Coagulative (PAC) for Iron Removal in Ferruginous Water

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ABSTRACT

The effect of PAC as a coagulant for the removal of iron in ferruginous raw water was investigated. The investigation involved an analysis of treatment through carrying out the flocculation and coagulation unit test in the determination of residual iron as well as the residual turbidity of the supernatants. The results show that the optimum iron removals were achieved at a pH of 5.2–8.0 PAC dosage of about 25 mg/l and with an almost 87% removal rate. The residual concentration iron in the treated water was 0.12 mg/l, which is in compliance with the National/WHO permissible limit of 0.30 mg/l, whereas the residual turbidity was around 1.17 NTU, well below the regulated limit of 5 NTU. These investigative research data hopefully could provide some technical information for the possibility of full domestic applications to remove and reduce the undesirable excess iron from ferruginous groundwater sources with an insight that PAC is readily available and locally produced PAC is going to reduce the coagulant cost significantly.

Keywords: *coagulation- flocculation, ferruginous water, PAC, residual iron and turbidity*

Introduction

Groundwater is a vital source of water supply and those extracted from an aquifer is usually low in suspended solids due to natural filtration that occurs as water percolates through the soil and is practically bacteriologically safe. However, groundwater frequently contains excessive amount and an unacceptably high level of inorganic ions due to its direct contact with soil or rock. Besides, specific ions do require removal before the water is suitable and this includes iron, the presence of which makes it objectionable for aesthetic reasons.

Ferruginous iron in groundwater is in reduced form of ferrous (Fe^{2+}) and is relatively soluble. An increase in the oxidation-reduction potential of water readily converts ferrous ions to ferric (Fe^{3+}) and subsequently allows ferric iron to hydrolyse and precipitate as hydrated ferric oxide. It is this oxide that makes iron-laden waters objectionable and imparts yellow-orange coloration with associated tastes and odor (Bartram & Balance, 1996). One of the series of steps for iron removal which exceeds a permissible National guideline for Drinking Water Quality limit of 0.3 mg/L is the coagulation-flocculation process which is to promote an agglomeration of impurities whereby the precipitates can be settled or floated in the sedimentation tank. Coagulation is an essential part in water treatment to reduce the undesirable impurities in water for many years and aluminium salt, alum has been the most popular coagulant for water treatment, although there are some concerns about possible health hazards for aluminium residuals following its use (Tebut, 1992).

However, one of the alternative coagulant proposed by The National Hydraulics Research Institute, Malaysia (NAHRIM) is the used of PAC for impurities removal (NAHRIM, 2000) and the main aim here is to investigate the possibility of precipitating iron from ferruginous water

using PAC from an existing tube-well located in UiTM Pahang through flocculation-coagulation technique. This a worth taking investigation since in Malaysia, iron ions seem to be common underground impurities, hence, an alternative coagulant which is effective and an economically cheaper is desirable for iron removal to encourage better utilisation of ferruginous groundwater.

Activated Carbon Treatment

The two most common effects of excess iron are rendering water unpalatable, thus, imparting a bitter taste and iron, upon exposing is likely to precipitate and the deposits because brown stains (Twort, 1974) and as an application purposes activated carbon is mostly used for a taste and odor removal from raw water supplies. Due to its significant porosity, it has the property of removing tastes and odours by absorbing gases, iron and manganese (Gucharan, 1999). Its principle is adsorption where the contaminant is attracted to and held on the surface of the carbon particles and due to its small pores and a large surface area will eventually lead to a better effectiveness in removing taste and particularly odor. It has been reported that a single gram of activated carbon can have a total surface area of more than 1000sq.ft. (Jossep, 2005). Gucharan et al. (1999) stipulated several advantages of activated carbon; (i) its over-dose is not harmful, (ii) it removes the organic matter present in water, (iii) it helps the process of coagulation, if added before filtration of water, (iv) it reduces the chlorine demand of treated water and (v) it reduces tastes due to hydrogen sulphide, iron, manganese, phenol and chlorine. The UK experience is also worth mentioning here where an approximately 100 potable water treatment works have the capability of using activated carbon and in most cases is used for controlling taste and odour problems, particularly earthy, musty tastes and odours (Robert, 1991).

Process of Coagulation-Flocculation

Coagulation is a conversion through coagulants of colloidal and dispersed particles into small visible clumps. It is a safe and effective method of treating water, which improves its quality by reducing levels of organic compounds, colour, iron and suspended particles. Flocculation on the other hand refers to the slower, gradual stirring of the coagulated particles in the treated water to encourage the formation of larger clumps (flocs) heavy enough to settle by gravity. The colloids of the suspended matter in water are microscopic in size and usually have a negative electrical charge. Much of smaller dissolved colloids do not settle readily under normal conditions and coagulation is therefore required to cause them to clump together into heavier mass that will settle. These colloids are also small enough to pass through sand filters if chemical treatment does not occur or is inadequate. Hence, successful coagulation effectively removes organic and inorganic colloids (common called turbidity), colour causing particles, micro-organisms and taste and colour causing substances. Good coagulation is going to improve filtration and more complete disinfection.

