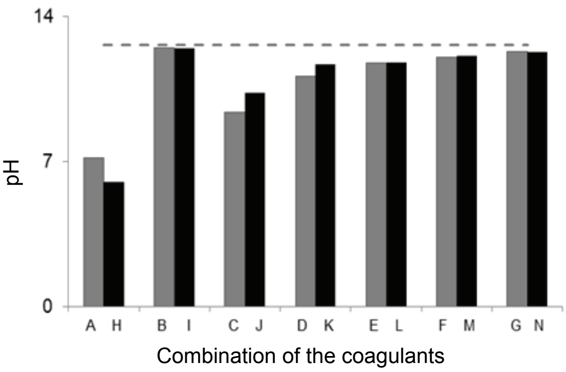


Figure 2. pH as a function of solution volume added per wastewater volume (in units of mL L^{-1}): (a) aluminum sulfate and (b) iron chloride.

Figure 3 shows the pH values obtained for the different dosages. For the $FeCl_3$ solution (dosage H), there was a difference between the graphical result obtained and the experimental data (the pH was reduced to 6.0, which is lower than the value obtained with the adjusted concentration curve). Regardless, the pH value is still within the limits found in Sautchuk et al. (2005), USEPA (2012), and NBR 15527 (ABNT, 2007).



Dosage Legend: A – 100% $Al_2(SO_4)_3$; B – 100% MO (38 mL L^{-1}); C – 80% $Al_2(SO_4)_3$ + 20% MO; D – 60% $Al_2(SO_4)_3$ + 40% MO; E – 50% $Al_2(SO_4)_3$ + 50% MO; F – 40% $Al_2(SO_4)_3$ + 60% MO; G – 20% $Al_2(SO_4)_3$ + 80% MO; H – 100% $FeCl_3$; I – 100% MO (15.5 mL L^{-1}); J – 80% $FeCl_3$ + 20% MO; K – 60% $FeCl_3$ + 40% MO; L – 50% $FeCl_3$ + 50% MO; M – 40% $FeCl_3$ + 60% MO; N – 20% $FeCl_3$+ 80% MO. Reference – wastewater (dashed line).

Figure 3. pH variation as a function of the different dosages of coagulants. The dashed line indicates the value of the reference wastewater.

In dosages B and I, which had only the MO extract, there was no change in the initial pH, indicating that MO alone cannot change the pH in these conditions. Additionally, the pH variation is minimal between the dosages with the same concentration of coagulants, especially for those with a larger amount of MO extract, such as E-L, F-M and G-N. Therefore, the only dosage with MO that satisfies the pH limit values from the reference documents, except NBR 15527 (ABNT, 2007), is dosage C (80% $Al_2(SO_4)_3$ + 20% MO).

Tables 4 and 5 show the residual turbidity data for each coagulant dosage and the results from a Scott-Knott test with a degree of significance of 0.05. The turbidity was measured at three different times after the end of the rotation cycles: 15, 30 and 60 min.

Dosages A and C showed statistically equal values and were less than 2 NTU for the 30 and 60 min. sedimentation times. According to Sautchuk et al. (2005), USEPA (2012) and NBR 15527 (ABNT, 2007), water from bodies of water with this turbidity concentration can be used for irrigation, washing vehicles, flushing toilets, and firefighting systems, among other applications. At the end of the process, dosages B and D showed similar results, indicating the potential for MO extract to be used to treat this type of wastewater in these conditions. For these dosages, along with dosages F and G, the turbidity levels in the water were low enough that it could be used to water gardens and other green areas (Sautchuk et al., 2005) and to irrigate with sprinklers (ABNT, 2007).

Table 4. Average residual turbidity values and results from the Scott-Knott test with 5% significance* for the dosages of $Al_2(SO_4)_3$ and MO coagulants. The initial turbidity is 132 NTU.

