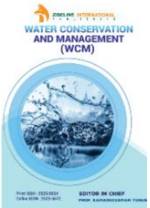
ZIBELINE INTERNATIONAL™
PUBLISHING

Water Conservation & Management (WCM)

DOI: http://doi.org/10.26480/wcm.04.2025.710.717

ISSN: 2523-5664 (Print)
ISSN: 2523-5672 (Online)
CODEN: WCMABD



RESEARCH ARTICLE

CRUSHED RECYCLED GLASS AS A SUSTAINABLE FILTER MEDIUM FOR ENHANCED PHOSPHORUS REMOVAL IN DIRECT FILTRATION

Aissat Miloud[a]*, Chellali Rachid[b], Sarra Hamouda[c], Chaker Yassine[d]

[a,b,d]Laboratory of Materials Chemistry and Applications, University of Tissemsilt, 38000, Algeria.,
[c]Scientific and Technical Research Center in Physico-Chemical Analysis (CRAPC), Industrial Zone, BP384, Bou-Ismail, Tipaza 42004, Algeria
**Corresponding Author Email : aissat.miloud@univ-tissemsilt.dz*

Article History:

Received 11 September 2025
Revised 21 October 2025
Accepted 17 November 2025
Available online 14 December 2025

ABSTRACT

Eutrophication, caused by excess phosphorus in water bodies, remains a significant environmental challenge globally. This comprehensive study investigated the efficacy of direct filtration employing crushed and treated recycled glass as a novel filter medium for efficient phosphorus removal from synthetic wastewater. Our primary objective was to systematically evaluate and optimize critical operational parameters, including filtration velocity, simulated turbidity (Kaolin), coagulant (Al2(SO4)3·16H2O) dosage, and glass grain size, to establish optimal conditions for maximal phosphate removal. The research demonstrated that optimal phosphorus removal, achieving greater than 90% efficiency, was attained under direct filtration with precise pH adjustment to approximately 5.7-6.2. This was coupled with an Al/P mass ratio of around 1.3-1.57, a filtration velocity of 8 m/h, and a crushed glass granulometry ranging from 1.00-1.25 mm. The integration of a dedicated upstream flocculation stage was found to be critical for achieving these high efficiencies. Furthermore, head loss development was continuously monitored, providing valuable insights into filter run times and potential clogging mechanisms. This study conclusively illustrates the significant efficacy of crushed recycled glass as a sustainable and cost-effective filter medium for phosphorus removal, presenting a viable and environmentally friendly alternative to traditional materials in wastewater treatment.

KEYWORDS

Wastewater Treatment, Nutrient Removal, Alum, eutrophication, coagulants

1. INTRODUCTION

Phosphate contamination in water bodies, primarily stemming from agricultural runoff, industrial discharges, and inadequate wastewater management, constitutes a significant global environmental challenge. This excess phosphorus often triggers eutrophication, leading to harmful algal blooms, oxygen depletion, and severe ecological degradation (Egbedi et al., 2023; Beniah et al., 2020; Daniel et al., 2009). While conventional treatment methods, such as chemical precipitation with metal salts, effectively remove phosphates, they frequently incur high operational costs, generate substantial chemical sludge, and raise concerns regarding long-term environmental sustainability (Morse et al., 1998).

Driven by the urgent need for more sustainable and cost-effective wastewater treatment solutions, there is a growing imperative to explore alternative filter media. Recycled crushed glass presents a highly promising candidate due to its inherent physical and chemical properties, including its porous structure and high surface area, which are conducive to adsorption and filtration processes. Although the potential of crushed glass in water treatment has been acknowledged, a comprehensive understanding of its performance within an integrated direct filtration system—specifically one optimized across multiple operational parameters including coagulation, pH, velocity, and granulometry for enhanced phosphorus removal.

Derived from recycled glass products, crushed glass has been studied for its potential to be an effective medium in filtration systems due to its physical and chemical properties. The porous nature and high surface area of crushed glass particles make it an ideal substrate for adsorbing phosphates from water. Furthermore, the utilization of recovered glass aligns with sustainable development principles, reducing landfill waste and promoting resource conservation (Evans et al., 2002).

The effectiveness of crushed glass in phosphate removal can be attributed to multiple mechanisms, including adsorption, ion exchange, and filtration. Phosphates adhere to the crushed glass particles surface through physical and chemical interactions. Certain ions present in the glass can facilitate the exchange phosphate ions from the water effectively reducing phosphate levels (Rowsell et al., 2004). Additionally, the physical structure of the crushed glass bed allows for the filtration of particulate-bound phosphates from the water.

Using crushed glass for phosphate removal offers various advantages, including sustainability, cost- effectiveness, and efficiency. The use of glass

Quick Response Code	Access this article online	
	Website: www.watconman.org	**DOI:** 10.26480/wcm.04.2025.710.717

Cite The Article: Aissat Miloud, Chellali Rachid, Sarra Hamouda, Chaker Yassine (2025). Crushed Recycled Glass As A Sustainable Filter Medium For Enhanced Phosphorus Removal In Direct Filtration. Water Conservation & Management, 9(4): 710-717.

promotes environmental sustainability by reducing landfill waste and encouraging recycling initiatives (Sandanayake et al., 2020). Crushed glass, as a low-cost raw material with minimal processing requirements, provides a cost-effective solution for water treatment. Research has shown the high efficiency of crushed glass in phosphate removal under different conditions. However, there are limitations to this method, such as the need for periodic glass regeneration or replacement, challenges in scaling up for large implementations, and performance variability based on water chemistry and phosphate concentration.

Recent studies have indicated that the effectiveness of crushed glass in removing phosphates can be influenced by factors such as particle size, contact time, and the existence of competing ions in water (Vierra et al., 2018).

The practical application of crushed glass filters in water treatment facilities is noteworthy. Moreover, the environmental impact of using crushed glass is positive as it addresses the dual challenge of waste management and water pollution (Chaves-Barquero et al., 2021). By diverting waste from landfills and utilizing it for water treatment, this approach contributes to resource recovery and circular economy principles, reducing the demand for traditional, often more expensive, water treatment materials and therefore lowering the overall environmental footprint.

This study, therefore, aims to fill this critical knowledge gap by rigorously investigating and optimizing the efficacy of crushed recycled glass within an advanced direct filtration setup. Our innovation lies in the multi-parametric approach to fine-tune the combined coagulation-flocculation-filtration process, elucidating the synergistic effects of these variables to maximize phosphate removal efficiency while simultaneously monitoring head loss development for practical application. By presenting an optimized, sustainable, and high-performance alternative, this research seeks to significantly advance the practical implementation of recycled materials in addressing global water quality challenges.

In conclusion, using crushed glass for phosphate removal from water offers a sustainable and effective solution to a pressing environmental issue. Despite the challenges, ongoing research and technological advancements show promise for its broader adoption and implementation. By integrating this approach into existing water treatment frameworks, significant improvements can be achieved.

