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Thermally activated laterite soil as an adsorbent for phosphate and fluoride removal from contaminated water

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ABSTRACT

The present study examines the efficiency of thermal-activated laterite soil in different grain sizes as an adsorbent for removing phosphate and fluoride ions from contaminated water under laboratory conditions. The fresh laterite was collected from the inner layers of the weathering profile by auger drilling method. Collected soil samples were air-dried to remove the excess moisture content. Air-dried soil was crushed to prepare powdered material (2 and 0.5 mm). Thermally activated soil samples were prepared by heating the laterite at 100°C, 200°C, 300°C, and 400°C for 3 h in a muffle furnace. Adsorption conditions of phosphate and fluoride ions for the soil samples were determined by batch experiments conducted at room temperature and natural pH. Based on the results of studies, 300°C and 400°C (2 and 0.5 mm gran sizes) thermal-activated laterite soil proved to be an effective adsorbent and had higher removal capacities. The phosphate and fluoride removal efficiencies of 300°C activated 0.5 mm laterite soil were 96.46% ± 0.63% and 99.33% ± 0.40%, respectively. Phosphate and fluoride removal efficiencies from 300°C activated 2 mm laterite soil were 92.72% ± 0.60% and 96.80% ± 0.60%, respectively. In contrast, 20 min for 2 mm grain size and 10 min for 0.5 mm were the optimal contact times for maximum phosphate and fluoride ion removal. Phosphate removal efficiency was 91.93% ± 0.24% and fluoride removal efficiency was 92.67% ± 0.24% after 10 min at 300°C, 0.5 mm laterite soil. At 20 min, the phosphate removal efficiency in 2 mm of 300°C soil was 77.88% ± 1.30%, and the fluoride removal efficiency was 81.60% ± 0.31%. 0.75 g of laterite soil was identified as the optimum soil dosage for both grain sizes of phosphate and fluoride removal. The removal efficiency of phosphate and fluoride from 0.75 g, 300°C 0.5 mm laterite soil were 90.08% ± 0.30% and 93.53% ± 0.30%, respectively. Phosphate and fluoride removal efficiency from 0.75 g, 300°C 2 mm laterite soil were 84.88% ± 0.10% and 79.33% ± 0.10%, respectively. The results concluded that the percentage of removal rises with the increase in temperature. In contrast, results revealed that thermal-activated laterite soil has a strong ability to remove phosphate and fluoride from water.

Keywords: Adsorption; Thermal activation; Laterite; Phosphate; Fluoride; Optimum condition

1. Introduction

The existence of elements at toxic levels in waterways creates critical environmental problems for the biodiversity of species and modern human life. Phosphate and fluoride can be present in excess amounts in water due to natural and anthropogenic activities. Heavy use of fertilizer for crops, industrial waste, human and animal sewage is responsible for phosphate accumulation in groundwater and surface

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waters [1]. Water bodies are polluted by phosphate and generate various environmental problems, including algal blooms and eutrophication in aquifers or surface water bodies, depletion of dissolved oxygen in the water.

Eutrophication is one of the common problems in the present world when water sources are observed. In rural areas, where cultivation and animal farming are the leading activities, waste from these actions will increase phosphorus content in water bodies [2]. They may cause possible health hazards due to harmful toxins. Problems with taste and odor occur in increased frequencies when eutrophication potentially affects the quality of drinking water [3] and for humans, algal blooms cause sicknesses [4]. Aside from that, potential effects of eutrophication caused by excessive phosphorus inputs to lakes, reservoirs, rivers, and coastal oceans can also result in the increase of phytoplankton biomass, increase in the number of fish kills, declining species diversity, reduced water transparency, and oxygen deficiency [5].

United Nations Environment Programme (UNEP) summarized global eutrophication problems, and according to them, in Spain, in the 1990s, 80% of lakes, 70% of reservoirs, and 60% of river sites were eutrophic [6]. Countries in central and southern Europe have generally higher proportions of rivers and lakes with high phosphorus concentrations. In order to minimize the catastrophic effects of ingesting polluted water World Health Organization (WHO) recommends to maintain the phosphate level in drinking water at 5 mg/L [7].

The fluoride presence in groundwater has its origin from the dissolution of surrounding geological materials [8]. If taken at a suggested concentration range, it is a needed micronutrient in avoiding dental caries and assisting the mineralization of complex tissues. The higher level of fluoride in groundwater is a global problem, embracing various countries from Africa, Asia, and the USA [9]. The recommended maximum permissible amount of fluoride in drinking water is 1.5 mg/L [7].