Concentrations	Time (min.)					
	15		30		60	
A	3.04	a B	1.18	b A	0.79	a A
B	10.18	d C	6.22	c B	3.34	b A
C	5.68	b C	0.61	a A	0.95	a B
D	8.54	c C	6.54	c B	3.41	b A
E	12.70	e C	8.14	d B	5.10	e A
F	10.27	d C	8.06	d B	4.68	d A
G	11.75	e C	8.86	e B	4.02	c A
Reference	25.70	f B	11.73	f A	11.65	f A

* the same uppercase letters indicate statistical similarity of the data in the row; the same lowercase letters indicate statistical similarity of the data in the column.

Table 5. Average residual turbidity values and results from the Scott-Knott test with 5% significance* for the dosages of $FeCl_3$ and MO coagulants. The initial turbidity is 132 NTU.

Concentrations	Time (min.)					
	15		30		60	
H	1.40	a A	0.78	a A	2.52	a B
I	11.25	c C	5.28	d B	3.19	b A
J	7.75	b C	2.47	b A	2.95	b B
K	11.83	c C	4.78	c B	3.31	b A
L	11.77	c C	4.41	c B	4.21	c A
M	16.87	d C	9.99	e B	5.91	d A
N	20.38	e C	10.09	e B	4.11	c A
Reference	25.70	f B	11.73	f A	11.65	e A

* the same uppercase letters indicate statistical similarity of the data in the row; the same lowercase letters indicate statistical similarity of the data in the column.

Among the different dosages of $FeCl_3$ and MO, dosage H (100% $FeCl_3$) showed the best turbidity removal results. At the end of the process, the turbidity value was above 2 NTU for all the investigated dosages (H, I, J, K, L, M and N). As was the case for $Al_2(SO_4)_3$, water treated with this coagulant could be used to water gardens and other green areas and to irrigate with sprinklers.

Comparing the results obtained for the dosages with MO alone (B and I), it is observed that changing the volume of added extract does not significantly change the resulting turbidity. Therefore, it can be concluded that a dosage of 15.5 mL L^{-1} MO is sufficient to remove turbidity.

It is important to note that more than 90% of the wastewater turbidity was already eliminated after only 30 min. of treatment, regardless of the type and proportion of coagulants in the dosage. For the dosages with $Al_2(SO_4)_3$, more than 90% was removed after only 15 min of sedimentation. The reference wastewater also showed a 91.2% removal of turbidity after 60 min., which is because the rapid agitation of liquids with colloidal particles can promote their sedimentation.

The wastewater also showed very high $CaCO_3$ values (Figure 4). Of the reference documents used in this study, only USEPA (2012) gave limiting values for alkalinity (between 50 and 150 mg L^{-1}). Dosages A (100% $Al_2(SO_4)_3$) and C (80% $Al_2(SO_4)_3$ and 20% MO) were the only dosages with alkalinity values within the limiting values, as shown in Figure 4.

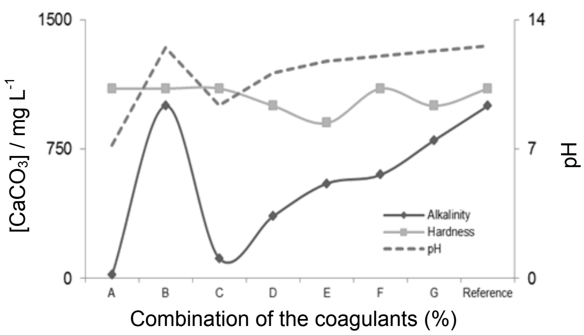


Figure 4. Variation of hardness, alkalinity and pH as a function of different dosages of Al2(SO4)3 and MO.

Although the hardness is essentially unchanged for the different dosages, treatments with dosages A and C produce water with sufficiently low alkalinity concentration that it can be reused for irrigation, washing vehicles, flushing toilets, firefighting systems, commercial air conditioning systems, and other similar uses.

