Synthesis and Characterization of Polyaluminum Ferric Chloride (PAFC) Coagulant with Superior Turbidity Removal Capacity from K-feldspar/NaOH Extraction Residues

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Authors’ contributions

This work was carried out in collaboration among all authors. Author MT designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author SC administered all instrumental analysis and reviewed the first draft of the manuscript and ZH managed the analyses of the study. Authors NL and AH managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The aim of this work was to synthesize polyaluminum ferric chloride coagulant with significant coagulation performance employing K-feldspar/NaOH leaching residue as precursor. Potassium extraction from K-feldspar through sodium hydroxide calcination method is carried out at optimum, activation temperature, time, mass ratio of NaOH to K-feldspar ore in a muffle furnace followed by deionized water conventional leaching. The extraction residues are engaged in co-polymerization of aluminum and iron for the synthesis of polyaluminum ferric chloride (PAFC). The favorable conditions, concentration of hydrochloric acid, hydrochloric acid to residue ratio (v/m), temperature, time and pH are comprehensively investigated. Main process conditions for K extraction are: ore particle mass ratio of NaOH/ore 1.5:1, calcination temperature at 500 °C, and calcination duration...
of 2 hours, which all jointly yielded an extraction of 95% potassium, whereas polyaluminum ferric chloride (PAFC) synthesis favorable conditions are: HCl concentration of 5M, HCl/residue 5.5:1(v/m), time 2 hours, temperature 100 °C and pH 7. 99.8% turbidity elimination efficacy from an initial turbidity of 125 NTU kaolin suspension is obtained. The XRD study is implemented for raw ore, slag and leach residue and proved existing all possible structural changes occurred in extraction routes, additionally FTIR and ICP-MS employed in investigation of polyaluminum ferric chloride (PAFC) to reveal the functional group configuration within the elements of a coagulant and component analysis respectively.

Keywords: K-feldspar ore; extraction; poly aluminum ferric chloride (PAFC); coagulation performance.

1. INTRODUCTION

Potassium (K) together with N, P, Mg and Ca are the most crucial micro nutritional components for plant growth and development [1]. Particularly, K makes significant contribution to enrichment of water uptake capability of plant roots and equivalently run up the food making process in quality, besides quantity which is worthy in synthesizing organic substances [2,3]. Moreover, it can rise up agricultural harvests and ensure food welfare. The world harvests massive quantity of K-fertilizers each year, even though majority of potassium based fertilizers are sourced from H2O-deliquescent potassium origins and there exist water insoluble at lesser amount. In point of fact, more than ninety percent of potassium fertilizers throughout the globe provided and dominated by three nations: Canada, Russia and Belarus [2,4]. Technically meaning, most states count on demand for sufficient K-fertilizers rather than self-supply. Most of demands for potassium come from India and China which makes among the highest consumers [2,5]. Thus to meet noble usage K-feldspar resources and to tackle shortage of K-fertilizer, numerous researchers devoted in exploration of effective methods to extract K from K-feldspar sources. In accordance with the research information found so far [6-8], the overwhelming methods which are under application for extraction potassium from K-bearing ores lie in three categories and they are dry processes, wet processes and microbiological methods. Su [4] studied K-feldspar decomposition in KOH–NaOH–H2O solution medium on varying concentration of NaOH and KOH at the same time at elevated reaction temperature; and inferred temperature was valuable to lessen the replacement of Na in the kalsilite and the conversion of K-feldspar to kalsilite or hydroxylcancrinite was a dissolution–precipitation process. It is evident that, treatment methods to achieve water soluble potash from K-feldspar and other potassium containing ores require high temperature to destabilize the structure, which is energy-intensive operation and less feasible. These routes produce more worthless wastes and require austere proper equipment operation [6,9,10]. To maintain environmental stability and avoid the detrimental effect of metallurgy wastes discharged from industries. The world is realizing and practicing to abate real long term aftermath of careless disposal regardless the content and intensity.

