

Optimization of the flocculating capacity of natural coagulants in water treatment

David Choque-Quispe ^a, Carlos A. Ligarda-Samanez ^a, Betsy S. Ramos-Pacheco ^a, Aydeé M. Solano-Reynoso ^b,
Yudith Choque-Quispe ^b, Diego E. Peralta-Guevara ^a & Yadyra Quispe-Quispe ^c

^a Departamento de Ingeniería y Tecnología Agroindustrial, Universidad Nacional José María Arguedas, Andahuaylas, Perú.
davidchoqueq@hotmail.com, carligarda@hotmail.com, bsramosp2@gmail.com, diepltagvra@gmail.com

^b Escuela Profesional de Ingeniería Ambiental, Universidad Tecnológica de los Andes, Perú. ayma_21@hotmail.com, yuditchoque@gmail.com

^c Escuela Profesional de Ingeniería Ambiental, Universidad Alas Peruanas, Cusco, Perú. yandhy95@gmail.com

Received: June 17th, 2019. Received in revised form: December 17th, 2019. Accepted: January 13th, 2020.

Abstract

The objective was optimize the flocculating capacity of three varieties of cacti *Echinopsis pachanoi* (San Pedro), *Neoraimondia arequipenses* (Ulluquite) and *Opuntia ficus* (Tuna) in the artificial wastewater treatment. They were applied 1%, 2% and 3% coagulant doses of the three varieties of cactaceae extracted with 96% ethanol. It was evaluated the flocculating activity (FA) and removal percentage (%R); a significant increase was observed (p -value < 0.05) with the increase in the coagulant dose. The optimization was carried out considering as objective function the %R which were subjected to FA, pH, hardness, alkalinity and BOD₅ of water treatment. Which were reported values of 99.09 %R for San Pedro variety, 92.42 %R for Ulluquite variety and 98.98 %R for tuna variety, for doses of 0.207%, 0.246% and 0.754% of coagulant respectively.

Keywords: artificial wastewater; flocculating activity; removal percentage.

Optimización de la capacidad floculante de coagulantes naturales en el tratamiento de aguas

Resumen

El objetivo del trabajo fue optimizar la capacidad floculante de tres variedades de Cactáceas *Echinopsis pachanoi* (San Pedro), *Neoraimondia arequipensis* (Ulluquite) y *Opuntia ficus* (Tuna) en el tratamiento de agua residual artificial. Se aplicaron dosis al 1%, 2% y 3% de coagulante de las tres variedades de cactáceas extraídas con etanol al 96%, se evaluó la actividad floculante (AF) y el porcentaje de remoción (%R), observándose incremento significativo (p -value < 0.05) con el aumento de dosis de los coagulantes. La optimización se realizó considerando como función objetivo el %R sujetas a las restricciones para AF, pH, Dureza, Alcalinidad y DBO₅ del agua tratada, reportándose valores de 99.09 %R para la variedad San Pedro, 92.42 %R para la variedad Ulluquite y 98.98 %R para la variedad Tuna, para dosis de 0.207%, 0.246% y 0.754% de coagulante respectivamente.

Palabras clave: agua residual artificial; actividad floculante; porcentaje de remoción.


1. Introduction

Cacti are one of the most abundant botanical families in Peru, being found in all altitudinal floors, in a large number of varieties. Thus, since ancient times cacti have been important and linked to a large number of Latin American cultures and peoples in many parts of the world. Cacti are

used in very different ways and applications such as water clarification or as a natural polymer.

These polymers are complex in their chemical composition and are constituted mainly by several types of polysaccharides and proteins. Some of them have coagulant or flocculating properties and in many places, they are used

How to cite: Choque-Quispe, D. Ligarda-Samanez, C.A. Ramos-Pacheco, B.S. Solano-Reynoso, A.M. Choque-Quispe, Y. Peralta-Guevara, D.E. and Quispe-Quispe, Y. Optimization of the flocculating capacity of natural coagulants in water treatment. DYNA, 87(212), pp. 90-95, January - March, 2020.

© The author; licensee Universidad Nacional de Colombia. 
DYNA, 87(212), pp. 90-95, January - March, 2020, ISSN 0012-7353
DOI: <http://doi.org/10.15446/dyna.v87n212.80467>

empirically to clarify turbid water with satisfactory results [20].