2. MATERIALS AND METHODS

2.1 Filtration Pilot

A storage tank with a capacity of 85 liters was used for preparing and holding the synthetic wastewater and a mechanical agitator with variable speed ensured homogeneity of the synthetic solution. The storage tank that supplies water to the column, a 95 cm high glass column with a 30 mm inner diameter, filled to a height of 80 cm with crushed and treated glass for filtration. A constant level tank ensures a stable water flow, fed by a pump from the storage tank. A dosing pump is used for alum addition, promoting coagulation, followed by a rapid mixer to enhance this process. A helical flocculator helps in the formation of flocs. To ensure optimal operation, a flowmeter and a control valve maintain a constant flow through the column.

2.2 Preparation of glass filter media

The discarded glass bottles were gathered from different local sources and meticulously cleaned to prevent contamination. The cleaned glass was placed inside a durable plastic bag, and than crushed by striking the bag with a hammer. Larger glass pieces greater than 4.75 mm in size were earmarked for the grinding process. The glass collector bucket was meticulously cleaned and carefully positioned within a crusher machine called "Los Angeles Abrasion". The crushed glass was then stored, awaiting the sieving process. The glass particles underwent sieving using mesh sieves of varying sizes. Glass particles ranging from 1 mm to 1.25 mm were separated for the experimental purposes. The filtration speeds investigated were 8 and 12 m/h. The studied ranges of the mass ratio (Al/P) were between 0 - 2.5. The filtration pilot is fed with synthetic water whose characteristics included a pH varying between 7.5 and 8.0; conductivity between 500 to 650 µS/cm; and ambient temperature between 21 and 25°C. The coagulation pH is adjusted to 6 to promote coagulation by adsorption of Al(OH)3 on which AIPO4 particles adsorbed. In fact, the zeta potential of aluminum hydroxide is positive due to the existence, in its structure, of positively charged species such as Al6 (OH)3+ and Al (OH)2 + (Laghari et al., 2018). Finally, the flocculation time is kept constant and equal to 20 minutes. Crushed glass used as a filter medium is pre-washed, dried, and sieved. The particle size used for experiments ranged from 1 to 1.25 mm; The bulk density and porosity of the filter bed, determined experimentally in the laboratory, are respectively equal to 1.52 g/cm^3 and 38.7%. After each filtration cycle, the crushed glass is washed with water in a counter-current manner until clear water is obtained. The duration of the filtration cycles has been set to 7-8 hours.

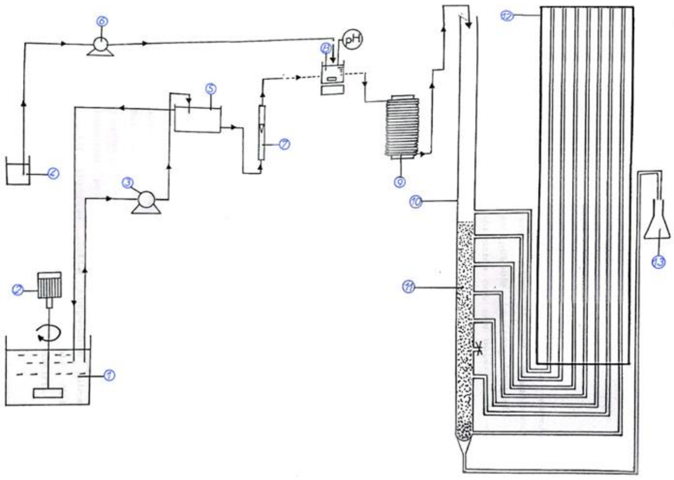


Figure 1 : The pilot installation of filtration process.1) synthetic suspension, 2) mechanical agitator, 3) pomp, 4) reagents (coagulants) , 5) constant level tray, 6) dosing pump, 7) flow meter, 8) rapid agitation, 9) helical flocculator, 10) glass filtration column, 11) Crushed Glass, 12) manometric table, 13) sample taking The first sample collection at the filter outlet is performed 15 minutes after starting the filtration operation, which is the time required to stabilize piezometric levels and achieve a steady flow regime. Sample collections are then carried out every half hour. The pH, turbidity, and residual phosphorus concentration in the water at the outlet are measured. Three main parameters were selected to evaluate the phosphate retention performance by filtration, residual phosphorus concentration, measured at the filter outlet using the AFNOR method and determination with a ZUZI 4255 spectrophotometer, and head loss, which is measured by direct reading on manometric tubes, expressed in centimeters of water.

The suspension used for the treatment is prepared from tap water and potassium dihydrogen phosphate (KH_2PO_4). A concentration of 10 mg/L of orthophosphates was used. The coagulating agent is hydrated aluminum sulfate $[Al_2(SO_4)_3 \bullet 16H_2O]$ with a molecular weight of 630.39 g/mol. The turbidity of the solution is induced by adding a concentration of 20 mg/L of kaolin to simulate turbid water (Zainol et al., 2022).

3. CHARACTERIZATION METHODS

3.1 Infrared spectroscopy

Fourier-transform infrared spectroscopy (FTIR) identifies functional groups and chemical bonds by measuring the absorption of infrared light across several wavelengths.

FTIR analysis was performed using an Agilent Cary 630 FTIR instrument. The spectra were collected over the range of 4000–600 cm^{-1}, with a resolution of 2 cm^{-1}.

Figure 2, shows the presence of band around 1000 cm^{-1} , it is characteristic of Si-O-Si stretching vibrations, predominant in silicate materials like glass. Another band around 800 cm^{-1} is associated with Si-O-Si bending vibrations, while a band around 450 cm^{-1} corresponds to Si-O-Si angle deformations. The roughness of crushed glass may introduce minor variations in some spectral regions, but overall the amorphous structure of the glass remains stable. This spectrum is consistent with the basic composition of glass, which is mainly made up of silicates and oxides.

Cite The Article: Aissat Miloud, Chellali Rachid, Sarra Hamouda, Chaker Yassine (2025). Crushed Recycled Glass As A Sustainable Filter Medium For Enhanced Phosphorus Removal In Direct Filtration. Water Conservation & Management, 9(4): 710-717.

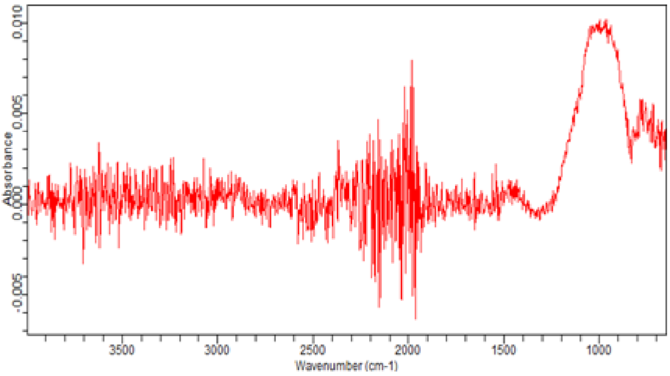


Figure 2: IR spectrum of crushed glass

The IR spectrum figure N⍰ 03, shows typical glass characteristics with a strong Si-O-Si band. The treatment with HCl appears to have only a minor impact on the main structure of the glass, as evidenced by the absence of major new peaks. However, variations in some regions may indicate minor changes to the glass surface or the presence of HCl-modified impurities.