Mankind have created several efforts on water treatment engaged technologies, such as ion exchange, adsorption, membrane filtration, coagulation/flocculation and others [11]. Coagulation is a well-designed physicochemical method which is under abundant application to achieve potable water [12,13]. Since most suspended colloids in water are negatively charged, trivalent aluminum and iron salts, such as poly aluminum chloride (PAC), ferric chloride are frequently opted as the coagulants for their significant charge neutralization properties [2,14]. Researchers have revealed that polymeric type inorganic coagulants are more operative than conventional inorganic coagulating salts [13,15]. To date, Al/Fe-based inorganic and composite coagulants are abundantly applied coagulants for removing particles and naturally existed organic matter from raw water [13,15-17]. PAC, has been accounted as less sensitive to temperature and thus to be more fitting for usage at lower temperatures. For the specific nature, at mild conditions of temperature and turbidity water, PAC at high quantity could be necessary to expedite the development of compact and settleable flocs to guarantee suitable coagulation effects [13,18]. However, the overdose of PAC may freely incur growth of residual Al, which is unwanted and even harm the human health [13,19-21]. Co-polymerization of aluminum and iron (PAFC) aggregates the benefits of aluminum and iron coagulants, and prohibits the inadequacies such as aluminum residue in H2O and color intensity of coagulants [15]. Concerns
to boost coagulation adequacy and declining the residual Al and Fe are the main tasks to get low turbidity containing water, particularly for the treatment of raw H₂O at inferior temperature and turbidity. Coordinated concerns and mechanisms in removal of turbidity and color became among the prevalently benefits of an effective coagulant. Zhang [15] studied the color exclusion capacity of PAFC and compared with commercial PAC and found that, PAFC possessing higher adaptability to pH, large settling flocs which eventually outperformed in color abatement. As widely reported most de-colorization operations are accompanied by charge neutralization, sweep flocculation and bridging flocculation which is evidencing that it is multi-mechanism process to reach the targeted efficiency due to natural chemistry (strong bond) of dyes and pigments.

Herein, we extracted K in K-feldspar through sodium hydroxide calcination. Then, the extraction residue was employed for the synthesis of inorganic polymeric coagulant PAFC and applied in water treatment purpose.

2. MATERIALS AND METHODS

2.1 Materials

Starting material for the experiment K-feldspar ore was purchased from Baiyun ebo, China. Size reduction operations crushing and milling then sieve sifting completed to achieve powder size of 150–200 μm. Raw K-feldspar ore was bought with a chemical composition given in the Table 1 NaOH (industrial grade > 99%), HCl (analytical reagent grade 37%), kaolin and distilled water.

2.2 Roasting Experiments

Powdered K-feldspar ore was mixed homogeneously with anhydrous sodium hydroxide at a varying mass ratio in a ceramic mortar. After even mixing the blends was added in to an Aluminum crucible resistant to high temperature and subjected to activation in a muffle furnace for two hours at 500 °C. The activated slag consequently attained was taken out, chilled to room temperature and extracted with deionized water. Leaching of potassium from the activated slag was accomplished in ion free H₂O at a mass ratio of liquid to solid of 10:1 at 80 °C for 40 min in a ceramic hot plate then the slurry solution was filtered. Concentration of Na⁺ and K⁺ with other trace elements from the leachate obtained were measured and calculated.

The raw ore, calcined slag and leach residue were investigated through XRD.

2.3 Coagulant Synthesis

PFAC was synthesized as follows. 33 g of the extract residue from K-feldspar leaching was filled in a 250 mL of polytetrafluoroethylene (PTFE) lined stainless steel autoclave followed by addition of 165 mL 5M HCl. The reaction mixture aged in an oven at 100 °C for 2 h, finally the reactants converted to a jelly type viscous product owning high yellowness. 300 mL of deionized water was added. After the filtration, the mother liquor was transferred to a rotary evaporator. The water and excess HCl are evaporated and collected for re-use. The solid product was re-dissolved with addition by 100 mL deionized water. pH was adjusted in the range of 3-4 by NaOH solution. After aging for 5 h, the solution was filtrated and the PAFC solution was obtained. In order to get the solid product, the water was rotary evaporated under vacuo.