Excessive fluoride in drinking water is a critical focus in public health for damaging effects. Dental and skeletal fluorosis arises due to excessive daily fluoride intake from drinking water is typically the most significant for daily fluoride intake [10]. Principally in common fluorosis regions among the less developed states, even though worldwide dental fluorosis remains an unresolved global public health issue [11].

In areas rich in fluoride-containing minerals, well water may contain up to 10 mg/L. Fluoride concentrations in the groundwater of certain hamlets in China were more significant than 8 mg/L [12]. A large-scale survey in China showed that, with drinking water containing 1 mg/L, dental fluorosis was detectable in 46% of the population examined [13]. According to the Ministry of Health, the National Oral Health Survey in 2002 and 2003 of dental epidemiological research on groundwater fluoride and fluorosis in Sri Lanka revealed varying degrees of commonness of dental fluorosis in different parts of the country.

Several technologies have been introduced to improve the drinking water quality. The most common technologies include chemical treatment, precipitation, ion exchange, reverse osmosis, and electrodialysis [14,15]. The most common problems in water treatment are expensive, less effective and generating additional by-products. The precipitation process most commonly used to purify phosphate and fluoride-containing water [16]. The limitation of the process is the daily addition of chemicals, a large amount of sludge production, high total dissolved solids, and high hardness. The iron exchange method is efficient, but it is complicated and high-cost [17,18]. Active carbon is favorable for removing pollutants from aqueous solutions due to its high cost, and irreversible nature usage is limited. Conversely, the adsorption process is better attractive technology due to its convenience, ease of operation, simplicity of design, and economics [19].

Laterite is an excellent adsorbent for phosphate removal and fluoride removal [20,21]. The straight use of laterite without activation is not suitable due to its relatively low sorption capacity. Laterite can be activated to enhance sorption capacity with thermal treatment, alkali treatment, and ultrasonication [22–24]. The practical application of laterite thermal treatment should be the record-fitting one among the activation methods [25].

Laterite soil is one of the major soils extensively present in hot, humid regions and subtropical climates, inter-tropical areas such as Africa, Australia, India, South-East Asia, and South America. Laterite generally occurs just below the surface of grasslands or forest clearings [26,27]. Laterites are the most greatly weathered soil and formed through weathering processes to form iron, aluminum, manganese, and titanium oxides. Weathering breaks down silicate minerals into clay minerals such as kaolinite and gibbsite. The major features of lateritic soil are their distinctive color, poor fertility, high clay content, and cation exchange capacity. In addition, lateritic soil retains a great amount of iron and aluminum oxides. Therefore, removing phosphate and fluoride using thermally activated laterite through adsorption can be effective, practical, and worth solving the problem of phosphate and fluoride contamination in water. The objective of this study is to investigate the adsorption features of an inexpensive thermally activated laterite soil material to remove phosphate and fluoride from contaminated water. Materials were tested and characterized to remove phosphate and fluoride from water to cover the objective.

2. Material and methods

2.1. Sample collection and material preparation

Laterite samples were collected as composite samples from southwestern Sri Lanka and packed in zip-lock polyethylene bags to minimize contamination. The sample collected in the wet zone has extensively developed in situ weathered laterites with lesser contamination. The collected samples were gently washed using distilled water to remove impurities and air-dried for 48 h to remove excess moisture. The dried laterite was ground and sieved using 0.5 and 2 mm. Thermally activated soil samples were prepared by heating the laterite at 100°C, 200°C, 300°C, and 400°C for 3 h in a muffle furnace.

Analytical grade chemicals and solvents were used for all experiments to maintain the accuracy of the results. Phosphate and fluoride solutions were prepared by dissolving potassium phosphate dibasic anhydrous (K_2HPO_4)

[21,28] and sodium fluoride (NaF) [9,29] in distilled water, respectively.

2.2. Physiochemical analysis for raw laterite

Scanning electron microscopy was used to examine the surface morphology and structure of the laterite soil sample. The analysis was carried out utilizing a Hitachi S-4200 field emission scanning electron microscope (SEM) and gold-sputtered soil samples mounted on the SEM sample holder with double-sided conductive carbon tape. At a steady current of 25 mA, gold sputtering of ground soil was accomplished [30].

X-ray fluorescence spectrometry (RIX 2000) was used to analyze the chemical composition of the laterite soil sample at the National Gem and Jewellery Research and Training Institute in Sri Lanka. For 60 s, powdered samples were compressed into briquettes with a force of 200 kN [21,31]. The most important oxides and trace elements were then analyzed in the briquettes. The average relative error for these elements was less than 10%. [32].

At the University of Sri Jayewardenepura in Sri Lanka, an X-Ray diffractometer Rigaku TTRAX III XRD equipment was used to examine the laterite soils. Cu K (alpha) radiation and wavelength (1.54 A) over 2 (theta) of 5–700 with a step size of 0.020/s were used to study the powdered samples, which are relevant factors for the clay mineral observations [33].

