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Evaluation of Starchy Maize Starch as a Natural Coagulant in the Treatment of Confined Aquifer Water: Removal of Iron, Turbidity and Colour

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The objective of the research was to evaluate the coagulation process with starchy maize starch to remove iron, turbidity and colour from the confined aquifer water. The coagulation efficiency was determined experimentally using the jar test equipment, carrying out tests at 6 levels of applied dose (1, 2, 3, 4, 5 and 6 mL) and at 5 levels of agitation speed (100, 150, 200, 250 and 300 rpm.) with defined times (1.5 minutes for fast mixing, 15 minutes for slow mixing and 10 minutes for sedimentation), after preparation of the coagulant at 3 concentrations (0.5%, 1% and 2%). The data obtained were statistically analysed for two contexts: to evaluate whether there are significant differences in removal between pre- and post-treatment values in the 3 parameters studied, using the paired Student's t-test; and to determine the most efficient treatment using the complete coagulation process (coagulant concentration, applied dose and mixing speed/time conditions), for which Duncan's test was used for a completely randomised design (CRD). As a result, it was obtained that when using a dose of 50 mg/L (ratio: weight/volume) at a concentration of 1% of solution, the appropriate agitation speed is 250 rpm for fast mixing and 63 rpm for slow mixing, as it has allowed an iron removal of 80% (0.55 mg/L), turbidity of 88.83% (4.94 NTU) and colour of 67.39% (50 Pt-Co).

1. Introduction

The water quality of an aquifer depends on several factors, both natural factors such as rock type, residence time, as well as anthropogenic factors such as industrial and agricultural wastes that over time accumulate in the soil and can be leached contaminating the aquifer. Due to these factors, it is possible that the water present in the aquifer has a different chemical composition associated with the different types of materials through which it flows (Tostado, 2010). Currently, treating water means making use of conventional engineering techniques, involving the use of supplies (inorganic coagulants), which guarantee efficiency in the treatment, undervaluing the risks they can cause to the environment and to the health of those who consume these waters, but it can be considered that these substances can be substituted by organic coagulants, such as vegetable starch, for example.

Starch is a complex polysaccharide, which is stored in the form of granules, with different sizes, chemical composition and physical characteristics, which vary according to the source from which it comes (Arias, 2016).

Maize has become one of the most widely consumed cereals in the world, with multiple applications for both nutritional and industrial purposes. It is used for starch production, as the grain consists of approximately 70 to 75 % of it (Grande and Orozco, 2013).

The importance of starch lies mainly in industrial and agro-industrial use, but very little has been studied as a natural coagulant in the treatment and / or purification of water (Huaringa and Vilcarano, 2019).

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In the study area (Yantaló - Peru), there is an aquifer that supplies water as a basic service to the surrounding community, which shows evidence of high iron concentration, turbidity and colour. Groundwater may contain iron, in soluble form (II), which generates complementary problems of turbidity and colour (Loaiza, 2009). The objective of this research is the evaluation of starchy maize starch as a natural coagulant in the removal of these parameters present in the water of the aquifer, through the application of laboratory tests and tests with jar test equipment, thus seeking to determine the optimal conditions of removal, as well as the optimal dose of coagulant, in order to generate an efficient, viable and safe alternative in the treatment of water. Groundwater, being in close contact with minerals of the earth's crust, solubilises elements, such as iron, so their respective treatment must be evaluated (Castañeda, 2015).

2. Materials and methods

The study was carried out through experimentation, the pre- and post-treatment values of the iron, turbidity and colour parameters present in aquifer waters were analysed and evaluated. The coagulation process was carried out with starchy maize starch at different coagulant concentrations, doses and conditions (mixing speed/time) using the jar test equipment.

2.1 Research design

Using the paired Student's t-test, with a significance level of 5%, it was determined whether or not there are significant differences between the pre-treatment and post-treatment values for each of the parameters studied. Analysis of variance (ANOVA) and Duncan's test with a significance level of 5% were used, based on the Completely randomized design (CRD), the blocks in each case being the experimental vessels of the jar test equipment. The treatment involves coagulation-flocculation-sedimentation, through the application of different doses of starchy maize, under mixing speed/time conditions; the removal values are sequential results of such a process for proper evaluation and determination of the most efficient treatment. Subsequently, the average percentage of removal was calculated for each parameter considered in the study, which allowed evaluating the efficiency of starchy maize starch.

2.2 Materials

The equipment and reagents used during the research are: Centrifuge, Cooker, jar test kit, colourimeter DR 900, turbidity meter, pH meter, sodium hydroxide (NaOH).