One of the cactaceae that has been widely used in coagulation is the genus *Opuntia* (family of cactaceae) which was characterized by the hydrocolloid production. It is known as mucilage, it forms molecular networks that retain large amounts of water [1]. Besides, it is a complex polymeric compound of glucidic nature with a highly branched structure [2]. Mucilage contains variable proportions of L-arabinose, D-galactose, L-rhamnose and D-xylose, as well as galacturonic acid in different proportions [3].

Another cactus that has coagulant properties is the *Echinopsis pachanoi*, which calls "San Pedro" as a common name in some areas of Peru. As well as the *Neoraimondia arequipensis* which receives the common name of Ulluquite. It is not really known whether it is related to the well-known Puyas de Raimondi, which grow in different parts of Peru including the Peruvian-Bolivian highlands.

Drinking water for human consumption must have quality characteristics such as free of turbidity, color and perceptible taste and other parameters regulated according to the regulations of the countries. Usually natural waters do not have satisfactory quality for human consumption or industrial use and generally should be treated [4], as well as wastewater according to their use.

Coagulation consists in the addition of chemical substances in order to mix the particles and some dissolved pollutants that can be agglutinated in larger particles and then being removed through solids removal processes or by sedimentation [5]. Coagulation as a physicochemical process destabilizes colloidal particles, precipitating and grouping suspended solids. This supplies their extraction by means of the flocs formation in water [6], reducing turbidity, color and to a lesser extent bacteria [7].

For coagulation, conventional chemical substances are used. However, there are disadvantages associated with the use of these coagulants such as high acquisition costs, large production volumes of sludge and the fact that they significantly affect the pH of the treated water [8,9]. Also, in some cases adverse neurological effects, such as the manifestation of Alzheimer's disease [10,11]. Therefore, it is necessary to carry out optimization processes to minimize the use of additives and chemical substances, and to maximize the parameters of water quality.

2. Materials and methods

2.1. Raw material

The *Echinopsis pachanoi* (San Pedro), *Neoraimondia arequipensis* (Ulluquite) and *Opuntia ficus* (Tuna) cacti varieties were obtained from wild crops located in Santa Rosa area from Talavera district at 3000 meters above sea level. At latitude 13° 36'07.89"S, length 73° 16'33.13"W. Andahuaylas province, Peru has an average temperature of 13 °C and an average annual rainfall of 930 mm.

The cactaceae collection criteria were physiological

maturity, morphology (external appearance and apparent color), size (length and width or diameter) and weight.

2.2. Preparation of artificial water

In order to simulate suspended particles in the artificial wastewater for its subsequent flocculation and coagulation. A stock solution was prepared by dissolving 25 g of kaolin ($2\text{SiO}_2 \cdot \text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$) in 500 ml of distilled water that was homogenized for 30 minutes manually. The solution was allowed to stand for 24 hours. Finally, 6 liters of drinking water was taken and 30 ml of kaolin stock solution was added to the solution.

2.3. Extraction of natural coagulant

The method proposed by Dujardin *et al.* [12] was modified. The thorns were completely eliminated from the cacti samples, then they were cut into small pieces and liquefied at high speed with distilled water in a 1:1 ratio. Afterward, the fine grinding was sifted in a 1000 micron mesh in order to eliminate the fiber and obtain only the mucilage (filtered juice). After that, a liquid - liquid extraction from the filtered juice was carried out by means of a solvent (96% Ethanol) in relation to 1 of juice:2 of solvent. Subsequently, as many changes of solvent as necessary were made until the color was eliminated and later the precipitate was dried at room temperature. After drying, the sample was finely ground and then sieved in a 300 micron mesh. A fine and crystallized coagulant powder was obtained.

