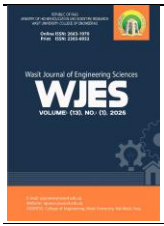

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Original Research

Impact of Operational Parameters on Nitrate Removal Using Fine Powder Brick in Continuous Systems

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ABSTRACT

This research looks at how to constantly remove nitrate from water using fine powder brick, which is a low-cost adsorbent material. The paper addresses the growing concern of nitrate contamination in water sources, particularly from agricultural runoff and industrial discharge, which generates significant health risks such as methemoglobinemia and environmental harm. The main goal of the study is to obsreve how well fine powder brick works under different conditions, like starting nitrate levels (7–21 mg/L), flow rates (4–16 L/hr), and the depth of the adsorbent bed (6–18 cm). Monitoring the effluent-to-influent concentration ratio (Ce/Co) over time showed breakthrough behavior. The results indicated that nitrate removal worked better at slower flow rates, lower starting concentrations, and shallower bed depths because there was more time for the nitrate to come into contact with the adsorbent and a larger area for it to stick to. At a flow rate of 4 L/hr, and a depth of 18 cm, the removal efficiency reached 53%. This work assesses nitrate adsorption utilizing fine brick in a fixed-bed column with dynamic models (Thomas, Yoon-Nelson, and Adams-Bohart). The Thomas and Yoon-Nelson models correlated quite well ($R^2 = 0.9513$), whereas the Adams-Bohart model was superior for mass transfer at the beginning ($R^2 = 0.91$). The findings indicate that the Thomas and Yoon-Nelson models are more precise for comprehensive column forecasts, whereas the Adams-Bohart model is appropriate for preliminary stages.The study emphasized the potential of recycling construction waste as an adsorbent for nitrate removal in continuous systems and provided helpful suggestions for optimizing fixed-bed column operations in real water treatment applications.

Keywords: Nitrates, Aquatic, Adsorbents, Bricks, Continuous

1. Introduction

Fast industrialization, agricultural development, and population growth are driving water pollution, especially in aquatic ecosystems, a major global issue [1]. Among the most damaging to both people and the environment are heavy metals, herbicides, dyes, and inorganic pollutants like nitrates [2]. The common origins of these pollutants are industrial effluents, which can significantly disturb aquatic ecosystems and compromise the water supplies people rely on for many different purposes, including agriculture and drinking [3]. Adsorption has attracted more notice than the other approaches for water treatment due to its efficiency, simplicity, and low cost [4-6]. Generally known as adsorbents, solid items can be physically or chemically modified to capture contaminants by means of adsorption [7]. This process can efficiently remove water tainted with dissolved pollutants like nitrates, heavy metals, and organic contaminants. Fine powders, including activated carbon, clay minerals, and metal oxide powders, are particularly good at absorbing impurities because of their huge surface areas, strong reactivity, and easy availability [8].

Taki et al. [9] looked at activated carbon made from agricultural waste for water nitrate ion filtering. The study found that under continuous flow conditions, activated carbon showed good nitrate removal and great adsorption capacity. By maximizing flow rates and bed depth, they could almost eliminate 90% of nitrates in the continuous adsorption system [9]. Salam et al. [10] conducted a similar investigation using iron oxide nanoparticles as adsorbents to remove nitrate in a continuous flow column. Their results show that because of their great surface area and high affinity for nitrate ions, iron oxide nanoparticles are a great choice for water filtration. It also emphasized increasing removal efficiency by changing flow rates and contact lengths. Belkada et al. [11] also investigated activated alumina for nitrate removal in continuous adsorption systems. Its low cost and recyclable character make activated alumina a potentially helpful material for large-scale nitrate removal. As covered in this paper [12], activated alumina might be a long-term nitrate adsorbent in water treatment. Nitrate pollution of water is a significant environmental problem since it damages aquatic life and human health [13]. Nitrates, which usually originate from agricultural runoff, industrial effluents, and wastewater discharge, can cause groundwater contamination and eutrophication [14,15]. Additionally, nitrates pose general health risks to humans, particularly affecting infants. Nitrate removal has been a main focus in water treatment [16]. The aim of this paper is to remove the nitrate aqueous solution with fine powder adsorbents. Maximizing the efficiency of these processes depends on optimizing operating parameters, including flow rate, bed depth, and regeneration strategies, and the continuous mode is used in this research.

This study presents an innovative methodology by employing recycled construction waste, particularly fine brick powder, as an efficient material for improving removal efficacy in the specified procedure. Prior research has primarily concentrated on materials like carbon, alumina, and iron oxides for analogous applications; however, the utilization of fine brick powder provides a sustainable option that not only repurposes construction waste but also demonstrates promise efficacy in the removal process. This unique portion of our study helps the process be more environmentally friendly and opens up the possibility of finding cheap solutions for use in industry. This makes our approach different from other research in this field.

2. Methodology

2.1. The preparation of nitrate solution

Magnesium nitrate $Mg(NO_3)_2$ is a white solid compound. Being highly water-soluble, magnesium nitrate occurs naturally only in mines and caverns as nitromagnesite (hexahydrate form). The magnesium nitrate used in commerce is made by the reaction of nitric acid and various magnesium salts.

2.2. Brick powder adsorbent

Sourced from nearby building sites, the bricks were crushed and ground into tiny particles, then sieved with a US standard sieve mesh (No. 200) to produce a fine particle size of 0.075 mm. To remove impurities, the particles were rinsed many times with deionized water and then sun-dried for 48 hours. After three hours in an oven at 115°C, the product was dried; the brick particles were kept in a sealed plastic container, as shown in Fig. 1. Table 1 shows the physical properties of fine powder bricks. Figure 1 shows final adsorbent prepared after grinding and drying.

(a) (b) (c)

Figure 1. The preparation of Bricks, (a) At the beginning before drying, (b) After grinding and drying, and (c) The final adsorbent prepared after grinding and drying.

Table 1 show the physical parameters of the burned clay pot, which was used as the adsorbent in this investigation. The material is yellow and has no smell, which shows that it is stable and not volatile. The burned clay pot looks like it is made up of little, even particles, which may help it have more surface area and interact with impurities.

Because the substance doesn't dissolve, it stays stable in water, which makes it a suitable adsorbent for water treatment. The burned clay pot has a lot of free space in its structure, as seen by its void ratio of 1.32 and porosity of 0.60. This high porosity makes it easier for pollutants to stick to the surface, which speeds up the adsorption process. The specific gravity of 2.15 is in line with the fact that burnt clay is rather dense, which makes it more stable mechanically. The most important attribute for this investigation, nevertheless, is the surface area of 1.75 m^2/mg. The burned clay's granular shape shows that it has a lot of surface area compared to its bulk, which makes it better at adsorbing pollutants. The size of the particles and the surface area are very important for determining how well the material works as an adsorbent. This is because they directly affect how much contaminant can be held by each unit of material. In short, the fired clay pot's particle size and surface area, as well as its other physical features, make it a good choice for use in adsorption procedures since they give the most surface area for removing pollutants. Table 1 indicates the physical properties of the bricks.

