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Research Article

The potential of kaolinite and perlite for the removal of pollutants from wastewater of paint industries

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Abstract

Paint industries constantly produce pollutants that are hazardous to the environment and water. Some clays and rocks can absorb contaminants and reduce environmental pollution. This study was conducted to investigate and compare the potential of kaolinite and perlite for removing pollutants from wastewater in paint industries. The effects of kaolinite and perlite were tested at different times (0, 10, 20, 30, and 60 minutes), dosages (0.3, 0.6, 0.9, 1.2, and 1.5 g), and temperatures (30 ºC, 40 ºC, 60 ºC, and 80 ºC) in a batch equilibration. The removal efficiency of biological oxygen demand (BOD), chemical oxygen demand (COD), sulfate, phosphate, chromium (Cr), cadmium (Cd), copper (Cu), lead (Pb), and silver (Ag) was examined. Increased time, temperature, and dosage enhanced the efficiency of perlite and kaolinite in removing BOD, COD, sulfate, phosphate, Cr, Cd, Cu, Pb, and Ag. Kaolinite showed better results for certain parameters compared to perlite. In conclusion, kaolinite and perlite, at higher dosages, temperatures, and longer contact times, can efficiently remove pollutants. We recommend kaolinite and perlite for the treatment of wastewater from paint industries.

1. Introduction

Water is a natural resource found all over the world and is necessary for human beings. The increase in urbanization and industrialization has led to greater water consumption. Faulty water resources pose a challenge in some countries. Studies have predicted a 40% deficit in water resources by the year 2030 [1]. Rampant industrialization, urbanization, and groundwater contamination are among the most important challenges for water sources. Water pollution is both an ecological and anthropological health hazard. In some countries, pollutants from industrial sectors are released into water bodies, contaminating water sources [2, 3]. Water resources must be managed due to global climate change, population growth, and the increased water demands of agriculture and industry [4]. In addition, potentially toxic elements in contaminated wastewater cause problems, such as bioaccumulation and bio-amplification in the food chain [5, 6]. Paint industries produce contaminants during the cleaning of mixers, reactors, blenders, packing machines, and floors. The discharge of wastewater from paint industries into the environment causes pollution. Pollutants in wastewater from paint industries must be removed.

The processes used to treat wastewater include biological processes (such as built wetlands and activated sludge) [7] and physical processes (like sedimentation and filtration), as well as sophisticated techniques (like membrane filtration and adsorption) [8] and chemical treatments (coagulation and disinfection) [9]. With the purpose of making wastewater safe for reuse or disposal, these techniques try to eliminate impurities and pollutants. Every wastewater treatment technique includes drawbacks, such as the possibility that physical techniques will be less successful in treating dissolved contaminants, the possibility of hazardous byproducts forming from chemical treatments, and the sensitivity of biological processes to changes in the surrounding environment. Advanced methods might not be practical for some applications due to their high maintenance and operating expenses [10-12].

Pollutants are removed from wastewater through conventional water treatment processes such as activated sludge (adsorption), biodegradation, and chemical treatment [13]. Because of its composition and surface charge properties, it is especially good at adsorbing contaminants from aqueous solutions. Kaolinite may adsorb both cationic and anionic species, such as metals and organic contaminants, according to its pH-dependent surface charge [14]. The adsorption process is commonly used to remove pollutants from fluids. Clays are widely used to remove toxic pollutants from contaminated water in some developing countries [4]. Kaolinite, montmorillonite, illite, and perlite are employed for pollutant removal due to their physical properties, such as stability and structure. These minerals are abundant in nature and can remove pollutants through ion-exchange and adsorption processes [4]. Kaolinite consists of silica ($SiO2$) sheets connected by oxygen and alumina sheets. It has a stable structure with a high cation exchange capacity [15]. Important characteristics that affect its adsorption efficacy are its cation exchange capacity (CEC) and specific surface area. Kaolinite's application in environmental remediation has been extensively researched, especially because of its capacity to eliminate a wide range of pollutants from industrial wastewater. Its applicability as a sorbent in wastewater treatment procedures is further highlighted by its abundant availability and potency in removing pollutants [16].