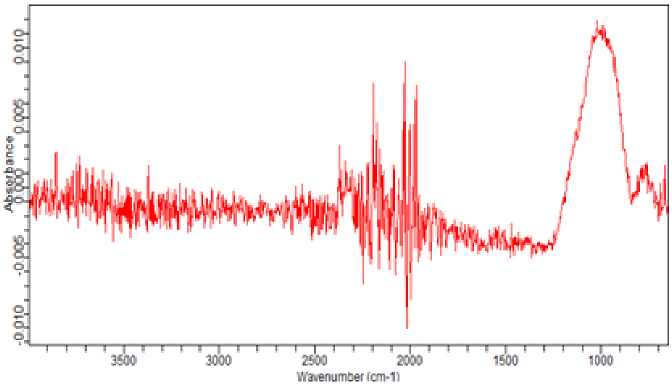


Figure 3: IR spectrum of crushed glass treated with HCL

3.2 X Rayon Diffraction

The provided diffractogram of crushed glass (CG marron) shows a single peak at 2θ = 24.6°,The presence of this peak is indicative of an amorphous structure. Figure 3.

The broad peak suggests that the crushed glass lacks a regular crystalline lattice and instead has a disordered atomic arrangement, which is typical for glassy materials. The peak position corresponds to a d-spacing of 3.62 Å, which is related to the average interatomic distances in the amorphous glass structure.

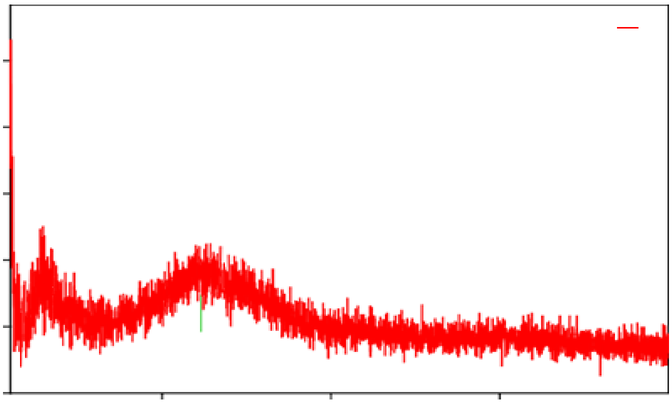


Figure 4: XRD pattern of the crushed glass

Like untreated glass, HCl-treated glass is expected to show a broad peak in the XRD pattern, characteristic of its amorphous nature. The peak may be centered around 2θ = 20 – 30°, depending on the composition of the glass. If the HCl treatment causes significant leaching or surface modification, the broad peak might show changes in the peak intensity could decrease if the treatment removes material from the glass surface. Figure 4.

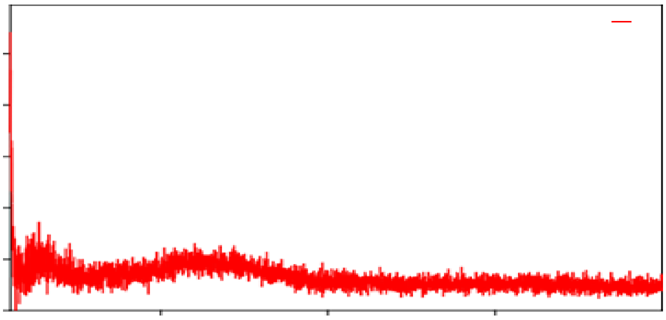


Figure 5: XRD pattern of the crushed glass treated with HCl

4. RESULTS AND DISCUSSION

This section discusses and interprets the experimental results, concentrating on the optimization of parameters for phosphorus removal by crushed glass direct filtration. This mode involved coagulant injection, flash mixing, followed by a controlled flocculation step in the helical flocculator before the water entered the crushed glass filter column.

4.1 Influence of the Coagulant Dose and pH

The coagulant dosage significantly influences floc characteristics, particularly size distribution, which in turn dictates the overall efficiency of the phosphate removal process. Conventional treatment processes relying on precipitation-sedimentation achieve optimal phosphate elimination when the aluminum-to-phosphorus (Al/P) molar ratio is maintained within the 1–3 range (Lürling et al., 2013). The primary mechanisms governing aluminum sulfate-induced coagulation include Sweep coagulation, where amorphous aluminum hydroxide ($Al(OH)_3$) precipitates enmesh colloidal particles (Duan et al., 2003). Aggregative adsorption, driven by electrostatic interactions between phosphate ions and Al-hydroxide surfaces. Chemical complexation, where Al^{3+} ions react with orthophosphates (PO_4^{3-}) to form sparingly soluble aluminum phosphate ($AlPO_4$) precipitates. (Stumm et al., 1996).

However, $AlPO_4$ precipitates exhibit submicron particle sizes (<1 µm), rendering them challenging to retain via gravitational sedimentation alone (Ebeling et al., 2003). Enhanced removal efficiency is achieved through synergistic interactions between $AlPO_4$ precipitation and adsorption onto aluminum hydroxide matrices. This process facilitates the formation of composite flocs ($AlPO_4$– $Al(OH)_3$–colloid aggregates) with increased hydrodynamic diameters (10–100 µm) and improved filterability (Wang et al., 2011). The co-precipitation mechanism is supported by spectroscopic analyses showing ligand exchange between phosphate and hydroxyl groups on Al $(OH)_3$ surfaces, followed by Ostwald ripening of the mixed-phase precipitates (Parfitt et al., 1978). The literature suggests that the optimal dose for $AlPO_4$ formation requires an Al/P mass ratio between 1 and 3 (Shaoyuan et al., 2010). Preliminary tests were conducted using a jar test to identify a suitable dosage range. As depicted in Figure 5, the phosphate removal efficiency increases with the reagent dose, consistent with established findings (Jiang et al., 2023). For instance, at a concentration of 60 mg/L of $Al_2(SO_4)_3{\cdot}6H_2O$, the efficiency rises from 27% to 79%.

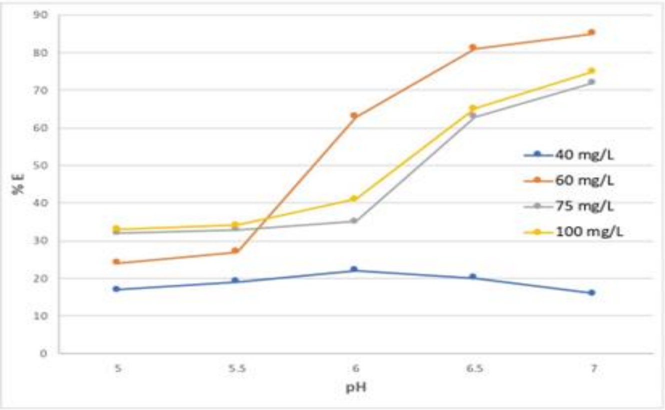


Figure 6: Jar-test tests, Variation in percentage elimination as a function of the pH of the water to be treated for different concentrations of Al2(SO4)316H2O

Phosphorus removal efficiency (E%) increased significantly with increasing coagulant dose. At low coagulant doses, removal was. minimal around 16 %.