Table 1. Physical properties of the bricks.

Item	**Property**
Color	Yelow
odor	odorless
Appearance	Grains
Solubility	Insoluble
Void Ratio	1.32
Porosity	0.60
Specific Gravity	2.15
Surface Area	1.75 m^2 /mg

2.3. Continuous experiments

2.3.1. Experimental procedure

1. The breakthrough curves for nitrate ions were established using column testing. Experiments were conducted at different bed depths beneath the surface (L), initial concentrations (Co), and flow rates (Q).
2. An adsorption column was employed to determine the thickness of the intended brick powder adsorbent layer.
3. A solution of nitrate ions with a specified concentration was prepared using distilled water in a feeding trough.
4. Sodium hydroxide or hydrochloric acid was used to adjust the solution's pH to 6.
5. The influent is combined with a centrifugal pump to produce a homogeneous solution.
6. The flow meters were calibrated, and the nitrate ion solution was introduced to the adsorption columns at the specified flow rate utilizing the flow meters.
7. An absorption spectrophotometer was utilized to measure the concentration of nitrate in samples collected at various periods.
8. Graphing the discharge concentration ratio (Ce/Co) versus time was employed to forecast the breakthrough curves.

Figure 2 represents the flowchart for the whole experimental work, and Fig. 3 shows the continuous mode of the experimental setup.

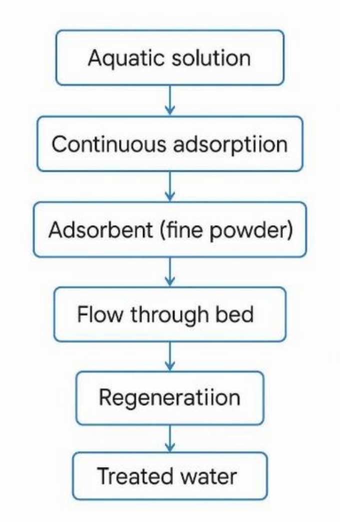

Figure 2. The Flowchart of the Experimental Procedure

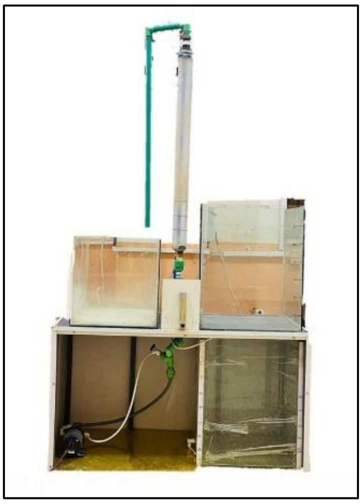

Figure 3. The Continuous Mode for the Experimental Setup

A synthetic nitrate solution was produced by dissolving magnesium nitrate $Mg(NO_3)_2$ in distilled water at a given concentration. The feed tank was the treatment process's principal source, holding the solution. We pumped the nitrate solution from the feed tank up a column. We controlled the flow rate of the solution to maintain a continuous supply throughout the process. As the column passed the nitrate solution, the powdered brick material on the column's surface absorbed the nitrate ions. The adsorption process determines the removal of nitrates from the solution. The wastewater, now treated and with its nitrate concentration reduced, collects in a separate tank. The study tracked the efficacy of the treatment by measuring nitrate concentration in the effluent at regular intervals through sample collection.

A UV-Vis spectrophotometer was used to investigate the nitrate concentrations in the gathered effluent samples. We conducted this measurement to assess the effluent's nitrate reduction level and the removal efficiency of the system. Distilled water was used to flush the whole system when the procedure was complete to remove any remaining nitrate solution from the column and related parts, as well as any impurities. This process emphasizes flow control, material capture, sampling, and result analysis to assess removal performance in running a nitrate treatment system.

It did not repeat the experiments, but we took steps to ensure that the data was accurate and reliable. We calibrated the equipment and kept the conditions the same for each experiment. To determine the accuracy of the measurements, blank and control samples were used. These steps were taken to ensure that the results were trustworthy.

3. Results and discussion

Nitrate is removed by using a continuous-mode adsorbent block made of fine powder, as shown in Fig. 4. The graph illustrates the time-dependent variation in the ratio of the starting concentration (Co) to the nitrate concentration after adsorption (Ce). With a starting concentration of 14 mg/l, a contact time of 60 minutes, and a flow rate of 4 L/hr, Fig. 5 displays the changes in the Ce/Co ratio at different depths. An increasing Ce/Co ratio over time indicates a decreasing nitrate concentration in the solution. The slow increase in Ce/Co suggests that the fine powder brick consistently adsorbed nitrate throughout the system's lifetime. Adsorption, in which an adsorbent takes in contaminants like nitrate ions from their environment and holds on to them, is compatible with this data. Nitrate removal appears to be an ongoing process, according to the results, provided that the adsorbent and nitrate-containing fluid remain in contact.

There are three distinct depths represented by the graph: 6 cm, 12 cm, and 18 cm. These depths correspond to different adsorbent layers or phases in the nitrate solution flow. At a depth of 6 cm, the results demonstrate that adsorption is most effective due to the rapid elimination of nitrate ions. A quicker adsorption rate could be due to the fine powder brick having more surface area exposed to the nitrate solution at the shallow depth. From 12 cm to 18 cm, the rate of nitrate removal drops as the depth grows. Deeper layers' lower contact between the adsorbent material and the solution could explain this; alternatively, it might indicate the saturation of adsorption sites at these depths. The fine powder brick's efficacy as an adsorbent seems to be strongest at the surface, where there is more direct interaction with the solution. Over time and over several depths, continuous mode enables continuous monitoring of nitrate removal performance. The graph's steady increase in the Ce/Co ratio shows how quickly the adsorbent works in these systems, where it keeps interacting with the solution. Using this method ensures that as water flows over the adsorbent, nitrate ions are always removed, preventing any delays and helping to continuously treat water that has nitrate contamination. Fine powder brick has proven to be an effective adsorbent, particularly at the shallower 6 cm depth, where it eliminates nitrate ions more quickly. The fine powder brick's great surface area and porosity most likely cause this problem, as they enable fast nitrate ion adsorption. This method is ideal for situations that require constant cleaning of water with nitrate pollution because it works continuously and uses the adsorbent very effectively. The results of this study agree with earlier work utilizing several adsorbents, including activated carbon and clay minerals, for nitrate removal from aqueous solutions [17]. The differences in how well the adsorbent works at different depths match findings from research that show adsorption rates usually go down as the depth of the adsorbent increases, likely due to factors like less time for contact and less surface area available in the deeper layers.

Similar to the preceding figure, Fig. 6 shows the removal of nitrate employing fine powder brick as an adsorbent under the stated parameters. This figure implies that the concentration of nitrate in the solution drops as the fine powder brick adsorbent interacts with the nitrate solution, hence representing the process of nitrate adsorption onto the adsorbent.