2.4. Flocculant activity - FA

The methodology by Sánchez and Untiveros [13] was adapted. 0.25 ml at 1% natural coagulant solution, 4.50 ml of kaolin suspension and 0.25 ml at 1% iron (III) solution were poured into a test tube. Which was homogenized for 15 seconds with a Vortex and then left for 5 min. 2.5 ml of the supernatant was carefully removed from the top of the test tube with a pipette and the absorbance was measured at 550 nm (A) and a control (B). The flocculant activity was calculated using eq. (1). The test was repeated with 2% and 3% of natural coagulant.

$$FA = \frac{1}{A} + \frac{1}{B} \quad (1)$$

2.5. Evaluation of the removal percentage

The process efficiency was determined by the percentage of turbidity removal (% R), according to eq. (2) [14]. For which the initial turbidity (T_0) and final turbidity (T_f) were determined with an Orbeco turbidimeter model TB300-IR from 0.01 to 1100 NTU range.

$$\%R = \frac{T_0 - T_f}{T_0} * 100 \quad (2)$$

2.6. Evaluation of physicochemical characteristics

The characterization of the treated water quality parameters was carried out, such as pH, total alkalinity, total hardness and BOD [15].

2.7. Optimization of flocculant capacity

The objective function for the optimization was the removal percentage of turbidity for each treatment. Which was evaluated through linear regression and nonlinear regression and taking as a convergence criterion the correlation coefficient R^2 . It was considered restrictions to the limits established by the Peruvian technical standards and WHO for the parameters evaluated in the treated water. For the optimization, the Excel Solver utility was used.

2.8. Statistical analysis

Analysis of variance and Tukey's multiple comparison means test were performed at a significance level of 5%. The data were processed with the statistical package Statgraphics Centurion XV.

3. Results and discussion

In Table 1, it can see that the AF is in the range from 28 to 48; Ferreira *et al.* [23] reported similar results. It is also observed that the removal percentages are greater than 92%; similar results showed Jiménez *et al.* [22] when treating artificial wastewater with a mixture of coagulants based on *Opuntia cochenillifera* although with doses of the order of 20 ppm likewise Arismendi [21] using modified tannins. Sánchez and Untiveros [13] used pectin with concentration

Table 1. Parameters of water treated with natural coagulants.

Variety	Coagulant solution (%)	Flocculant activity			Removal percentage			pH			Hardness (ppm CaCO ₃)			BOD (mg O ₂ /L)		
		\bar{x}	\pm	s	\bar{x}	\pm	s	\bar{x}	\pm	s	\bar{x}	\pm	s	\bar{x}	\pm	s
E.P.	1	47.39 ^a	\pm	0.46	99.21 ^a	\pm	0.06	6.98	\pm	0.04	266.3	\pm	1.5	2.41	\pm	0.1
	2	48.39 ^b	\pm	0.19	99.31 ^a	\pm	0.06	7.25	\pm	0.02	268	\pm	1.0	2.65	\pm	0.04
	3	48.58 ^b	\pm	0.06	99.44 ^b	\pm	0.06	7.28	\pm	0.01	269	\pm	1.0	2.72	\pm	0.04
N. A.	1	28.41 ^a	\pm	0.94	92.64 ^a	\pm	0.33	6.75	\pm	0.03	262	\pm	1.0	3.08	\pm	0.02
	2	30.36 ^b	\pm	0.11	92.79 ^a	\pm	0.18	6.93	\pm	0.04	263.7	\pm	0.6	3.32	\pm	0.02
	3	30.38 ^b	\pm	0.11	92.78 ^a	\pm	0.09	7.02	\pm	0.01	263.7	\pm	1.5	3.34	\pm	0.03
O. F.	1	46.13 ^a	\pm	0.39	99.02 ^a	\pm	0.15	6.68	\pm	0.03	269.3	\pm	1.2	3.35	\pm	0.11
	2	46.41 ^a	\pm	0.11	99.11 ^a	\pm	0.18	6.9	\pm	0.02	270.7	\pm	0.6	3.64	\pm	0.11
	3	46.48 ^a	\pm	0.22	99.15 ^a	\pm	0.06	6.96	\pm	0.02	271	\pm	1.0	3.66	\pm	0.05
Initial value		---			---			6.61			260			0.57		

Where: E.P. is *Echinopsis pachanoi*; N.A. is *Neoraimondia arequipensis*; O.F. is *Opuntia ficus*; \bar{x} is the average; s is the standard deviation.

* Equal letters mean that there is no significant difference evaluated through the Tukey test, with $\alpha = 5\%$.