Efficiency reached approximately 80% at a coagulant dose of 60 mg/L $Al_2(SO_4)_3 \cdot 16H_2O$. This dose corresponded to an Al/P mass ratio of 1.57. These jar test results confirmed the fundamental requirement of sufficient coagulant for effective phosphorus precipitation. The 80% removal achieved under these "ideal" laboratory settling conditions provided a benchmark for subsequent filtration experiments. It's important to note that jar tests often represent an upper limit of removal via precipitation/settling, as filtration dynamics (capture, detachment) introduce additional complexities

All the experimental results obtained in the 40 - 100 mg/l range show that the elimination efficiency is closely linked to the pH of the solution: this efficiency is all the higher as the pH tends towards neutrality. Figure 6. In fact, this neutral pH of the suspension becomes acidic and lies within the optimum range for precipitation after addition of the reagent. This parameter was therefore taken into consideration.

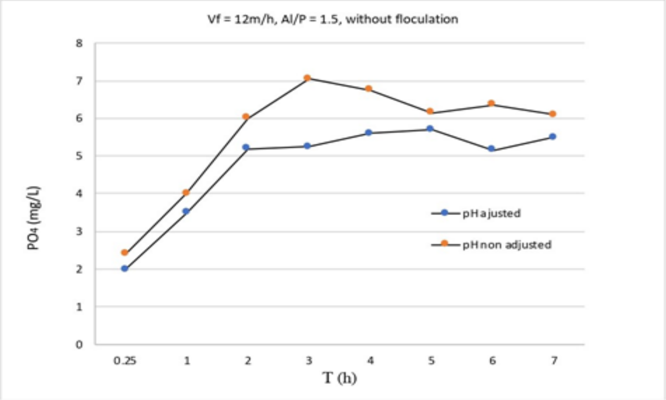


Figure 7 : Variation in concentration of PO4 as a function of the Time with adjusted and non- adjusted pH

Adjusting the pH prior to filtration through a crushed glass bed has a significant positive impact on phosphate removal. It leads to lower PO_4 concentrations in the effluent throughout the filtration cycle and allows for more effective breakthrough management. This indicates that pH control is a key parameter for optimizing the performance of this type of treatment for phosphate removal, particularly when aluminum-based coagulants are used. Figure 7.

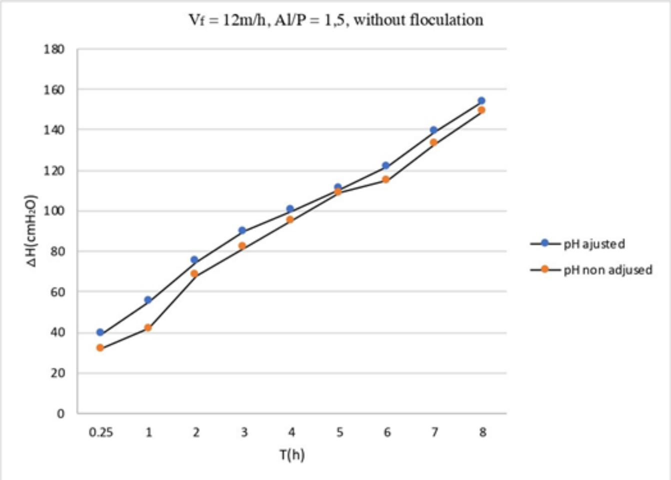


Figure 8: Head loss versus time

In an in-line filtration process without flocculation, pH adjustment results in a higher initial head loss. Figure 8 This is a direct consequence of its superior phosphate removal efficiency, a phenomenon consistent with the optimization of aluminum phosphate precipitation within a specific pH range (Crittenden et al., 2012). Furthermore, the clogging mechanism appears to differ. The higher-quality precipitates, formed at an optimal pH, likely promote more effective surface straining, while the less ideal precipitates, formed without pH adjustment, can lead to deeper penetration into the bed and a different head loss profile over time. This is consistent with filtration theories that directly link precipitate characteristics such as size, density, and adhesiveness to capture mechanisms and the development of head loss in the filter (Tobiason et al., 1988). The primary advantage of pH adjustment therefore remains the dramatic improvement in the quality of the treated water.

4.2 Effect of pH Adjustment

Recognizing the critical role of pH, experiments were conducted with pH adjustment at the inlet of the flocculator with Conditions of $[Al_2(SO_4)_3 \cdot 16H_2O]$ = 60 mg/L, Al/P=1.57, [Kaolin] = 20mg/L, Vf = 8 m/h. pH adjusted to an optimal value of 5.7 at the flocculator inlet (pHf). This resulted in an initial pH of 7.8, and a solution pH (pHs) of 6.2 after coagulation/flocculation.

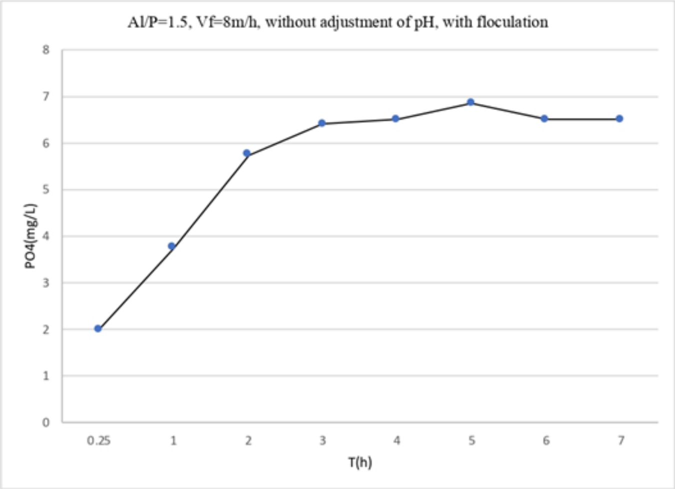


Figure 9: Variation in percentage elimination as a function of the Time without adjustment of pH

This finding demonstrates that under sub-optimal pH conditions, coagulation forms poor-quality aluminum phosphate flocs that are small, less dense, and structurally fragile. The system, however, successfully compensated for this poor chemistry through optimized physical processes. Two factors were critical: the flocculation step, which provided residence time for the small, fragile flocs to agglomerate, and the low filtration velocity, which shielded these weak flocs from high shear forces. Figure 9.

Floc strength is defined as the capacity of a floc to resist hydraulic shear. This parameter is crucial for predicting the performance of solid-liquid separation processes like filtration. It is well- established that coagulation chemistry, particularly pH, directly governs the resulting floc strength (Jarvis et al., 2005).

