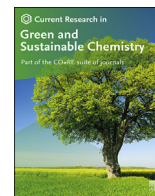


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## Fluoride removal in drinking water using activated carbon prepared from palmyrah (*Borassus flabellifer*) nut shells



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### ABSTRACT

Fluoride is a useful ion for human health and fluoride related health problems can occur due to the deficiency or excess intake. Human intake of fluoride is consumed mainly from drinking water. The removal of fluoride ions from its aqueous solutions and water samples using activated carbon, was conducted in this study. For the preparation of activated carbon dried palmyrah (*Borassus flabellifer*) nut shells were used as a low cost adsorbent. Activation of dried palmyrah nut shell charcoal was done with concentrated  $H_3PO_4$  and 25% NaOH separately as activating agents. Characterization of the non-activated carbon (NAC), phosphoric acid activated carbon (PAC) and sodium hydroxide activated carbon (SHAC) was conducted using different parameters. Fluoride removal efficiency of PAC was investigated for a synthesized fluoride solution which was prepared using NaF and deionized water in four different conditions such as contact time, adsorbent dosage, initial fluoride concentration and temperature. Fluoride concentration in samples was measured by SPADNS method. Then seven different field water samples were collected from Nochchiyagama area, Anuradhapura district which is a major fluoride contaminated ground water containing area in Sri Lanka. The physicochemical characteristics of PAC was found to be high compared to NAC and SHAC.

Optimum conditions for the highest fluoride removal efficiency of PAC were observed as 45 min contact time, 0.2g adsorbent dosage, 1 mg/L initial fluoride concentration at 30 °C temperature with 61% adsorption efficiency. The pseudo-first order and pseudo second order kinetic models were applied in this experiment. The pseudo second order exhibited the best fit for the kinetics studies that indicates the chemisorption process. The experimental isotherm data were analysed by different models; the adsorption follows the Freundlich model providing better fit for the equilibrium data. PAC from palmyrah nut shells would make an alternative source of activated carbon and low cost adsorbent for the fluoride ions.

### 1. Introduction

Fluorine is an essential element for human health because it plays a major role in bone and dental mineralization [1]. 70–90% of fluoride intake into the human body is fulfilled by drinking water [2]. Fluoride can be affected to the human, plants and animals' health based on the concentration [3]. At low concentrations, fluoride is an essential nutrient for human body but at high concentrations fluoride can be caused to several health problems such as skeletal fluorosis, thyroid disorder, neurological damage, mottling of teeth [4]. Plants can show a reduction in growth, stomatal conductance and leaf expansion due to the watering with fluoride contaminated irrigation water (100–150 mg/L). And also,

high fluoride concentrations can lead to induces the necrosis, leaf curl on tender leaves which unwanted by product [5]. Accumulation of fluoride ions in human body over a long period of time can be lead to change the structure of DNA [6]. Due to the elevated levels of fluoride, long term diseases such as dental fluorosis (1.5–4.0 mg/L) and skeletal fluorosis (4–10 mg/L) can be occurred in human body. In china, dental and skeletal fluorosis is mainly due to the high fluoride intake from both drinking water and tea infusion [7]. Dyspepsia can be raised with fluoride distributing thyroid hormone function through enzyme inhibition and drinking water with 0.85–1.0 mg/L fluoride concentration can lead to chronic ill health with dyspepsia [8].

Ground water in many countries which are exceeding concentrations

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of fluoride possessing a health threat to millions of people around the world [9]. World health organization has expressed 1.5 mg/L should be the maximum level of fluoride ions in drinking water [10–12]. In Sri Lanka, most of the dry zone areas in north central province and western province have affected by high fluoride concentration in ground water. Anuradhapura district is the highest fluoride contaminated ground water in Sri Lanka [13]. Fluoride concentration of ground water in Sri Lanka differs from dry zones to wet zones due to the types of rocks and minerals present in the particular area and climate effects. Due to high temperature and extensive evaporation fluoride concentration in ground water can be increased. In wet zones normally fluoride concentration in ground water is very low due to the extensive leaching of rocks and minerals and subsequent flushing out with heavy rain which is 2500 mm/annum [14].

The process of removal of excessive fluoride ions in aqueous solution is known as de-fluoridation [15]. Several techniques such as coagulation, membrane process, ion exchange and adsorption can be used for de-fluoridation [5]. Adsorption method is the widely used method for the de-fluoridation because it is an effective, convenient, low cost and environmentally compatible technology [16]. In the adsorption process several adsorbents can be used such as alumina and aluminium-based materials, carbon-based adsorbents, calcium-based adsorbents, oxides/hydroxides and layered double hydroxides, nanoparticles, natural materials, building materials, industrial waste adsorbents, agricultural and biomass adsorbents [5,13].