Source: The Authors.

Table 2. Models for parameters in treated water.

	Model	R ²
<i>Echinopsis pachanoi</i> (San Pedro) variety		
%R	$\%R = 0.108 * LnC + 99.218$	0.97
AF	$\%FA = 1.119 * LnC + 47.456$	0.95
pH	$pH = 0.282 * LnC + 6.999$	0.92
D	$D = 2.425 * LnC + 266.33$	1.00
A	$A = 30.113 * exp(0.0055 * C)$	0.80
BOD	$BOD = 0.293 * LnC + 6.415$	0.98
<i>Neoraimondia arequipensis</i> (Ulluquiute) variety		
%R	$\%R = 0.138 * LnC + 92.65$	0.83
AF	$\%FA = 1.907 * LnC + 28.576$	0.87
pH	$pH = 0.247 * LnC + 6.756$	0.99
D	$D = 1.613 * LnC + 262.15$	0.87
A	$A = 1.561 * LnC + 31.734$	0.97
BOD	$BOD = 0.249 * LnC + 3.098$	0.91
<i>Opuntia ficus</i> (Tuna) variety		
%R	$\%R = 0.117 * LnC + 99.024$	0.98
AF	$\%FA = 0.324 * LnC + 46.143$	0.96
pH	$pH = 0.265 * LnC + 6.691$	0.97
D	$D = 1.561 * LnC + 269.40$	0.97
A	$A = 2.206 * LnC + 36.46$	0.94
BOD	$BOD = 0.302 * LnC + 3.368$	0.90

Where: %R, Removal percentage; AF, flocculant activity; D, Hardness; A, Alkalinity, BOD, Biochemical Oxygen Demand; C is the percentage of coagulant application; R^2 is correlation coefficient.

Source: The Authors.

Table 3.
Optimum values and their restrictions for the coagulant behavior

Properties		Minimum	Maximum	Optimum
<i>Echinopsis pachanoi</i> (San Pedro) variety				
Objective function	Removal percentage	---	100	99.092
Restrictions	Flocculant activity (%)	---	50	46.011
	pH	6.6	7.2	6.600
	Hardness (ppm CaCO ₃)	200	300	264.536
	Alkalinity (ppm CaCO ₃)	20	30	30.00
	BOD (mg O ₂ /L)	---	15	2.097
	Coagulant dose percentage (1% in sol)	0.1	3.0	0.207
	<i>Neoraimondia arequipensis</i> (Ullquite) variety			
Objective function	Removal percentage	---	100	92.419
Restrictions	Flocculant activity (%)	---	50	25.667
	pH	6.6	7.2	6.558
	Hardness (ppm CaCO ₃)	200	300	259.641
	Alkalinity (ppm CaCO ₃)	20	30	30.000
	BOD (mg O ₂ /L)	---	15	2.754
	Coagulant dose percentage (1% in sol)	0.1	3.0	0.246
	<i>Opuntia ficus</i> (Tuna) variety			
Objective function	Removal percentage	---	100	98.988
Restrictions	Flocculant activity (%)	---	50	46.026
	pH	6.6	7.2	6.600
	Hardness (ppm CaCO ₃)	200	300	268.852
	Alkalinity (ppm CaCO ₃)	20	30	25.586
	BOD (mg O ₂ /L)	---	15	3.230
	Coagulant dose percentage (1% in sol)	0.1	3.0	0.754

Source: The Authors.

of 30 ppm (0.003%) in artificial wastewater formulated with kaolin and iron (III). Yagual and Torres [14] found removal percentages between 95% to 99.6% for river water samples when using coagulants such as aluminum sulphate, floater praestol 650 TR and artisanal chemical flocculant. Quirós *et al.* [16] found a solids removal of 83% with coagulant extracted from Moringa at 400 ppm.

On the other hand, slight variation of the pH in the treated water is observed for all the cases with basic tendencies. Solís *et al.* [18] showed that the pH of the water treated with mixtures of cassava starch coagulants and aluminum sulfate did not vary significantly presenting less acidic tendencies up to 6.7 from an initial value of untreated water of 6.9. In addition, the hardness shows a slight increase compared to its initial value of untreated water a similar behavior was reported by Mgombezi *et al.* [17]. However, Miranda *et al.* [19] showed a slight increase when adding cal and kollpa coagulants (Alum from Altiplano).

