AJCHE 2012, Vol. 12, No. 1, 42 – 50

Water Treatment by Coagulation-Flocculation Using Ferric Sulphate as Coagulant

Hary Sulistyo *
Suprihastuti Sri Rahayu
Wahyudi Budi Sediawan
Sarto
Yusuf
Ronald Nainggolan
Chemical Engineering Department, Gadjah Mada University,Yogyakarta, Indonesia
**e-mail:* hsulistyo@chemeng.ugm.ac.id

Coagulation and flocculation are two essential processes in water treatment. Their improvement on effectiveness and efficiency will give a significant influence for the overall process. The coagulation and flocculation processes involve a coagulant subsequently used to form flocks that can sink precipitate easily. In this research, the sample taken from Sermo Reservoir located in Kulon Progo Regency. The water was containing 320 ppm of colloid and suspended solids. Here, using a magnetic mixer stirrer, 500ml of raw water was mixed with a certain dosage of ferric sulfate in that used as the coagulant at a certain pH in a beaker glass through a high-speed mixing (240 rpm) for five minutes and low-speed mixing (60 ppm) for 10 minutes, respectively. Subsequently, the absorption was measured using UV/Visible. The result then shows 100 ppm for the optimum dosage of ferric sulfate and 9 for the optimum pH.

The results indicate that a higher precipitation constant (k_d) has resulted in a higher flock diameter. The correlation between the precipitation constant (k_d) and the Reynolds number can be expressed as the following equation, k_d = 51.98 $Re^{0.3735}$ with an average relative error of 9.8%.

Keyword: Water Treatment, Coagulation, Flocculation, Suspended Solids, Precipitation Constant

INTRODUCTION

The more increase the population is, the more consumption the water will be. As a matter of fact, the supply of clean water somehow comes to decrease for the natural forces. For example the quality of water either in reservoirs, lakes or rivers as the potential sources of clean water depends upon the season. In reservoir, water will contain suspended solid in various forms, sizes and mass densities in a rainy season. As the consequences, for drinking water purposes, it requires an adequate water treatment. Coagulation related to this matter becomes the most important part of water treatment, purposively to separate colloids and suspended solids from the water. In its process, coagulation is highly determined by types, concentration of coagulant and flocculant, temperature and speed of mixing (Powel, 1954). Furthermore, an adjustment of acidity and alkalinity of water is performed for the regulation of water pH considering that the solution acidity will influence the coagulant's hydrolysis reaction which afterward determines its performance capability (Tschobanoglous, et. al., 2003).

A coagulant, once the colloid flocks have been formed, is used to neutralize the surface of colloids and suspension particles dispersed in water. In this case, the higher the colloid and suspended solids concentration in water, the higher dosage of coagulant required (Sorochenco, 2003). In addition, the coagulation and flocculation processes are influenced by the coagulant solubility in water and there will be more coagulants required at a lower temperature (Powel, 1954). The coagulation process further needs a high-speed mixing and low-speed one following through, commonly ranging from 120 to 240 rpm and from 20 to 60 rpm, respectively (Aguilar, et. al., 2003). The solid size in the same way will influence the flocculation speed and the agglomeration among the solids which in turn influence the separation process (O'Melia, et. al., 1997). In line with this, Muhle (1985) states that the adhesive forces among solid particles will result in an acceleration of flocculation.

Aluminum, ferrous and ferric compounds are chemicals mostly used as coagulant. Here, the use of a ferric compound is able to increase the coagulation rate up to 10 times when compared with the use of aluminum compound (Ronnholm, et. al., 1999). Ferric sulfate itself can be made of iron waste and sulfuric acid (Sulistyo, et. al., 2006). To evaluate the separation process, Adin et al. (1998) analyzed the solid contents just before and after the addition of coagulant.

This research purposively is to examine the decrease of the concentration of colloids and suspended solids in water, in this case, by using ferric sulfate as the coagulant. The optimum water treatment process will be developed later.