Nowadays, researches are mostly focusing the activated carbon as the adsorbent material for the adsorption technology in defluoridation. Activated carbon is a form of carbon containing small and low volume pores that increasing the surface area available for adsorption and chemical reactions [17]. Activated carbon has a complex porous structure with associated energetic as well as chemical inhomogeneities [18]. The specific surface area and pore structure of activated carbon are mainly related with physical adsorption properties of activated carbon. Activated carbon has a strong absorptivity and a large adsorption capacity due to large specific surface area and developed micropores [19]. Charcoal is the foremost adsorbent used in water purification [20]. Commercially activated carbon is normally prepared by coal as the precursor [21]. Due to the high production cost and environmental problems, it needs to look for new sources for production of activated carbon [22]. Agricultural waste products such as peanut hull, tea dust leaves, paddy straw, wood products and parthenium plants can be used to prepare activated carbon [23]. Preparation of activated carbon includes several steps such as dehydration, carbonization and activation. In dehydration and carbonization slowly heat the carbon source in anaerobic conditions. Activation is done with chemicals such as acids, bases and salts [24]. Microwave heating also can be used in carbonization [25]. Activated carbon plays a major role in chemical, pharmaceutical and food industries [26]. Activated carbon can be used to remove metal ions from drinking water and industrial waste water [1] for the adsorption of pollutants in gaseous phase or liquid phase [27].

Several parts of the palmyrah palm tree such as leaves, inflorescence and fruit nut shells can be used for the preparation of activated carbon [28]. Palmyrah palm tree is a plant which is belonging to the Arecaceae family and it is widely distributed and cultivated in tropical Asian countries such as Thailand, India, Sri Lanka, Malaysia and Bangladesh [7].

Palmyrah nut shells are the waste materials from the fruit palm and constitute to the solid waste in Sri Lanka. The use of palmyrah is to be a biomass for cooking. In this study, palmyrah nut shell is used as a potential source of activated carbon and employing this by-product as an adsorbent for removal of fluoride from the drinking water. It would be an environmental friendly method to prepare activated carbon. Therefore, this study was aimed to investigate the fluoride removal efficiency by using palmyrah nut shell activated carbon as an adsorbent material.

## 2. Materials and methods

### 2.1. Preparation of activated carbon

Palmyrah nut shells were collected from Jaffna, Sri Lanka and the nut shells were crushed into small pieces, washed well with tap water, distilled water and allowed to dry in sunlight for three days. Dried palmyrah nut shell pieces were carbonized in a muffle furnace at 500 °C for 2 h. Carbonization and activation of Palmyrah nut shell were performed using H<sub>3</sub>PO<sub>4</sub> and NaOH solutions. Carbonized nut shell sample was ground and sieved at 250 µm the samples were chemically activated by H<sub>3</sub>PO<sub>4</sub> and 25% NaOH solution separately. Sieved palmyrah nut shell sample was mixed with Conc. H<sub>3</sub>PO<sub>4</sub> acid ( $W_{\text{nut shell}}: H_3PO_4 = 1:2$ ) for the preparation of activated carbon with Conc. H<sub>3</sub>PO<sub>4</sub> for 24 h at 40 °C and the sample was washed several times with deionized water until a neutral pH was achieved and kept in a hot air oven at 110 °C for 8 h. For the preparation of activated carbon with 25% NaOH, the above mentioned procedures were repeated [29].

### 2.2. Physical and chemical characteristics

#### 2.2.1. pH measurement

The suspensions samples of NAC, PAC, SHAC were prepared with deionized water and heated at 90 °C for 30 min. The suspensions were allowed to cool to room temperature and pH was measured using pH meter (Hach pH Bench Top meter).

#### 2.2.2. Bulk density

A glass cylinder (25 mL) was filled to a specified volume with 40 µm powder activated carbons and dried in an oven at 80 °C overnight. The cylinder was tapped to compact the carbon and bulk density was calculated using the following formula.

$$\text{bulk density} = \frac{\text{weight of dry material (g)} \times 100}{\text{volume of packed dry material (mL)}}$$

All the experiments were carried out in triplicate and the average were presented.

#### 2.2.3. Functional group analysis

The functional groups of samples were analysed through Fourier-Transformation Infrared spectroscopy (FTIR-2000, PerkinElmer). A pellet was prepared with KBr and group samples using Perkin-Elmer hydraulic pump and the spectra were recorded in the range of 4100–400 cm<sup>-1</sup>.

#### 2.2.4. Proximate analysis

Proximate analysis was used to determine the composition of activated carbon according to the literature [30]. The moisture content, volatile matter, ash content and fixed carbon of the NAC, PAC & SHAC were measured. All the experiments were carried out in triplicate and the average were presented.

**2.2.4.1. Moisture content (Mc).** 1.0g of adsorbent was weighed and was placed in a cleaned dried, and pre-weighed crucible in a preheated oven at 110 °C for 3 h. After cooled in desiccator to ambient temperature and weighed.

