

# Effective treatment of fishery effluents using locally recovered chitosan: A case study with effluents from El Centenario Beach, Callao

Galindo Herreras, Odaliz Kiyoshi <sup>1</sup>; Achata Böttger, Jorge <sup>1</sup>

<sup>1</sup>Universidad Peruana de ciencias Aplicadas, Peru, [U201817469@upc.edu.pe](mailto:U201817469@upc.edu.pe), [pcigjach@upc.edu.pe](mailto:pcigjach@upc.edu.pe)

**Abstract**– *Insufficiently treated fish processing effluents contain high concentrations of organic matter and suspended solids, posing a risk to coastal ecosystems. In this study, we extracted chitosan from *Litopenaeus vannamei* using fertilizer grade phosphoric acid for demineralization to avoid using mineral acids difficult to obtain in Peru. We evaluated the extracted chitosan as a coagulant for the primary treatment of effluents discharged at the Callao Bay. Increasing doses of chitosan were applied to an effluent sample and the water quality variables that must be met to comply with local discharge regulations were evaluated. After this primary treatment, the water met almost all the necessary standards to be discharged, opening the discussion on the potential contribution of chitosan treatment as an agent capable of delivering performance beyond what is expected of primary treatment. The potential role of chitosan for water treatment in Peru and the enabling factors to develop its production are discussed in the context of building circularity in the fishery business.*

**Keywords**– *fishery effluent, coagulation, chitosan, waste valorization.*

## I. INTRODUCTION

Industrial fishery effluents constitute a relevant organic pollution source in marine coastal zones, however, scientific reports on the dimension of the problem and its impacts are particularly scarce in Peru, even for high industrial intensity zones like Callao [1]. Scientific and regulatory attention has been drawn mostly to the heavy metals [2], [3], microplastics [4] and organic contaminants they contain [5]. When said effluents are not sufficiently treated, they can exceed the maximum permissible pollutant limits for discharge [6] by one to even two orders of magnitude, thus generating conditions of reduced dissolved oxygen and increased organic matter in the sediments that can cause imbalances in receiving water bodies, especially in coastal areas with intensive fishery and urban activities [7], [8]. These processes lead to chronic degradation of coastal marine ecosystems, with direct implications for the sustainability of small-scale artisanal fisheries, coastal water quality, and compliance with environmental regulations [9]. In Callao, monitoring reports from El Centenario Beach associated with industrial fish-processing discharges have documented BODs concentrations exceeding 4,000 mg O<sub>2</sub> L<sup>-1</sup> and total suspended solids approaching 1,000 mg L<sup>-1</sup>, substantially above applicable discharge standards [6]. Three fish

processing plants and one wastewater plant discharge effluents at El Centenario, thus developing effective primary treatment technologies that can be locally implemented is a sensitive way to improve the environmental management in the Peruvian fisheries.

Shrimp farms have become a major business in Peru, where the northernmost tropical region of Tumbes is the country leader in shrimp production. In 2025, Peru exported approximately 8,800 tons of shrimp and prawn products, a 12% growth compared to 2024. Between exports and domestic consumption, this is a growing industrial activity that generates 60% of biomass waste relative to the net animal weight produced, thus representing a significant source of high potential biomass waste for valorization endeavors [10]. Solid waste derived from white shrimp production is composed mostly of exoskeletons, which are disposed in landfills, coastal dumping areas, or directly into water bodies due to limited valorization pathways, generating environmental burdens associated with organic decomposition, gas emissions, and leachate formation. They are seldom used in other industrial processes and that constitutes an environmental challenge due to their final disposal. Shrimp processing residues are frequently disposed of in sanitary landfills [11], however, these residues are rich in chitin, a biopolymeric compound that can be transformed through physicochemical treatments into high-value chitosan [12]. Chitosan presents a polymeric structure with protonated amino groups that confer it a high electrostatic affinity for negatively charged colloidal particles, facilitating coagulation and flocculation processes in wastewater, linked particularly to its degree of deacetylation [13], [14], [15]. Although these biochemical characteristics would make it an industrially desirable supply, the industry favors commodity chemicals for water treatment applications.