THEORETICAL BACKGROUND

Added in the water, coagulants will adsorb particles and build up bridges to combine colloids and suspended particles into bigger ones. Meanwhile, a ferric sulfate coagulant when added in water will undergo hydrolysis as described below (Tschobanoglous, et al., 2003)

$$Fe_2(SO4)_3 + 12\ H_2O \longrightarrow 2[Fe(H_2O)6]^{3+} + 3[SO_4]^{2-} \quad (1)$$

Mononuclear species

$$8[Fe(H_2O)_6]^{3+} + 20OH^- \longrightarrow [Fe_8(OH)_{20}]^{4+}(aq) + 6\ H_2O \quad (2)$$

Polynuclear species

$$[Fe_8(OH)_{20}]^{4+}(aq) + 4OH^- + 24H_2O \longrightarrow 8[Fe(OH)_3(H_2O)_3]_{(s)} \quad (3)$$

Ferric in mononuclear and polynuclear will adsorb particles in order to form flocks. The solid concentration in water can be measured in the adsorption of particle using UV/Visible, as in the following equation (Tchobanoglous, et. al., 2003):

$$A = log\left(\frac{I_o}{I}\right) \quad (4)$$

$$C_S = f\,(A) \quad (5)$$

After the coagulation and flocculation processes, the solid concentration in water can be evaluated by equation:

$$N_t = N_{to}\, exp(-k_d.\, t) \quad (6)$$

If the volume is constant, equation (6) will be formed.

$$C_t = C_{to}\, exp(-k_d\, .\, t) \quad (7)$$

Equation (7) can be expressed into

$$ln\left(\frac{C_t}{C_{to}}\right) = -k_d t \quad (8)$$

The diameter of flocks is determined using the equation of particle movement in liquid:

$$C_d = \frac{4g(\rho_S - \rho)d_p}{3\rho v t^2} \quad (9)$$

for laminair flow Re < 1

$$C_d = \frac{24}{Re} \quad (10)$$

for transition flow 1<Re<1000

$$C_d = \frac{24}{Re}(1 + 0.5\,Re^{0.687}) \quad (11)$$

The solid recovery percentage in sample (X) can be calculated with the following equation:

$$X = \frac{C_{to} - C_t}{C_t}100\% \quad (12)$$

EXPERIMENTAL PROCEDURE

Materials

a. Clay from the area of Sermo Reservoir in Kulon Progo, Indonesia.

b. Ferric sulphate of 90% purity

Equipment

A beaker glass with a magnetic stirrer with an adjustable speed

Method

To obtain a similar sample between water taken from reservoir and the raw water in the rainy season, the clay was`taken from the reservoir area was put into a beaker glass containing distilled water. Having subsequently mixed evenly for one hour, the mixing would be stopped. After 48 hours, the upper part of the water was then separated from its sediments to obtain water containing solids of the suspension and colloid. The next process was to measure the adsorption of the water sample using UV/Visible. To obtain certain acidity or pH of water sample, sulfuric acid was then added prior to adding and mixing a certain dosage of ferric sulfate to the sample respectively at the high speed of 240 rpm for five minutes and at the low speed of 60 rpm for 10 minutes. When the process above was over, the settling rate and the adsorption of the sample were measured in every 15 minutes. The last experiment was repeatedly performed by varying the ferric sulfate and pH levels.

Analysis

The analysis was performed in order to obtain the data of solid concentration in liquid using a UV/Visible spectrometer. It is started by constructing a standard curve to show a correlation between the solid concentration in liquid and its adsorption. The k_d value and the flock diameter are calculated using equations 8 and 9, followed by calculating the equation of correlation between k_d and Reynolds number.

RESULT AND DISCUSSION

A standard curve is drawn to show a correlation between the solid concentration in liquid and its absorbance value. The measurement of the absorbance level is performed to identify the solid concentration in water after adding ferric sulfate at a certain pH to the water sample. Table 1 and Figure 1 present the obtained optimum of ferric sulfate. The minimum absorbance value of the sample meanwhile is obtained at the ferric sulfate concentration of 100 ppm. Principally, the occurrence of adsorption value above 100 ppm is mostly due to the over-addition of ferric sulfate. In this case commonly indicated by the change of the liquid to be yellowish due to the ferric sulfate solution color. Not only being not effective, this occurrence can make the level of clarity decreased. In some cases, in the coagulation and flocculation of melanoidin waste using ferrous sulfate, the optimum dosage of ferrous sulfate is 3000 ppm (Novita, 2001). Similarly, Anguliar et al. (2003) using ferric sulfate as a coagulant for household waste water found the optimum ferric sulfate dosage of 500 ppm. The results of those two researches are obviously significantly different from what has been found in this research considering that the optimum dosage in coagulation and flocculation processes was highly determined by the type, concentration of coagulant, the type of colloid and suspension solids in the sample. In fact, an optimum ferric sulfate dosage at the solid concentration can be determined