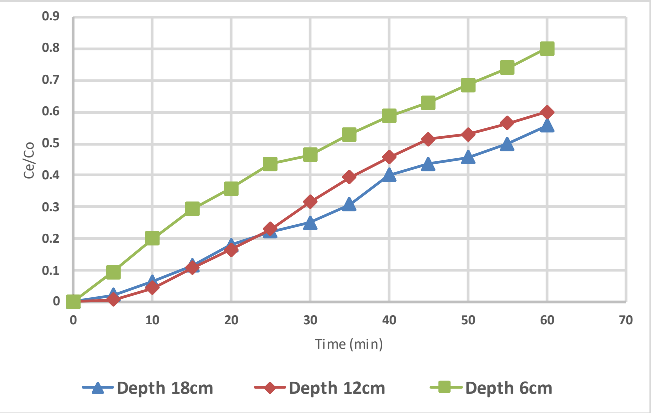

Figure 4. The Relation Between Time and Ce/Co for Different Depths (6, 12, and 18 cm) at Co is Equal to 14 mg/L, Time (60 min), and Flow Rate is Equal to 4 L/hr

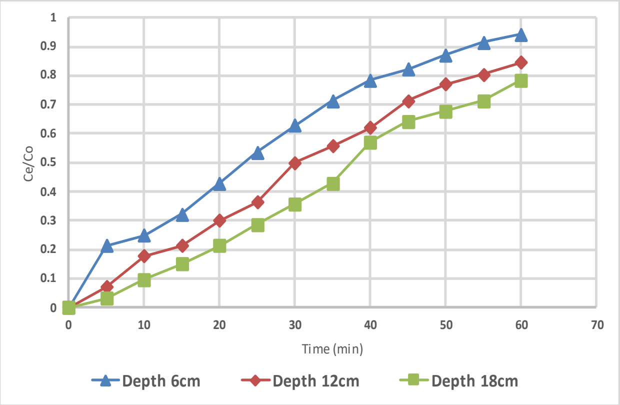

Figure 5. The Relation Between Time and Ce/Co for Different Depths (6, 12, and 18 cm) at Co is Equal to 14 mg/L, Time (60 min), and Flow Rate is Equal to 12 L/hr

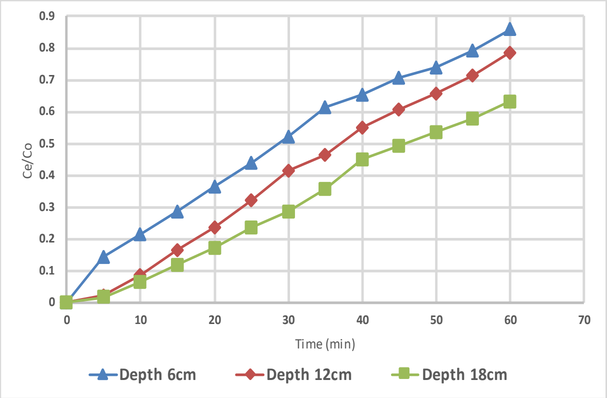

Figure 6. The Relation Between Time and Ce/Co for Different Depths (6, 12, and 18 cm) at Co is Equal to 14 mg/L, Time (60 min), and Flow Rate is Equal to 8 L/hr

For the 6 cm depth, the fastest nitrate adsorption occurs with the greatest rise in the Ce/Co ratio, suggesting that the fine powder brick at this depth is most efficient at removing nitrate throughout the span of 60 minutes. The ratio shows a slight rise at 12 cm, implying a slower but still notable adsorption mechanism. With a smaller rise in the Ce/Co ratio, the nitrate removal rate at 18 cm deep is the slowest. This scenario implies that deeper depths either make the adsorbent material less efficient or have less accessible active sites for nitrate adsorption, which would lower the removal rate. The 8 L/hr suggests a steady flow system; 60 minutes appears reasonable to evaluate the adsorption process. This setup means that the nitrate solution is constantly passed through the fine powder brick adsorbent during the experiment, allowing us to keep an eye on how well the adsorption process is working. Like earlier research on continuous adsorption systems, this setup allows us to assess how well the adsorbent works over time because stable conditions are usually achieved after a certain period. The results of this study match those of other studies examining the effects of adsorbents on nitrate removal. Studies, for instance, have revealed that at deeper depths, they are less efficient due to decreased surface area and interaction with the solution; materials like activated carbon and clay operate swiftly to remove nitrates at shallow depths. Furthermore, the continuous flow approach employed in this study is often used in water treatment systems to guarantee a consistent and dependable removal of contaminants, thereby providing a practical illustration of how environmental engineering functions.

With an initial nitrate concentration of 14 mg/L, a time of 60 minutes, and a flow rate of 12 L/hr, Fig. 5 illustrates how the ratio of Ce/Co (equilibrium concentration) relates to Co (initial concentration) and time at three different depths: 6 cm, 12 cm, and 18 cm. The graph reveals that the ratio of Ce/Co rises with time, suggesting that the nitrate content in the solution falls as the adsorption process advances. The graph clearly shows that the adsorption process happens most quickly at 6 cm depth with the greatest rise in the ratio Ce/Co. At this shallow level, where the surface area exposure is greatest, the fine powder brick appears to be most effective at removing nitrate ions. The 12 cm depth reveals a more gradual rise in the Ce/Co ratio, suggesting modest nitrate removal effectiveness. At last, the 18 cm depth reveals the least increase, implying that the adsorption process is less efficient at this depth, either because of lower contact time or saturation of adsorption sites at deeper depths.

Adsorption efficiency, especially, is usually better at shallower depths because the adsorbent is exposed more to the solution, which enables a faster rate of ion interaction with the material [18]. Deeper depths reduce the accessible surface area for adsorption, hence slowing the rate of adsorption. Data at 12 cm and 18 cm depths reveal this impact; therefore, the nitrate clearance rate is slower.

Under a 14 mg/L initial nitrate concentration, the relationship between Ce and Co at three different depths changes with time, as shown in Fig. 7. The graph suggests that, at this level, the fine powder brick adsorbent is more successful in removing nitrate. This benefit is probably because it interacts with the solution more effectively and has more surface area exposure.

The small increase in the Ce/Co ratio suggests that at 12 cm depth, the adsorption rate is lower than at 6 cm. In any case, deeper slows the pace of nitrate elimination. Since the rise in the Ce/Co ratio is the slowest at this depth, the fine powder block seems less effective at removing nitrate at 18 cm depth. Possible causes are a smaller active surface area or less interaction between the nitrate solution and the deeper adsorbent layers.

At a flow rate of 16 L/hr, the nitrate solution is passing through the system more quickly than in prior testing. An increase in flow rate would reduce contact time between the adsorbent and the solution, which could influence the efficiency of the adsorption process. The data does show a clear trend, though: even if efficiency declines with depth, nitrate removal is still successful at lower levels.