2.3 Procedure

Experimental obtaining of starchy maize starch: Collection of starchy maize grains (variety: white maize from Cusco), drying of the grains, obtaining flour by milling, sieving the flour to eliminate the pericarp, disinfection of the flour with 0.1% NaOH (sodium hydroxide) for 24 hours, centrifugation at 7000 rpm for 30 minutes, drying and storage (Grande and Orozco, 2013).

Water treatment. Coagulation, flocculation and sedimentation were carried out by applying different concentrations of the coagulant starchy maize starch (0.5%, 1% and 2%), at different agitation speeds (100, 150, 200, 250 and 300 rpm), with defined mixing times of 1.5 minutes for fast mixing, 15 minutes for slow mixing and 10 minutes for sedimentation. The organic coagulant was injected at different doses (1, 2, 3, 4, 5 and 6 mL), into each beaker of the jar test and the analyses were performed.

3. Results and discussion

Table 1 shows the average values of the initial concentrations of the study parameters, which show a poor quality of this water source, requiring a primary treatment of removal, so that its use is reliable without posing any risk to health. Bracho et al. (2013), evaluated how to reduce these same parameters present in iron-rich groundwater, which indicates that the presence of soluble iron in water raises the concentration of colour and turbidity. With this in mind, Castañeda (2015) states that groundwater with a high iron content can be treated with maize starch.

Table 1: Average of initial concentrations of the parameters evaluated in the confined aquifer

Parameter	Unit	average values
Iron	mg/L	2.75
Turbidity	NTU	44.22
Colour	Pt-Co	153.33

Table 2 shows the results of the values of the parameters evaluated with the coagulant, at 0.5% concentration, it can be seen that there is a significant removal of these parameters, with the lowest and most acceptable values being found at low doses and at high agitation speeds and mixing times; for iron, turbidity and colour, the best result was found in the second test with a dose of 1 mL. Moscozo (2015) in his research managed to remove a total of 58.56% turbidity using only cassava starch at low doses (as in this table). However, in the present investigation, using starchy maize starch, a value of 7.51 NTU was achieved as the best final concentration for turbidity, which means a removal of 83.02%; therefore, it represents a better alternative.

Table 2: Evaluation conditions and test results with starchy maize starch at 0.5% concentration

Test number	Agitation speed and mixing time	Parameter	Beakers					
			1 (1 mL)	2 (2 mL)	3 (3 mL)	4 (4 mL)	5 (5 mL)	6 (6 mL)
1	300 rpm (1,5'): Fast mixing	Iron (mg/L)	1,18	1,12	1,14	1,20	1,27	1,26
	75 rpm (15'): Slow mixing	Turbidity (NTU)	7,89	8,91	9,21	10,62	11,20	9,48
	10': Sedimentation	Colour (Pt-Co)	85	61	62	63	80	85
2	250 rpm (1,5'): Fast mixing	Iron (mg/L)	1,06	1,60	1,46	1,25	1,43	2,00
	63 rpm (15'): Slow mixing	Turbidity (NTU)	7,51	11,24	12,01	10,76	13,67	13,34
	10': Sedimentation	Colour (Pt-Co)	60	90	90	82	88	90
3	200 rpm (1,5'): Fast mixing	Iron (mg/L)	1,97	1,53	1,61	1,45	1,57	1,57
	50 rpm (1,5'): Slow mixing	Turbidity (NTU)	12,04	14,56	13,33	12,36	12,32	13,10
	10': Sedimentation	Colour (Pt-Co)	89	95	90	90	89	90
4	150 rpm (1,5'): Fast mixing	Iron (mg/L)	1,48	1,43	1,36	1,37	1,39	1,34
	38 rpm (15'): Slow mixing	Turbidity (NTU)	13,60	13,78	13,76	12,40	13,20	13,01
	10': Sedimentation	Colour (Pt-Co)	85	85	89	82	86	85
5	100 rpm (1,5'): Fast mixing	Iron (mg/L)	1,32	1,55	1,48	1,47	1,40	1,43
	25 rpm (15'): Slow mixing	Turbidity (NTU)	10,71	13,07	12,29	12,73	13,44	13,87
	10': Sedimentation	Colour (Pt-Co)	78	85	85	86	85	80

Table 3 shows the results of the values of the parameters studied, after treatment with the coagulant at 1% concentration. It is evident that the best results were obtained at this concentration; the lowest removal values were recorded when the coagulant was applied at a dose of 5 mL for the three study parameters at a moderately high agitation and mixing time (second test), registering percentages of removal of 80% in iron, 88.83% in turbidity and 67.39% in colour; these values allow us to confirm the efficiency of the coagulant. This can be contrasted with Vela (2016), who states that he obtained the highest efficiency, in turbidity removal at 300 rpm (2.0 min): fast mixing and 80 rpm (15 min): slow mixing, with 93.10% removal. Moreno (2016), for his part, reduced the turbidity of surface water using extracts of Opuntia ficus-indica, Aloe vera and Caesalpinia spinosa, achieving a removal of 61.09% of the turbidity.