Table 1. Sample absorbance value at various ferric sulfates concentration

Ferric sulfates conc, ppm	Absorbance
50	0.100
100	0.085
150	0.093
200	0.096
250	0.120
300	0.151
350	0.192
400	0.222
450	0.234
500	0.243

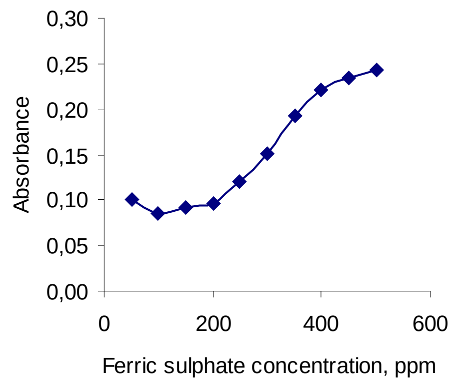

Fig. 1: The correlation between the sample absorbance value and the ferric sulfate concentration

by diluting the sample and reducing the ferric sulfate amount in which the diluting factor afterwards can be used as the ratio between the solid concentration and the ferric sulfate in the sample such as 320 ppm: 100 ppm. It is additionally found that the solid concentration in water sample is not constant. It will be dependently fluctuated on the seasons - rainy or dry season. In other words, the solid concentration in the water sample will affect the addition of ferric sulfate. As seen in Table 2 and Figure 2, to obtain an optimum process, the adsorption of the sample ahead of the coagulation and flocculation processes must be measured to determine how much ferric sulfate should be added.

Table 2. The sample absorbance on optimum ferric sulfate

Ferric sulfates conc, ppm	Absorbance
2.5	0.034
5.0	0.063
10.0	0.109
20.0	0.207
50.0	0.359
100.0	0.589

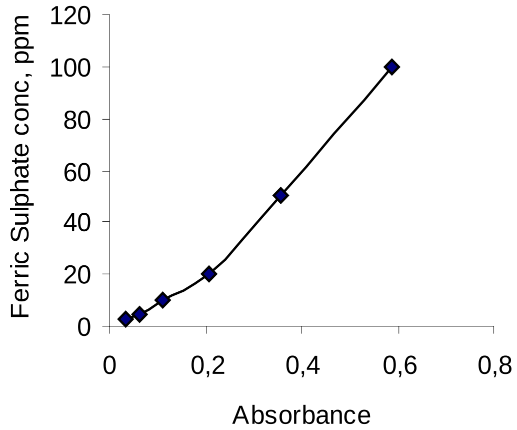

Fig. 2: The correlation between the optimum ferric sulfate concentration and the absorbance value

Furthermore, in optimizing the pH value, the ferric sulfate concentration obtained from the optimization of ferric sulfate concentration should be at 100 parts per million (ppm). Given the different pH, a sample with the minimum adsorption value is used. As seen in Table 3 dan Figure 3 presenting the result of pH optimization, the minimum solid concentration in the sample is at 8 – 9 for level of pH - meaning that it is more alkaline. This result is supported with the reaction of (1), (2) and (3) where OH ions are obtained to form polynuclears as coagulant to be flocculated into bigger flocks. For a pH above 9, it is found that the amount of suspended solids left in the liquid phase sample will be higher due to the less effective coagulation and flocculation processes. As a comparison, the optimum pH in the coagulation and flocculation processes using ferrous sulfate for melonoidin waste is 12 (Novita, 2001). Thus, the optimum pH difference between ferrous sulfate and ferric sulfate coagulants are related to the different equilibrium conditions in the polynuclear formation.