Moisture content of the adsorbent was calculated using following equation.

$$Mc (\%) = \frac{(W_w - W_d)}{(W_w - W_c)} \times 100$$

Where MC is the moisture content in percentage, W<sub>w</sub> is the weight of the

sample and crucible before drying (g).  $W_d$  is the weight of the crucible and sample after drying (g) and  $W_c$  is the weight of the crucible (g).

**2.2.4.2. Ash content (Ac).** Dry samples of both activated and non-activated (0.1g) were weighed in an oven dried crucible and placed into a muffle furnace at 600 °C for 4 h. Then the samples were removed from the furnace and stored in a desiccator and reweighed. The ash content was obtained from the following equation.

$$Ac (\%) = \frac{(W_a - W_c)}{(W_w - W_c)} \times 100$$

Where  $W_a$  is the weight of the crucible and ashed sample (g)

**2.2.4.3. Volatile matter (Vm).** Volatile matter of the sample was analysed using muffle furnace at 800 °C for 8 min. The volatile matter content was obtained from the following equation.

$$Volatile\ matter (\%) = \frac{(W_v - W_c)}{(W_w - W_c)} \times 100$$

Where  $W_v$  is the weight of the crucible and ashed sample (g)

Fixed carbon content (FC) was calculated using the equation of  $FC (\%) = 100\% - [Mc\% + Vm\% + Ac\%]$ .

**2.2.4.4. Iodine value (In).** Powdered carbon (0.3g) was taken in a stoppered bottle and 10 mL of 5% HCl was added and stirred. Then 100 mL of 0.10 N iodine solution which was standardized using standard solution of  $Na_2S_2O_3$  (0.1 M) added to it. The mixture was shaken for 20 min. The samples were filtered through Whatman No.1 filter paper. An aliquot portion of the solution (30 mL) was titrated with 0.1 M  $Na_2S_2O_3$  using starch as an indicator. A blank was prepared without adding carbon. The percentage of iodine removal by each carbon sample was calculated by following formula.

$$In(\%) = \frac{Adsorbed\ iodine\ weight\ (mg) \times 100}{Mass\ of\ the\ adsorbent(g)}$$

**2.2.4.5. Acid and water soluble content.** Acid and water soluble content of both activated and non-activated samples were determined according to the test methods [30].

### 2.3. Equilibrium studies by the use of batch adsorption

A fluoride solution of  $100\text{mgL}^{-1}$  was prepared by dissolving (2.219g) of NaF salt in 1L of deionized water and standard solutions were prepared by diluting the stock solution with deionized water. Based on the chemical and physical properties of activated carbon  $H_3PO_4$  activated carbon was selected for adsorption studies. Fluoride ion concentration was estimated spectrophotometrically using SPADNS method and it involves the reaction of fluoride with a red zirconium-dye solution.

The effect of dosage of adsorbent (PAC) was studied by agitating in different weights (0.05, 0.1, 0.15, 0.2 and 0.25g) at 30 °C, 100 rpm, 45 min. The initial tested concentrations of  $F^-$  were 0.5, 1.0, 1.5 and 2.0 mg/L and they were analysed with 0.2g of PAC sample at 30 °C for 45 min stirring at 100 rpm. The effect of temperature on adsorption was tested at 30 °C, 40 °C, 60 °C and 80 °C with sample of 0.2g PAC and 100 mL of 1 mg/L  $F^-$  ions and stirred at 100 rpm. The effect of contact time to the adsorption capacity of PAC was carried out at 15, 30, 45, 60 and 120 min with 0.2g of PAC sample and 100 mL of 1 mg/L  $F^-$  ion solution at 100 rpm rotating speed at 30 °C.

### 2.4. Kinetics studies

The different mixtures were stirred within a time interval between 15

and 120 min for equilibrium time determination. The percentage removal and adsorption efficiency at equilibrium ( $q_e$ ) were given by equations.

The amount of  $F^-$  adsorption onto the PAC sample was calculated using the following expressions.

$$\% \text{ of fluoride removal} = \frac{(C_o - C_f)}{C_o} \times 100$$

The adsorption efficiency of sample at equilibrium ( $Q_e$ )

$$q_e = \frac{(C_o - C_f)}{m} \times v$$

Where  $v$  is the volume of  $F^-$  ion,  $m$  is the adsorbent weight,  $C_o$  and  $C_f$  are the initial and final concentration of  $F^-$  ion respectively.

### 2.5. Adsorption isotherms

The variation of extent of adsorption with concentration of solution has been correlated by the Langmuir and Freundlich adsorption isotherms [6]. The adsorption isotherm was determined by using initial fluoride concentrations of 0.5, 1.0, 1.5 and 2.0 mg/L at 30 °C temperature, 100 rpm shaking speed, 0.2 g adsorbent dosage and 45 min contact time.