Perlite, an amorphous volcanic alumina-silicate rock, also removes pollutants from wastewater [17]. When exposed to high temperatures, the volcanic glass perlite expands, creating a structure that is incredibly porous. This property increases its adsorption capacity, which makes it appropriate for a number of environmental uses, such as the treatment of wastewater [18]. Chemically, the main component of perlite is silica (SiO_2), with significant amounts of trace elements and alumina ($Al3O_3$) as well. The material's enormous surface area and enlarged porous structure allow for the effective adsorption of a variety of pollutants, including organic and heavy metal contaminants [19]. Perlite has been shown in earlier research to be useful in eliminating harmful materials from industrial effluent, highlighting its potential as an economical and effective adsorbent [20].

Studies have reported the efficiency of perlite and kaolinite in treating wastewater [4, 17], but their potential has not been investigated in the wastewater of paint industries. This preliminary study explores the potential of kaolinite and perlite for the removal of pollutants from paint industry wastewater. The specific aims of the study include evaluating the adsorption efficiency of these materials for various pollutants commonly found in paint industry effluents. Additionally, the study seeks to compare the performance of kaolinite and perlite under different experimental conditions, such as varying pH, pollutant concentrations, and contact time, to determine the optimal parameters for pollutant removal. The research also aims to understand the adsorption mechanisms involved and assess the suitability of kaolinite and perlite as cost-effective and environmentally sustainable adsorbents for industrial-scale wastewater treatment applications. This study is intended to contribute to the development of more efficient and eco-friendly wastewater treatment technologies for industries that produce complex waste streams, such as the paint industry.

2. Materials and methods

2.1. Materials

The clay samples used were prepared from Kermanshah city (Kermanshah, Iran). Kaolinite had

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an area ranging from 10.20 m^2/g and a microporous structure with pore diameters of 1.65 nm. Its cation exchange capacity (CEC) was 7.50 cmol/kg, with a pH between 5.5 and 7. Perlite had a higher surface area 22.5 m^2/g or more, characterized by a macroporous structure with pores between 10 nm and several micrometers in diameter. Perlite had a bulk density of 0.32 g/cm^3 and exhibits a neutral pH, around 6.5 to 7.5. The chemical composition of perlite included silicon (34.52%), aluminum (8.35%), sodium (4.05%), potassium (3.88%), iron (0.95%), calcium (0.73%), and magnesium (0.32%). The chemical composition of kaolinite included SiO2 (58.65%), Al2O3 (23.12%), Na2O (0.12%), K2O (0.35%), Fe2O3 (2.02%), CaO (2.67%), TiO2 (0.05%), and MgO (0.67%). Impurities were removed from the clay samples as described in previous studies [21]. Briefly, 100 g of clay was soaked in 1000 cm^3 of deionized water overnight. The resulting mixture was screened and allowed to settle to remove impurities.

2.2. The evaluation of absorption

To assess the adsorption by kaolinite and perlite, a batch equilibration method was used. We introduced 0.30 g of perlite and 0.30 g of kaolinite into a 300 cm^3 flask containing 60 cm^3 of wastewater obtained from paint industries. The mixture was shaken at 150 rpm using an orbital shaker. The effects of a 0.3 g dosage of kaolinite and perlite were investigated at different times (0, 10, 20, 30, and 60 minutes). To investigate the effect of dosage, varying amounts (0.3, 0.6, 0.9, 1.2, and 1.5 g) of perlite and kaolinite were used in a flask containing 60 cm^3 of wastewater. To study the effects of temperature, 0.3 g of kaolinite and 0.3 g of perlite were added to a 300 cm^3 flask containing 60 cm^3 of wastewater at temperatures of 30 ºC, 40 ºC, 60 ºC, and 80 ºC. The conditions for the time effects experiment were a 0.3 g adsorbent dose, 150 rpm agitation speed, a temperature of 30 ºC, and a pH of 5.84. The conditions for dosage and time effects were the same, with varying doses and times. Biological oxygen demand (BOD), chemical oxygen demand (COD), sulfate, and phosphate were analyzed. The mixtures were filtered, and the indicators were evaluated as reported by APHA (2005). The concentrations of chromium (Cr), cadmium (Cd), copper (Cu), lead (Pb), and silver (Ag) were determined using an atomic absorption spectrophotometer, as described in previous studies [22]. Calibration was conducted for each element. The removal efficiency (%) was calculated as follows:

$$R\ (\%) = \frac{C1 - C2}{C1} \times 100$$

3. Results and discussion

3.1. The effects of time period on removal percentage of biological parameters

The results for the effects of kaolinite and perlite on the removal of BOD, COD, phosphate, and sulfate are shown in Fig. 1. The results indicate that treatment with kaolinite and perlite effectively removed BOD, COD, phosphate, and sulfate 10 minutes after the start of the treatment. The removal efficiency of both perlite and kaolinite increased up to 30 minutes, with kaolinite demonstrating a higher removal capacity compared to perlite during this period. Phosphate had the lowest removal rate.