Chitosan has been extensively studied and is already commercially available as a natural coagulant–flocculant for wastewater treatment due to its cationic nature, biodegradability, and high affinity for colloidal particles and dissolved organic matter [16]. Large-scale industrial chitosan production is led by Asia-Pacific countries, using shrimp waste as a major feedstock [17] and it is supported by well-established proprietary and patented technologies

for extraction and processing [18], [19], [20], [21]. While chitosan performance to decontaminate water is well established, its widespread application in developing and middle-income countries is often constrained by cost, dependence on imports, and limited integration between upcycling industries and national waste streams [22].

The challenge for chitosan application is no longer the demonstration of its technical effectiveness, but rather the adaptation of its production and use to local regulatory, economic, and operational conditions. In Peru, the recovery of chitosan from crustacean waste faces practical constraints, since the extraction with hydrochloric and sulfuric acid requires permits [23] that are not readily accessible for small-scale or decentralized operations. We applied a modified extraction method using fertilizer-grade phosphoric acid that does not require the abovementioned permits as an alternative demineralization agent, enabling the recovery of chitosan from *L. vannamei* exoskeleton waste in compliance with national regulations. While modest in scope, this process-level adaptation represents a meaningful step toward the localized valorization of fishery by-products and the practical deployment of chitosan-based treatment systems in Peru. The study therefore evaluates not only the performance of the recovered chitosan in treating real fishery effluents but also presents its potential role as a tool for improved effluent management at fish meal and canning factories in Peru.

## II. METHODS

### A. Effluent characterization

Wastewater samples were collected from the final discharge line of a fish processing facility at El Centenario Beach (11.998234° S 77.137575° W). Sampling was conducted at 18:00 through five consecutive days to reduce the influence of daily variability. 3300 ml samples were collected in polyethylene containers, previously rinsed with the effluent. Samples were stored at 4°C and analyzed within 24 h of collection.

Out of each sample, 300 ml were used to measure pH and turbidity with a handheld pH meter and a nephelometer. 1000 ml were used to measure biochemical oxygen demand during five days (BOD<sub>5</sub>), chemical oxygen demand (COD), total suspended solids (TSS) each. Oil and grease was measured according to the procedure in the 5520 standardized method for wastewater [24].

### B. Chitosan extraction

Chitosan was recovered from white shrimp exoskeleton waste (*Litopenaeus vannamei*) obtained from a commercial seafood supplier. A 3 kg exoskeleton sample, including heads, shells, and tails, was collected. Subsequently, heads and non-usable fractions were removed, yielding approximately 1.35 kg of biomass suitable for extraction. Biomass was washed,

chopped, and oven-dried at 60 °C until constant weight, resulting in 400 gr of dry material, which was mechanically ground and sieved, producing 320 gr of fine powder suitable for chemical processing. Chitosan was extracted from a 50 gr fine powder sample by deproteinization in 4% NaOH stirring for 2 hours, followed by 24-hour incubation at room temperature without agitation. The supernatant was discarded and the solids were demineralized with an 8.5% H<sub>3</sub>PO<sub>4</sub> solution. The supernatant was discarded again, and the remaining solids were deacetylated in 50% NaOH stirring for 2 hours, followed by 24-hour incubation at room temperature without agitation. After the extraction steps, 20 gr chitosan was recovered and thoroughly washed with deionized water, dried, and stored in sealed containers.

### C. Effluent treatment assays

The flocculation-precipitation performance of the recovered chitosan was evaluated using a jar test protocol. Chitosan doses of 0, 100, 200, 300, 400, and 500 mg L<sup>-1</sup> were tested on 500 mL effluent samples, with six independent replicates per treatment as defined through a statistical power analysis using Minitab. Due to laboratory capacity constraints, the experiments were conducted using four beakers operating simultaneously, and the remaining replicates were subsequently completed until the six repetitions per treatment were achieved. Tests were carried out under controlled laboratory conditions and consisted of a rapid mixing step at 100 rpm for 1–3 minutes to ensure coagulant dispersion, followed by a slow mixing step at 40 rpm for 15–30 minutes to promote floc formation, and a final sedimentation period of 60 min without agitation to allow solid–liquid separation. After sedimentation, the supernatant was recovered and analyzed for BOD<sub>5</sub>, COD, TSS, turbidity, pH, and oils and greases.