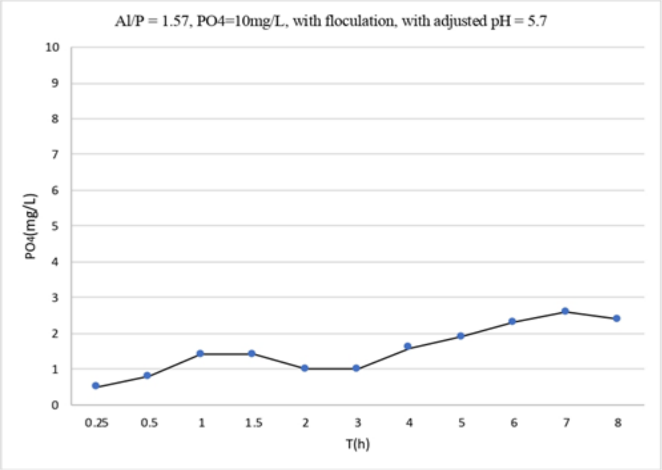


Figure 10: Variation in head loss as a function of the Time with adjusted pH

This experiment represents the benchmark scenario for effective phosphorus removal. It demonstrates that combining rigorous chemical control (pH adjustment) and proper process design (flocculation) achieves exceptional performance Figure 10. The high removal efficiency is a direct result of forming strong, easily filterable flocs, a principle well-established in coagulation chemistry where pH is the master variable controlling

Cite The Article: Aissat Miloud, Chellali Rachid, Sarra Hamouda, Chaker Yassine (2025). Crushed Recycled Glass As A Sustainable Filter Medium For Enhanced Phosphorus Removal In Direct Filtration. Water Conservation & Management, 9(4): 710-717.

precipitate characteristics (Jinming et al., 2003).

Furthermore, the system exhibits stable and predictable filtration behavior, highlighted by a beneficial ripening phase. This initial improvement in filter performance, where previously captured particles enhance the removal of subsequent ones, is a well-documented mechanism in granular media filtration theory.(Logan et al., 1995). Together, these results prove that when conditions are optimized, granular media filtration is an extremely robust and high-performing technology for phosphorus removal.

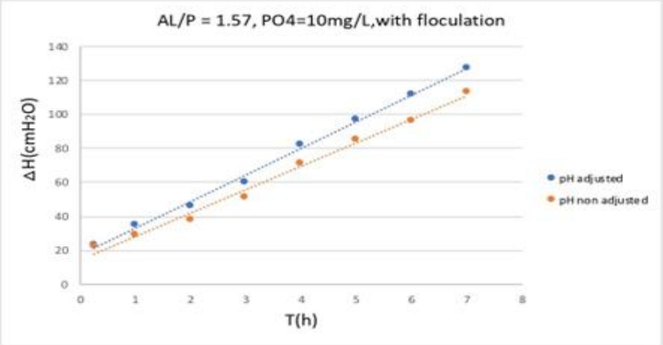


Figure 11: Head loss versus time

pH adjustment has a direct and often paradoxical impact on head loss, as it reflects the treatment's efficiency. A more efficient system captures more solids, which logically accelerates clogging and the increase in head loss. Figure 11. Consequently, the head loss curve for the adjusted pH condition is almost always steeper than for the non-adjusted one. Without pH adjustment, head loss increases more slowly as a portion of the pollutants is not retained and passes through the filter. At a lower velocity, the deposit of solids is less compact, making the head loss buildup gentler and more linear. This phenomenon, where the compressibility and permeability of the filter cake are highly dependent on the hydraulic flux, is a fundamental principle of granular media filtration (Crittenden et al., 2012).

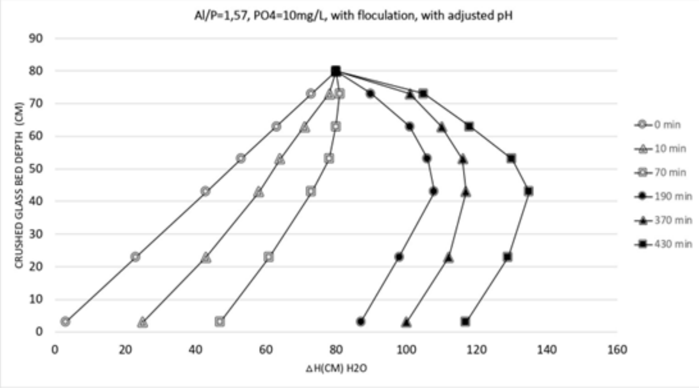


Figure 12: Crushed glass bed depth

The head loss profiles provide clear evidence of a surface filtration or straining mechanism. The optimized pretreatment, operating at a specific pH and coagulant dose, likely functions within the "sweep floc" coagulation domain, which is known to generate large, enmeshing precipitates ideal for filtration (Amirtharajah et al., 1982). These large flocs are then removed at the filter surface because their size exceeds that of the media pores. This results in the characteristic rapid head loss development at the top of the bed, a classic outcome when pretreatment is successfully tailored to produce particles optimal for surface removal (Charles et al., 1985).Figure 12.

4.3 Optimization of Coagulant Dose

With pH adjustment and flocculation established as beneficial, the coagulant dose was re-evaluated for direct filtration. With $[PO_4^{3-}]$ = 10 mg/L, [Kaolin] = 20 mg/L, Vf = 8 m/h, with flocation and pH adjusted. Coagulant doses tested is 50, 60, 75 mg/L $Al_2(SO_4)_3{\cdot}16H_2O$ corresponding to Al/P mass ratios of 1.31, 1.57, and 1.97 respectively.

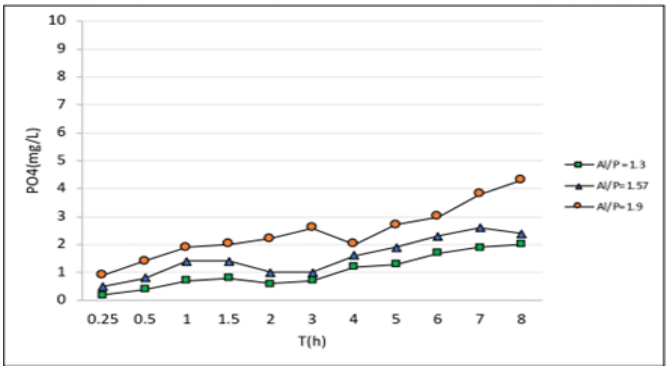


Figure 13: Variation in percentage elimination as a function of the time with different doses of coagulant

This graph crucially demonstrates that there is an optimal coagulant dosage for phosphate removal. Exceeding this dosage is not only a waste of chemical but is also counterproductive, as it significantly degrades the treatment performance. While the primary goal of adding the positively charged coagulant is to neutralize the negative surface charge of phosphate-containing particles, an excess of coagulant coats these particles with positive charges. Figure 13. This causes the particles to repel one another again, preventing effective flocculation. The resultant stable, positively charged micro-flocs are insufficiently large to be successfully eliminated by the filter, explaining the poor removal efficiency at higher doses (John et al., 2016).