### 2.6. Investigation of field water samples

Seven different ground water samples were collected from Nochchiyagama area in Anuradhapura district, Sri Lanka. Then the initial fluoride concentration of each water sample was measured using a multi-parameter bench photometer according to the SPADNS method. The optimized conditions of above parameters were used to find fluoride removal efficiency.

## 3. Results and discussion

### 3.1. Characterization of activated carbon

NAC, PAC, and SHAC samples were characterized according to the quality standards for activated carbon in the Indonesian National Standards, SNI 06-3730-1995 values for  $V_m$ ,  $A_c$ ,  $M_c$  and fixed carbon content [31]. When comparing the PAC and SHAC, PAC has high fixed carbon content (76.91%) than SHAC (73.52%). With increasing the fixed carbon value in the activated carbon sample shows high quality activated carbon (Fito, J. et al., 2019).

For the activated carbon bulk density will be in the range of 0.35–1.2 g/mL [16]. According to the results for PAC bulk density was 0.457 g/mL and for SHAC 0.341 g/mL which are nearly similar to the above range. pH values for NAC (6.9), PAC (6.72), and SHAC (7.3) are nearly neutral. Iodine values for PAC (62.04%) and for SHAC (64.8%) had similar results observed in the study of [33]. Water soluble content for PAC was 1.535% and for SHAC was 1.4%. Acid soluble content for PAC was 2.25% and for SHAC was 2.025%. Both values were similar to the results mentioned in Ref. [34]. Acid-soluble content and water-soluble content in PAC are higher than SHAC (Table 1).

FTIR spectra for respective NAC, PAC and SHAC were presented in Fig. 1. At the 3300-3600  $\text{cm}^{-1}$  wavelength those containing small broad peaks due to the presence of hydroxyl groups which could be associated with organic acid, alcohol or phenol functional group. At 1500-1600  $\text{cm}^{-1}$ , long sharp peaks due to the stretching frequency of C=O bonds of carboxylate groups. These two broad and long peaks indicate adsorbent has probably associated with the chemical activation process of the adsorbent. The small peaks at 1400-1350  $\text{cm}^{-1}$  is due to the C-C stretching frequency of the aromatic compound. At 1000-1050  $\text{cm}^{-1}$  range, NAC shows sharp peak due to C-O deformation vibrations and in PAC and SHAC there are no relevant peaks. Some peaks of the activated

**Table 1**  
Characterization of activated carbon.

Sample	Mc%	Ac%	Vm%	Fixed carbon content (%)	Bulk density	pH value	Iodine Value (%)	Acid soluble Content (%)	Water soluble content (%)
NAC	6.32%	10.01%	16.73%	66.94%	0.514 g/mL	6.9	28.7	1.54	1.14
PAC	7.61%	9.95%	5.53%	76.91%	0.457 g/mL	6.72	62.04	2.25	1.535
SHAC	11.07%	8.61%	6.83%	73.52%	0.341 g/mL	7.30	64.8	2.025	1.4
SNI Standard No. 06-3730-1995 (%)	4.5%	2.5%	15%	80%	Masthura, E. and Abdul, H. D. [32],				

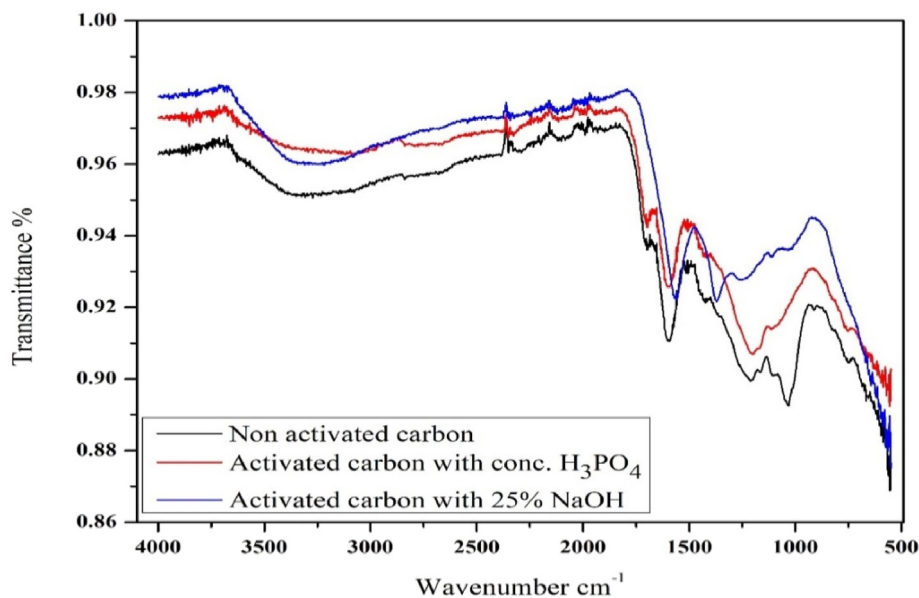


Fig. 1. FT-IR spectra of NAC, PAC and SHAC.

carbons and non-activated carbon have similar properties and those are indicating they have similar chemical properties.