Table 3: Conditions for evaluation and test results using starchy maize starch at 1,0% concentration

Test number	Agitation speed and mixing time	Parameter	Beakers					
			1 (1 mL)	2 (2 mL)	3 (3 mL)	4 (4 mL)	5 (5 mL)	6 (6 mL)
1	300 rpm (1,5'): Fast mixing	Iron (mg/L)	0,74	0,62	0,59	0,61	0,55	0,55
	75 rpm (15'): Slow mixing	Turbidity (NTU)	7,26	7,52	7,36	8,15	6,61	7,11
	10': Sedimentation	Colour (Pt-Co)	65	60	60	50	55	60
2	250 rpm (1,5'): Fast mixing	Iron (mg/L)	0,90	0,88	0,94	0,68	0,55	0,67
	63 rpm (15'): Slow mixing	Turbidity (NTU)	9,01	9,94	7,18	6,13	4,94	5,99
	10': Sedimentation	Colour (Pt-Co)	63	70	71	50	50	58
3	200 rpm (1,5'): Fast mixing	Iron (mg/L)	1,06	0,84	0,96	0,79	1,03	0,92
	50 rpm (1,5'): Slow mixing	Turbidity (NTU)	8,67	11,31	12,11	7,93	10,46	11,08
	10': Sedimentation	Colour (Pt-Co)	53	59	66	73	68	60
4	150 rpm (1,5'): Fast mixing	Iron (mg/L)	1,01	0,94	0,98	0,90	0,85	0,80
	38 rpm (15'): Slow mixing	Turbidity (NTU)	12,58	12,80	12,54	13,18	13,49	14,59
	10': Sedimentation	Colour (Pt-Co)	64	69	75	85	75	85

Table 3: Conditions for evaluation and test results using starchy maize starch at 1,0% concentration (Continued)

Test number	Agitation speed and mixing time	Parameter	Beakers					
			1 (1 mL)	2 (2 mL)	3 (3 mL)	4 (4 mL)	5 (5 mL)	6 (6 mL)
5	100 rpm (1,5'): Fast mixing	Iron (mg/L)	0,87	0,99	0,57	0,68	0,86	1,12
	25 rpm (15'): Slow mixing	Turbidity (NTU)	14,08	13,37	13,82	12,27	12,71	14,91
	10': Sedimentation	Colour (Pt-Co)	86	70	70	72	80	95

Table 4 shows the results of the values of the 3 parameters studied after treatment with the coagulant at 2% concentration, showing that there is a removal of these parameters, although to a lesser extent compared to previous treatments. The lowest and most acceptable values were obtained at the lowest dose (1 mL) and at the highest agitation speed and mixing time (first test, 300 rpm for fast mixing and 75 rpm for slow mixing); however, (Trujillo et al., 2014); obtained the best turbidity removal efficiency (using natural coagulant) with a fast mixing speed of 150 rpm and with a slow mixing speed of 20 rpm.

Table 4: Conditions for evaluation and test results using starchy maize starch at 2,0% concentration

Test number	Agitation speed and mixing time	Parameter	Beakers					
			1 (1 mL)	2 (2 mL)	3 (3 mL)	4 (4 mL)	5 (5 mL)	6 (6 mL)
1	300 rpm (1,5'): Fast mixing	Iron (mg/L)	0,96	0,81	0,95	0,87	0,82	1,09
	75 rpm (15'): Slow mixing	Turbidity (NTU)	7,87	6,81	7,36	7,31	7,92	9,22
	10': Sedimentation	Colour (Pt-Co)	65	50	50	50	55	68
2	250 rpm (1,5'): Fast mixing	Iron (mg/L)	1,27	1,35	1,34	1,69	1,43	1,40
	63 rpm (15'): Slow mixing	Turbidity (NTU)	9,49	11,41	11,75	13,25	12,72	12,70
	10': Sedimentation	Colour (Pt-Co)	67	70	70	90	76	72
3	200 rpm (1,5'): Fast mixing	Iron (mg/L)	1,99	1,47	1,31	1,66	1,49	1,36
	50 rpm (1,5'): Slow mixing	Turbidity (NTU)	12,43	13,38	13,07	13,59	13,16	12,91
	10': Sedimentation	Colour (Pt-Co)	95	90	90	85	90	82
4	150 rpm (1,5'): Fast mixing	Iron (mg/L)	0,99	1,02	1,02	0,83	0,98	1,10
	38 rpm (15'): Slow mixing	Turbidity (NTU)	13,59	12,77	12,46	13,57	12,87	12,98
	10': Sedimentation	Colour (Pt-Co)	66	70	65	66	65	70
5	100 rpm (1,5'): Fast mixing	Iron (mg/L)	1,46	1,36	1,21	1,05	1,02	1,48
	25 rpm (15'): Slow mixing	Turbidity (NTU)	13,05	13,42	13,28	14,08	15,95	16,01
	10': Sedimentation	Colour (Pt-Co)	80	79	83	80	80	85