Among the factors that can have an effect on how well a chosen coagulant performs include nature of dissolved material being coagulated, pH, alkalinity, mixing conditions and water temperature. PH is important as each coagulant has an effective range of operation, having an outside range the floc, either does not form properly or it dissolves after formation. This factor is going to be evaluated in this investigation. Alkalinity is, therefore, an important factor for floc formation and will be also duely investigated. The mixing conditions are vital because the reactions responsible for coagulation occur within seconds of the addition of a coagulant and the initial rapid mixing of the jar test will enhance the reactions of the chemical added. The water temperature is generally warm and this will help in a more complete and quicker reaction.

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Laboratory Tests and Analysis

This research work was carried out in Water and Hydrology Laboratory, Faculty of Civil Engineering, UiTM Pahang. The flocculation process was carried out using a standard jar test procedure in a six 1-litre beakers. All the jar tests were carried out at room temperature. 1000 mL of the test water was added to each 1-litre beakers. The water samples were all from an existing tube-well located in UiTM Pahang. The solutions were stirred rapidly at 100 rpm for 3 minutes during coagulant addition, followed by slow stirring at 30 rpm for 10 minutes and quiescent settling for 30 minutes. Following settling, a supernatant samples were withdrawn and filtered through a filter paper before being analysed for turbidity and residual iron.

The pH of the water was adjusted with 1M NaOH or 1M HCl solutions. Residual iron was measured using a DRH 890 Harch Colorimeter. Distilled water was used in all the experiments. A liquid polymer of concentration of 0.1% was used as a coagulant aid. However alum and PAC were diluted with distilled water to a concentration of 10 mg/L as Al or PAC before used. All the stock solutions of coagulants, coagulant aids and other chemicals were prepared on daily basis to prevent degradation over time. Basic raw sample parameters are; 79 NTU, pH of 7.63 and 0.40 mg/l ferrous contents. Since the water had an excess iron for drinking water standard limit but not exceeding a raw water standard permissible limit of 1.0 mg/L the iron concentration in the raw water was increased to about (0.8–1.1 mg/L) range by the addition of ferrous sulphate solution. The first set of jar tests was conducted to select the coagulant dosage (optimum dosage) *without zero in* on the above dosage. The second set test was then followed for selecting the optimum pH based on the coagulant dosage in the first set.

Results and Discussion

The following section presents the result of the tests for both alum and PAC coagulants. Summary of parameters for alum coagulants are presented in Table 1 and 2 and those for PAC are in Table 3 and 4.

Effect of the Dosages of Coagulants on Coagulation Performance

The effect of the dosages of coagulants on their coagulation performance was carried out at pH 7.63 for alum and at pH 7.60 for PAC. The results are shown in Figures 1 and 2 respectively. It can be seen that the removal pattern of turbidity using alum and PAC under the dosage range were identical. The optimum coagulation doses for alum and PAC were about 45 mg/L and 25 mg/L respectively. During testing, macro-flocs formation could be noted under the around optimum coagulant dosage range. However, a good and better noticeable flocs formation was noticed for PAC.

Figure 1 clearly indicates that PAC and alum produced similar turbidity removal performance of around 98%. However, this is not so for iron removal as can be seen in Figure 2. The PAC coagulants produced the general trend of increased removal rate for both under and over dosing leaving a residual content of 0.11 mg/L at 87.8% removal in comparison to alum with 0.15 mg/L at 83.3% removal. The alum on other hand produced the opposite trend. Under or over dosing resulted in lower iron removal rate. Figure 2 seems to provide clear evidence that PAC is going to offer a better iron removal rate.
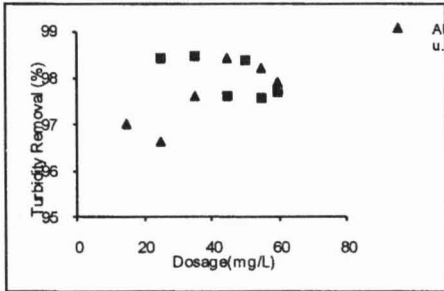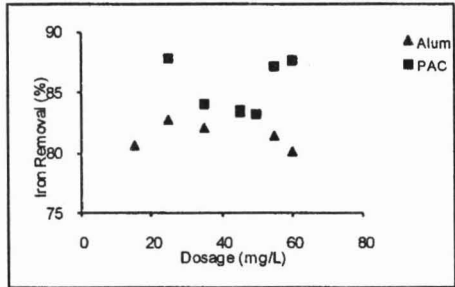
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Figure 1: Effect of coagulants dosages on