The behavior of adsorption sites in laterite soils was studied using Fourier-transform infrared spectroscopy (FTIR) analysis. The soil samples are placed directly on the ZnSe crystal of the equipment, an FTIR Thermo Nicolet iS10, in the spectrum range of 4,000–400 cm^{-1}, with 16 scans and 2 cm^{-1} resolution, in the spectral range of 4,000–400 cm^{-1} [30].

2.3. Adsorption experiment

The stock solutions for phosphate and fluoride were prepared by dissolving weighed chemicals to produce a concentration of 1,000 ppm. The solutions used in batch experiments were produced by diluting the stock solution to different initial concentrations. All solutions were prepared using distilled water. The adsorption studies of phosphate and fluoride with laterite soil were carried out using a series of batch experiments using 50.0 mL solutions of 5 ppm initial phosphate and fluoride concentration. The effect of the temperature, contact time, and adsorbent dosage were studied to investigate the optimum conditions.

The percentage removal efficiency of phosphate and fluoride from aqueous solutions was calculated using the following equation.

$$\text{Percentage Removal efficiency} = \frac{(C_0 - C_e) \times 100}{C_0} \tag{1}$$

where C_0 is the initial phosphate or fluoride (ppm) concentration, and C_e is the equilibrium concentration of the phosphate or fluoride (ppm). The experiments were conducted in triplicates under similar conditions.

2.4. Batch adsorption studies

2.4.1. Determination of the optimum activated soil temperature

Initial phosphate and fluoride concentration was prepared to 5 ppm. 50.0 mL of the phosphate solution was added to 1 g of 0.5 mm and 2 mm of 100°C, 200°C, 300°C, and 400°C thermally activated laterite soil to identify the optimum activated soil temperature. The solutions were shaken at 120 rpm for 3 h at room temperature under natural pH conditions. After 3 h, the solid phase was separated by using centrifugation at 4,000 rpm for 10 min, and then solutions were filtered by millex-GP syringe filter unit pore size 0.22 μm. Concentrations of remaining phosphate were determined in supernatants immediately by the Hach DR900 Multiparameter Portable Colorimeter. This procedure was carried out for fluoride samples, and the remaining phosphate and fluoride concentrations were measured.

2.4.2. Determination of the optimum contact time

Fifty milliliters of 5 ppm phosphate solution were mixed with 1 g of 0.5 and 2 mm of 300°C, and 400°C activated soil, and optimum contact time were observed at different time intervals (10, 20, 30, 60, 90, 120, 150 and 180 min) to find out the optimum contact time. The solutions were shaken at 120 rpm at room temperature and natural pH conditions. The solid phase was separated by using centrifugation at 4,000 rpm for 10 min, and then solutions were filtered as mentioned above. Concentrations of remaining phosphate were determined in supernatants by the Hach DR900 Multiparameter Portable Colorimeter. This procedure was carried out for fluoride samples, and the remaining fluoride concentrations were measured.

2.4.3. Determination of the optimum thermally activated soil dosage

The determination of optimum thermally activated soil dosage of phosphate and fluoride adsorption was studied with an initial phosphate and fluoride concentration of 5 ppm and by adding the varying adsorbent dosage (0.1, 0.25, 0.5, 0.75, and 1 g). The mixtures were shaken with a speed of 120 rpm using a shaking assembly at room temperature and natural pH for 10 min for 0.5 mm and 20 min for 2 mm soil particle size. Then the solid phase was separated by using centrifugation at 4,000 rpm for 10 min, and then solutions were filtered by millex-GP syringe filter unit pore size 0.22 μm. The concentrations of remaining phosphate and fluoride were determined in supernatants by the Hach DR900 Multiparameter Portable Colorimeter.

3. Results and discussion

3.1. Characterization of the raw laterite soil samples

The raw laterite soil samples were examined by X-ray diffraction (XRD), X-ray fluorescence (XRF) spectrometry, scanning electron microscope-energy-dispersive X-ray spectroscopy (SEM-EDX), and Fourier-transform infrared spectroscopy (FTIR).

The laterite XRD studies revealed clay minerals such as goethite, gibbsite, quartz, kaolinite, and hematite (Fig. 1). Previous studies have been found comparable outcomes for laterite soil [31,34,35]. The XRF analysis was done to recognize the composition of raw laterite soil samples and the most abundant are summarized in Table 1. For laterite, 33 elements and compounds were recognized. In the samples, Fe was the greatest common element (65.1%). Other than that, Al and Si were also rich. Al_2O_3 and Fe_2O_3 also existed in great quantities. Additional noticed compounds consist of, TiO_2, CaO, and K_2O.