Similarly, the data in Figure 5 show that the only alkalinity value within the USEPA (2012) range is that for dosage J, which is a combination of $FeCl_3$ and MO.

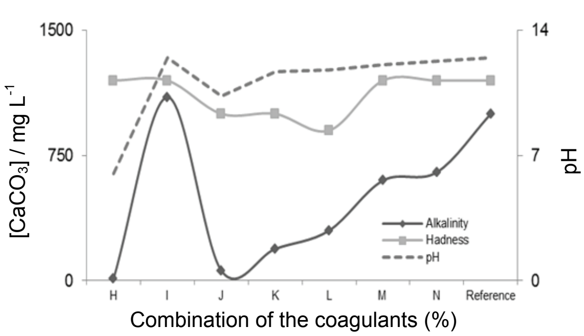


Figure 5. Variation of hardness, alkalinity, and pH as a function of different dosages of FeCl3 and MO.

Contrary to the results published by Muyibi and Evison (1995), the hardness is essentially the same for the different dosages with both coagulants. This discrepancy may be because the referenced authors used synthetic water in neutral conditions. However, the results in this study agree with the studies by Egbuikwem and Sangodoyin (2013), who investigated the use of MO for the treatment of water from lakes, streams, and artesian wells.

Even though the $CaCO_3$ concentration obtained at the end of the treatment differs from the exclusive addition of $FeCl_3$ (dosage H) by 10 mg L^{-1}, excess $FeCl_3$ may cause corrosion problems. For example, the presence of chloride ions in the production of reinforced concrete could locally destroy the passive film on the reinforcement surface, causing pitting. This type of corrosion can lead to the failure of the steel bars, thus prohibiting the reuse of water treated with $FeCl_3$ in concrete production.

To avoid this potential problem, the concentration of chloride ions present at the end of each treatment was analyzed; the results are shown in Figure 6.

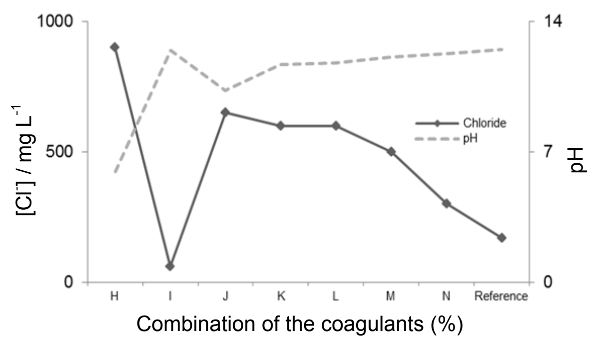


Figure 6. Variation of the concentration of chlorides (solid line) and pH (dashed line) as a function of the dosages of the FeCl3 and MO coagulants.

The concentration of chlorides was below the 350 mg L^{-1} limiting value established in Sautchuk et al. (2005) for Class 3 reuse water only for dosages I and N (neglecting pH correction). The dosages with $Al_2(SO_4)_3$ and MO have no added chlorides; however, as the potable water has residual chlorine, the residual chlorine concentrations (in the form of chlorides) of the dosages with $Al_2(SO_4)_3$ and MO were also evaluated. For all the dosages investigated, the values at the end of the treatment were well below the 350 mg L^{-1} limit. Additionally, measurements of the free chlorine (in the form of hypochlorous acid and hypochlorite ion) resulted in values close to 0.06 mg L^{-1} for all the dosages. In this case, the wastewater would need to be chlorinated before reuse.

Another possible issue with $FeCl_3$ as a coagulant is its tendency to precipitate in aqueous media from aeration or chlorination of the water, which produces a reddish color in the solution. In combination with MO, it is expected that the Fe^{3+} ions will not act as flocking agents but will remain in their soluble form in the water, although at low concentrations. To evaluate this, the soluble residual iron concentrations were also measured after treatment. For all the dosages, the results confirmed low iron concentrations that oscillated between 0.5 mg L^{-1} and 1.0 mg L^{-1}. These values (Figure 7) are well below the reference value (5.0 mg L^{-1}).