This behavior corresponds to previous studies on adsorption dynamics, which show that faster transit through the adsorbent results from less frequent interaction of the solution with the adsorbent material under higher flow rates. Deeper layers of adsorbent are less exposed to the solution, so their efficacy may be reduced at quicker flow rates [19]. The steady rise in Ce/Co, therefore, indicates that even at faster flow rates, the fine powder block stays efficient in eliminating nitrate. Faster flow rates also imply less contact time, which could lower the adsorption capacity at deeper levels [20].

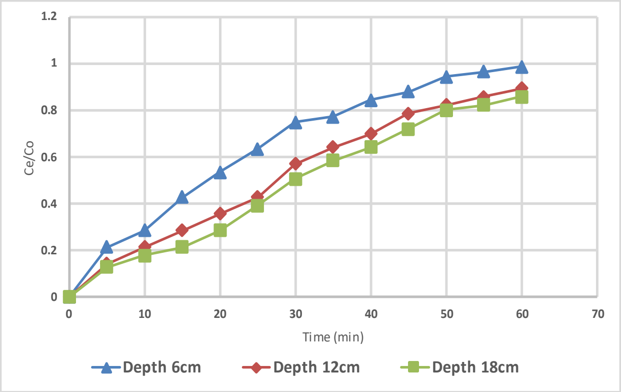

Figure 7. The Relation Between Time and Ce/Co for Different Depths (6, 12, and 18 cm) at Co is Equal to 14 mg/L, Time (60 min), and Flow Rate is Equal to 16 L/hr

Different flow rates at a depth of 6 cm reveal the relationship between time and the ratio Ce/Co in Fig. 8. The graph indicates that a slower increase in the Ce/Co ratio results from greater flow rates. At a flow rate of 4 L/hr, the ratio goes up the fastest, meaning the nitrate solution has more time to mix with the fine powder brick adsorbent, which helps with better adsorption. As the flow rate increases to Q = 8 L/hr, the adsorption rate decreases slightly, and the curve slope flattens. Where the curves show increasingly slower increases in the Ce/Co ratio, the flow rate rising to Q = 12 L/hr and Q = 16 L/hr maintains this trend. The least slope indicates that at the maximum flow rate (16 L/hr), a shorter time for adsorption results in a lower rate of nitrate removal. Longer contact durations typically allow the adsorbent more time to interact with the pollutants in the solution, resulting in more effective adsorption [19]. Faster flow rates lead to a lower overall removal efficiency and less time for nitrate absorption because the solution moves through the adsorbent more quickly.

Higher flow rates result in decreased adsorption capacity since the adsorbent material has less time in contact with the nitrate solution. More nitrate ions can be adsorbed when the flow rate is lower, like 4 L/hr, since the solution stays in contact with the fine powder brick for a longer amount of time. Increasing the flow rate reduces the contact period, thereby limiting the quantity of nitrate the adsorbent can capture at once. This tendency underlines the need to adjust flow rates in water treatment systems depending on adsorption [21] in order to strike a compromise between efficient operation and effective removal.

These findings highlight even more the need for flow rate in continuous flow adsorption systems. Research has shown that quicker flow rates might cause adsorbent saturation, hence compromising its effectiveness, as there is less time for interaction. Knowing the ideal flow rate helps to maximize the removal efficiency of pollutants like nitrate in water treatment systems.

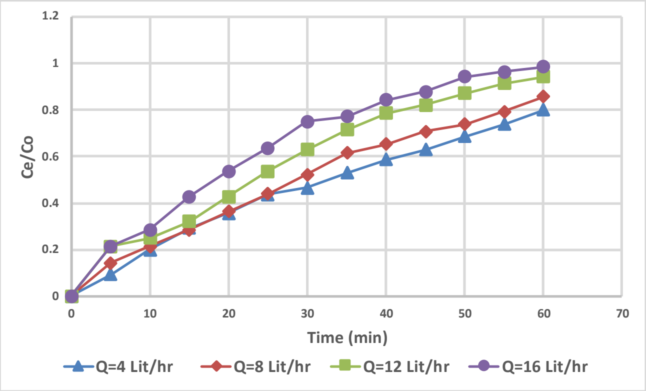

Figure 8. The Relation between Time and Different Values of Flow Rate at Depth is Equal to 6 cm

Starting at 14 mg/L, Fig. 9 shows the relationship between time and the ratio Ce/Co for different flow rates at a depth of 12 cm. Ce/Co rises quickly, though, depending on the flow rate. As indicated by the greatest increase in the ratio, the adsorption process is most efficient when Q = 4 L/hr. This means that at this flow rate, the solution stays in touch with the fine powder brick adsorbent longer, giving more time to remove nitrate ions from the solution. When the flow rate increases to 8 L/hr, the increase in Ce/Co becomes less dramatic, indicating a slower rate of adsorption. A similar pattern applies for 12 L/hr and 16 L/hr; increasing the flow rate causes the nitrate removal rate to drop progressively. The flattest slope on the Q = 16 L/hr graph indicates the adsorbent's lowest efficiency at this fast flow rate. The rate of nitrate removal is reduced when the flow across the adsorbent is accelerated because less time is available for adsorption. Nitrate ion removal efficiency decreases with increasing flow rate because the system has less time to interact with the adsorbent. When the adsorbent is filled quickly at higher flow rates, it can't capture as many nitrate ions because its active sites get used up. Hence, the flow rate–contact time balance should be considered for adsorption process optimization. Operational needs may require faster flow rates, but they must be controlled to maintain nitrate removal efficiency.

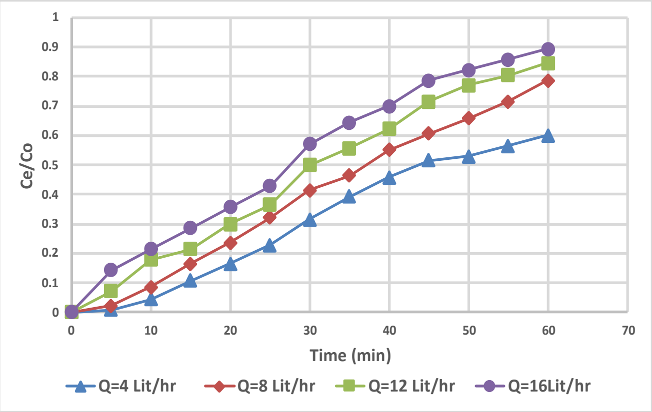

Figure 9. The Relation between Time and Different Values of Flow Rate at Depth is Equal to 12 cm

Figure 10 reveals the link between time and the ratio Ce/Co at a depth of 18 cm. At the lowest flow rate (4 L/hr), the adsorption process shows the most pronounced increase in the Ce/Co ratio. This suggests that the adsorbent contacts the solution for a longer time, hence allowing more effective nitrate removal. The curve's slope reveals that the adsorption rate drops as the flow rate rises to 8, 12, and 16 L/hr. The flattest curve is at a flow rate of 16 L/hr, as there is less time for the adsorbent to operate, indicating that nitrate removal is the least effective. Higher flow rates cause the adsorbent and solution to spend less time in contact, which leads to less effective adsorption and slower nitrate removal.