### 3.2. Adsorption studies

#### 3.2.1. Effect of the adsorbent dosage

The effect of adsorbent dosage on fluoride concentration (1 mg/L), constant temperature (30 °C), constant shaking rate (100 rpm), constant

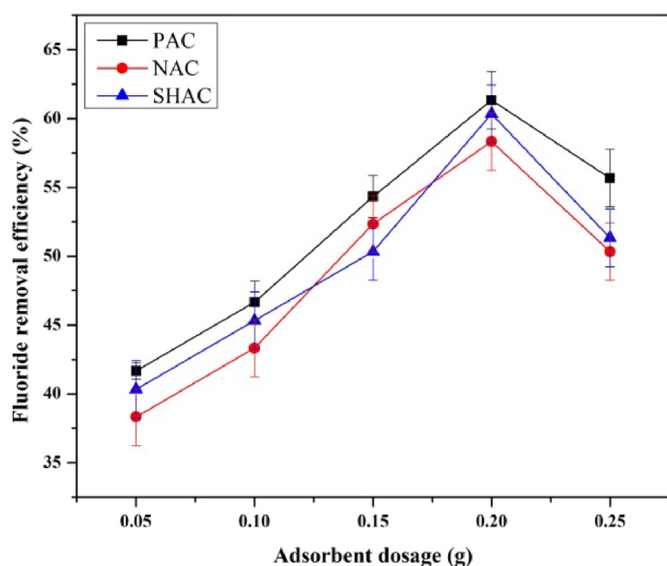


Fig. 2. Effect of adsorbent dosage on fluoride removal.

contact time (45 min) by varying the adsorbent dosage between 0.05 g and 0.25 g. The removal efficiency of fluoride for PAC, SHAC and NAC was increased from 0.05 g to 0.20g and from 0.20 g to 0.25 g it was decreased as shown in Fig. 2. However, PAC is the highest adsorbent among all three samples. The maximum fluoride removal efficiency showed at 0.20 g adsorbent dosage. This trend of the graph in Fig. 2 is observed similarly with [15]. The level of solute adsorption increases with the increase of dosage of adsorbent as the increased dosage of adsorbent transforms the active adsorption sites. But the whole solute adsorption in unit weight of an adsorbent may lower with increasing dosage of adsorbent. It happens due to the interaction of active sites of an adsorbent [35–37]. Optimum adsorbent dosage depends on type of materials and its surface functional groups presented. It was observed that the optimum adsorbent dosage varies from 0.05 to 0.2 g/L for fluoride removal and the highest adsorption dosage of 0.2 g was reported in this study.

#### 3.2.2. Effect of initial fluoride concentration

The effect of initial fluoride concentration on the removal of fluoride adsorbed on the PAC, SHAC and NAC adsorbents have been studied with a fixed adsorbent dose (0.20g), constant temperature (30 °C), constant shaking rate (100 rpm), and constant contact time (45 min) by varying the initial fluoride concentration between 0.5 mg/L to 2.0 mg/L. According to the results (Fig. 3), removal efficiency of fluoride with the initial fluoride concentration, initially increased from 0.5 mg/L to 1.0 mg/L then decreased. Removal efficiency of the adsorbents has shown in similar patterns. Maximum fluoride removal efficiency showed at 1 mg/L initial fluoride concentration. This trend of the graph in Fig. 3, had shown similar results observed in Ref. [38].

#### 3.2.3. Effect of temperature

The effect of the temperature on the removal of fluoride in terms of

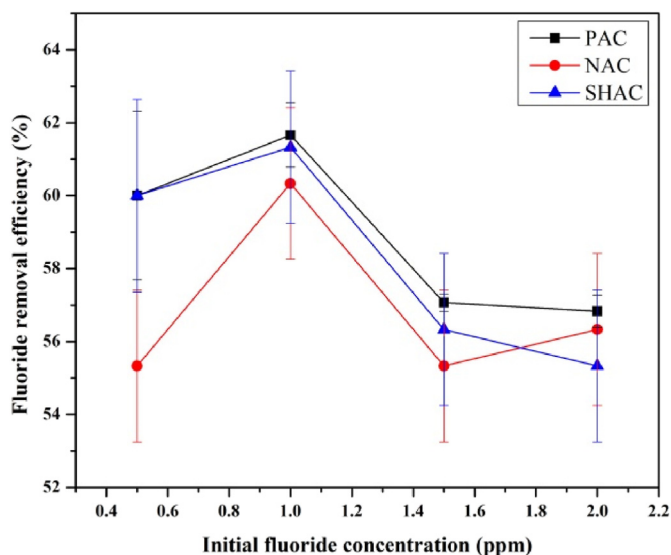


Fig. 3. Effect of fluoride concentration on fluoride removal.

amount of fluoride adsorbed on the PAC, SHAC and NAC adsorbents have been studied with a fixed adsorbent (0.2g) constant contact time (45 min) constant shaking rate (100 rpm) and constant initial fluoride concentration (1 mg/L) by varying the temperature between 30 °C to 80 °C. According to the results (Fig. 4) removal efficiency of fluoride with the temperature has decreased from 30 °C to 80 °C. Maximum fluoride removal efficiency showed at 30 °C.