2.4 Simulate Water

Kaolin suspension with turbidity of 125 NTU and variable of pH was prepared. Synthetic kaolin solution suspension pH was attuned to a desired value by using 1 M H₂SO₄ or NaOH solution.

2.5 Jar Experiment

Jar experiments was executed at natural temperature of 23 ± 2 °C in a jar-test equipment. The test water of 1000 mL was poured to every of the six. 1000 mL plexiglass beakers having six rectangular suspended paddled stirrer of an area with dimensions (2x3) cm² was applied for blending. Pre-determined concentration of PAFC was poured to the kaolin suspension. The blends of coagulant PFAC and test suspension were firstly underwent mixing at 150 rpm for 3 min, then slowed down to 50 rpm for 10 min, and finally allowed to sediment for 30 min. The samples were withdrawn at 5 cm deep from the surface for test liquid.

2.6 Analysis and Characterization

Filtrates from extracted slag of K-feldspar and PAFC solution were analyzed for Na, K, Mg and Ca by ion chromatography measurement (DIONEX ICS-600), the other elementals were analyzed by an ICP-MS, and treated water was tested using turbidity meter.
Table 1. Chemical content of K-feldspar ore

<table>
<thead>
<tr>
<th>Chemical content (as oxide)</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>K₂O</th>
<th>Na₂O</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage (%)</td>
<td>67.1</td>
<td>17.5</td>
<td>2.2</td>
<td>10.2</td>
<td>1.3</td>
<td>1.7</td>
</tr>
</tbody>
</table>

Fig. 1. Synthesis route of PAFC coagulant from K-feldspar/NaOH residue

Potassium extraction efficiency was computed by the formula given below:

\[ E = \frac{39 \times 2 \times V \times C}{94 \times W_k \times m} \times 100 \]

Where,

- \( E \) is efficiency of extraction,
- \( V \), volume in liter of extracted solution containing potassium (mL),
- \( C \), Concentration from ion chromatography measurement (mg/L),
- \( W_k \), mass percent of K in the ore,
- \( m \), mass of K-feldspar used for extraction.

2.7 XRD Analysis

XRD was performed on a Bruker X-ray diffractometer. Diffraction patterns are ranged from 5° - 80° obtained from Cu Kα radiation (λ=0.154 nm) at a tube voltage of 40 kV and a tube current of 30 mA.

2.8 FTIR analysis

The nature and role of the functional groups binding the PAFC synthesized at variable HCl concentrations were performed on an FTIR instrument (Nicolet iS10). Samples were scanned 32 times with 4 cm⁻¹ at the range of 500 – 4000 cm⁻¹.

3. RESULTS AND DISCUSSION

3.1 The Impact of NaOH/K-feldspar Mass Ratio on K-extraction

To probe the impact of loading ratio NaOH:ore on the extraction results, successive extraction experiments was executed in constant temperature of 500 °C, activation time 2 h and mass of K-feldspar ore kept fixed in every reaction 10 gram. Rising mass ratio between NaOH and K-feldspar, potassium extraction rate showed increasing tendency, as stated by the laws of chemical reaction that the rate of chemical reaction is proportional to the amount of reactant. So, when the concentration was improved at initial stage, the rate of chemical reaction was improved, which enhanced the potassium extraction rate, and amounted to maximum potassium extraction rate when NaOH:K-feldspar mass ratio was equal to 1.5:1. However, potassium extraction rate experienced a decreasing trend when NaOH:K-feldspar mass ratio was above 1.5:1. This could be elucidated by the fact that a packed solid environment can influence the reaction surface area. When the solid:solid ratio increased beyond the optimum
level, it occludes the active reaction surface which can retard the ion exchange process and lead to the potassium extraction rate decrease. The mass ratio of NaOH to K-feldspar was determined to be 1.5:1 for the entire experiments.