Fig. 2 shows the effects of kaolinite and perlite at different time intervals on the removal percentage of elements. Both kaolinite and perlite significantly improved element removal as contact time increased, though kaolinite consistently exhibited a higher removal efficiency for all elements. Chromium showed the highest removal rate. Contact time was investigated to determine the equilibrium time for pollutant removal. The removal rate for all parameters was rapid during the first 30 minutes, then continued to increase at a slower rate. Kaolinite had a more pronounced effect on the removal of heavy metals compared to perlite during the first 30 minutes. Similar results have been reported by others [4], where kaolinite was found to have higher adsorption efficiency within the first 10 minutes. The fast adsorption observed within the first 30 minutes could be attributed to the availability of active sites on kaolinite and perlite. The diffusion process typically governs adsorption, and the reduction in adsorption rate could be due to the saturation of active sites by metal ions. The higher adsorption efficiency of kaolinite might be explained by its greater surface area for pollutant adsorption and/or its ability to form bonds with pollutants.

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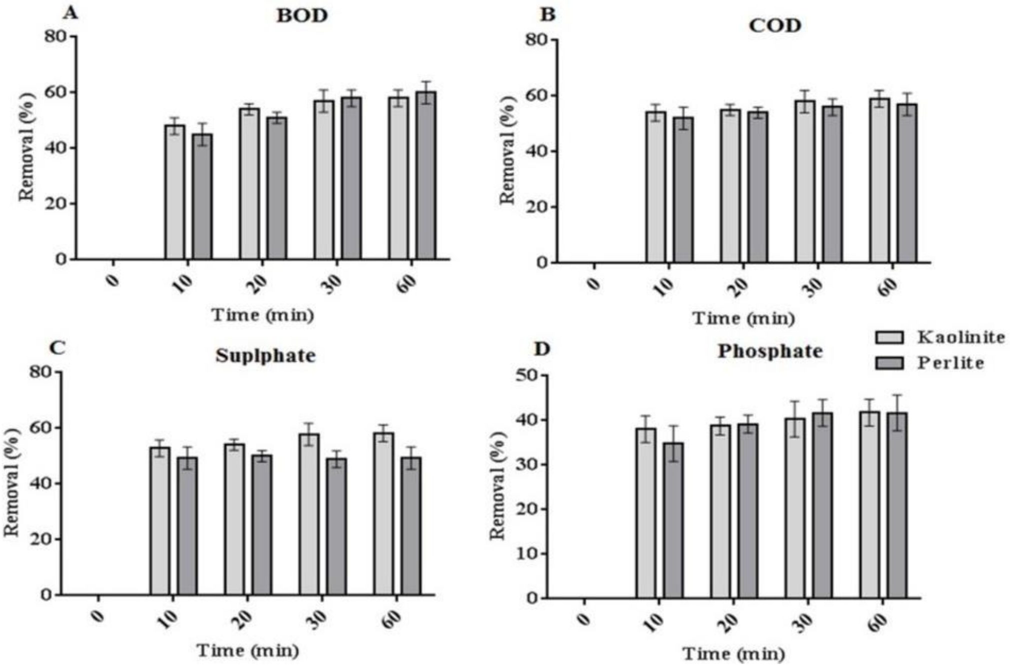

Figure 1. The effects of contact time on the removal percentage of COD, BOD, sulfate, and phosphate using kaolinite and perlite.