### 3.2.4. Effect of contact time

The effect of contact time on the removal of fluoride in terms of fluoride adsorption on PAC SHAC and NAC have been studied with a fixed dose of adsorbent (0.2 g), constant temperature (30 °C), constant initial fluoride concentration (1 mg/L), and constant shaking rate (100 rpm). The removal efficiency of fluoride with the contact time was not a constant manner and maximum fluoride removal efficiency showed at 45 min contact time (Fig. 5). After 40 min fluoride removal efficiency has reached to maximum level which had similar pattern observed in the study of Hanumantharao, Y., 2012.

### 3.3. Kinetics of adsorption studies

Two kinetic models have been studied in describing the adsorption phenomenon of fluoride ions: pseudo -first order and pseudo second order models.

#### 3.3.1. Pseudo-first-order model

Kinetic parameters for the adsorption procedure were considered for contact times ranging between 15 and 120 min by evaluating the quantity of fluoride adsorbed. The data was regressed by using the Lagergren equation which represents the first order reaction as mentioned in the study of [39].

$$\log q_e - q_t = \log q_e - K_1 t$$

Where  $K_1$  is the first order rate constant,  $q_e$ , and  $q_t$  are the adsorption efficiencies at equilibrium and at a given time  $t$ . Due to the correlation coefficient ( $r^2$ ) is  $-0.299$ , the pseudo first order is not linear fit for this study.

#### 3.3.2. Pseudo-second-order model

The linearized pseudo-second order chemisorption kinetic model has been used in experiments involving the adsorption of fluoride ions.

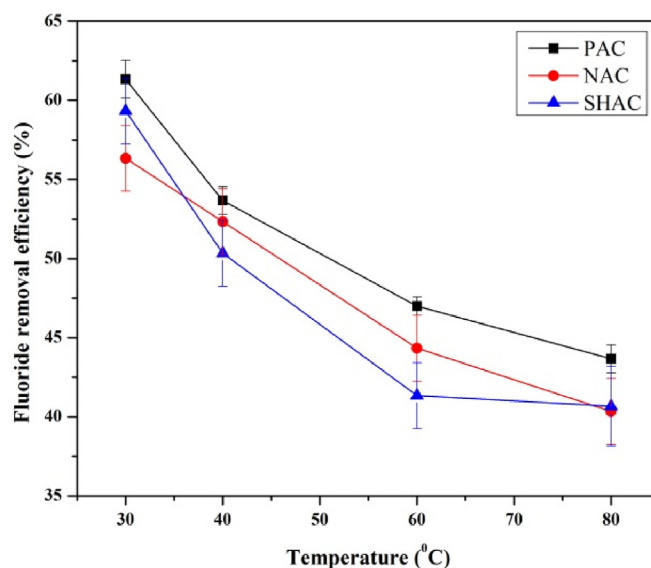


Fig. 4. Effect of temperature on fluoride removal.

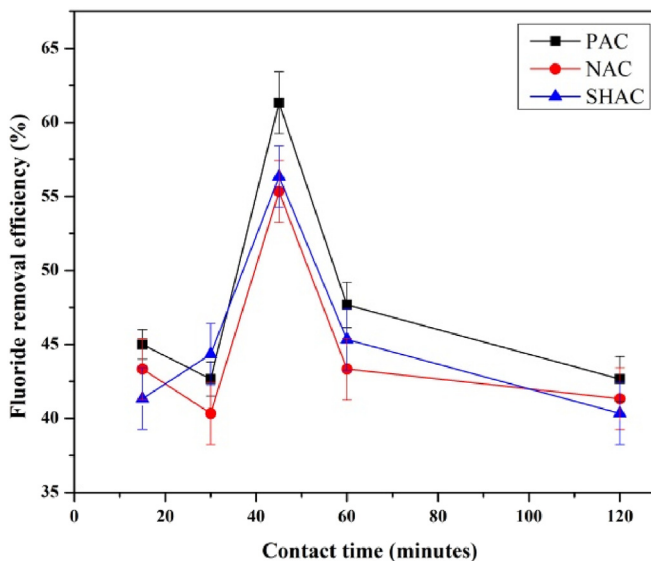


Fig. 5. Effect of contact time on fluoride removal.

$$\frac{t}{q_t} = \frac{1}{K_2 q_e^2} + \frac{1}{q_e} t$$

Where,  $K_2$  is the second order rate constant.

According to the results obtained from kinetics (Fig. 6 and Fig. 7), indicated that adsorption process follows the second order rate equation for the adsorbent with correlation coefficient  $r^2$  for 0.979 PAC.