Table 3. The solid concentration in the sample at various of solution pH

pH	solid conc, ppm
1	285.95
2	273.89
3	141.05
4	88.84
5	70.87
6	53.60
7	51.97
8	45.99
9	41.76
10	179.28
11	210.01
12	262.06
13	276.28
14	298.25

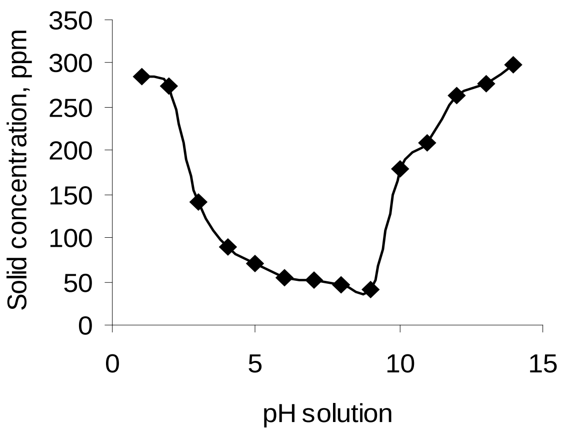

Fig. 3: The correlation between solid concentration in the sample the solution pH

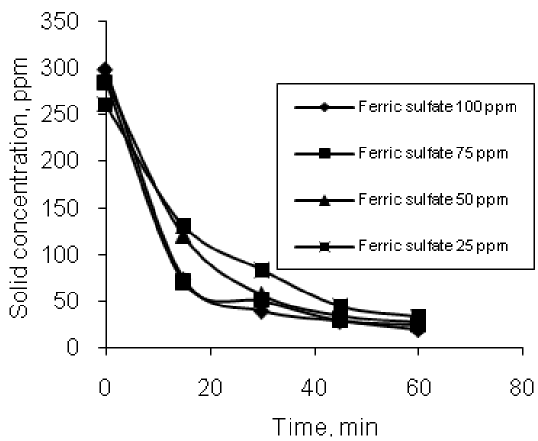

Fig. 4: The correlation between concentration in the sample and the time at various ferric sulfate dosages

Table 4. Parameter values calculated at various ferric sulfate concentration levels

Ferric sulfate concentration, ppm	k_d, h^{-1}	v_m settling, cm/min	d, micron	Reynolds number, 10^4	Recovery, %
25	2.160	0.10	3.5	2.06	89.70
50	2.652	0.14	4.1	3.38	91.57
75	2.880	0.16	4.4	4.14	92.82
100	3.156	0.20	4.9	5.77	94.07

The precipitation constant (k_d) is evaluated by using equation (8) in which the solid concentration is calculated from the standard curve of adsorption data. Figure 4 shows a correlation between the solid concentration and time at the ferric sulfate dosages of 25 to 100 ppm.

Using concentration data in Figure 4, the solid recovery percentage in the sample can be calculated as the result of which is presented in Table 4. Meanwhile, the flock diameter is calculated with the equation of particle movement in fluid as in equation (9). The calculation results at various ferric sulfate concentration levels show that, as presented in Table 4, the higher concentrated of ferric sulfate concentration used will result in the bigger flock diameter and the higher flocculation rate.

Figure 5 and Figure 6 below present the correlation between flock diameter and ferric sulfate concentration and that of between the precipitation constants and Reynolds numbers (Re), respectively. The precipitation constant obtained at the optimum ferric sulfate concentration of 100 ppm is 3.156 h^{-1}, found to be the highest flocculation rate in the sample. The approximate solid recovery is around 94.07%. It is much higher than the use of ferrous sulfate (only 53.23%) at the ferrous sulfate dosage of 3000 ppm (Novita, 2001).