Laterite soil's adsorption surface has a very much porous arrangement with heterogeneous texture. The outward morphology of laterite soil presents a flaky-shaped constituent part in SEM analyses. The ordinary laterite is consolidated clay, typically forming blocky structures (Fig. 2). The EDX analyzed laterite samples have very little organic matter and inorganic carbons. The samples mostly contained aluminum, silicon, and iron, which accounted for the total mass the lesser quantity of trace elements (Table 2). The outcomes are comparable to prior studies by Vithanage and his team [35]. In the OH stretching vibration region (3,700–3,300 cm^{-1}), the FTIR spectra (Fig. 3) indications three absorption bands (3,688; 3,619 and 3,419 cm^{-1}). The stretching modes of OH bands correlated to free water (around 3,600 cm^{-1}) and the bending mode of the H–O–H band (around 1,643 cm^{-1}) were also visible (1,645 cm^{-1}). The band at 3,688 cm^{-1} can be attributed to stretching vibrations of outer hydroxyl groups synchronized to iron, aluminum or silica existing in laterite [36], and the band at 3,619 cm^{-1} can be allied with inner hydroxyl groups. The absorption band near 3,419 cm^{-1} is described by the hydroxyl bonded to trivalent cations such as Al^{3+} or Fe^{3+}. For that reason, the bands at 3,419 cm^{-1} point out some quota of Al^{3+} or Fe^{3+} in the octahedral layer of laterite. In the area of 1,200–900 cm^{-1}, the bands in the region 1,113; 1,024; 998 and 908 cm^{-1} are due to them being there of Si–O–Fe, Al–OH, Fe–OH vibrations bands placed at 788 and 908 cm^{-1} may be recognized to Si–O bonds connected with trivalent cations (e.g., Al^{3+} and Fe^{3+}). Thus, the occurrence of absorption bands at 788, and 908 cm^{-1} specifies the existence of tetrahedrally coordinated trivalent cations in laterite. The band at 541 cm^{-1} denotes the presence of Fe–O bond stretching [30].

3.2. Effect of temperature

Figs. 4 and 5 show the removal efficiencies of 0.5 mm and 2 mm of activated laterite soil for 5 ppm of phosphate and fluoride solutions along with different activation temperatures. The removal efficiency was increased with the increase in activation temperature. When the activation temperature of laterite soil is increased from 100°C to 400°C in 0.5 mm and 2 mm grain size, the amount of phosphate removal efficiency increases from 89.94% ± 1.36% to 97.18% ± 0.37% and 89.80% ± 2.61% to 97.87% ± 0.43%, respectively. The efficiency of fluoride removed by laterite soil increases from 96.8% ± 1.20% to 98.8% ± 2.00% and 94.6% ± 1.30% to 97.87% ± 0.30% with increases in activation temperature from 100°C to 400°C in 0.5 mm and 2 mm grain sizes, respectively. The highest removal efficiency was seen in 0.5 mm and 2 mm grain size laterite soil, activated at 400°C in both phosphate and fluoride