3.2 The Impact of Temperature on K-extraction Ratio

Admixture of NaOH (15 g) and K-feldspar (10 g) were added into an aluminum crucible and charged in a muffle furnace for activation process applied at variable temperature by setting duration of activation 2 h. The whole experimental run was implemented at the scope temperature among 400 °C to 700 °C with a difference of 50 °C. The extraction ratio of potassium exhibited an upward trend, in which it attributes to the migration of K⁺ from the intensively packed K-feldspar structure by forming loose bonds in the outer part of activation products as the most Na⁺ from NaOH supersede void which was afore occupied by potassium ions, consequently water extractable potassium easily was achieved. The maximum extraction was recorded when the temperature of reaction system was increased and reached maximum at 500 °C and showed downward trend when the temperature surpassed 500 °C.

3.3 Impact of Time on K-extraction Ratio

A series of experiments at varying time containing blends of NaOH (15 g) and 10 (g) K-feldspar were added into an aluminum crucible and charged in a muffle furnace for roasting/activation reaction at 500 °C. The extraction ratio/rate of potassium was up surging, which could be correlated that it needs ample time to establish complete contact between NaOH and K-feldspar and to demolish the structure of K-feldspar, however it was only observed that extraction ratio increasing rapidly till reaction time reaches 2 h, later the growth rate of potassium extraction rate turned out to be declining continuously when activation compounds are charged in the furnace more than 2 h, which is assumed to be because of disintegration of blends due to excessive residence time.

3.4 XRD Results

To verify the structural transformation of K-feldspar through variable stages of the process XRD analysis was employed. XRD patterns of raw, activated ores and residue were achieved and shown in Fig. 2. The abundant phases of raw ore are KAISi₃O₈ (PDF 71-1543), Na(AlSi₂O₆) (PDF 75-2335), silicon dioxide (PDF 78-1422) and NaFeSi₂O₆ (PDF 71-1492). According to the activation products, it can be concluded that the Si-Al-O component in K-feldspar structure underwent decomposition which led to decrease in intensity and peak shifts during the roasting process, additionally the ion exchange process of Na ions in NaOH and K ions in KAISi₃O₈ occurs and generates a rise in NaFeSi₂O₆ and NaAlSi₂O₈. The peaks of k(AlSi₃O₈) and SiO₂ became very weak, by which this provide a good sign of successful activation process done by Na ions, consequently the peaks of Na(AlSi₂O₆) and NaFeSi₂O₆ displayed to be stronger. After leaching of the activated K-feldspar/NaOH slag by water all the strong peaks main phases disappeared, which evidenced that, despite the higher exchange capacity of Na⁺ to K⁺ in K-feldspar/NaOH mixture much of the Na based phases showed in the leachate.

3.5 Effect of HCl in Extraction of Residue

3.5.1 Effect of molar concentration of HCl in extraction of residue and coagulation capacity of PAFC

Extraction of NaOH/K-feldspar residue was executed at variable concentration of HCl (M) keeping constant temperature, time, mass of residue and volume to mass ratio (HCl: residue) at, 110 °C, 2 h, 33 g, 5.5:1 respectively. It was clearly spotted that the extraction efficacy showed a noticeable increasing trend till 5 molar HCl then the extraction rate presented constancy at six molar HCl. Therefore, we can perceive that concentration and dissociation rate was directly proportional up to 5 molar HCl concentrations, and then kept steady at 6 molars, which implies residue was at thoroughgoing leachable condition no matter what the concentration of extracting agent. The variation in extraction capacity for components of PAFC coagulant with alteration in concentration of HCl is given in Fig. 3a, quantity of PAFC in grams synthesized from those variable experimental runs was compared in mass which witnessed the role of difference in concentration, the lowest mass (8 grams) of PAFC was obtained from the least HCl concentration i.e. 1 molar and the highest (28 grams) at 5 and 6 molars of HCl. Besides performance for turbidity removal, PAFC coagulant synthesized at aforementioned conditions at different experimental runs was compared at variable dosage, provided in Fig. 3b.
It is obvious that the removal capacity of each coagulant sample improved with escalating dosage. The highest turbidity eradication efficacy of 99.6% was obtained from 5 and 6 molars at 40 and 45 (mg/L) dosage respectively.