### 3.4. Isothermal studies

#### 3.4.1. Langmuir model

Langmuir model assumes adsorption energies are uniform and it is independent on surface coverage. Complete coverage of the surface by monolayer of adsorbate indicates maximum adsorption (Fig. 8 and Fig. 9).

The linearized Langmuir isotherm equation is expressed as

$$\frac{1}{q_e} = \frac{1}{K_L q_{max}} \frac{1}{C_e} + \frac{1}{q_{max}}$$

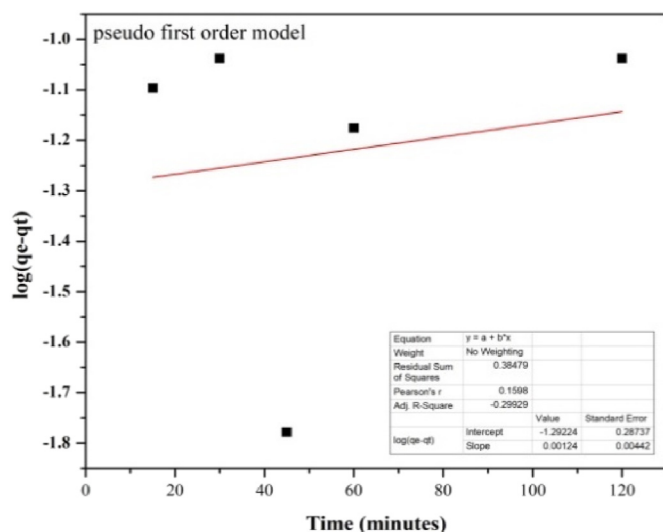


Fig. 6. First-order kinetics trend of PAC.

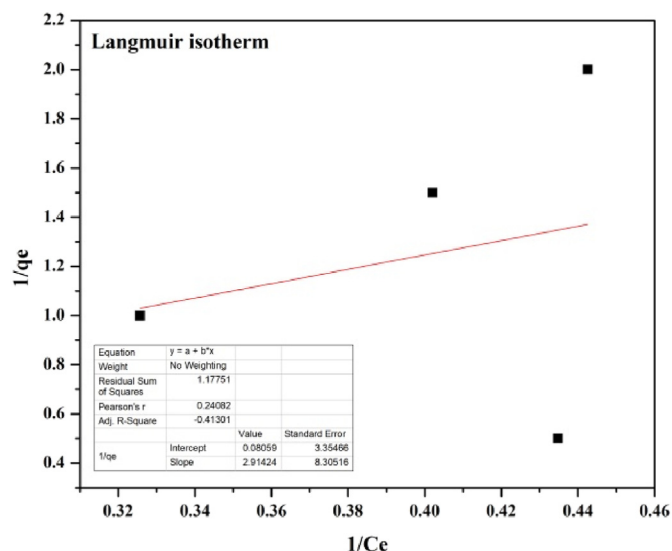


Fig. 8. Langmuir model for PAC.

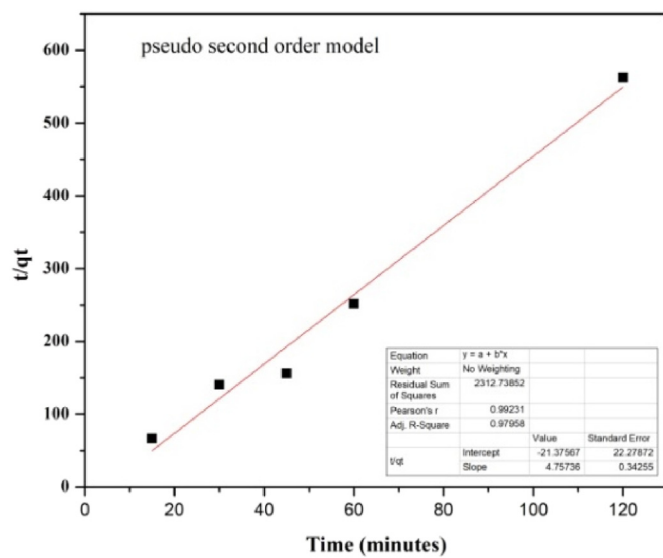


Fig. 7. Second-order kinetics trend of PAC.