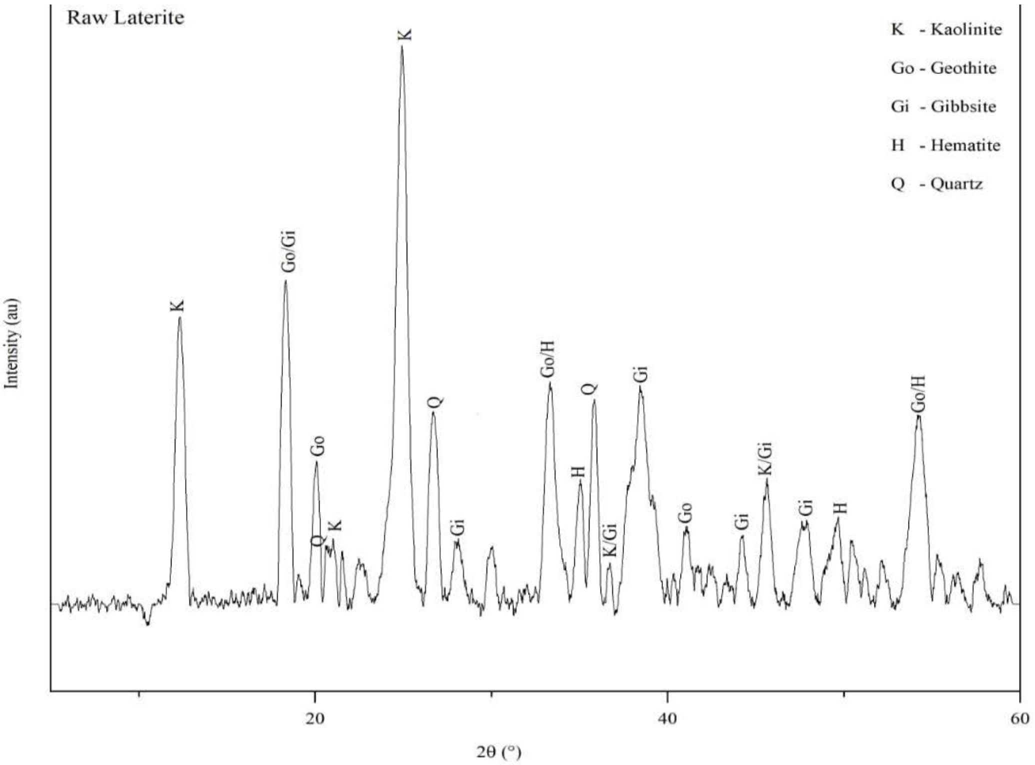

Fig. 1. XRD patterns of raw laterite.

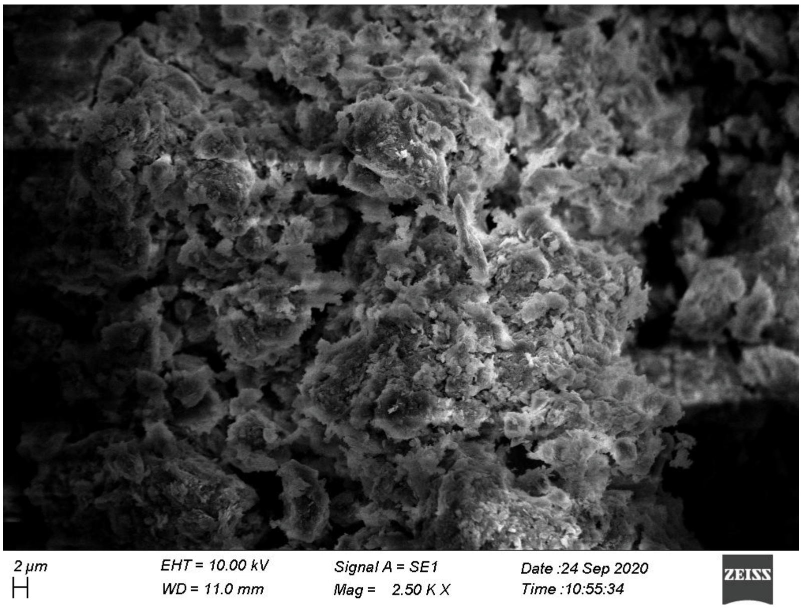

Fig. 2. Photomicrographs by SEM of raw laterite.

Table 1
X-ray fluorescence results of elements and minerals in raw laterite soil samples

Minerals/wt.%	Average	Min.	Max.	SD
SiO_2	44.6	44.3	44.8	0.252
Al_2O_3	33.1	32.9	33.5	0.321
Fe_2O_3	19.0	18.8	19.3	0.265
TiO_2	2.32	2.31	2.34	0.015
K_2O	0.167	0.162	0.171	0.005
CaO	0.078	0.07	0.085	0.008
Minerals/wt.%				
Fe	65.1	64.6	65.8	0.643
Al	16.0	15.8	16.3	0.289
Si	15.1	14.7	15.6	0.473
Ti	1.9	1.87	1.91	0.023
Zr	1.0	0.984	1.00	0.009
Tb	0.3	0.196	0.347	0.076
Co	0.2	0.181	0.201	0.010
Gd	0.2	0.164	0.175	0.008
K	0.1	0.129	0.131	0.001
V	0.1	0.085	0.088	0.002

Table 2
EDX results of raw laterite

Elements	Weight %
C	3.04
O	55.01
As	1.11
Al	20.32
Si	18.78
Ti	0.59
Fe	1.15

(more than 97%). 300°C laterite soil showed more than 92% removal efficiency in phosphate and more than 96% removal efficiency in fluoride.

Zhang et al. [28] showed with the increasing temperature, the phosphate adsorption capacity and removal increases by the laterite sample and Gomoro et al. [9] observed the highest fluoride removal efficiency and removal capacity in the laterite soil sample treated at 400°C. According to Osei et al. [37], when the samples were pre-treated at 400°C, the performance of laterite improved in removing fluoride from water. The high performance of laterite soil is attributed to the de-hydroxylation of kaolinite, goethite, and muscovite minerals, during heat treatment, which increased the surface area and thus enhanced the adsorption properties of the laterites.