The Ce/Co ratio is rising at a slower pace at 18 cm depth relative to earlier shallower depths (e.g., 6 cm and 12 cm). The adsorbent's smaller surface area and weaker interaction at deeper levels would likely account for the slower rate of rise in the Ce/Co ratio, which would limit the adsorbent's chances to contact the nitrate ions in the solution [22]. At a depth of 6 cm and a flow rate of 4 L/hr, Fig. 11 depicts the relationship between time and the ratio Ce/Co. The system attains equilibrium more slowly with fewer nitrate ions available for adsorption. The ratio's rate of increase gets steeper when the starting concentration is 14 mg/L, indicating a higher adsorption rate. A larger starting concentration gives the adsorbent more nitrate ions to absorb; therefore, such an increase is to be expected. Reflecting the most efficient adsorption, the rise in Ce/Co and Ce is fastest for C_0 = 21 mg/L since this concentration has the most nitrate ions available for interaction with the adsorbent, therefore accelerating adsorption and a faster drop in nitrate concentration over time.

Lower concentrations mean less accessible ions, which leads to a slower adsorption rate and a longer time to reach equilibrium. The beginning concentration of nitrate, as opposed to the contact duration, which remains constant across the different concentrations, is the main factor driving nitrate removal in this case, considering the constant flow rate of 4 L/hr. The results agree with earlier research indicating that greater initial pollutant concentrations cause faster adsorption [23]. A higher starting nitrate content increases the driving power of the adsorption process, thereby accelerating removal. Studies on water treatment systems have shown that higher concentrations lead to quicker saturation of the adsorbent, resulting in faster equilibrium because there are more ions available for the material to absorb.

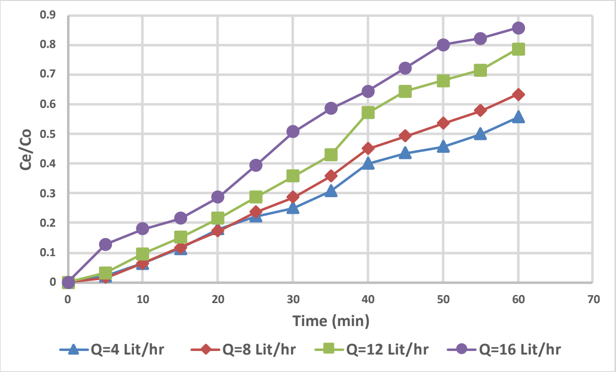

Figure 10. The Relation between Time and Different Values of Flow Rate at Depth is Equal to 18 cm

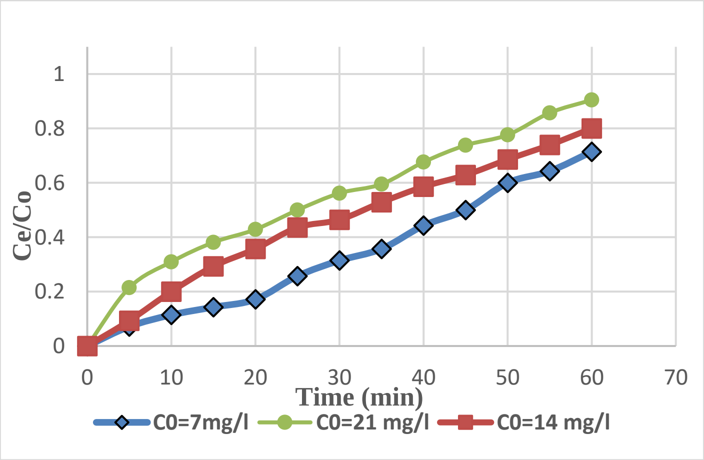

Figure 11. The Relation Between Time and the Different Initial Concentrations at Q is Equal to 4 L/hr and a Depth of 6 cm

Different beginning nitrate concentrations at a flow rate of 4 L/hr and a column depth of 12 cm produce the concentration ratio ce/Co over time, as shown in Fig. 12. This ratio shows the degree of nitrate breakthrough in the effluent in relation to the influent concentration.

According to these results, the adsorbent may maintain its effectiveness for a longer time with lower concentrations of nitrate ions in the system, allowing for relatively low effluent levels to be maintained. In comparison, the data at 21 mg/L shows a quick increase in Ce/Co, suggesting that the adsorbent gets full faster because of the higher amount of nitrate ions. The 14 mg/L case is moderately increasing and lies somewhere in the middle. These patterns fit the theory of adsorption kinetics: an increase in the initial concentration increases the mass transfer driving force, thereby increasing the initial adsorption rate. On the other hand, it causes faster depletion of adsorption capacity [24]. The greater breakthrough values shown at 21 mg/L reflect this behavior since the system's capacity is reached sooner than at lower concentrations. This behavior corresponds with results by Bhatnagar and Sillanpää [25], who underlined that column saturation tends to increase with larger initial pollutant concentrations, lowering the total removal effectiveness over long durations.

The constant flow rate of 4 L/hr also guarantees stable contact duration between the adsorbent and the solution, allowing the starting concentration to be the main influencing element in the breakthrough behavior. Higher concentration levels, indicated by increased Ce/Co values, lead to a greater loss of adsorption efficiency for each unit of adsorbent when the load is heavier. Fig.13 shows how time changes the concentration ratio Ce/Co for three starting nitrate levels 7 mg/L, 14 mg/L, and 21 mg/L. The increase in Ce/Co over time indicates that nitrate is slowly being released as the adsorption sites become full. Ce/Co's rise over time suggests nitrate's slow breakout as adsorption sites get saturated. The increase in Ce/Co at 7 mg/L is the slowest, implying that the adsorbent keeps nitrate effectively because of the smaller ion loading. The breakthrough gets quicker, and Ce/Co climbs faster when the starting concentration increases to 14 mg/L and 21 mg/L, suggesting lower adsorption efficiency. The rise in concentration makes it easier for particles to move, which speeds up how quickly they stick to surfaces and fills up available spots faster. Additionally, earlier studies [30] show that having a depth of 18 cm increases the difficulty for nitrate to be absorbed, especially when there is a higher load. Under the same flow and depth, the efficiency of nitrate removal falls with rising starting concentrations, thereby stressing the need to maximize input concentrations for continuous systems' sustainable adsorption performance.