**3.5.2 Effect of ratio of HCl (volume) to residue (mass) on extraction of PAFC**

To explore optimum HCl (v) to residue (mass) for maximum PAFC coagulant components extraction, reaction process was executed at fixed temperature, time, concentration of HCl, at 110 °C, 2 h, 5M respectively, with varying HCl:residue (v:m). The obtained results signposted that the extraction efficacy increases through increasing v:m ratio up to 5.5:1, then displayed constancy while the volumetric ratio of HCl to mass of residue was growing. The lower in extraction efficacies at lower HCl: residue ratio implies, the distribution of liquid molecule throughout the solid surface are not sufficient enough for demolishing the intricated bond within the components of our material of interest and the residue material, which correlates the lower dissociation power generate the lesser extraction yield. Besides samples with lower HCl concentration possessed lower filtration rate, which is assumed to be due to inadequate solubilization of constituents of residue matterial, which formed large gel like aggregate which could block most the surface area of the filter. The variation of v:m contributed noticeable changes as we see in Fig. 3a, the rate of extraction increased monotonously till it reached a ratio of 5.5:1 and plateaued at the ratio of 6.5:1, thus for a reason of cost and energy saving the ratio 5.5:1 is selected as an optimum condition for the maximum extraction of constituents of PAFC coagulant. Evidently, concentration affect removal capacity aside the extraction, because the competence of the components of (PAFC) rely on the content of the filtrate so does the volume to mass ratio, according to the experimental results we acquired the extraction efficacy increased in a steady way with increasing (v:m) up to the optimum ratio. In line with many experimental reports regarding to extraction using different methods the extraction mechanism are either ion exchange between elements within the mixture or dissociation of the weaker component by the stronger one, suggesting of our experiment we presume extraction was dominated by dissociation due to two reasons, (1) almost all the exchangeable ions of Na⁺ and K⁺ are extracted via conventional leaching, (2) the concentration of HCl is high which is better suited for dissociation. Increase in concentration enhance quantity of Cl⁻ same as in rise of PFAC coagulant component from residue. As we see Fig. 4a, the extraction rate (mass) improved by boosting v:m and peaked to an amount of 28 grams at v:m ratio of 5.5:1 and displayed constancy at v:m ratio 6.5:1. We could assume that the better extraction effectiveness of PAFC from residue owing to even distribution of HCl throughout the residue material which ensue leaching of extractable component at maximum possible amount which play crucial part in facilitating the Co-polymerization of the residue constituents for production of a coagulant containing it’s supposed elements Fe³⁺ and Al³⁺.

![Fig. 2. (a) XRD of leachate residue, (b) activated K-feldspar/NaOH mixture and (c) raw K-feldspar ore](image-url)
3.5.3 Effect of v/\(m\) (HCl/residue) on PAFC coagulation capacity

Coagulation capability of each PAFC coagulant sample synthesised from 5 molar HCl and residue at different v:\(m\) ratio was tested under routine jar method for synthetic kaolin suspension of an initial turbidity 125 NTU, PAFC sample prepared at 110 °C and (5.5:1, 6.5:1) v:\(m\) ratio obtain the highest turbidity exclusion of 99.6% at 40 (mg/L) dosage of PAFC solution. As shown in Fig. 4b increasing v:\(m\) not only run up yield quantity, it also improves component quality, in which the active and driving component of a coagulant presence in filtrate and finally in the dried PAFC upturn to maximum level at 5.5:1 and became steady at 6.5:1.

3.5.4 The effect of temperature on PAFC coagulation efficiency

To narrow the preparation conditions regarding temperature for PAFC coagulant experimental runs was executed to discover the bare minimum optimum temperature for production of PAFC with maximum possible turbidity removal efficiency, despite majority of prepared samples had quite close removal capacity and some with...
equal efficiency, the one with highest capability and implemented at lowest possible temperature was picked for feasibility samples prepared at 100 °C yielded 99.8% turbidity elimination capacity at the lowest dosage of 35 mg/L. PFAC coagulant indicted by scatter plot in Fig. 5. Albeit increasing temperature has a role in extraction efficacy of PAFC, it showed inferior increase in turbidity removal with rising the temperature, however their extraction efficiency was superior.