3.3. Effect of contact time

Figs. 6 and 7 show the removal efficiencies of 300°C and 400°C with 0.5 and 2 mm of activated laterite soil for 5 ppm phosphate and fluoride solutions along with different time intervals, respectively. 300°C and 400°C of 0.5 mm of activated laterite soil showed around 90% removal efficiency, followed by a higher consequent removal rate at the beginning that gradually came up to a constant. The solution adsorption initiates the fast removal at the start, while the rate tends to be slightly slowed down with the saturation of the adsorption sites at the late hours in all cases. This phenomenon might be due to the presence of a more significant number of active sites for the adsorption of ions during the initial stages. 0.5 mm grain size laterite was showed higher removal efficiency than 2 mm laterite grain size due to high surface area in all cases. Removal

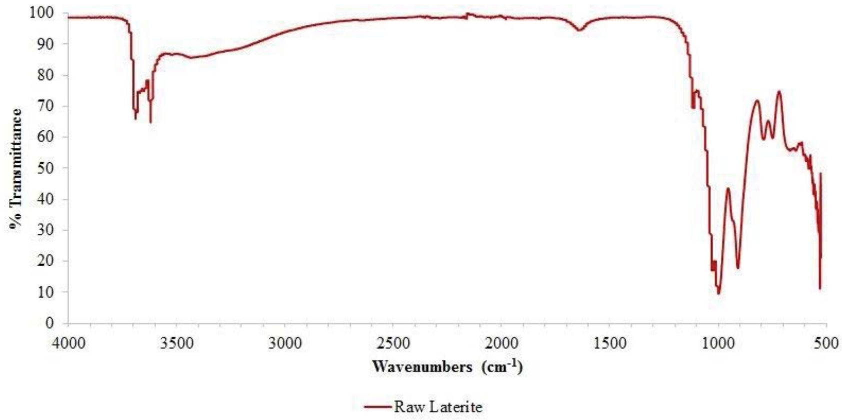

Fig. 3. FTIR Spectra of Raw Laterite.

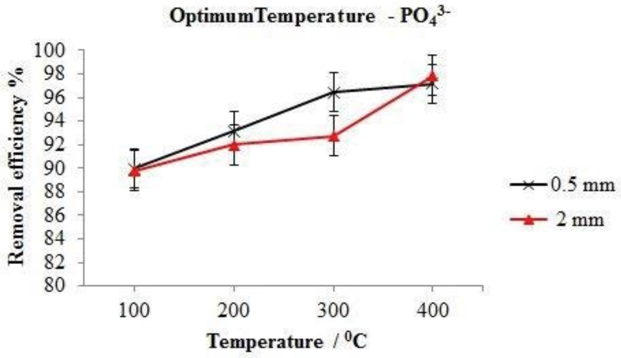

Fig. 4. Determination of optimum temperature of phosphate.

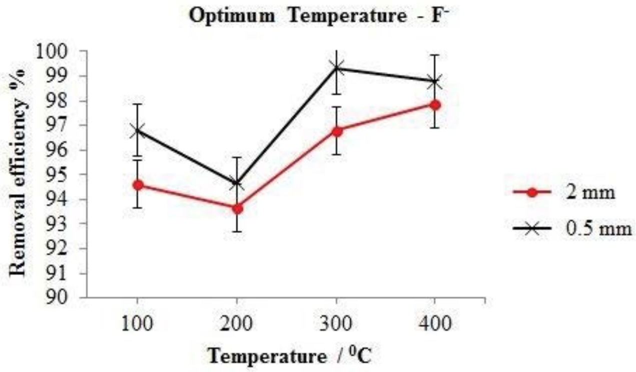

Fig. 5. Determination of optimum temperature of fluoride.

efficiency remains above 90% after 10 min in 0.5 mm and around 80% after 20 min in 2 mm in both phosphate and fluoride solutions both.

At 10 min, 300°C, 0.5 mm laterite soil had a phosphate removal efficiency of 91.93% ± 0.24% and 400°C 0.5 mm laterite soil had a phosphate removal efficiency of 92.67% ± 1.48%. At 20 min, the phosphate removal efficiency in 2 mm of 300°C and 400°C laterite soil was 77.88% ± 1.30% and 75.87% ± 1.21%, respectively. At 10 min, the fluoride removal efficiency of 300°C, 0.5 mm laterite soil was 92.67% ± 0.24% and that of 400°C, 0.5 mm laterite soil was 95.60% ± 0.35%. At 20 min, the removal efficiency of fluoride in 2 mm of 300°C and 400°C laterite soil was 81.60% ± 0.31% and 85.80% ± 1.13%, respectively.