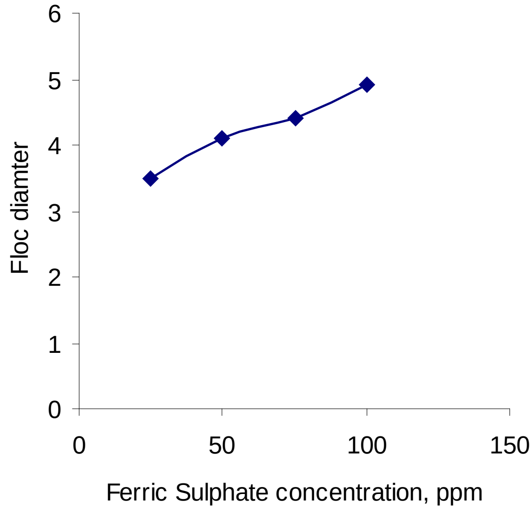

Fig. 5: The correlation between flock diameters with various ferric sulfate concentration levels

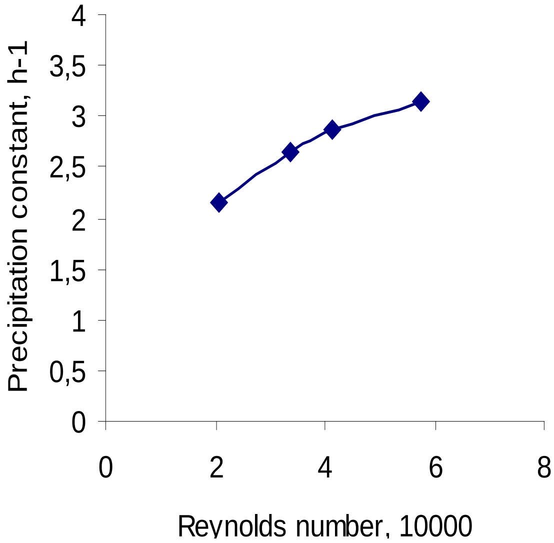

Fig. 6: The correlation between the precipitation constant (k_d) and the Reynolds number (Re)

The difference as shown in equations (1), (2), and (3) is due to the given higher Fe ion in ferric sulfate bringing an impact on the reaction. Meanwhile, the flock diameter obtained from the calculation ranges from 3.5 to 4.9 micron with a Reynolds number lower than 1, showing that the flow is as laminar as Stokes' law equation. Anguliar, et al. (2003) reported that the coagulation and flocculation processes using ferrous sulfate in household waste water show the photographed flock diameters of 1 to 10 microns with a recovery percentage of 87%. Similarly, the diameter resulting of the present research calculation is still within the range of the photographed flock diameter, which means that the calculation approach using Stokes' law equation (the laminar curve) can be used.

The relation between the precipitation constant and the Reynolds number can be expressed in the following equation:

$$k_d = 51.98\ Re^{0.3735} \qquad (13)$$

where the k_d unit is hour^{-1}, with an average relative error of 9.8%.

To increase the k_d value, it can be done by increasing the Reynolds number or by adjusting its variables: diameter, fluid mass density and viscosity. Equation (13) is applicable for various diameter flocks, settling rates, and media in the coagulation and flocculation processes using coagulant of ferric sulfate.

CONCLUSION

Based on the research results and the discussion on the coagulation and flocculation of water taken from Sermo Reservoir using ferric sulfate as the coagulant, several conclusions can be presented as follows:

1. The optimum condition on the coagulation and flocculation process of the water taken from Sermo Reservoir, Kulon Progo is at which the ferric sulfate dosage is 100 ppm and the pH is 9.
2. Ferric sulfate comes to be a good coagulant with a suspended solid decrease of 94.07%.

3. The correlation between the precipitation constant (k_d) and the Reynolds number (Re) for the coagulation and flocculation processes using ferric sulfate is found to be $k_d = 52.98\ Re^{0.3735}$

ABBREVIATION

A	= adsorption
C_d	= drag coefficient
C_s	= concentration of ferric sulphate
C_t	= concentration of solid
C_{to}	= initial concentration of solid
d_p	= solid diameter
g	= gravitation acceleration
I	= light intensity
I_o	= initial light intensity
k_d	= precipitation constant,
N_t	= number of solid in solution
N_{to}	= initial number of solid in solution
Re	= Reynolds number
t	= time
v_m	= precipitation velocity
X	= solid recovery percentage
ρ	= fluid density
ρ_s	= solid density

ACKNOWLEDGEMENTS

The present researchers are very grateful to the Directorate General of Higher Education for funding this research through Competitive Research Grant Program XIV/2 of 2007 for Gadjah Mada University.

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