### D. Statistical analysis

The goodness of fit to normal distribution and homogeneity of variances were evaluated using the Shapiro–Wilk and Levene’s tests, respectively. Statistical differences among chitosan doses were evaluated using one-way analysis of variance (ANOVA), followed by Tukey’s Honestly Significant Difference *post hoc* test. Comparisons with maximum permissible limits were performed using a one-sample Student’s t-test. Data processing and statistical analyses were carried out using IBM SPSS Statistics v25.

## III. RESULTS

The overall chitosan recovery yield was 8% relative to the 1.35 kg processed biomass (Figure 1). The recovered material presented a uniform granular texture and a yellow–orange coloration (Figure 2), consistent with chitosan produced through similar chemical processes [25]. While the yield was modest, the process demonstrated technical feasibility with locally accessible reagents and produced sufficient material for the subsequent coagulation–flocculation tests [26].

Effluent quality directly improved in response to the chitosan dose applied to samples. Both biochemical oxygen demand (BOD<sub>5</sub>) and chemical oxygen demand (COD) decreased progressively with increasing chitosan concentration (Figure 3, Figure 4). Untreated effluent exhibited very high organic loads, with BOD<sub>5</sub> and COD exceeding 4,000 mg L<sup>-1</sup> and 11,000 mg L<sup>-1</sup> in average respectively. At 500 mg chitosan L<sup>-1</sup>, BOD<sub>5</sub> was reduced to below 500 mg L<sup>-1</sup> and COD to approximately 600 mg L<sup>-1</sup>, reductions greater than 90% in both variables. Significant differences were found between all treatments ( $p < 0.05$ ), indicating a consistent and robust response to increasing coagulant dosage.



Figure 2. Extracted chitosan

Changes in pH responded to chitosan dose in a moderate way (Figure 6). Chitosan application led to a slight pH reduction to mildly acidic conditions at higher doses; however, the pH in all treated effluents remained within the LMP range established for fishery effluent discharges. Visual appearance of the treated samples (Figure 8) was consistent with the biochemical results, showing a progressive increase in clarity and floc formation with increasing chitosan dosage. Overall, the treatment with 500 mg L<sup>-1</sup> of chitosan was the most effective within the tested range as it consistently produced the greatest improvements across all the evaluated variables.

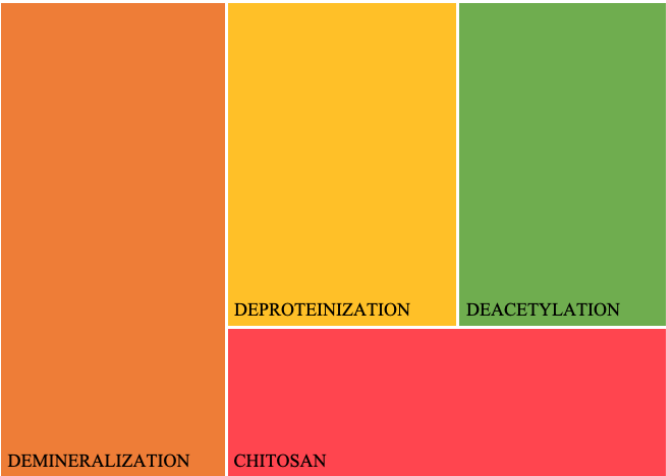


Figure 1. Chitosan yield and losses through the extraction process

A similar trend was observed for variables related to solids. Total suspended solids (TSS) and oils and greases decreased markedly as chitosan concentration increased (Figure 5, Figure 7). The untreated effluent presented high levels of suspended matter and hydrophobic contaminants, and the application of 400–500 mg L<sup>-1</sup> of chitosan resulted in substantial clarification of the supernatant and a pronounced reduction in visible turbidity (Figure 8). At the highest dose, TSS values approached 500 mg L<sup>-1</sup> and oils and greases were reduced by approximately 85% relative to the untreated condition. These results indicate that chitosan effectively promotes particle aggregation and sedimentation, facilitating contaminants removal in fishery effluents.