The coagulant addition increases significantly the BOD₅ of the artificial water due to the tests were realized in solution with the coagulant, which showed that its composition is made up by proteins and carbohydrates.

The objective function to optimize the flocculant capacity was the removal percentage of solids in artificial treated water for three coagulant varieties of cacti, thus, mathematical models or equations were determined, which are shown in Table 2, which show $R^2 > 0.9$.

Table 3 shows the results for coagulant *Echinopsis pachanoi* (San Pedro) variety with its respective restrictions. It is observed that optimum removal percentage is 99.092%

for an application percentage of 0.27% coagulant at 1% in the solution. Thus, achieving values of the flocculant activity of 46.01%, pH of 6.6, Hardness of 264.536 ppm of CaCO₃, Alkalinity 30.00 ppm of CaCO₃ and BOD of 2.097 mg O₂/L.

On the other hand, the coagulant from *Neoraimondia arequipensis* variety shows a 92.42% of removal percentage, it must be applied 0.246% of coagulant at 1% in solution. Being that, under this condition the flocculant activity will be 25.667%, pH of 6.558, hardness of 259.641 ppm of CaCO₃, alkalinity 30.0 ppm of CaCO₃ and BOD of 2.754 mg of O₂/L. While the optimum removal percentage was 98.988%, for an application of 0.754% coagulant of the *Opuntia ficus* variety (1%) in solution. The pH was 7.2, hardness of 268.852 ppm of CaCO₃, alkalinity of 25.586 25.586 ppm of CaCO₃ and BOD of 3.230 mg O₂/L.

4. Conclusions

The optimization of the flocculant capacity of three natural coagulants in the artificial treated water evaluated through the removal percentage shows values of 99.09% for *Echinopsis pachanoi* (San pedro) variety, 92.419% for *Neoraimondia arequipensis* (Ullquite) variety and 98.98% for *Opuntia ficus* (Tuna) variety. For dosages of 0.207%, 0.246% and 0.754% respectively in coagulant solution at 1%.

References

- [1] Deshmukh, S. and Hedaoo, M.N., Wastewater Treatment using bio-coagulant as cactus opuntia ficus indica - A review. IJSRD, 6(10), pp.