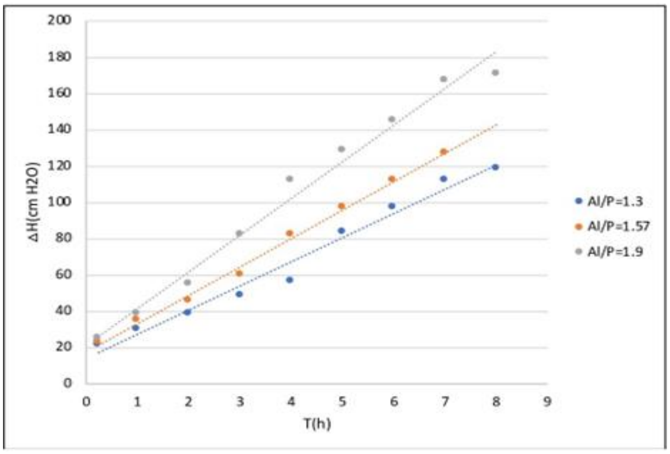


Figure 14: Variation in head loss as a function of the Time with different doses of coagulant

This graph vividly demonstrates that the optimal dosage is not only a target for water quality but also for the operational and hydraulic efficiency of the system. It is therefore imperative to avoid overdosing so as not to simultaneously degrade both treatment performance and the length of the filtration cycles. Figure 14.

4.4 Effect of Filtration Velocity

The effect of varying filtration velocity 8 m/h, 10m/h and 12 m/h, was studied under otherwise optimal conditions of pH and coagulant dose.

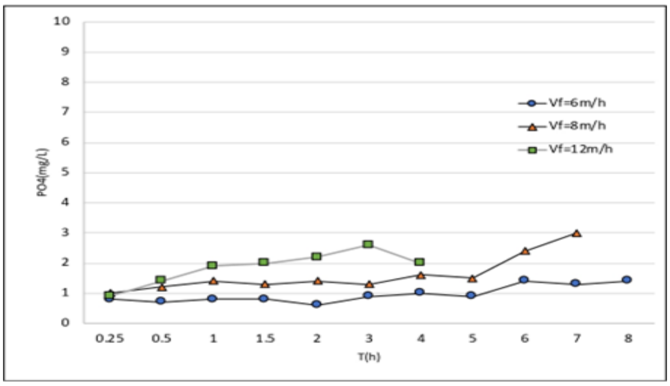


Figure 15: Variation in percentage elimination as a function of the Time with different Filtration Velocity

Figure 15. Higher filtration velocities reduce the contact time between the flocs and the filter media and increase shear forces, which can lead to the breakage of flocs and the detachment of particles, thereby reducing removal efficiency and causing an earlier breakthrough (Mörgeli et al., 1979). The rapid increase in pressure drop at 12 m/h also suggests that the higher flow rate may have compressed the captured solids or led to faster surface clogging. The results clearly favor the lower filtration rate for this system.

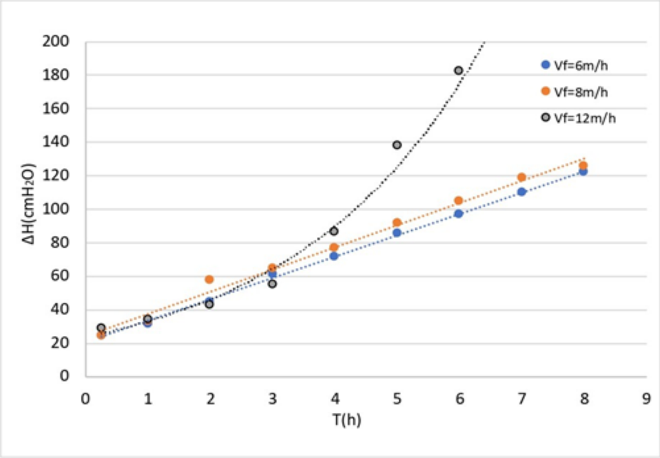


Figure 16: Variation in head loss as a function of the Time for different filtration velocity

Figure 16. The phenomenon is explained by the existence of a critical filtration velocity, which lies between 8 and 12 m/h. Below the critical velocity at 6 and 8 m/h, clogging is a stable and controlled process. Particles are captured progressively within the filter bed (depth filtration) or form a permeable cake on the surface. As a result, the head loss increase is linear and predictable. Above the critical velocity at 12 m/h, the intense hydraulic forces change the mechanism. They deform and compress the flocs, which then act like plugs, sealing the pores of the filter media. This phenomenon, known as "pore blinding" or "plugging", creates a chain reaction: as fewer pores remain open, the velocity through them increases, which further accelerates the plugging. It is that causes the exponential head loss observed at 12 m/h.

4.5 Effect of Turbidity

Studied under otherwise optimal conditions of pH and coagulant dose. By varying the kaolin concentration (0, 10, 20, 50 mg/L), we noted that there were no significant variations in removal efficiency. This shows that the contribution of kaolin is negligible, but its addition was maintained to better approximate real-world conditions. As for the head loss, it tends to increase with the kaolin concentration. We observed that the head loss deviates significantly from linearity when the kaolin concentration reaches 50 mg/L. The observed curvilinear portion indicates clogging on the filter surface; indeed, the formation of a filter cake was visually observed.Figure 17 and figure 18.

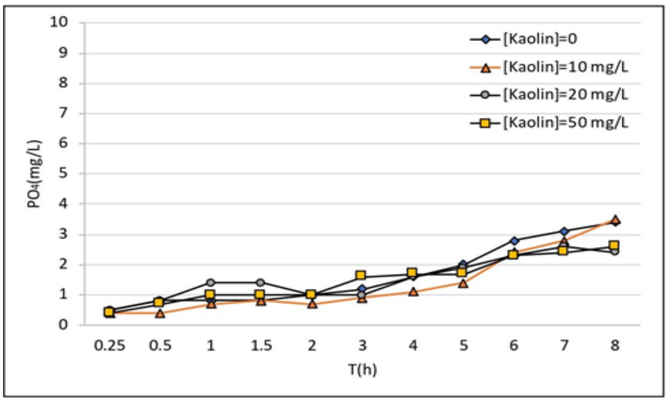


Figure 17: Variation in percentage elimination as a function of the Time for different concentration of kaolin

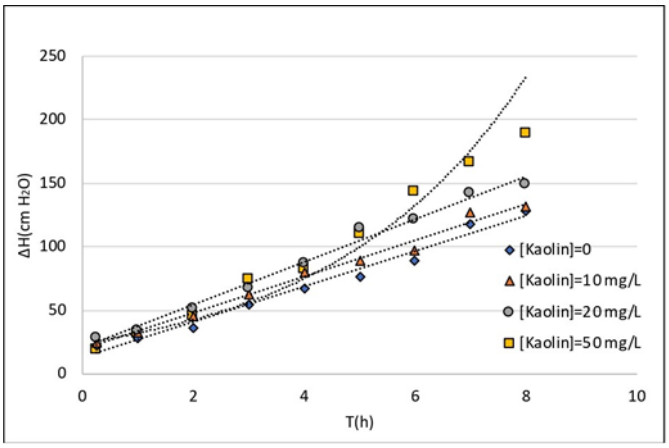


Figure 18: Variation in head loss as a function of the Time for different concentration of kaolin