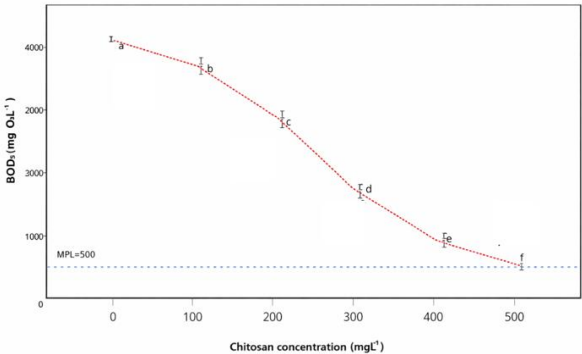


Figure 3. Biological oxygen demand

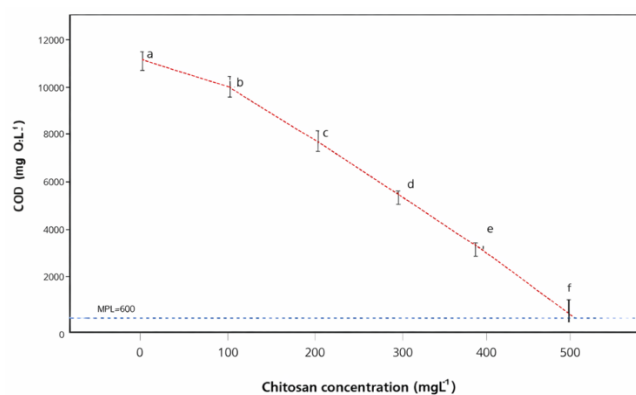


Figure 4. Chemical oxygen demand

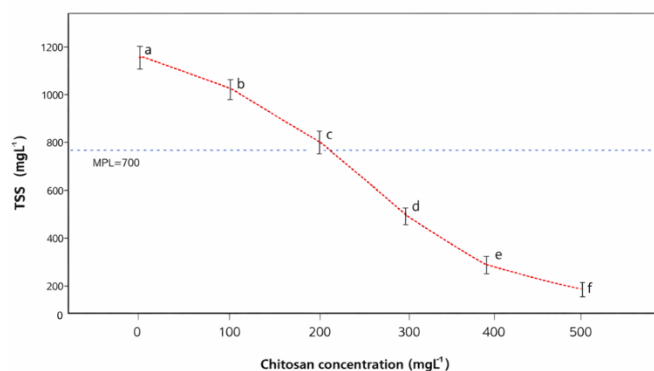


Figure 5. Total suspended solids

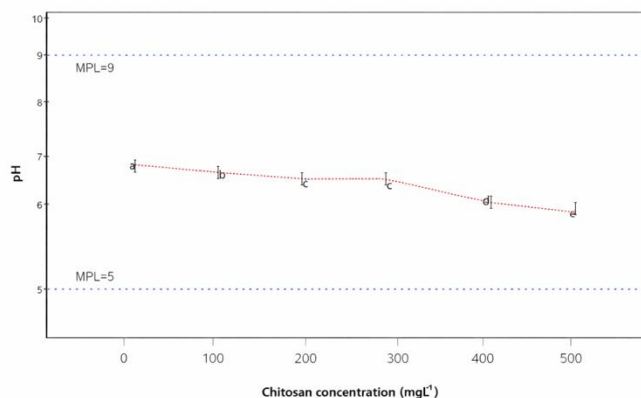


Figure 6. Effluent acidity

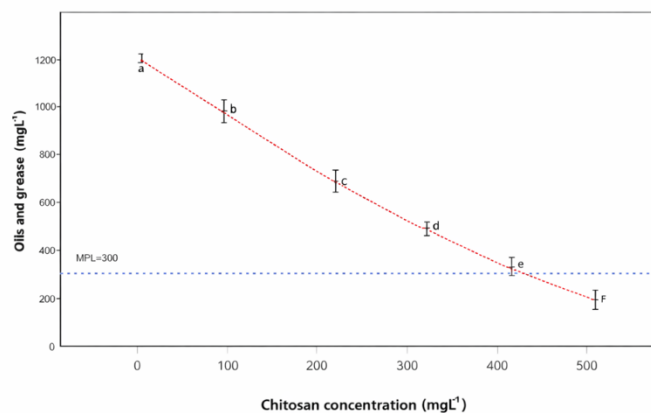


Figure 7. Oil and grease



Figure 8. Effluent appearance upon chitosan treatments

#### IV. DISCUSSION

The use of phosphoric acid as demineralizing agent proved effective and provided sufficient chitosan for the evaluations planned, however, the yield resulted low when compared to reports under similar conditions and feedstock [15], [27]. Considering the chitosan recovery yields modelled for *L. vannamei* under different conditions range between 10% and 30% [27], [28], we believe the yield we report here has room for improvement by developing better extraction processes and making sure they are aligned to scaling up considerations. Chitosan recovery should be improved, but resource consumption and externalities should also be minimized. Each step in the process we executed could be subject to improvement [29], but shrimp shell pretreatment and process intensification by microwave-assisted extraction could also contribute to improving the yield efficiency while reducing the operational burden at larger scales [30], [31]. If higher yield is not achieved, the externalities of the extraction alone could negate the environmental benefits of the local chitosan recovery altogether by requiring local resources for the disposition of solid waste and effluents from the process.

However modest the yield, our results confirm the

chitosan recovered from *L. vannamei* exoskeleton waste is highly effective as a natural coagulant–flocculant for treating fishery effluents characterized by high organic load and particulate material. The extent of BOD<sub>5</sub>, COD, TSS, turbidity and oil and grease reduction exceeds what is typically expected from conventional primary treatment processes [32], [33], indicating that chitosan-based coagulation may provide the industry with an enhanced primary or hybrid primary–secondary treatment potentially sufficient to meet the current regulation on discharges [6]. Similar removal efficiencies have been reported in previous studies, where chitosan dosages between 400 and 500 mg L<sup>-1</sup> achieved reductions above 90 % for BOD, COD, TSS, and oil and grease in comparable industrial effluents [26], [34], supporting the consistency of the performance observed in this study. This level of performance is particularly relevant for fishery effluents, where reducing organic load prior to biological treatment can improve downstream treatment efficacy and facilitate regulatory compliance using relatively simple physicochemical infrastructure.