- 711-717, 2018. DOI: 10.13140/RG.2.2.28932.99202
- [2] Matsuhira, B., Lillo, L., Sáenz, C., Urzúa, C. and Zárate O., Chemical characterization of the mucilage from fruits of *Opuntia ficus indica*. *Carbohydrate Polymer*, 63(2), pp. 263-267, 2006. DOI: 10.1016/j.carbpol.2005.08.062
- [3] Villabona, Á., Paz, I.C. y Martínez, J., Caracterización de la *Opuntia ficus-indica* para su uso como coagulante natural. *Revista Colombiana de Biotecnología*, 15(1), pp. 137-144, 2013.
- [4] Mumbi, W., Fengting, L. and Karanja, A., Sustainable treatment of drinking water using natural coagulants in developing countries: a case of informal settlements in Kenya. *Water Utility Journal*, 18, pp. 1-11, 2018. DOI: 10.13140/RG.2.2.21105.94563
- [5] Abidin, Z.Z., Shamsudin, N.S.M., Madehi, N. and Sobri, S., Optimization of a method to extract the active coagulant agent from *Jatropha curcas* seeds for use in turbidity removal. *Industrial Crops and Products*, 41, pp. 319-323, 2013. DOI: 10.1016/j.indcrop.2012.05.003
- [6] Ramírez, H. y Jaramillo, J., Agentes naturales como alternativa para el tratamiento del agua. *Revista Facultad de Ciencias Básicas*. 11(2), pp. 136-153, 2015. DOI: 10.18359/rfcb.1303
- [7] García, S.A., Estudio de la eficiencia de eliminación de radionúclidos naturales en procesos compatibles con el de potabilización de aguas, Tesis Dr, en Ciencias Físicas, Universidad de Extremadura, Badajoz, España, 2005, 246 P.
- [8] Yin C.Y., Emerging usage of plant-based coagulants for water and wastewater treatment. *Process Biochem.*, 45(9), pp. 1437-1444, 2010. DOI: 10.1016/j.procbio.2010.05.030
- [9] Haaroff, J. and Cleasby, J., Comparing aluminum and iron coagulants for in line filtration of cold waters. *J. Am. Water Works Assoc.*, 80(4), pp. 168-175, 1988. DOI: 10.1002/j.1551-8833.1988.tb03022.x
- [10] Matilainen, A., Vepsäläinen, M. and Sillanpää, M., Natural Organic matter removal by coagulation during drinking water treatment: a Review. *Adv. Colloid Interface Sci.*, 159(2), pp. 189-197, 2010. DOI: 10.1016/j.cis.2010.06.007
- [11] Vara, S., Screening and evaluation of innate coagulants for water treatment: a sustainable approach. *International Journal of Energy and Environmental Engineering*, 3(1), pp. 2-11, 2012. DOI: 10.1186/2251-6832-3-29
- [12] Dujardin, E., Laszlo, P. and Sacks, D., The chlorophylls. An experiment in bio-inorganic chemistry. *Journal of Chemical Education*, 52(11), pp. 742-748, 1975. DOI: 10.1021/ed052p742
- [13] Sánchez, S. y Untiveros, G., Determinación de la actividad floculante de la pectina en soluciones de hierro (III) y cromo (III). *Rev. Soc. Quím. Perú*, 70(4), pp. 201-208, 2004.
- [14] Yagual, M.G., Análisis comparativo del proceso de floculación-coagulación en la potabilización de agua de río, usando como fuente de captación el Río Daule y el Río Babahoyo en la Provincia del Guayas, Tesis Licenciatura en Ingeniería Química, Instituto de Ciencias Químicas y Ambientales, Escuela Superior Politécnica del Litoral (ESPOL), Guayaquil, Ecuador, 2012, 159 P.
- [15] APHA, Standard methods for the examination of water and wastewater, 22nd Ed., American Public Health Association (APHA), American Water Works Association (AWWA) and Water Environment Federation (WEF), Washington, DC, USA, 2012.
- [16] Quirós, N., Vargas, M., y Jiménez J., Desarrollo de coagulantes y floculantes para la remoción del color en aguas de consumo humano, el río Humo, reserva forestal río Macho, Costa Rica. Centro de Investigación en protección ambiental, Instituto Tecnológico de Costa Rica, [en línea]. 2010 [Consulta 22 diciembre de 2018]. Available at: <https://repositoriotec.tec.ac.cr/handle/2238/2930>
- [17] Mgombezi, D., Maheswara, V., Hamad, S. and Singh, S., An investigation on effectiveness of cactus materials (*Opuntia* Spp.) As adsorbents for hard water treatment. *International Journal of Scientific & Technology Research*, 6(10), pp. 239-244, 2017.
- [18] Solís, R., Laines, J. y Hernández J.R., Mezclas con potencial coagulante para clarificar aguas superficiales. *Revista internacional de contaminación ambiental*, 28(3), pp. 229-236, 2012.
- [19] Miranda, R., Tито, S., Palacios, R., y Alvarez, A., Tratamiento de aguas residuales minero metalúrgico por floculación y sedimentación con uso de floculantes naturales mejorados, Tesis Licenciatura en Ingeniería Química, Universidad Nacional del Altiplano, Puno, Perú, 2012, 160 P.
- [20] Choque-Quispe, D., Choque-Quispe, Y., Solano-Reynoso, A.M. y Ramos-Pacheco, B.S., Capacidad floculante de coagulantes naturales en el tratamiento de agua. *Tecnología Química*, 38(2), pp. 298-309, 2018.
- [21] Arismendi, W.A., Evaluación y comparación de la capacidad floculante de taninos modificados (quebracho, acacia, castaño) y su aplicación en el tratamiento de aguas residuales, Tesis MSc en Ciencias Biológicas, Pontificia Universidad Javeriana, Bogotá, Colombia, 2016, 110 P.
- [22] Jiménez, J., Vargas, M. y Quirós, N., Evaluación de la tuna (*Opuntia cochenillifera*) para la remoción del color en agua potable. *Tecnología en Marcha*, 25(4), pp. 55-62, 2012. DOI: 10.18845/tm.v25i4.619
- [23] Ferreira, M.T., Ambrosio, E., Andrade, C., Formicoli, T.K., Briola, L., Cinque, V. and Garcia, J.C., The use of a natural coagulant (*Opuntia ficus-indica*) in the removal for organic materials of textile effluents. *Environ Monit Assess.*, 186(8), pp. 5261-5271, 2014. DOI: 10.1007/s10661-014-3775-9