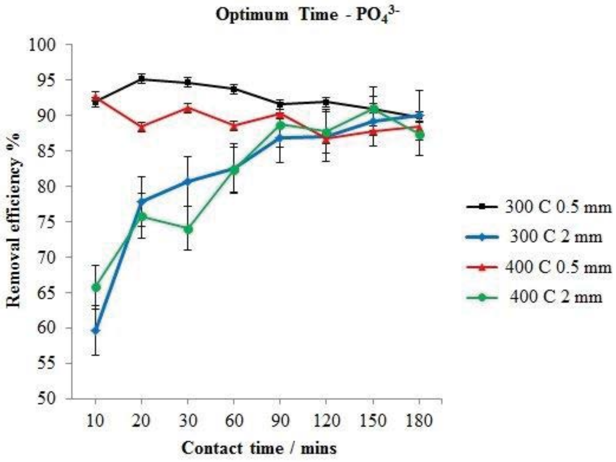

Fig. 6. Determination of optimum contact time of phosphate.

Zhang et al. [28] revealed that with the reaction time increasing, the phosphate adsorption capacity increases step by step until it reaches equilibrium. Sreekumar et al. [38] showed removal efficiency of phosphate was found to increase with the increase in contact time. According to Bhattacharjee et al. [39], laterite soil adsorbs 69% of phosphate in 120 min. Patil Mansing and Raut [40] demonstrated that 120 min was sufficient time to achieve maximum phosphate removal by laterite soil, which was approximately 75%. Sarkar et al. [41] demonstrated that the amount of fluoride adsorbed by laterite soil increases with time. Gomoro et al. [9] indicated that fluoride removal efficiency rises with an increase in contact time. On the other hand, the increase was not important for longer contact times. This pointed out that, longer contact time has not as much significance since the reaction is fast during the initial minutes.

According to the test results, the removal efficiency of phosphate of 300°C and 400°C 0.5 mm laterite at 10 min of contact times has no significant difference with other contact time.

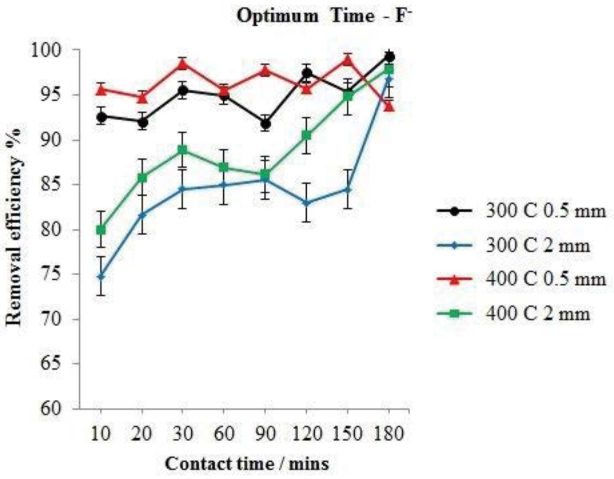

Fig. 7. Determination of optimum contact time of fluoride.

The removal efficiency of phosphate of 400°C, 2 mm, 20 min of contact times has no significant difference in other contact time levels. The removal efficiency of fluoride from 300°C and 400°C 0.5 mm laterite at 10 min of contact time has no significant difference with other contact times, according to the test results. Fluoride removal effectiveness at 300°C 2 mm, 20 min of contact time does not differ significantly from other contact time levels. Therefore, contact time of 10 min for 0.5 mm and 20 min for 2 mm was chosen for further experiments.

3.4. Effect of soil dosage

Adsorbent dosage is another important factor that determines the optimum adsorbent dose which is required to remove a definite amount of pollutants from the solution. Varying initial soil amount, research was conducted to find out the optimum soil dosage required to attain the highest removal efficiency during 300°C activated laterite soil of 0.5 mm and 2 mm in phosphate and fluoride contact. Variation in the removal efficiency of phosphate and fluoride at different initial soil dosages is shown in Figs. 8 and 9. These figures show the removal efficiency of phosphate and fluoride increases rapidly with an increase in the amount of activated laterite soil due to greater availability of the surface area for the adsorption of phosphate and fluoride. The phosphate removal efficiency increases from 88.23% ± 0.10% to 90.88% ± 0.10% and from 70.66% ± 0.60% to 86.12% ± 0.10% when the laterite soil dosage is increased from 0.1 g to 1 g in 0.5 mm and 2 mm grain size, respectively. The fluoride removal effectiveness increases from 75.40% ± 0.10% to 95.13% ± 0.60% and 66.13% ± 0.10% to 81.67% ± 0.30% when the laterite soil dosage is raised from 0.1 g to 1 g in 0.5 mm and 2 mm grain size. A significant increase in uptake was observed when the dose was increased from 0.1 to 1 g. The figures show 2 mm laterite soil around an 80% rate of removal of phosphate and fluoride and 0.5 mm laterite soil showed more than 90% removal efficiency.