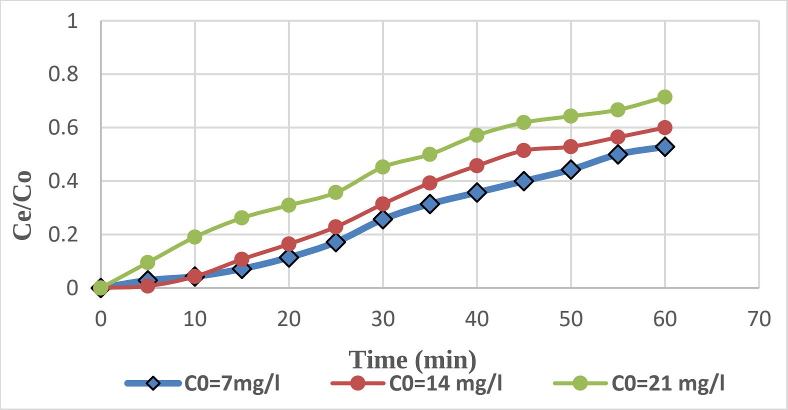

Figure 12. The Relation Between Time and the Different Initial Concentrations at Q is Equal to 4 L/hr and a Depth of 12 cm

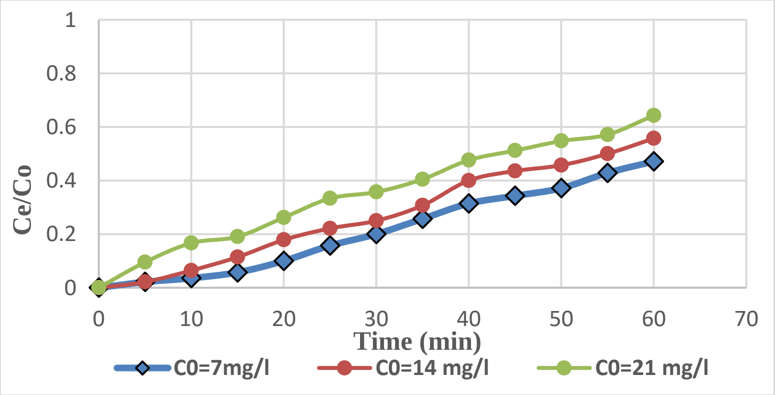

Figure 13. The Relation between Time and the Different Initial Concentrations at Q is Equal to 4 L/hr and a Depth of 18 cm.

To avoid any confusion, it's crucial to know that the Ce/Co ratio, which shows the concentration of effluent to influent, is the opposite of the effectiveness of nitrate removal. A higher Ce/Co ratio means that less nitrate is being removed, which means that adsorption is less effective. On the other hand, a lower Ce/Co ratio means that the removal efficiency is higher, which shows that the fine powder brick adsorbent works well to get rid of nitrates? This relationship is important for understanding the experimental results and figuring out the best conditions for removing nitrate. In conclusion, the fine powder brick adsorbent has a lot of promise for removing nitrates. The results also show that flow rate, nitrate content, and bed depth should all be adjusted for the best results.

4. Modelling of fluidized bed column

In this study, four kinetic models, Thomas, Yoon-Nelson, Adams-Bohart, and Bed Depth Service Time (BDST), were employed to evaluate and predict the adsorption performance of nitrate ions in a fluidized bed column system. These models provide insight into the dynamics of the fixed-bed adsorption process and allow for the estimation of essential design parameters such as breakthrough time, bed saturation behaviour, and adsorption kinetics.

The experiments were conducted under optimal operating conditions previously determined from batch studies. Specifically, the initial nitrate concentration was maintained at 14 mg/L, the flow rate was 4 L/h, the depth is 18 cm, and the grain size of the fine brick powder used as adsorbent was 0.075 mm.

The experimental breakthrough data for nitrate adsorption using fine brick in a fixed-bed column ($C_0 = 14$ mg/L, Q = 4 L/h, bed depth = 18 cm) were evaluated using three common dynamic models: Thomas, Yoon-Nelson, and Adams-Bohart. As shown in Figures 14-17, both the Thomas and Yoon-Nelson models demonstrated excellent correlation with the experimental data, with identical determination coefficients ($R^2 = 0.9513$), confirming their suitability for describing the overall adsorption behaviour under continuous flow conditions. The Adams-Bohart model also showed a reasonable fit ($R^2 = 0.91$), particularly for the initial breakthrough phase.

The fitted parameters for each model are summarized in Table 2, which offers a comparative overview of model performance. The findings suggest that while all three models are applicable, the Thomas and Yoon-Nelson models are more accurate for full-column predictions, whereas the Adams-Bohart model is more suitable for assessing early-stage mass transfer dynamics.

Table 2. Dynamic model parameters for nitrate adsorption in a fixed-bed column (bed depth of 18 cm).

Thomas	**The value**
R^2	0.9513
K_{TH} (L/mg.min)	0.0002
q_m (mg/g)	0.7325
Yoon and Nelson	**The value**
R^2	0.9513
$K_{YN}\ (min^{-1})$	0.0028
τ (min)	898
$\tau_{exp.}$(min)	780
$t_b\ (min)$	210
$t_{exh.(min)}$	1770
Adams-Bohart	**The value**
R^2	0.912
K_{AB} (L/mg.min)	0.00025
N_0 (mg/L)	1619

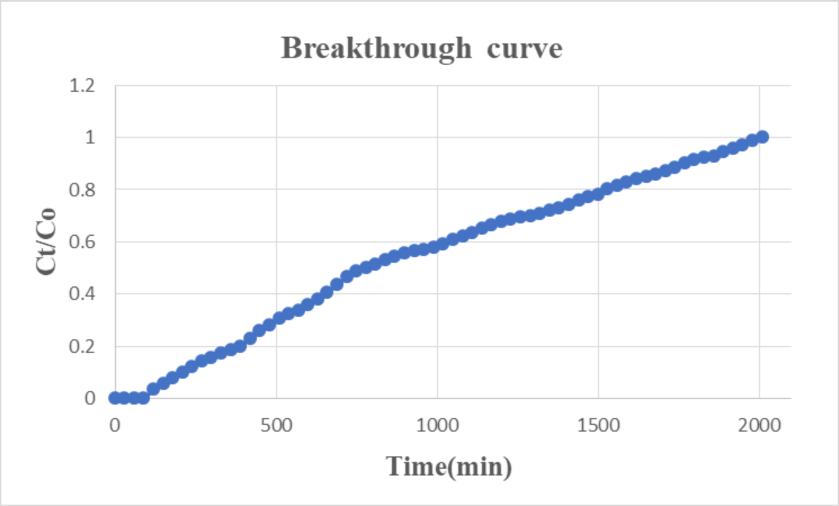

Figure 14. Breakthrough curve for nitrate adsorption using fine brick in a fixed-bed column (C_0 = 14 mg/L, Q = 4 L/h, bed depth = 18 cm).