3.5.5 The effect of temperature on extraction PAFC

When we come to the impact of temperature in extraction of a coagulant from residue strange properties occur, which is amount PAFC coagulant extracted found to be 23 and 24.5 grams at temperature of 80 and 90 °C respectively, and steady mass of 28 grams for 100, 110 and 120 °C. See Fig. 6 this ascertain that change in temperature in this range had little effect on extraction capacity of residue in the presence of HCl.

3.5.6 The effect of time on coagulation efficiency

Fig. 7. illustrates reliance of coagulation capacity of PAFC on time, performance experienced fluctuation with varying extraction time, in the beginning it showed an increase then after 90 minutes decreased, suddenly it displayed an improvement in 2 h and declined continuously in the late hours. The lower coagulation capacity of PAFC is a sign for scarcity of multi valent ions of Fe$^{3+}$ and Al$^{3+}$, whereas the highest signify to the optimum extraction efficiency comprising large quantities of multivalent ions of Fe$^{3+}$ and Al$^{3+}$.

![Fig. 5. Effect of temperature on PAFC coagulation efficiency](image1)

![Fig. 6. The effect of temperature on extraction PAFC](image2)
3.6 FTIR Results

FTIR analysis was applied to examine functional group formation and to ascertain existence of effective constituents of PAFC coagulant synthesized at variable concentration of HCl (Fig. 8), test coagulants displayed relevant absorption peaks except the coagulant synthesized rom one molar HCl which is line up with, that low degree of polymerization which cause shortage of extraction in the principal elements of PAFC. The spectral bands around 587 cm\(^{-1}\) was ascribed to the bending vibration of of Al-OH and Fe-OH [22,23], the bands appeared at 1100 cm\(^{-1}\), assigned to asymmetric stretching of Al-OH-Al or Fe-OH-Fe [22,23] and the sharp spectral bands around 3383 cm\(^{-1}\) and 1629 cm\(^{-1}\) contributed to stretching vibration of OH and bending vibration of H\(_2\)O respectively [22-24].Owing to absorption frequencies confirmed all the entities of our material interest (i.e.) PAFC was successfully synthesized.