Figure 2: Effect of coagulant dosages on turbidity removal

Effect of pH on Coagulation Performance

The effect of pH on the removal of turbidity and iron at the dosage of 45 mg/L for alum and at the dosage of 25 mg/L for PAC is shown in Figure 3 and 4 respectively. It can be seen that for both coagulants, the efficiency of turbidity and iron removal is not much of pH dependent within the narrowly tested range. However, the optimum dosage at pH of 6.44 for alum is within the expected optimum range of (5–7.5). The fact is that the solubility of $Al(OH)_3$ is pH dependent and is low between pH 5–7.5; outside this range coagulation with aluminium salts is not successful (Tebut, 1992). The same goes for PAC, with optimum pH of around 6.34. However, it is worth noting that at the optimum pH, alum produced a slightly better iron removal rate from 83.3% (Table 1) to 100% (Table 2) and turbidity removal rate from 98.4% to 98.6%. This trend, however, is not clearly marked for PAC where the removal rate for iron and turbidity were around 87% and 98% respectively.
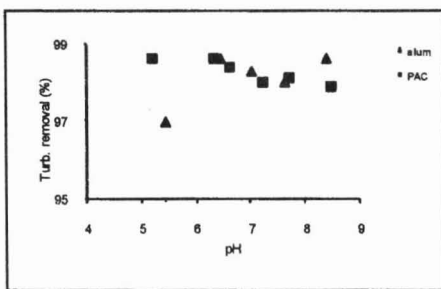

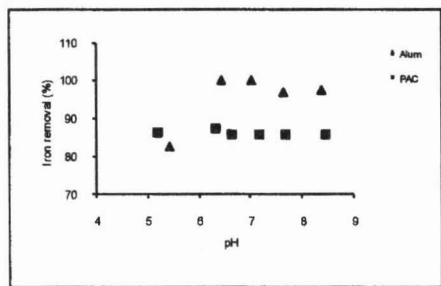Figure 3: Effect of pH on turbidity removal at optimum dosage

Figure 4: Effect of pH on iron removal at optimum dosage

Table 1: Summary of Alum Results

Jar no.	Turbidity (NTU)	Iron (Fe) (mg/L)	Alum (mg/L)	Res. turbidity (NTU)	Res. iron (mg/L)	% removal	
						Turbidity	Iron (Fe)
1	71.7	0.77	15	2.12	0.15	97.0	80.5
2	68.0	0.87	25	2.30	0.15	96.6	82.7
3	68.7	0.84	35	1.64	0.15	97.6	82.1
4	72.7	0.90	45	1.16	0.15	98.4	83.3
5	71.6	0.86	55	1.25	0.16	98.2	81.3
6	68.4	0.85	60	1.37	0.17	97.9	80.0

Optimum dose: **45mg/L**, % iron removal: **83.3%**, res. iron: **0.15 mg/l** res. turbidity (NTU): **0.17**

Table 2: Summary of Alum Results (at Optimum Dosage)

Jar no.	Turbidity (NTU)	Iron (Fe) (mg/L)	pH	Alum dose (mg/L)	Res. turbidity (NTU)	Res. iron (Fe) (mg/L)	% removal	
							Turbidity	Iron (Fe)
1	72.1	0.98	5.43	45	2.16	0.17	97.0	82.6
2	76.5	1.00	6.44	45	1.03	0	98.6	100
3	69.1	1.06	7.03	45	1.14	0	98.3	100
4	71.4	0.96	7.65	45	1.40	0.03	98.0	96.8
5	68.4	1.10	8.39	45	0.92	0.03	98.6	97.2

Optimum pH: **6.44**, % iron removal: **100%**, res. Iron: **0 mg/l**, res. turbidity: **1.03 NTU**

Table 3: Summary of PAC Results

Jar no.	Turbidity (NTU)	Iron (Fe) (mg/L)	PAC (mg/L)	Res. Turbidity (NTU)	Res. iron (mg/L)	% removal	
						Turbidity	Iron (Fe)
1	71.80	0.90	25	1.13	0.11	98.4	87.8
2	72.00	0.80	35	1.09	0.13	98.5	84.0
3	74.10	0.97	45	1.75	0.16	97.6	83.4
4	77.50	0.83	50	1.26	0.14	98.4	83.1
5	72.50	0.94	55	1.78	0.12	97.5	87.2
6	75.20	0.90	60	1.75	0.11	97.7	87.7