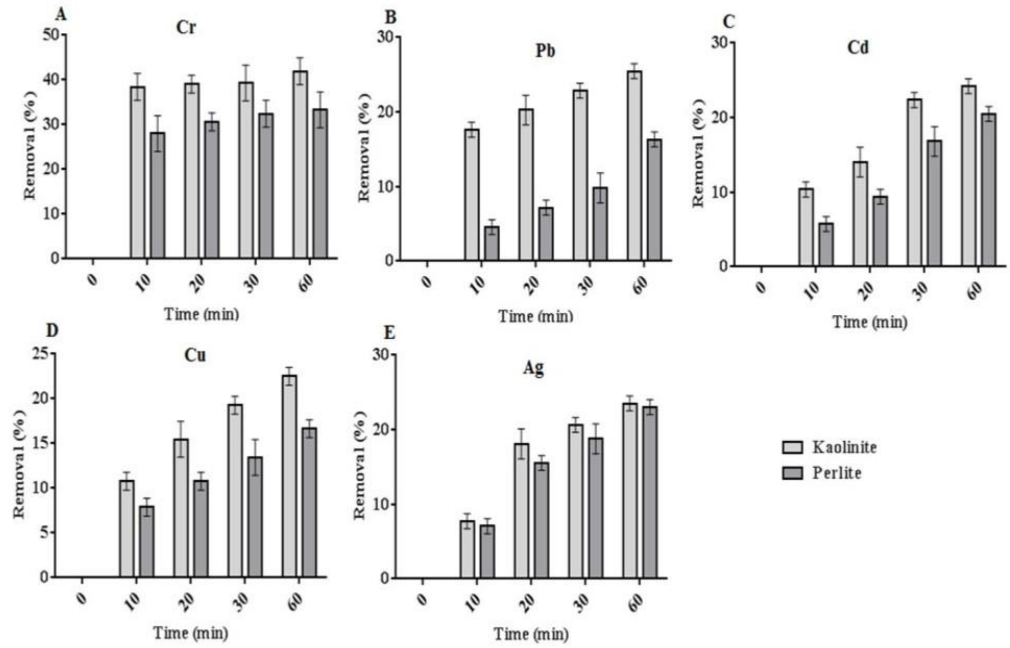

Figure 2. The effects of contact time on the percentage removal of elements using kaolinite and perlite.

3.2. The effects of dosage on removal percentage of biological parameters

Fig. 3 shows the effects of different doses of kaolinite and perlite on biological parameters. As observed, higher dosages of both kaolinite and perlite increase the removal of biological parameters, with the highest removal achieved at a dosage of 1.5 g. Kaolinite demonstrated greater effectiveness in removing biological parameters compared to perlite, with the highest removal observed for BOD and COD.

Fig. 4 illustrates the effects of different doses of kaolinite and perlite on the removal of various

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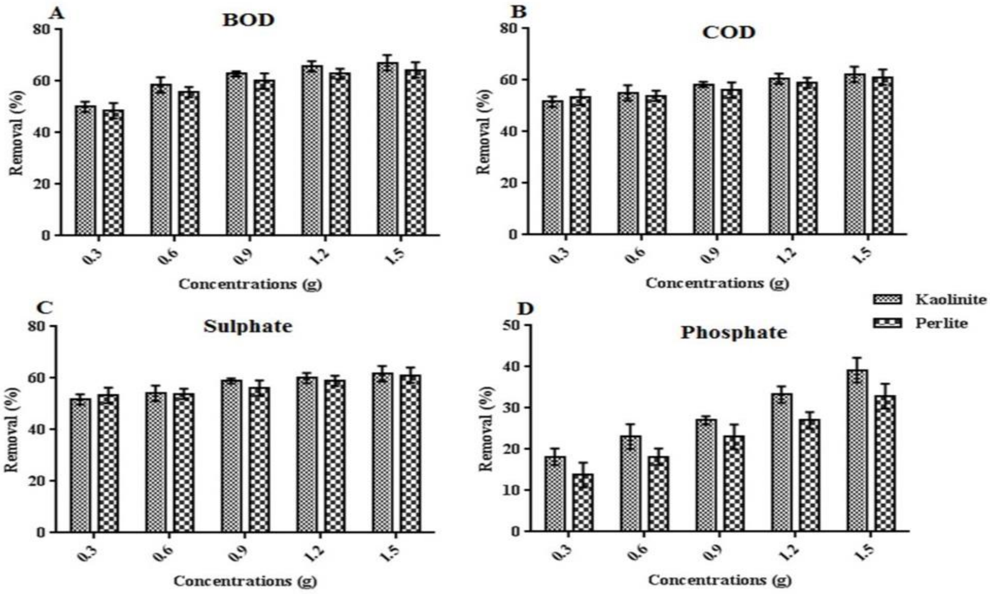

Figure 3. The effects of dosage on the percentage removal of COD, BOD, sulfate, and phosphate using kaolinite and perlite.