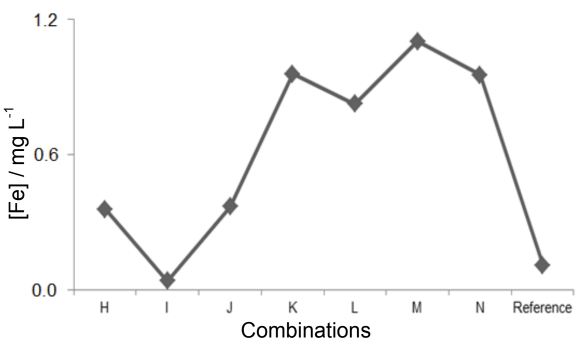


Figure 7. Iron concentration of the treated concrete wastewater for dosages with FeCl3 and MO.

In general, the results for the coagulants in soluble form were better than those from the previous studies by the authors of this work (De Paula et al., 2014), in which the coagulants were used in powdered form. This is most notable when comparing the removal of turbidity by MO alone (dosage B - 38 mL L^{-1}). It is believed that the higher efficiency is caused by the preparation of the solution, which allows a greater extraction of the protein responsible for the coagulating action. The efficiency reached 92.3% for dosage B at 15 min. of sedimentation in soluble form, compared to 52.8% when the coagulants were used in powdered form. Figure 8 compares the results obtained with the two forms of the coagulants (powder and extract).

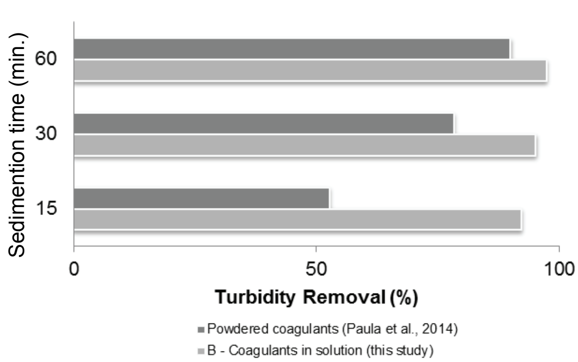


Figure 8. Comparison of the efficiency of turbidity removal (%) for the coagulants in powdered form and in solution.

Dosage I (100% MO – 15.5 mL L^{-1}) also showed 97.6% turbidity removal after 60 min. This shows that for the range of volumes tested (between 15.5 and 38 mL L^{-1}), the MO extract shows excellent potential for the neutralization and dragging of suspended particles.

Conclusion

The use of coagulants in soluble form improves the efficiency of concrete wastewater treatment, especially for treatment with MO, as it enhances the extraction of the coagulating protein.

The treated wastewater met all the quality parameters required for Class 3 reuse water found in Sautchuk et al. (2005), with the exception of pH for the dosages with volumes of MO greater than or equal to 40% (D, E, F and G). Dosage C (20% MO and 80% $Al_2(SO_4)_3$) showed the best results for the reduction of pH, turbidity, chloride concentration, and alkalinity in the concrete wastewater.

The use of iron chloride alone (dosage I) or in combination with MO resulted in an elevated concentration of chlorides, primarily in the dosages with larger volumes of $FeCl_3$ (greater than 40%). This prohibits the use of the treated water for washing vehicles, as it can cause corrosion and can damage the paint.

The use of MO alone demonstrated a good ability to remove turbidity and decreased the concentration of chlorides by particle dragging and charge neutralization. However, the same efficacy was not found for the reduction of alkalinity and hardness. Additionally, treatment with MO alone requires a longer sedimentation time (at least 60 min.) to obtain the same levels achieved by the chemical coagulants.

From the obtained results, it is concluded that the use of MO as a coagulation aid for treating concrete wastewater is very promising because use in its soluble form (extract) shows the best results.

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