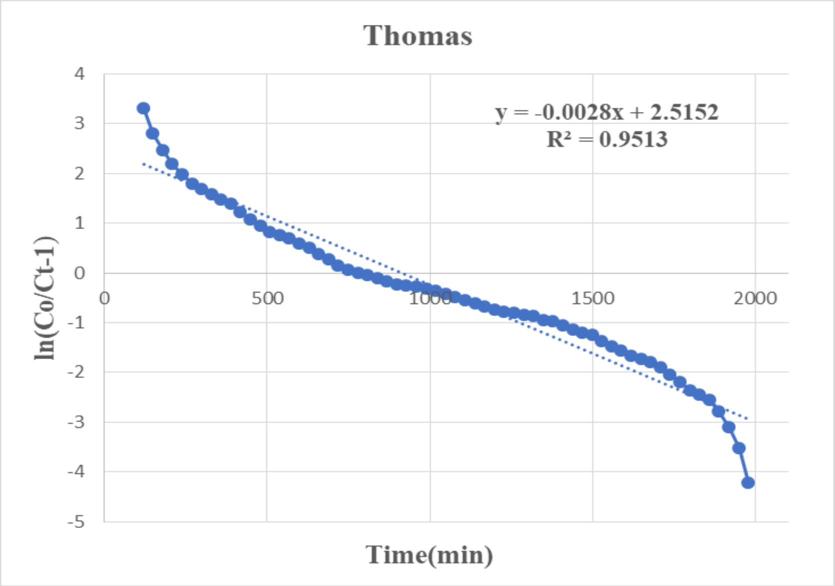

Figure 15. Thomas model for nitrate adsorption using fine brick in a fixed-bed column (C_0 = 14 mg/L, Q = 4 L/h, bed depth = 18 cm).

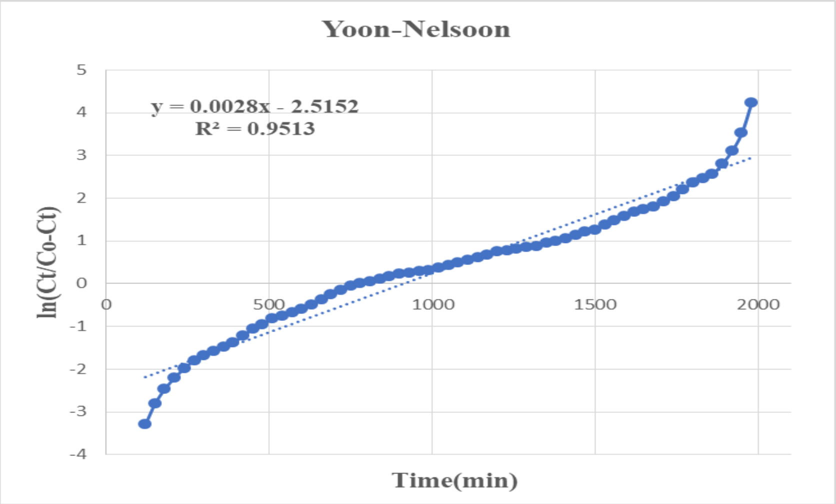

Figure 16. Yoon-Nelsoon for nitrate adsorption using fine brick in a fixed-bed column (C_0 = 14 mg/L, Q = 4 L/h, bed depth = 18 cm).

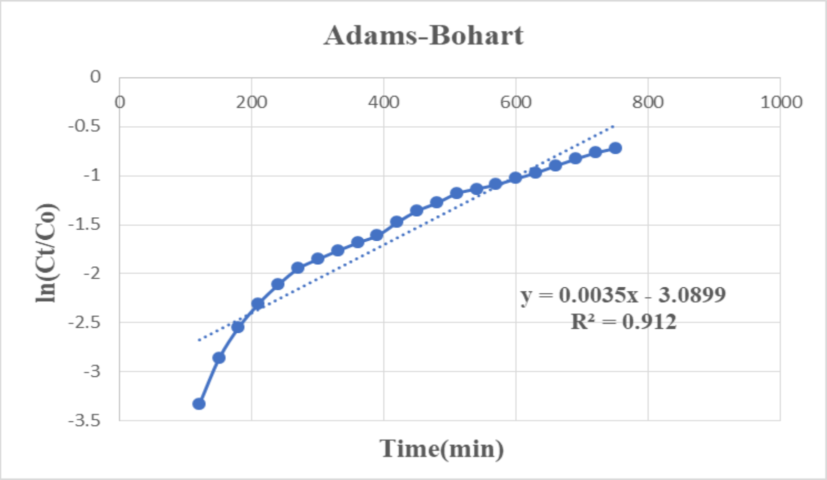

Figure 17. Adams-Bohart model for nitrate adsorption using fine brick in a fixed-bed column (C_0 = 14 mg/L, Q = 4 L/h, bed depth = 18 cm).

Scalability and Long-term Viability: Even though the experiment was done in a controlled setting, it is important to test how well fine powder brick works in bigger, more complicated water treatment systems. In practical applications, factors including changing flow rates, the makeup of the water, and the conditions under which it is used could affect how well fine powder brick adsorbs. Therefore, future research should look into how well the fine powder brick works in pilot-scale or full-scale systems to learn more about how it can be used in real life."

Also, the long-term durability of fine powder brick as an adsorbent should be taken into account, especially its ability to regenerate and how easily it can acquire dirty. Regeneration techniques, such as light chemical or thermal treatments, could restore the fine powder brick's ability to adsorb after many cycles. Fouling is a typical problem in systems that treat water continuously, but the fine powder brick's strength and capacity to be utilized in multi-cycle processes suggest that it could be a suitable choice for long-term use.

Mechanistic Understanding of Nitrate Adsorption: The adsorption of nitrate on fine powder brick seems to include both physical and chemical processes. Electrostatic interactions between nitrate ions and the positively charged surface sites of fine powder brick are probably what cause the physical adsorption. Furthermore, surface functional groups like hydroxyl groups could help chemisorption happen by forming bonds with the nitrate ions. This mix of interactions makes fine powder blocks better at adsorbing things.

Environmental and Sustainability Factors: Fine powder brick is an eco-friendly adsorbent, but there are some environmental concerns that need to be addressed. One important thing to think about is the possibility of harmful substances leaching from the fine powder brick, depending on the materials used to make it. Future studies should include leaching tests to make sure that the material does not release toxic substances into treated water. The byproducts of fine powder brick usage are also minimal compared to other adsorbents, like activated carbon, which need to be regenerated and disposed of often. Using fine powder brick made from recycled construction waste not only effectively removes nitrates, but it also supports sustainability by reducing the need for raw materials and keeping waste out of landfills.

5. Statistical analysis

A regression model was developed using 117 observations, including time, initial nitrate concentration, and bed depth as predictors. The table 3 indicates the important output of the regression model for continuous system. The resulting regression equation is:

$$C_e/C_0 = 0.009 + 0.011\,tim + 0.012\,initial\ concentration - 0.013\,depth \qquad (1)$$

Table 3. Summary of regression model.

R	R^2	$R^2_{adjusted}$	**Tolerance**	**Sig.**
0.98	0.96	0.959	1	0.000

As presented in Table 4.7, Regression Model 1 demonstrated a high correlation coefficient (R=0.98) and a coefficient of determination (R^2 = 0.96, $R^2_{adjusted} = 0.959$) indicating that the model explains more than 96% of the variance in nitrate removal efficiency.