On a unit-cost basis commercial chitosan (8000-20000 USD Mg<sup>-1</sup>) is currently unlikely to compete directly with conventional commodity coagulants such as poly aluminum chloride, aluminum sulphate, ferric chloride or ferrous sulfate (100-400 USD Mg<sup>-1</sup>), particularly considering the process costs at the laboratory scale we conducted. The chitosan dosage we found effective to treat this effluent is higher than the doses of mineral coagulants used in conventional wastewater treatment, however, a direct price-per-mass comparison may oversimplify the operational advantages of chitosan in wastewater management systems. The significant water quality improvement achieved by adding one single input in one step suggests that chitosan-based coagulation may reduce downstream treatment requirements while improving the likelihood of regulatory compliance. This supports the potential viability of locally recovered chitosan should be evaluated not only in terms of coagulant cost, but also according to treatment performance, sludge characteristics, connection with waste valorization incentives, and its contribution to localized circularity within the fishery sector.

The main contribution of this study is providing evidence on the viability of technological adaptation to local regulatory and operational constraints by replacing a regulated mineral acid with a readily available fertilizer-grade alternative. Upon process improvement, its viability could enable decentralized chitosan recovery within the national regulatory framework. Such partial substitution could contribute to reducing the metal outputs to the sea and the environmental footprint of effluent treatment itself [33]. This incremental integration approach aligns with the realities of industrial wastewater management, where gradual transitions are often more feasible than complete technological shifts [35], [36]. In the Peruvian context,

transforming locally sourced chitosan could serve as a practical bridge to shift from farm-to-landfill waste stream management in shrimp farm [37] while providing effective supplies for effluent treatment for the fish processing businesses and others that also need to discharge wastewater.

Should this bridge be functional, waste streams generated through the seafood value chain can be reintegrated as treatment inputs for the same industrial system, effectively reducing dependence on imported mineral coagulants while improving primary effluent quality. The implementation of sustainable industrialization policies is likely necessary to enable these developments. The innovation policy mix should move beyond traditional end-of-pipe inspection and remediation approaches, into the territory of instruments and conditions favoring systemic solutions that integrate environmental performance with local industrial development and innovation [38]. Future work should focus on improving extraction yield and evaluating pilot-scale integration under the current industrial context and technology and include life cycle analysis of the chitosan produced and used to maintain transparency on the externalities and a rigorous balance between environmental burden of the process.