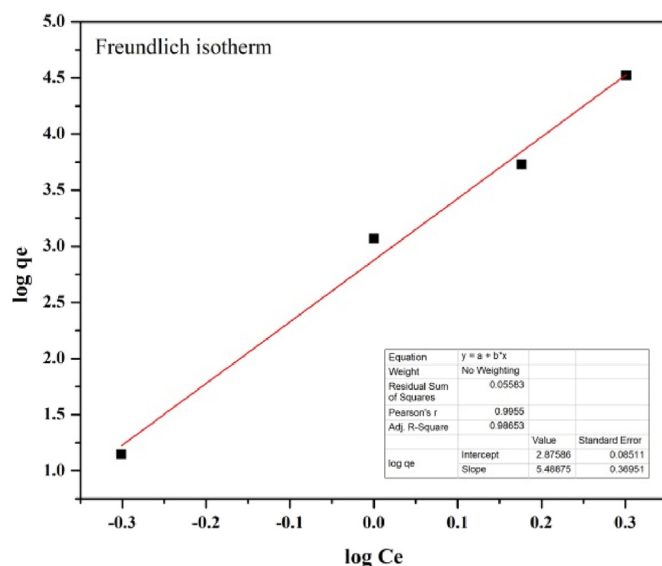


Fig. 9. Freundlich model for PAC.

Where  $K_L$  is the Langmuir adsorption constant,  $C_e$  is the equilibrium concentration and  $q_e$  is the quantity adsorbed per gram of adsorbent at equilibrium and  $q_{max}$  is an indicator of monolayer of adsorption capacity.

Langmuir isotherm was determined by plotting  $1/q_e$  versus  $1/C_e$  as indicated in Fig. 6. The maximum efficiency ( $q_{max}$ ) and Langmuir adsorption constant were calculated from the intercept and slope of the Langmuir equation respectively. The value of  $r^2$  indicated the experimental studies couldn't fit the isotherm, therefore, the assumption of monolayer adsorption mechanism has not well described.

### 3.4.2. Freundlich model

The Freundlich isotherm is shown in the following equation

$$\log q_e = \log K_F + \frac{1}{n} \log C_e$$

Where  $K_F$  is the Freundlich adsorption efficiency,  $n$  is the Freundlich intensity. The linear plot of  $\log q_e$  versus  $\log C_e$  is shown in Fig. 7. Value of  $n$  indicates that the adsorption is normal adsorption and also heterogeneous and multilayer surfaces. From the Freundlich equation  $R^2$  suggest

that it could be considered as good fitness with Freundlich model (Table 2 and Table 3).

## 4. Investigation of field water samples

For the investigation of fluoride removal efficiency in drinking water samples using PAC, initial fluoride concentration in each water sample was measured using SPADNS method using the optimum conditions obtained for above parameters (0.20 g adsorbent dosage, 30 °C temperature, 45 min contact time) (Table 4). The pH of water samples are in the range of 6.7–7.2 that almost neutral pH. According to the results, above 50% of fluoride ions were removed from drinking water samples using PAC.

## 5. Conclusion

According to analysis activated carbon prepared from palmyrah nut shells can be used as a good adsorbent of fluoride ions in water. In the characterization studies of non-activated charcoal for moisture content,

**Table 2**  
Langmuir isotherm values for PAC.

Langmuir isotherm	Q <sub>max</sub> (mg/g)	K <sub>L</sub> (L/mg)	R <sup>2</sup>
PAC	12.50	4.289	-0.413

**Table 3**  
Freundlich isotherm values for PAC.

Freundlich isotherm	n	K <sub>F</sub>	R <sup>2</sup>
PAC	1.18	0.034	0.986

**Table 4**  
Results for field water sample analysis.

Sample	Initial [Fluoride] [Fluoride]	Remaining [Fluoride]	Absorbed [Fluoride]	Adsorption efficiency
Tap water	0.59 mg/L	0.27 mg/L	0.32 mg/L	54.24%
Cannel 1	1.11 mg/L	0.49 mg/L	0.62 mg/L	55.85%
Cannel 2	1.44 mg/L	0.66 mg/L	0.78 mg/L	54.17%
Tank	1.33 mg/L	0.61 mg/L	0.72 mg/L	54.13%
Well 1	0.71 mg/L	0.33 mg/L	0.38 mg/L	53.50%
Well 2	1.04 mg/L	0.43 mg/L	0.61 mg/L	58.65%
Well 3	1.57 mg/L	0.68 mg/L	0.89 mg/L	56.70%

ash content, volatile matter content, fixed carbon content, bulk density, pH value, functional group analysing, iodine value, acid soluble content and water soluble content were 6.32%, 10.01%, 16.73%, 66.94%, 0.514 g/ml, 6.9, 28.7%, 1.54% and 1.14% respectively, for the PAC were 7.61%, 9.95%, 5.53%, 76.91%, 0.4576 g/ml, 6.72, 62.04%, 2.25%, 1.535% respectively and for SHAC were 11.07%, 8.61%, 6.83%, 73.52%, 0.3412 g/ml, 7.30, 64.8%, 2.025%, 1.4% respectively. Optimum conditions for the highest fluoride removal efficiency of PAC acid were observed as 45 min contact time, 0.2 g adsorbent dosage, 1 mg/L initial fluoride concentration at 30 °C temperature with 61% adsorption efficiency. Therefore, activated carbon prepared from palmyrah nut shells can be used as an effective and low-cost adsorbent material for the fluoride ions removal from drinking water.

#### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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