3.7 PAFC Chemical Composition Analysis

To assign the available elements in PAFC coagulant, elemental analysis was executed by a joint instrumentation aimed for obtaining results with higher accuracy. Elements Na, Mg, K and Ca inspected by ion chromatography and for elements Al, Si and Fe were tested by (ICP-MS). The respective amount (mg/L) of individual
component is provided in Table 2, in which sample for analysis was prepared by dissolving 0.1 gram of PAFC coagulant in one liter of deionized water. As stated in extraction of potassium the principal components of activation and starting material for synthesis of PAFC coagulant are NaOH/or virgin and NaOH/or residue, by which 5% of the potassium left unextracted. Elemental analysis for Na corresponds with the extraction data, because all the potassium left in the residue/waste was extracted by HCl during synthesis of PAFC coagulant. Just like potassium ions did in activation of K-feldspar, it is evident that the greater amount of Na ions was detected owing to Na ions exchanged during activation process of K extraction from K-feldspar/ NaOH composite. A common decreasing trend was shown in amount of Na, Mg, K and Ca with growing amount of HCl (M), which indicate that an inverse proportionality of with the extraction of Al and Fe. Analysis result on silicon attested that removal for silicic acid via NaOH precipitation pursued by pH adjustment was successful as presented in Table 2. Unlike the other extracted ions, amount of Al and Fe increased monotonously with upturning concentration of HCl (M) and resulted rise in turbidity removal which concur to the concept that increment in concentration of extracting agent boosts yield quality as quantity did. The existence of those elements detected from analysis as impurities apart the principal constituents of PAFC coagulant are assumed to incur deterioration of removal efficiency. Fig. 9a, illustrate the ratio of Al/Fe at variable HCl molar concentration, it rapidly decreased with improving concentration of HCl. In fact, at inferior HCl concentration Fe extraction was low in comparison of Al, this is assumed as a result of, (1) lower mass ratio of Fe$_2$O$_3$ in the starting material and (2), and compact bond of Fe$_2$O$_3$ in K-feldspar which could not be dissociate at lower concentration of HCl. Despite the fact that, both Al$^{3+}$ and Fe$^{3+}$ ions experienced a remarkable growing trend via HCl molar quantity up scaling, Fig. 9a, whereas Fe/Al an upward trend given Fig. 9b, which is the result of big gap in the growth rate of Al$^{3+}$ and Fe$^{3+}$ concentration with respect to HCl (M). Besides an increment factor Fe$^{3+}$ excelled to Al$^{3+}$ with boosting molar concentration HCl reagent, which means that this conditions favors more to Fe$^{3+}$ than Al$^{3+}$ regardless the original content of those metallic ions in the residue.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Na</th>
<th>Mg</th>
<th>Al</th>
<th>Si</th>
<th>K</th>
<th>Ca</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>42.07</td>
<td>1.1</td>
<td>0.03</td>
<td>0.00</td>
<td>4.98</td>
<td>5.04</td>
<td>0.002</td>
</tr>
<tr>
<td>M2</td>
<td>34.11</td>
<td>1.22</td>
<td>1.55</td>
<td>0.02</td>
<td>4.30</td>
<td>3.47</td>
<td>0.11</td>
</tr>
<tr>
<td>M3</td>
<td>32.00</td>
<td>1.14</td>
<td>1.83</td>
<td>0.03</td>
<td>3.68</td>
<td>2.74</td>
<td>0.23</td>
</tr>
<tr>
<td>M4</td>
<td>32.65</td>
<td>1.26</td>
<td>2.37</td>
<td>0.04</td>
<td>3.94</td>
<td>2.9</td>
<td>1.02</td>
</tr>
<tr>
<td>M5</td>
<td>29.05</td>
<td>1.07</td>
<td>3.37</td>
<td>0.03</td>
<td>3.38</td>
<td>2.33</td>
<td>0.87</td>
</tr>
<tr>
<td>M6</td>
<td>27.77</td>
<td>1.01</td>
<td>3.85</td>
<td>0.03</td>
<td>3.25</td>
<td>2.22</td>
<td>1.33</td>
</tr>
</tbody>
</table>

Fig. 9. (a) Al/Fe mass (m:m) ratio and (b) Fe/Al mass (m:m) ratio at variable HCl (M) molar concentration
3.8 The Effect of pH and Dosage on Turbidity Removal

The impact of pH on coagulation/flocculation process of kaolin suspension was examined in pH range of 4–10. NaOH and H₂SO₄ were employed for pH adjustment purpose. Experimental run results are provided in Fig.10a. Fig. 10a illustrates the impact of kaolin suspension initial pH on the turbidity abatement. It demonstrated that as pH rises from 4 to 7, turbidity elimination efficacy experienced remarkable increase. The driving parameter for an increment in removal process could be attributed to the rise of pH, more OH⁻ ions reacted with the (Fe–Al), Al or Fe atoms to create extra cationic polymers which expedite precipitation of flocs [25]. At elevated alkaline conditions, the coagulant would be sensitive to hydrolysis, impeding the settling of precipitates. Therefore, there was a noticeable decline in turbidity abatement at pH more than 7. Thus, there was favorable pH value to maximize the yield in coagulation.

As given in fig. 10a the impact of kaolin suspension pH on eradicating suspension and pH value after coagulation by PAFC was determined for which the kaolin suspension tested at pH of 7, after coagulation with PAFC was lesser than in virgin suspension under the favorable condition pH at 7. It was clearly showed that turbidity abatement gradually increases with improving dosage of PAFC coagulant till it reached 35 mg/L, later it decreased a little as the amount of dosage increases as given in Fig. 10a.