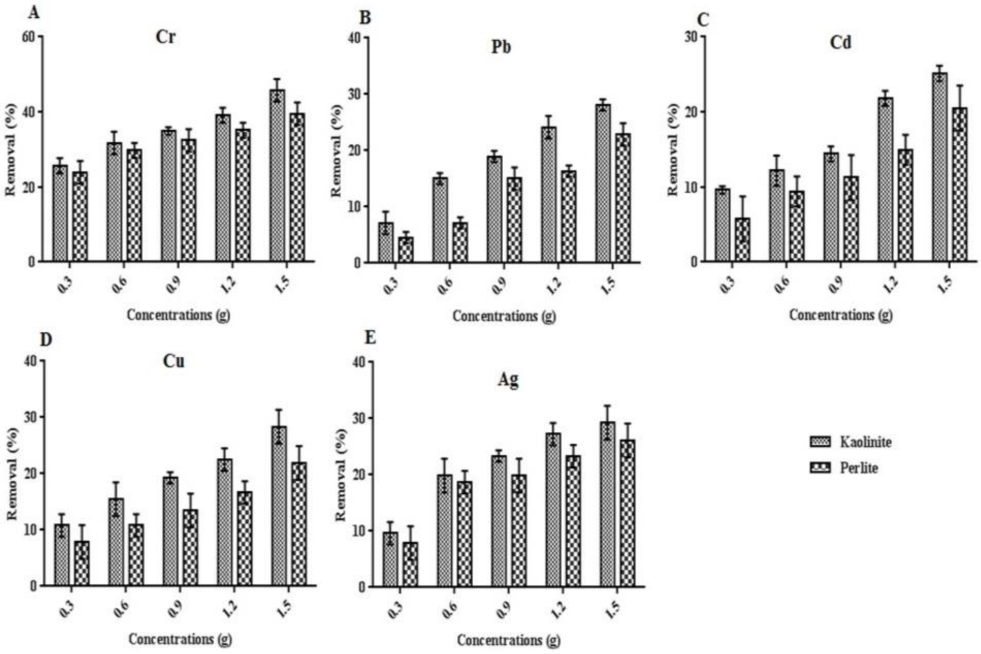

Figure 4. The effects of dosage on the percentage removal of elements using kaolinite and perlite.

elements. Increasing the dosage of kaolinite and perlite enhanced the removal of elements, with perlite exhibiting lower removal efficiency compared to kaolinite. The highest removal was noted for chromium. These findings are consistent with previous studies, which reported similar results. It appears that ion competition influences the adsorption process at lower dosages, while higher dosages enhance adsorption. Increased dosage provides more active sites and surface area for adsorption. Kaolinite, having more active binding sites compared to perlite, adsorbs more contaminants.