The phosphate and fluoride removal efficiencies of 0.75 g, 300°C 0.5 mm laterite soil were respectively 90.08% ± 0.30% and 93.53% ± 0.30%. The removal efficiencies of phosphate and fluoride from 0.75 g, 300°C 2 mm laterite soil were 84.88% ± 0.10% and 79.33% ± 0.10%, respectively. Further increase in adsorbent dosage beyond 0.75 g did not significantly affect the phosphate and fluoride adsorption capacity.

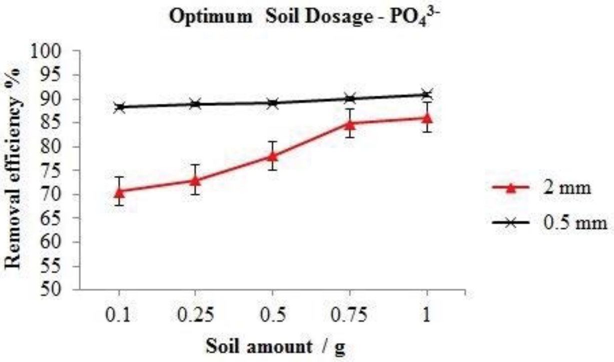

Fig. 8. Determination of optimum soil dosage of phosphate.

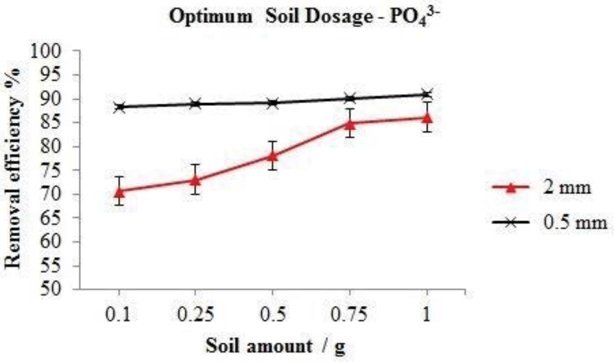

Fig. 9. Determination of optimum soil dosage of fluoride.

Zhang et al. [28] experimental results revealed that phosphate removal efficiency increased with the adsorbent dosage. Sreekumar et al. [38] exhibited the percentage removal of PO_4^{3-} was found to increase at the start with an increase in the adsorbent dosage, which is attributed to the availability of many exchangeable sites for adsorption. Kpannieu et al. [42] demonstrated that increasing adsorbent dosage resulted in a high phosphate removal efficiency of 100% with laterite at 20 g/L. Phosphorus removal increases with laterite dose and phosphorus removal effectiveness increases with decreasing laterite material size, according to Patil Mansing and Raut [40]. Sarkar et al. [41] demonstrated that fluoride adsorption is poor at laterite doses less than 0.4 g; it improves with increasing laterite dose and reaches a maximum value at 1.0 g. Gomoro et al. [9] demonstrated that, fluoride removal efficiency and adsorption capacity increase significantly with the adsorbent dose for a fixed initial fluoride concentration and contact time. Therefore, based on the results of this study, the adsorbent dosage of 0.75 g was selected from both samples for further experiments.

There are several advantages to using laterite soil as an adsorbent to remove contaminants from water. The main advantage is the lower cost. Other adsorbents must be thoroughly purified, prepared, and activated before they can be used in practical applications. Laterite, on the other hand, demonstrated significantly higher phosphate and fluoride removal efficiency without any prior steps, requiring only simple thermal activation. This is one of the reasons for the lower price. Laterite soil is also readily available in Sri Lanka [43], which is advantageous and cost effective. Aside from that, because laterite soil is a natural adsorbent, no environmental harm is expected during the preparation stages. Similar studies have been conducted in China using laterite soil [28], but the phosphate and fluoride removal efficiency of Sri Lankan laterite is significantly higher.

4. Conclusion

The results of this study suggest that activated laterite soil is effective adsorbents for the phosphate and fluoride adsorption from aqueous solutions. Therefore, thermally activated laterite soil is highly effective in the removal of phosphate and fluoride from drinking water. Laterite soil of 0.5 mm grain size showed higher removal efficiency than that of 2 mm laterite in both phosphate and fluoride removal. Laterite soil activated to 300°C and 400°C were better to increase the removal efficiency of phosphate and fluoride. The obtained results showed that adsorption equilibrium was reached within 10 and 20 min respectively, for 0.5 and 2 mm grain size laterite soil for removing phosphate and fluoride from aqueous solutions. The optimum adsorption efficiency of laterite soil phosphate and fluoride ions was obtained as 0.75 g.

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