The tolerance value of 1 confirms the absence of multicollinearity among the predictors, while the statistical significance (Sig.= 0.000) confirms that the model is highly significant at the $p < 0.05$ level.

6. Comparing with Other Adsorbents

To further understand how well fine brick powder works, we evaluated how well it removes things and how much it costs to use with common adsorbents like activated carbon and alumina. Previous studies have demonstrated that activated carbon generally possesses substantial adsorption capabilities for a range of contaminants, including nitrates, attributable to its extensive surface area and porosity. The fine brick powder used in this study, on the other hand, shows similar removal efficiency, especially at greater flow rates, while employing a material that is better for the environment and more sustainable.

Fine brick powder has a big advantage when it comes to pricing. Activated carbon and alumina are good at adsorbing things, but they are expensive and typically need special methods to be reused. Fine brick powder, on the other hand, is a cheap option made from old building materials. This not only cuts down on waste, but it also makes large-scale use cheaper. Fine brick powder seems to be a good, cheap replacement for classic adsorbents like activated carbon and alumina. It works just as well at a much lower cost.

In the comparative performance with other adsorbents, the usage of fine powder brick is new, but the paper would be better if it compared it to other adsorbents that are used a lot, like activated carbon or zeolites. It would be helpful to compare how well fine powder brick works against these other materials to see how well it can remove nitrates in terms of both cost and efficiency.

Fine powder brick has shown promising results, but it is important to compare its performance with other common adsorbents like activated carbon and zeolites. These materials are known for their high nitrate adsorption capacities, but fine powder brick may be just as effective at a lower cost. Recent research has shown that activated carbon works well for removing nitrates, but it is expensive and needs to be regenerated often, making it less sustainable. Zeolites, on the other hand, work well in some situations but can take longer to adsorb. Fine powder brick, on the other hand, is an eco-friendly material that is relatively cheap and easy to find, making it a promising alternative.

Z. He et al. [26] stated that this thorough research looks at the possibility of using drinking water treatment sludge (DWTS) in the building and construction materials business. The authors talk about many ways to use DWTS, like mixing it with cement-based products, to make construction processes more sustainable. The study emphasizes the advantages of mitigating environmental risks linked to DWTS disposal and fostering the circular economy within the building industry.

S. Kaewunruen, Y. H. Lin, and Y. Guo [27] reported that for real-time data updates, BIM-Navisworks and a digital twin simulate D.C. townhouse destruction. Optimizing demolition waste classification and transport boosts efficiency and sustainability. Building demolition debris management is supported by the case scenario. Recycling demolition trash improves economic growth, according to BIM-Dynamo. The framework optimises demolition and recycling with BIM, which may affect building waste management laws.

Y. R. Patil et al. [28] reported that as population growth drives urbanization and infrastructure expansion, concrete consumption will approach 50 billion tons of NA by 2025. Over 3.57 billion tons of C&D waste are produced annually. C&D waste recycling helps the environment, circular economy, and sustainable construction. Poor C&D waste management increases soil and water leaching. Construction C&D, structural applications, and RCA prospects and issues are examined in this article. RCA's compressive strength, durability, structural engineering use, and treatment were examined. C&D waste in building reduces trash, improves recycling, and benefits the environment.

7. Conclusions

Three key operating parameters—initial nitrate concentration, flow rate, and adsorbent bed depth—strongly affect the efficiency of nitrate removal using fine powder brick as an adsorbent in continuous flow mode, as clearly shown by the experimental data and graphical analysis presented in this work. Results indicate that lower starting nitrate concentrations (e.g., 7 mg/L) produce greater removal efficacy over a longer period because of slower saturation of active adsorption sites and a lower mass transfer driving force. In contrast, higher starting concentrations (like 21 mg/L) lead to a faster increase in the ratio of the treated water to the incoming water, showing that the system reaches its limit sooner and the adsorbent gets used up faster. Adsorption kinetics theory supports this; it indicates that whereas high concentrations raise the initial absorption rate, they also reduce the adsorbent's service life. At lower flow rates (4 L/hr), nitrate stays in the adsorption bed longer, which means it has more time to interact with the fine powder brick and improves how well it is removed. The contact time reduces as the flow rate rises to 8, 12, and 16 L/hr, which causes a drop in adsorption performance and a quicker increase in Ce/Co. This pattern shows common ideas in fixed-bed adsorption systems, where effectively removing pollutants relies on having enough time for the liquid to stay in contact with the adsorbent.

The depth of the adsorption bed also matters greatly. Shallower depths like 6 cm work better because they have less resistance to movement and allow more of the adsorbent surfaces to contact the flowing solution. Performance gradually declines as depth rises to 12 and 18 cm, perhaps as a result of uneven flow distribution and minimal use of the lower bed areas. Using a lower flow rate (4–8 L/hr) maximizes contact duration and enhances adsorption efficiency. Shallow to moderate bed depths (6–12 cm) should be used to ensure the best use of the adsorbent material and lower internal resistance to nitrate transport. Future research should investigate how solution chemistry, including pH, temperature, and the presence of competing anions like sulphate and chloride, affects nitrate adsorption. Pilot-scale experiments should also be undertaken to confirm laboratory results and direct full-scale uses in agricultural runoff treatment systems or drinking water.

The Thomas and Yoon-Nelson models accurately predicted the full-column behavior of nitrate adsorption in a fixed-bed column. The Adams-Bohart model worked better for figuring out how things were changing in the early stages. It showed that fine brick could be used to continuously remove nitrate from water.

Practical Implications:

The study's findings suggest that fine brick powder could be a good, long-lasting way to purify water, especially in rural places where it's hard to get pricey adsorbents like activated carbon. Fine brick powder, which comes from recycling building waste, is a great choice for large-scale water treatment systems because it is cheap. The fact that it works well to get rid of nitrates, as shown in this study, also means that it might be utilized in small-scale water purification systems. This makes it especially useful for rural areas or places with few resources. Using a recycled material is even more appealing because it is good for the environment and offers a long-term solution to water pollution problems.

Future Research Directions:

Although the present study yields encouraging outcomes, subsequent research must concentrate on expanding the technique to pilot-scale applications to evaluate the practicality of employing fine brick powder in actual water treatment systems. Also, it will be important to look at how competing ions in the water, like chloride or sulfate, affect the removal effectiveness in order to understand how it might be used in different types of water sources.

Another significant area for future research is how to turn fine brick powder back into an adsorbent and use it again. For adsorbents to be useful and cost-effective in the long run, they need to be able to be regenerated. Finding cheap ways to recycle fine brick powder or looking into how it may be used again and again will make it more useful for large-scale use in water treatment systems.

Declaration of Competing Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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Author Contributions

All authors proposed the research problem. In addition to author Khadim T.J. and Jwaid A. collected recent articles and organized them in simple shapes. Authors Khadim T.J. and Jwaid A. verified the recommendation in the proposed work. Authors Khadim T.J. designed and proposed work. Authors Khadim T.J. and Jwaid A. discussed the proposed design. All the authors discussed the results and the final version of this paper.

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