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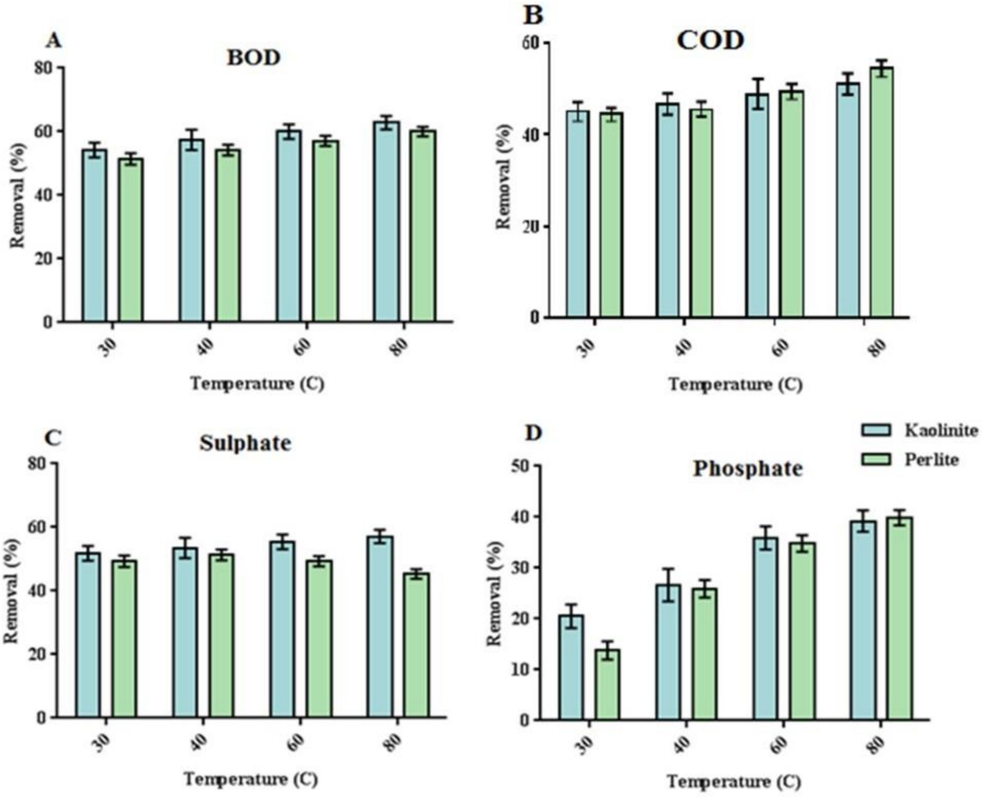

Figure 5. The effects of temperature on the percentage removal of COD, BOD, sulfate, and phosphate using kaolinite and perlite.

3.3 The effects of temperature on the removal percentage of biological parameters

Fig. 5 displays the effects of temperature on the removal percentage of biological parameters. Both kaolinite and perlite demonstrated significant efficiency in removing biological parameters. However, the use of higher dosages of perlite resulted in decreased removal of sulfate at 80 ºC. Kaolinite was more effective than perlite in removing BOD, with the highest removal observed for BOD. While higher temperature can improve the efficiency but there are limitations. A cost-benefit analysis is crucial to balance the efficiency of pollution removal against energy expenditures since elevated temperatures can lead to increased energy prices that can have a substantial influence on operating expenses. Furthermore, a lot of adsorbents have temperature thresholds; greater temperatures can cause thermal degradation, which eventually lowers the adsorbents' effectiveness. Finding a balance between cost and efficiency requires not only investigating alternative approaches that produce comparable outcomes at lower temperature, but also optimizing temperature settings.

Fig. 6 shows the effects of different temperatures on the removal efficiency of kaolinite and perlite for various elements. Increasing the temperature enhanced the efficiency of both kaolinite and perlite in removing elements. Perlite showed lower effectiveness in removing Pb, Cr, and Ag compared to kaolinite, with the highest removal observed for chromium. The results indicate that higher temperatures improve the removal of contaminants. Temperature influences the adsorption process, and both kaolinite and perlite exhibited similar trends, with increased temperatures leading to greater contaminant removal. Similar results have been reported in other studies [4]. Increased temperature raises the kinetic energy of molecules, which enhances the adsorption rates. Higher temperatures also increase the potential interactions between pollutants and active sites, leading to greater dissolution and solubility of pollutants.

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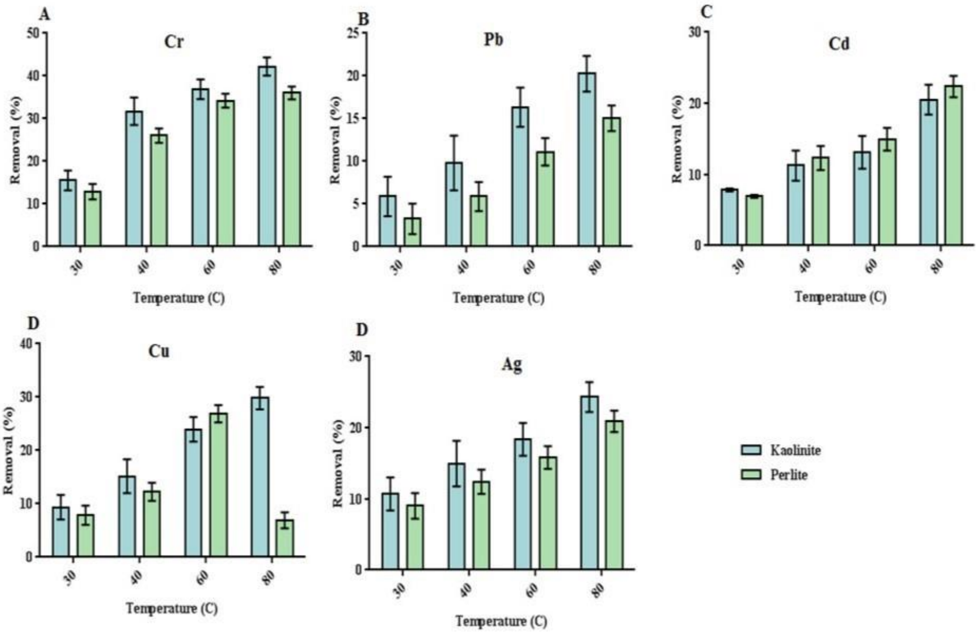