## REFERENCES

- [1] J. A. Gonzales Rossel, L. A. Aguirre Mendez, N. D. Arenazas Gonzales, and C. F. Gutiérrez Rojas, "Evaluación ambiental de la bahía del Callao durante el año 2017." Accessed: Apr. 11, 2025. [Online]. Available: <https://repositorio.oefa.gob.pe/handle/20.500.12788/192>
- [2] A. Guabloche, L. Alvaríño, T. M. da S. Acioly, D. C. Viana, and J. Iannacone, "Assessment of Essential and Potentially Toxic Elements in Water and Sediment and the Tissues of *Sciaena deliciosa* (Tschudi, 1846) from the Coast of Callao Bay, Peru," *Toxics*, vol. 12, no. 1, p. 68, Jan. 2024, doi: 10.3390/toxics12010068.
- [3] L. Alvaríño, G. Saez, T. M. da S. Acioly, D. Carvalho Viana, and J. Iannacone, "Biochemical indicators of contamination in the coastal area of Callao, Peru," *Lat. Am. J. Aquat. Res.*, vol. 51, no. 3, pp. 351–362, Jul. 2023, doi: 10.3856/vol51-issue3-fulltext-2946.
- [4] S. Purca and A. Henostroza, "Presencia de microplásticos en cuatro playas arenosas de Perú," *Rev. Peru. Biol.*, vol. 24, no. 1, pp. 101–106, Apr. 2017, doi: 10.15381/rpb.v24i1.12724.
- [5] O. Herrera Amezcúta *et al.*, "Caracterización de POPs y PAHs en fragmentos plásticos: Estudio de Caso en el Callao," *Revista del Instituto de investigación de la Facultad de minas, metalurgia y ciencias geográficas*, vol. 27, no. 54, p. e28862, Dec. 2024, doi: 10.15381/iigeo.v27i54.28862.
- [6] Ministerio del Ambiente, *Límites Máximos Permisibles para Efluentes de Establecimientos Industriales Pesqueros de Consumo Humano Directo e Indirecto*. Peru, 2018, pp. 3–5.
- [7] A. Rudolph, R. Ahumada, and C. Pérez, "Dissolved Oxygen Content as an Index of Water Quality in San Vicente Bay, Chile (36°S)," *Environ. Monit. Assess.*, vol. 78, no. 1, pp. 89–100, Aug. 2002, doi: 10.1023/A:1016140819487.
- [8] Guevara del Aguila José, "Evaluación de los indicadores de impacto ambiental por el vertimiento de los efluentes industriales pesqueros en la Bahía de Coishco-Perú-2018," *Ciencia Latina Revista Científica Multidisciplinar*, vol. 6, no. 1, pp. 2249–2272, Feb. 2022, doi: 10.37811/cl\_rm.v6i1.1646.
- [9] G. Velaochaga, C. P. Rojas, H. Xu, and E. Alburqueque, "Monitoreo de las aguas residuales vertidas en la bahía del Callao utilizando imágenes Landsat (1985-2015)," *Boletín Instituto del*