3.9 Comparison of Turbidity Removal between PAFC and PAC

For synthetic kaolin suspension treatment with an initial turbidity of 125 NTU, the coagulation capabilities of PAFC and commercial PAC was assessed. Around their optimum dosage both inorganic coagulants showed an increasing, removal efficiency, floc size, sedimentation rate with rising dosage. The PAC coagulant experienced higher coagulation performance than PAFC at lower dosage, however the competence of PAFC 35 mg/L, 99.8% equated to PAC at a dosage of 30 mg/L with an efficacy of 99.8% Fig. 11. The maximum efficacy of turbidity eradication by PAFC and PAC obtained from our research work are, 99.8% and 99.9% with dosage of 35 and 40 mg/L respectively. Apart from turbidity removal efficacy comparison residual sodium, potassium, calcium, aluminum and ferric content of PAFC treated kaolin suspensions was analyzed. The concentration achieved at optimum PAFC dosage conditions are 26 mg/L Na⁺, 3 mg/L K⁺, 2.1 mg/L Ca²⁺, 145 μg/L Al³⁺ and 50 μg/L Fe³⁺, which are quite below the legislation limit. Thus, relying on PAFC coagulant proficiency on turbidity exclusion and content of residual Al³⁺ and Fe³⁺, it could be used as a substitute coagulant for the reason that is cheap and possession of high production rate from little mass of residue/waste and the treated water complied the requirement of drinkable water, thus it can be used as potable water.

![Fig. 10. (a) Effect of pH and (b) Effect of dosage on turbidity removal](image-url)
Fig. 11. Comparison of PAFC and PAC on turbidity removal

![Graph comparing PAFC and PAC on turbidity removal](image)

Fig. 12. (a) Effect of pH on color removal and (b) Effect of PAFC dosage on color removal

3.10 Color Removal Capacity of PAFC

Color removal efficacy of synthetic PAFC coagulant on methylene blue (MB) dye 5 mg/L was examined through optimum pH and dosage using UV spectrophotometer, Fig. 12a and Fig. 12b respectively. It was perceived that color elimination efficacy was highest at lower pH, with increasing pH efficiency experienced a downward trend. The maximum value was achieved at pH of 3, which amounted 50% and lowest at pH of 7, 36%. Following the investigation of optimum pH, appropriate dosage test was executed and the best elimination efficacy was obtained from 200 mg/L dosage. Efficiency of removal gradually decreased with increasing loading in PAFC, however the size of suspension outsized the lower dosed ones, the primary reason for the decline in color removal of coagulant sample is assumed to be the higher solubilities of sodium and potassium ions which drives them to appear in the residual phase instead of in precipitate phase as part of PAFC.

The size of suspension particles was larger in the higher dosed samples, even at greater dosage the suspension settled too little, thus could offer to an assumption, as most inorganic coagulants combine with organic flocculant additive for synthesis of composite coagulant for higher decolorization efficiency, PAFC could obtain appreciable performance [16].

4. CONCLUSION

K-feldspar/NaOH residue containing high concentrations of Al₂O₃, SiO₂ and NaOH with
little Fe₂O₃, was successfully employed for PAFC components extraction which finally verified through instrumentation and silica content of extract was removed as silicic acid by dissolving concentrate of extract pursued by pH adjustment in the range 3-4, afterwards the synthesized PAFC coagulant properties was investigated variable parameters, v:m ratio, temperature, time, pH and dosage. Moreover, FTIR and ICP-MS analysis was executed to verify the presence of coagulant functional components and elemental composition respectively. The analysis results verified that there exists Al–O–Al, Fe–O–Fe, Al-OH, Fe-OH bonds in FTIR spectra, and Al³⁺ and Fe⁶⁺ atoms from ICP-MS in the synthesized coagulant. It was clearly observed from the whole experimental run concentration molar of HCl and v: m are the main driving parameters in extraction and performance of PAFC coagulant and time, temperature and pH are found the least influential parameters. The favorable conditions picked for feasibility are 5M, 5:5:1, 35 mg/L, 2 h, 100 °C and 7, for HCl concentration, v:m, PAFC dosage, time, temperature and pH, respectively. Those all parameters sum up to obtain turbidity removal efficacy of 99.8 which is quite high and the treated water could serve for drinking purposes. Besides maximum color removal efficiency, 50% PAFC was attained at pH of 3 in 200 mg/L PAFC dosage which is promising for better removal/settling of large size suspensions with the auspices of organic polymer flocculants.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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