Figure 6. The effects of temperature on the percentage removal of elements using kaolinite and perlite.

In sum, Kaolinite and perlite could decrease the pollutants. Over time, the impurities build up on their surfaces and become immobile due to ion exchange, coordination, or ion-dipole interactions [14]. Both kaolinite and perlite work well to remove contaminants from water through different methods. Because of its high surface area and ability to exchange ions, kaolinite is an excellent adsorbent and is especially useful in the removal of heavy metals and nutrients. Its capacity to flocculate improves suspended particles removal even further. On the other hand, because of its porous nature, perlite effectively filters out organic pollutants through physical filtering and also adsorbed them, preventing the introduction of new pollutants.

Given their adsorption and filtration capabilities, kaolinite and perlite are useful minerals for treating wastewater. Washing and heat treatments can be used to regenerate both, albeit the viability of this process varies depending on the kinds of pollutants and regeneration techniques employed. Both materials have modest initial costs, but regeneration costs can differ depending on the methods selected. Through resource conservation and waste reduction, their reuse can improve sustainability. To determine the overall environmental impact and cost-effectiveness of using regenerated materials in wastewater treatment, a lifecycle evaluation must be performed. The utilization of kaolinite and perlite in wastewater treatment has environmental ramifications that involve managing by-products, sustainable sourcing, and regeneration potential. Although both elements are found in abundance in nature, their extraction can result in emissions from transportation and habitat loss, which should be reduced by using responsible methods. By decreasing waste and lengthening their lifespan, the possibility of regenerating these materials supports the ideas of the circular economy. Nonetheless, effective resource and energy management is necessary for regeneration. Sludge and other byproducts produced during treatment should be closely watched and maybe recycled to avoid contaminating the environment. All things considered, highlighting environmentally friendly methods can strengthen the beneficial effects of kaolinite and perlite on wastewater treatment and environmental preservation.

The study has limitations, such as the adsorption effectiveness of kaolinite and perlite, which can be significantly impacted by the variations in pollutant

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concentrations in actual wastewater. In contrast to well regulated lab settings, real wastewater from the paint industry may have varying pollution levels, which could affect how well these adsorbents work in practical settings. Another drawback is that while perlite and kaolinite may be able to remove some contaminants from an environment, using them may cause dangerous materials to build up and require special handling and disposal of the wasted adsorbents. Large-scale applications may face difficulties in moving from laboratory-scale research, including those related to cost-effectiveness, material availability, and operational viability, all of which must be taken into account for practical implementation.

4. Conclusions

In conclusion, kaolinite and perlite demonstrated significant effectiveness in removing pollutants and heavy metals during the adsorption process. The highest removal efficiencies were observed with longer treatment times, higher dosages, and elevated temperatures. These results provide valuable information for the removal of contaminants in the paint industry. We recommend using kaolinite and especially perlite for the removal of pollutants in paint industry wastewater treatment.

Disclaimer (artificial intelligence)

Author(s) hereby state that no generative AI tools such as Large Language Models (ChatGPT, Copilot, etc.) and text-to-image generators were utilized in the preparation or editing of this manuscript.

Authors' contributions

Both authors contributed equally.

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Availability of data and materials

The data used to support the findings of this study can be obtained from the corresponding author upon request.

Conflicts of interest

The authors declare no conflict of interest.

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