4.5 Effect of Crushed Glass Granulometry

The 1.00–1.25 mm range is finer and more uniform than a broader 0.80–1.25 mm if the D_{10} of the latter is lower. This would make the media slightly coarser on average if the D_{10} shifts up, or more uniform if the D_{60} remains similar. If the 1.00-1.25mm media is indeed slightly coarser or more uniform (higher D_{10}, lower CU), it could offer deeper bed penetration and less surface clogging, potentially explaining the lower head loss. The improved PO4 removal is interesting; perhaps the more uniform pore sizes in the 1.00-1.25 mm media provided more optimal capture conditions, or the flow distribution was better. The 98% initial efficiency is excellent. The deeper retention (60% of bed height) compared to some previous profiles (e.g., 34% or 50%) suggests better utilization of the filter depth, which is desirable for longer runs. Figure 19, Figure 20 and Figure 21.

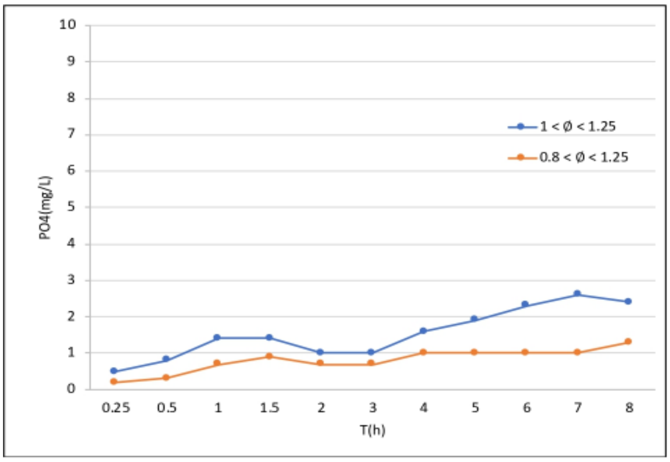


Figure 19: Variation in percentage elimination as a function of the Time for Reducing Granulometry

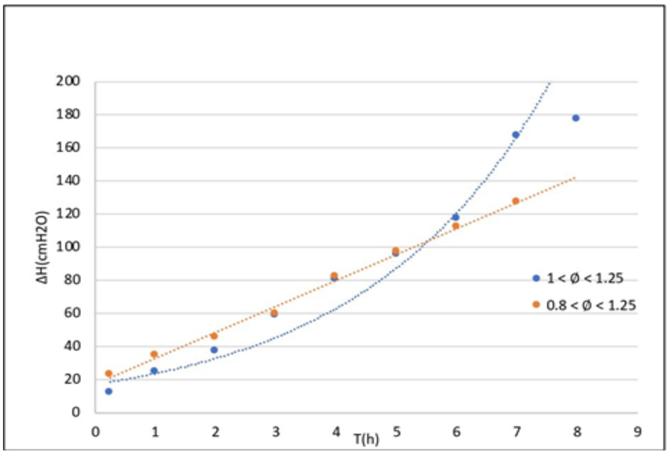


Figure 20 : Variation in head loss as a function of the Time for Reducing Granulometry

Cite The Article: Aissat Miloud, Chellali Rachid, Sarra Hamouda, Chaker Yassine (2025). Crushed Recycled Glass As A Sustainable Filter Medium For Enhanced Phosphorus Removal In Direct Filtration. Water Conservation & Management, 9(4): 710-717.

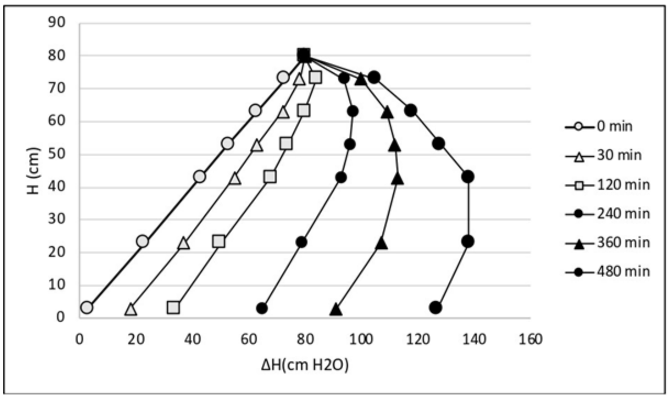


Figure 21 : Crushed glass bed depth for Reducing Granulometry

5. CONCLUSION

This comprehensive study on phosphorus removal using direct filtration with crushed recycled glass media yielded several key conclusions, logically structuring our findings. We demonstrated that direct filtration, incorporating a dedicated upstream flocculation stage, was significantly effective for phosphorus removal, achieving efficiencies exceeding 90-95%. Optimal chemical conditions, specifically a coagulation pH of 5.7-6.2 at the flocculator inlet and an Al/P mass ratio of approximately 1.31, were crucial for maximizing aluminum phosphate precipitation and robust floc formation, while minimizing chemical consumption. Regarding physical parameters, a filtration velocity of 6-8 m/h offered the best balance between high phosphorus removal and manageable head loss development, facilitating typical filter run times of approximately 8 hours. Furthermore, utilizing crushed glass with a granulometry of 1.00–1.25 mm resulted in the highest efficiencies (>95%) and excellent filter bed utilization. The helical flocculator played an essential role in developing these robust, filterable flocs. Collectively, these results confirm that crushed recycled glass is an effective and sustainable filter medium for this application, exhibiting performance characteristics well-suited for phosphorus removal when coupled with optimized pre-treatment. This research strongly supports its use as an environmentally responsible and viable alternative to conventional media for wastewater treatment, contributing significantly to sustainable resource management and environmental protection.

While this study successfully demonstrated the high efficacy of crushed recycled glass in direct filtration for phosphorus removal under optimized conditions, several avenues warrant further investigation to enhance its practical implementation and broaden its applicability. We strongly recommend future research focus on the following key areas:

To study the sustained performance of crushed glass filter beds over extended operating periods in real-world wastewater treatment scenarios.

To conduct further studies using advanced analytical techniques to better understand the precise mechanisms of phosphate interaction with the crushed glass surface.

To evaluate the potential of crushed recycled glass beds for the removal of other contaminants, such as nitrogen compounds, heavy metals, and organic pollutants.