Table 5 shows that the t-value (61.929) > tabulated t-value (1.699), therefore the proposed method is valid; there is statistical evidence to affirm that there are significant differences between the values of the concentrations recorded before treatment with the values obtained, it is confirmed that the coagulation process with 1% of starchy maize starch significantly removes iron concentrations.

Table 5: Paired t-test for initial iron - final iron with 1% of starchy maize starch

Paired samples test								
	Paired differences					T	Degrees of freedom	Significance (bilateral)
	average	Typical deviation	Average error deviation	95% confidence interval of the difference				
				Lower	Upper			
Par 1. Initial CT - Final CT	1.93500	0.17114	0.03125	1.87110	1.99890	61.929	29	0.000
Initial Media CT: 2.7500 / Final media CT: 0.8150							CV: 8.8444%	
N Initial CT: 30 / N final CT: 30								
T-value = 61.929 / tabulated T-value = 1.699 / P-value = 0.000								

CT: Average concentration, CV: Coefficient of Variation, N: Number of data entered

Table 6 shows that the t-value (61.589) > tabulated t-value (1.699), therefore, the proposed method is valid; there is statistical evidence to affirm that there are significant differences between the values of the concentrations recorded before treatment with the values obtained, the coagulation process with 1% of starchy maize starch significantly removes the turbidity concentrations.

Table 6: Paired t-test for Initial Turbidity - Final Turbidity with 1% of starchy maize starch.

Paired samples test								
	Paired differences					T	Degrees of freedom	Significance (bilateral)
	average	Typical deviation	Average error deviation	95% confidence interval of the difference				
				Lower	Upper			
Par 1. Initial CT - Final CT	33.91667	3.01628	0.55069	32.79037	35.04296	61.589	29	0.000
Initial Media CT: 44.2200 / Final media CT: 10.3033								CV: 8.8932%
N Initial CT: 30 / N final CT: 30								
T-value = 61.589 / tabulated T-value = 1.699 / P-value = 0.000								

CT: Average concentration
CV: Coefficient of Variation
N: Number of data entered

Table 7 shows that the t-value (41.330) > tabulated t-value (1.699), therefore, the proposed method is valid; there is statistical evidence to affirm that there are significant differences between the values of the concentrations recorded before treatment with the values obtained, confirming that the coagulation process with 1% starchy maize starch significantly removes the colour concentrations.

Table 7: Paired t-test for Initial colour - Final colour with 1% of starchy maize starch

Paired samples test								
	Paired differences					T	Degrees of freedom	Significance (bilateral)
	average	Typical deviation	Average error deviation	95% confidence interval of the difference				
				Lower	Upper			
Par 1. Initial CT - Final CT	86.09667	11.40987	2.08315	81.83615	90.35718	41.330	29	0.000
Initial Media CT: 153.3300 / Final media CT: 67.2333 CV: 13.2524%								
N Initial CT: 30 / N final CT: 30								
T-value = 41.330 / tabulated T-value = 1.699 / P-value = 0.000								

CT: Average concentration
CV: Coefficient of Variation
N: Number of data entered

4. Conclusions

Starchy maize starch as a coagulant is a viable and safe alternative in the primary treatment of water, the post-treatment values show the removal efficiency of turbidity, colour and iron.

The concentration of starchy maize starch, dosage, mixing speed and time conditions, influence the removal of water parameters, the results indicate that the optimum values were obtained at intermediate starch concentrations.

The optimum dose of starchy maize starch found in the various tests carried out on the jar test equipment was 50 mg/L (ratio: weight/volume) at a concentration of 1% solution. The optimal stirring speeds and mixing times found correspond to the second trial with starchy maize starch. These values are as follows: fast mixing or coagulation (250 rpm in 1.5 minutes), slow mixing or flocculation (63 rpm in 15 minutes) and sedimentation (10 minutes).

The values achieved with the application of starchy maize starch at optimum doses and conditions (post-treatment) were favourable, with an iron removal of 80% (0.55 mg/L), turbidity of 88.83% (4.94 NTU) and colour of 67.39% (50 Pt-Co), results that indicate the efficiency of this coagulant in the treatment of water from the confined aquifer.

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