- Mar del Perú*, vol. 33, no. 1, pp. 5–12, Jun. 2018, Accessed: Apr. 11, 2025. [Online]. Available: <https://revistas.imarpe.gob.pe/index.php/boletin/article/view/47>
- [10] PROMPERÚ, “Exportaciones de los demás los demás camarones, langostinos y demás decápodos natantia excepto camarones de río de los géneros macrobrachium. (0306179900) | PROMPERÚ.” Accessed: Feb. 12, 2026. [Online]. Available: <https://exportemos.pe/descubre-oportunidades-de-exportacion/producto/camaron-0306179900>
- [11] N. Rossi, C. Grosso, and C. Delerue-Matos, “Shrimp Waste Upcycling: Unveiling the Potential of Polysaccharides, Proteins, Carotenoids, and Fatty Acids with Emphasis on Extraction Techniques and Bioactive Properties,” *Mar. Drugs*, vol. 22, no. 4, p. 153, Mar. 2024, doi: 10.3390/md22040153.
- [12] C. S. Liyanage, S. T. Gonapinuwala, C. A. N. Fernando, and M. D. S. T. de Croos, “A Simple and Effective Method to Extract Chitosan from Crustacean Shell Waste,” *Journal of Aquatic Food Product Technology*, vol. 32, no. 4, pp. 396–415, Apr. 2023, doi: 10.1080/10498850.2023.2228793.
- [13] I. Aranaz *et al.*, “Chitosan: An Overview of Its Properties and Applications,” *Polymers (Basel)*, vol. 13, no. 19, p. 3256, Sep. 2021, doi: 10.3390/polym13193256.
- [14] D. M. Rodríguez Jimenez and D. D. J. Gallego Suárez, “Evaluación del quitosano como coagulante para el tratamiento de efluentes piscícolas,” *Rev. Colomb. Biotecnol.*, vol. 21, no. 1, pp. 6–17, Jan. 2019, doi: 10.15446/rev.colomb.biote.v21n1.73340.
- [15] A. Hosney, S. Ullah, and K. Barčauskaitė, “A Review of the Chemical Extraction of Chitosan from Shrimp Wastes and Prediction of Factors Affecting Chitosan Yield by Using an Artificial Neural Network,” *Mar. Drugs*, vol. 20, no. 11, p. 675, Oct. 2022, doi: 10.3390/md20110675.
- [16] J. Rosero, M. Suárez, S. Mora, B. Achig, A. Chamba, and A. Anrango, “Obtención de quitina a partir del exoesqueleto de camarón (*Litopenaeus vannamei*) como coagulante - floculante en aguas de baja turbidez,” *infoANALÍTICA*, vol. 8, no. 2, Jul. 2020, doi: 10.26807/ia.v8i2.113.
- [17] Future Market Insights, “Chitosan market share analysis & industry leaders.” Accessed: Feb. 15, 2026. [Online]. Available: <https://www.futuremarketinsights.com/reports/chitosan-market-share-analysis>
- [18] D. P. Mukherjee, “METHOD FOR PRODUCING CHITIN OR CHITOSAN,” US 6,310,188 B1, Oct. 30, 2001
- [19] W. Li, “A process for extracting chitosan from shrimp shells,” CN104558240A, Apr. 29, 2015
- [20] J. Bristow, “Chitosan manufacturing proces,” US 8,318,913 B2, Nov. 27, 2012
- [21] K. Le Roux, J.-P. Berge, R. Baron, E. Leroy, and A. Arhaliass, “Extraction of chitins in a single step by enzymatic hydrolysis in an acid medium,” US 2014/0100361 A1, Apr. 10, 2014
- [22] A. Riofrio, T. Alcivar, and H. Baykara, “Environmental and Economic Viability of Chitosan Production in Guayas-Ecuador: A Robust Investment and Life Cycle Analysis,” *ACS Omega*, vol. 6, no. 36, pp. 23038–23051, Sep. 2021, doi: 10.1021/acsomega.1c01672.
- [23] Ministerio de Economía y Finanzas, *Aprueban las listas de insumos químicos, productos y sus subproductos o derivados que son objeto de control, y definen los bienes fiscalizados considerados de uso doméstico y artesanal, conforme lo establecido en los artículos 5 y 16 del Decreto Legislativo N° 1126*. Peru, 2019, pp. 1–4. Accessed: Feb. 15, 2026. [Online]. Available: <https://www.gob.pe/institucion/mef/normas-legales/290067-268-2019-ef>
- [24] W. C. . Lipps, E. Burton. Braun-Howland, and T. E. . Baxter, *Standard methods for the examination of water and wastewater*, 24th ed. American Public Health Association, 2023.