REFERENCES

Amirtharajah, A., and Mills, K. M. 1982. Rapid-mix design for mechanisms of alum coagulation. Journal AWWA, Research and Technology. https://doi.org/10.1002/j.1551-8833.1982.tb04890.x

Isiuku, B. O., and Enyoh, C. E. 2020. Pollution and health risks assessment of nitrate and phosphate concentrations in water bodies in South Eastern Nigeria. Environmental Advances, 2, 100018. https://doi.org/10.1016/j.envadv.2020.100018

O'Melia, C. R. 1985. Particles, pretreatment, and performance in water filtration. Journal of Environmental Engineering, 111(6). https://doi.org/10.1061/(ASCE)0733-9372(1985)111:6(874)

Chaves-Barquero, L. G., Humeniuk, B. W., Luong, K. H., et al., 2021. Crushed recycled glass as a substrate for constructed wetland wastewater treatment: A case study of its potential to facilitate pharmaceutical removal. Environmental Science and Pollution Research, 28, Pp. 52306–52318. https://doi.org/10.1007/s11356-021-14483-4

Crittenden, J. C., Trussell, R. R., Hand, D. W., Howe, K. J., and Tchobanoglous, G. 2012. MWH's water treatment: Principles and design (3rd ed.). John Wiley and Sons. https://doi.org/10.1002/9781118131473

Conley, D. J., Paerl, H. W., Howarth, R. W., Boesch, D. F., Seitzinger, S. P., Havens, K. E., Lancelot, C., and Likens, G. E. 2009. Controlling eutrophication: Nitrogen and phosphorus. Science, 323(5917), 1014–1015. https://doi.org/10.1126/science.1167755

Duan, J., and Gregory, J. 2003. Coagulation by hydrolyzing metal salts. Advances in Colloid and Interface Science, 100–102, Pp. 475–502. https://doi.org/10.1016/S0001-8686(02)00067-2

Ebeling, J. M., Sibrell, P. L., Ogden, S. R., and Summerfelt, S. T. 2003. Evaluation of chemical coagulation–flocculation aids for the removal of suspended solids and phosphorus from intensive recirculating aquaculture effluent discharge. Aquacultural Engineering, 29 (1–2), Pp. 23–42. https://doi.org/10.1016/S0144-8609(03)00029-3

Brakemi, E., Kinsella, M., Tan, S. P., and Hughes, H. 2023. Phosphate removal from wastewater using scallop and whelk shells. Journal of Water Process Engineering, 55, 104159. https://doi.org/10.1016/j.jwpe.2023.104159

Evans, G., Dennis, P., Cousins, M., and Campbell, R. 2002. Use of recycled crushed glass as a filtration medium in municipal potable water treatment plants. Water Science & Technology: Water Supply, 2(5–6), Pp. 9–16. https://doi.org/10.2166/ws.2002.0144

Jarvis, P., Jefferson, B., Gregory, J., and Parsons, S. A. 2005. A review of floc strength and breakage. Water Research, 39(14), Pp. 3121–3137. https://doi.org/10.1016/j.watres.2005.05.022

John, B. 2016. Coagulation and flocculation in water and wastewater treatment (3rd ed.). IWA Publishing. https://doi.org/10.2166/9781780407500

Jiang, G., Liu, Y., Liu, X., Shen, Y., Zhang, A., and Li, Z. 2023. Enhanced efficiency and mechanism of low-temperature biochar on simultaneous removal of nitrogen and phosphorus by combined heterotrophic nitrification–aerobic denitrification bacteria. Bioresource Technology, 373, 128720. https://doi.org/10.1016/j.biortech.2023.128720

Morse, G. K., Brett, S. W., Guy, J. A., and Lester, J. N. 1998. Phosphorus removal and recovery technologies. Science of the Total Environment, 212(1), Pp. 69–81. https://doi.org/10.1016/S0048-9697(97)00332-X

Laghari, A. N., Walasai, G. D., Jatoi, A. R., Shaikh, F. A., and Siyal, Z. A. 2018. Performance analysis of water filtration units for reduction of pH, turbidity, solids and electrical conductivity. Engineering, Technology & Applied Science Research, 8(4), Pp. 3209–3212. https://doi.org/10.48084/etasr.2100

Logan, B. E., Jewett, D. G., Arnold, R. G., Bouwer, E. J., and O'Melia, C. R. 1995. Clarification of clean-bed filtration models. Journal of Environmental Engineering, 121(12). https://doi.org/10.1061/(ASCE)0733-9372(1995)121:12(869)

Lürling, M., and van Oosterhout, F. 2013. Case study on the efficacy of a lanthanum-modified bentonite (Phoslock) in controlling eutrophication in Lake Het Groene Eiland (The Netherlands). Hydrobiologia, 710(1), Pp. 253–263. https://doi.org/10.1007/s10750-012-1141-x

Mörgeli, B., and Ives, K. J. 1979. New media for effluent filtration. Water Research, 13(10), Pp. 1001–1007. https://doi.org/10.1016/0043-1354(79)90195-7

Parfitt, R. L., and Smart, R. S. C. 1978. Adsorption of mercury(II) by iron hydrous oxide gel. Soil Science Society of America Journal, 42(1), Pp. 48–50. https://doi.org/10.2136/sssaj1978.03615995004200010010x

Rowsell, J. L., and Yaghi, O. M. 2004. Metal–organic frameworks: A new class of porous materials. Microporous and Mesoporous Materials, 73(1–2), Pp. 3–14. https://doi.org/10.1016/j.micromeso.2004.03.034

Sandanayake, M., Bouras, Y., Haigh, R., and Vrcelj, Z. 2020. Current sustainable trends of using waste materials in concrete—A decade review. Sustainability, 12(22), 9622. https://doi.org/10.3390/su12229622

Bai, S., Zhu, Y., Zhang, X., Zhang, H., and Gong, Y. 2010. Enhanced phosphorus removal from municipal wastewater by coagulation with alum and iron salts. Environmental Pollution and Public Health (CBBE Special Track). https://doi.org/10.1109/ICBBE.2010.5517496

Stumm, W., and Morgan, J. J. 1996. Aquatic chemistry: Chemical equilibria and rates in natural waters (3rd ed.). Wiley-Interscience.

Tobiason, J. E., and O'Melia, C. R. 1988. Physicochemical aspects of particle removal in depth filtration. Journal of the American Water Works Association, 80(12), Pp. 54–64. https://doi.org/10.1002/j.1551-8833.1988.tb03150.x

Vierra, B., Coelho, L. H. G., and De Jesus, T. A. 2018. Phosphate sorption in shellfish shell (Venerupis pulastra) substrates: Development of green and low-cost technology for tertiary treatment of effluents. Journal of Environmental Engineering, 145(2). https://doi.org/10.1061/(ASCE)EE.1943-7870.0001489

Wang, D., Wu, R., Jiang, Y., and Chow, C. W. K. 2011. Characterization of floc size, strength, and structure under various coagulation mechanisms. Powder Technology, 168(1), Pp. 104–110. https://doi.org/10.1016/j.powtec.2006.07.003

Zainol, N. A., Khalilullah, P. B., Azlinda, A. G., Najihah, A. R., and Salwa, M. Z. M. 2022. Turbidity removal from kaolin synthetic wastewater via coagulation process using sludge from water treatment plant. International Journal of Integrated Engineering, 14(9). https://doi.org/10.30880/ijie.2022.14.09.028

* * *