D. Choque-Quispe, received a Dr. in Environment and Sustainable Development at the Universidad Andina del Cusco, Peru, and he is an Eng Dr. candidate in Water Resources and Environmental at the Universidad Federal de Paraná, Brazil. Therefore, is a MSc. in Food Science and Technology at the Universidad Nacional de San Antonio Abad del Cusco, Peru. He is a full-time professor and researcher in bioactive compounds and water treatment with biopolymers in the Department of Agroindustrial Engineering and Technology at the Universidad Nacional José María Arguedas, Andahuaylas, Peru.
ORCID: 0003-4002-7526

C.A Ligarda-Samanez, is a Dr. candidate in Environment and Sustainable Development at the Universidad Andina del Cusco, Peru. Received a MSc. in Food Technology at the Universidad Nacional Agraria La Molina Lima, Perú. Received a BSc. Eng. in Civil Engineering. He is a full-time professor and researcher in bioactive compounds, emerging compounds and water treatment with biopolymers at department of agroindustrial engineering and technology at the Universidad Nacional José María Arguedas, Andahuaylas, Peru.
ORCID: 0000-0001-7519-8355

B.S. Ramos-Pacheco, is a Dr. candidate in Environment and Sustainable Development at the Universidad Andina del Cusco, Peru. Received a MSc. in Environmental Engineering at the Universidad Nacional de San Cristóbal de Huamanga, Ayacucho, Perú. She is a fulltime professor at the school of agroindustrial engineering at the Universidad Nacional José María Arguedas, Andahuaylas, Peru. Has interest in researches that including quality and pollution of water resources, bioactive compounds and natural polymers.
ORCID: 0000-0002-0286-0632

A.M. Solano-Reynoso, received a Dr. in Environment and Sustainable Development at the Universidad Andina del Cusco, Peru. She is a full-time professor at the school of environmental engineering at the Universidad Tecnológica de los Andes. She participates in researches related to water treatment with biopolymers and water quality in lakes.
ORCID: 0000-0002-1835-2210

Y. Choque-Quispe, received a MSc. in Civil Engineering - Water Resources at the Universidad Nacional de San Antonio Abad del Cusco, Peru. She is a professor at the school of environmental engineering at the Universidad Tecnológica de los Andes. She participates in researches related to water treatment with biopolymers and quality waters.
ORCID: 0000-0002-3690-7267

D.E. Peralta-Guevara, received a BSc. Eng. in Agroindustrial Engineering and is a MSc. candidate in Food Science and Technology at the Universidad Nacional de San Antonio Abad del Cusco, Peru. He is a specialist in the analysis and control of water resources and the operation of high-sensitivity equipment (Inductively Coupled Plasma Emission Spectroscopy ICPE-OES and Total Organic Carbon Analysis, TOC-L). His research interests include edible biopolymers, storage conditions and water treatment.
ORCID: 0000-0003-2988-0809

Y. Quispe-Quispe, is a MSc. candidate in Water Resources at the Universidad Andina del Cusco, Peru. She is part of the research team in water treatment with biopolymers and water quality.
ORCID: 0000-0002-5232-693X



UNIVERSIDAD NACIONAL DE COLOMBIA

SEDE MEDELLÍN
FACULTAD DE MINAS

Área Curricular de Ingeniería Mecánica

Oferta de Posgrados

Doctorado en Ingeniería - Mecánica y
Mecatrónica

Maestría en Ingeniería - Ingeniería
Mecánica

Especialización en Mantenimiento

Mayor información:

E-mail: acmecanica_med@unal.edu.co
Teléfono: (57-4) 4259262