- [25] Hernández Caridad, Palacio Yadira, and Fanego Sandra, “DESACETILACIÓN DE QUITINA OBTENIDA POR VÍA QUÍMICA DE EXOESQUELETOS DE CAMARÓN LITOPENAEUS VANNAMEI,” *AIP Conf. Proc.*, vol. 1823, Mar. 2017, doi: 10.1063/1.4978144.
- [26] D. M. Rodríguez-Jiménez, E. Burbano-Erazo, and Y. J. Díaz-Rodríguez, “Quitosano aplicado en el tratamiento del agua residual de la producción de aceite de palma,” *Agronomía Mesoamericana*, p. 44288, Oct. 2021, doi: 10.15517/am.v33i1.44288.
- [27] C. Engku Noramalina Che Engku Chik *et al.*, “Extraction and Characterization of *Litopenaeus vannamei*’s Shell as Potential Sources of Chitosan Biopolymers,” *J. Renew. Mater.*, vol. 0, no. 0, pp. 1–17, 2022, doi: 10.32604/jrm.2023.022755.
- [28] K. Tokatlı and A. Demirdöven, “Optimization of chitin and chitosan production from shrimp wastes and characterization,” *J. Food Process. Preserv.*, vol. 42, no. 2, p. e13494, Feb. 2018, doi: 10.1111/jfpp.13494.
- [29] A. Hosney, S. Ullah, and K. Barčauskaitė, “A Review of the Chemical Extraction of Chitosan from Shrimp Wastes and Prediction of Factors Affecting Chitosan Yield by Using an Artificial Neural Network,” *Mar. Drugs*, vol. 20, no. 11, p. 675, Oct. 2022, doi: 10.3390/md20110675.
- [30] T. S. Trung *et al.*, “Improved method for production of chitin and chitosan from shrimp shells,” *Carbohydr. Res.*, vol. 489, p. 107913, Mar. 2020, doi: 10.1016/j.carres.2020.107913.
- [31] H. EL Knidri, J. Dahmani, A. Addaou, A. Laajeb, and A. Lahsini, “Rapid and efficient extraction of chitin and chitosan for scale-up production: Effect of process parameters on deacetylation degree and molecular weight,” *Int. J. Biol. Macromol.*, vol. 139, pp. 1092–1102, Oct. 2019, doi: 10.1016/j.ijbiomac.2019.08.079.
- [32] T. M. S. Land *et al.*, “Evaluation of a Coagulation/Flocculation Process as the Primary Treatment of Fish Processing Industry Wastewater,” *Water Air Soil Pollut.*, vol. 231, no. 9, p. 452, Sep. 2020, doi: 10.1007/s11270-020-04811-8.
- [33] N. Jaafarzadeh, N. Mengelizadeh, M. Jalil, A. Takdastan, N. Alavi, and N. Niknam, “Removal of zinc and nickel from aqueous solution by chitosan and polyaluminum chloride,” *Int. J. Environ. Health Eng.*, vol. 5, no. 1, p. 16, 2016, doi: 10.4103/2277-9183.190642.
- [34] A. J. Santiaguín-Padilla *et al.*, “Aguas residuales de la industria pesquera: Retos y oportunidades en la recuperación de proteínas y péptidos con alto valor biológico y funcional- Una revisión,” *TIP. Revista especializada en ciencias químico-biológicas*, vol. 25, Nov. 2022, doi: 10.22201/FESZ.23958723E.2022.512.
- [35] A. Soares, “Wastewater treatment in 2050: Challenges ahead and future vision in a European context,” *Environmental Science and Ecotechnology*, vol. 2, p. 100030, Apr. 2020, doi: 10.1016/j.ese.2020.100030.
- [36] F. Ahmed, D. Johnson, R. Hashaikeh, and N. Hilal, “Barriers to Innovation in Water Treatment,” *Water (Basel)*, vol. 15, no. 4, p. 773, Feb. 2023, doi: 10.3390/w15040773.
- [37] G. M. Mathew, R. K. Sukumaran, R. Sindhu, P. Binod, and A. Pandey, “Green remediation of the potential hazardous shellfish wastes generated from the processing industries and their bioprospecting,” *Environ. Technol. Innov.*, vol. 24, p. 101979, Nov. 2021, doi: 10.1016/j.eti.2021.101979.
- [38] J. E. . García de Alba Verduzco, B. Catalina. Ramírez Hernández, and Melissa. Lis Gutiérrez, *El poder de la sustentabilidad*. Prometeo Editores, S.A. de C.V. : Universidad de Guadalajara, 2021.