Optimum dose: **25mg/L**, % iron removal: **87.8%** res. Iron: **0.11mg/l**, res. turbidity: **1.13** NTU

Table 4: Summary of PAC Results (at Optimum Dose)
Optimum pH: **6.34**, % iron removal: **87.5%**, res. iron: **0.12 mg/l** , res. turbidity: **1.17 NTU**

Jar no.	Turbidity (NTU)	Iron (Fe) (mg/L)	pH	PAC (mg/L)	Residual turbidity (NTU)	Residual iron (mg/L)	% removal	
							Turbidity	Iron (Fe)
1	82.9	0.95	5.21	25	**1.12**	**0.13**	98.6	86.3
2	83.9	0.96	6.34	25	**1.17**	**0.12**	98.6	87.5
3	84.1	0.92	6.63	25	**1.29**	**0.13**	98.4	85.8
4	84.4	0.98	7.21	25	**1.61**	**0.14**	98.0	85.7
5	83.9	0.97	7.71	25	**1.55**	**0.14**	98.1	85.5
6	82.2	0.91	8.43	25	**1.65**	**0.13**	97.9	85.7

Residual Iron and Effect of pH Range on Residual Iron in the Treated Water.

Residual iron in the water following coagulation by aluminium salt and PAC should be minimised because any hydrated ferric oxide makes the iron-laden waters objectionable and its colloidal suspensions can give the water a uniformly yellow-orange, murky cast. It is this coloration together with associated tastes and odour can make the water undesirable for domestic use once the level exceed 0.3 mg/L. Figures 5 and 6 illustrate the residual iron content for both alum and PAC range as well as residual iron for varying pH range. Figure 5 is a useful indicator to verify that both coagulants were successful in reducing the iron content to less than exceeding limit of 0.3mg/L within that initial raw water iron content of around 1.0 mg/L. As can be seen, PAC shows a better performance with under and over dosing of coagulants. That trend seems to indicate that under and over dosing will result in deterioration in iron content. The trend for the effect of pH range on residual iron shown in Figure 6 needs to be further elaborated. The concluding remark would be that alum was just slightly better in terms of residual iron content of less than 0.1 mg/L but the effectiveness was at a narrow pH range. PAC on the other hand as shown in Figure 6 offered a slightly wider range performance on the final residual iron. Lastly for both tested coagulants, the optimum iron removal was achieved basically in the range of 5.0– 8.4. This is also consistent with findings of other researchers (Gao Yu, 2005). The possible explanation would be; as the pH is increased say higher than optimum pH value, the increase of pH favoured the hydrolysis of metal-ions and decreased the formation of positively charged ions. Hence, the ability for coagulants to neutralise the negative charge on colloids became small and, thus, colloidal matter could not be removed effectively.

Conclusions

As a conclusion the performance of PAC as coagulative agent for removing iron from ferruginous water was found to be highly successful and it was also found to be optimum at under and over dosing. The optimum iron removals were achieved at pH 5.2–8.4 with dose of about 25 mg/L with an almost 87.5% removal rate for PAC and at pH 6.4–8.4 and dose of about

45 mg/L with over 95% removal rate for Alum. These reported results seem to prove the possibility of PAC to offer a better performance with a slightly better pH range as well as at lower coagulant dose if we are to achieve over 85% removal rate. The removal rate for turbidity was at par to alum coagulant. On top of that, it was also found that the floc formed with PAC coagulant is heavier and larger in size at its optimum dosage. The concentration of *residual iron* in treated water by the selected PAC was 0.12 mg/L well below the national regulated limit of 0.30 mg/L.
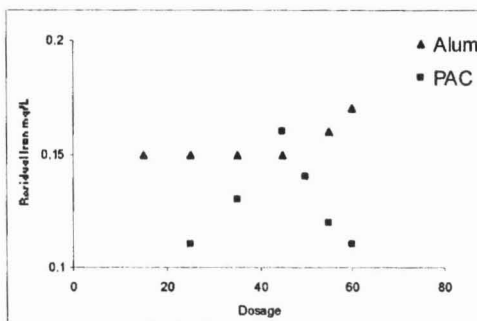

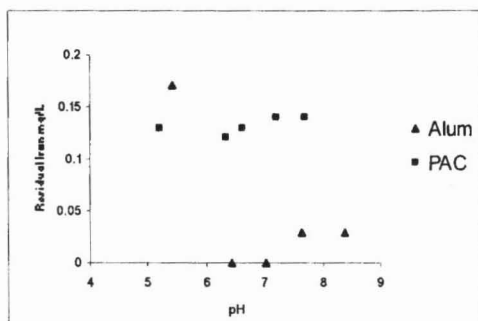Figure 5: Effect of coagulant dosages on residual iron

Figure 6: Effect of pH on residual iron

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