Journal homepage www.jzs.univsul.edu.iq
Journal of Zankoy Sulaimani
Part-A- (Pure and Applied Sciences)

Removal of Water Turbidity Using Different Coagulants

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Article info

Original: 24 August 2016
Revised: 27 November 2016
Accepted: 9 January 2017
Published online: 20 June 2017

Key Words:
Different coagulants,
Optimum pH and dosage,
Residual turbidity,
Turbidity removal performance

Abstract

Free Water turbid with high quality of potable water supply is the most important environmental issue. Surface water is usually rich in turbidity. Turbidity imparts a great problem in water treatment. In this present work, the performance and effectiveness of four different inorganic coagulant salts including alum, copper sulphate, ferric sulphate, and ferrous sulfate in water turbidity removal were investigated. No coagulant aids are used in the current study. Desired turbid samples with 100NTU (turbidity of surface water does not exceed 100NTU in no rain condition) are prepared in laboratory, mixing kaolin powder with tap water. The optimum conditions for maximum suspended solid removal are examined. A set of jar test experiments are conducted to find the optimum pH and coagulant dosage to reach appropriate operational conditions. The samples in jar apparatus underwent rapid mixing with speed of 100rpm for 1min. in order to attain uniform concentration of coagulants in water. Slow mixing with speed of 25rpm for 25 min. is used to give the colloidal particles favor to approach from each other to make flocs, and then allow the samples in the beakers to settle for 25 minutes to precipitate the agglomerates by gravity and sludge formation at the bottom of beakers. Results demonstrated that turbidity removal is dependent on pH and coagulant dosage. The highest turbidity removal efficiency was within % 97.9 for Alum when pH value is 6.5, %90.8 for copper sulphate when pH is 7, % 87 for ferric sulphate when pH is 4, and %72 for ferrous sulphate when pH is 4. Results indicated that alum has the best potential ability of water turbidity removal compared with other used coagulants.

Introduction

Water supply and treatment are critical needs of society. It was recognized earlier that water quality involves both aesthetic and health concerns depending on the purpose of consumption and the contaminants present. Therefore, the purpose of water treatment is to produce a safe and aesthetically pleasing water. This requires that the water be free of harmful chemicals and microbes, as well as have an acceptable taste and odor [1]. Suspended matters in water and wastewater result in turbidity. Not only due to the aesthetical reasons but also due to its potential health risks, turbidity is an important parameter stated in drinking water quality criteria. In order to meet the criteria, the removal of colloidal particles causing the turbidity is required. Moreover, raw water containing colloidal particles should be treated via water treatment processes for several reasons such as:

- Particles are removed in order to make the water aesthetically pleasing to the consumers.
- Particles are also removed because pathogenic microorganisms often attach them and when the particles are removed, so are the pathogens.

- Particles in raw water can influence the disinfection process in a negative way. When shielded by particles the disinfectant may not be as effective in inactivating pathogens. Meaning that particles may decrease the efficiency of disinfection, because a higher degree of treatment might be required for effective water treatment. Therefore, by the removal of the particles, the efficiency of disinfection can be as significant as possible [2].

The suspended material in water arise from land erosion, the dissolution of minerals, the decay of vegetation and from several domestic and industrial waste discharges. It can be inorganic in nature, e.g. sand or clay particles or organic in nature such as algae or humic material from decaying plant material. The presence of these particulate materials in water often causes deterioration of water quality by reducing the clarity (e.g. causing turbidity or colour), causing infection, and eventually carrying toxic compounds, adsorbed on their surfaces. In addition, organic matter is the vital precursor to the formation of disinfection by-products, when chlorine is applied as disinfection agent. The settle ability of the particulate depends on the density of the material and the size of particles. The particles with mass more than water should eventually precipitate due to gravitational force. Small particles, especially those with density close to water such as bacteria and colloidal particles may never settle and remain suspended in the water. Therefore, agglomeration of particles into a larger floc is a necessary step for their removal by sedimentation [2].

The nature of suspended material in water can vary from relatively coarse to colloidal particles. Table (1) classifies according to size the mutual substances present in water. Particles smaller than around 10-5 mm may be referred as colloids and particles smaller than 10-6 mm as solutions. It can be noticed that with decreasing size, the time required for settling increases, up to several years solutions ingredients. Due to minute size, the only way for settling and the subsequent separation is to come closer, to make contacts and to form larger particles, which can be settle easier. This procedure however, is hindered due to the homonymous negative charge this material carries. The electrostatic repulsive forces constrain the particles from approaching each other and the suspension is characterized as stable; therefore, long time is required for settling [3]. They must be chemically destabilized or coagulated to neutralize the charge on them and to form larger flocs that can settle, thereby facilitating their removal from water [4].

Table 1: Classification of particle sizes

Particle size (mm)	**Classification**	**Examples**	**Total surface area (m2/cm2)**	**Time required to settle 100mm, if specific gravity=2.65**
10	Coarse dispersion (visible to naked eye)	Gravel, coarse sand, mineral substances, precipitated and flocculated particles, silt, macro plankton	$6*10^{-4}$	0.1s
1			$6*10^{-3}$	1s
10^{-1}			$6*10^{-2}$	13s
10^{-2}	Fine particulate dispersion(visible under microscope)	Mineral constituents, precipitated and flocculated particles, mud, bacteria, plankton, and other organisms	0.6	11minutes
10^{-3}			6	20hours
10^{-4}			60	80days
10^{-5}	Colloidal dispersion (submicroscopic)	Mineral substances, hydrolysis and precipitated products, macromolecules biopolymers, viruses	600	2years
10^{-6}			6000	20years
$<10^{-6}$	Solution	Inorganic and complex ions, molecules and polymeric species, polyelectrolytes, organic molecules, undissociated molecules		

Coagulation is one of the most important physicochemical operations used in water, and wastewater treatment that can be achieved by chemical and electrical means [5]. Coagulation and flocculation occur in successive steps intended to overcome the forces stabilizing the suspended particles, allowing particle collision and growth of floc. Coagulation has been defined as the addition of a positively charged ion of metal salt that results in particle destabilization and charge neutralization. Coagulation targets colloid particles between 0.001 to 1 micron size diameters. The colloid particles exhibit Brownian movement through the water; their surface is negatively charged so they repel one another, and they form a stable dispersed suspension [6]. Flocculation refers to the successful collision that occurs when destabilized particles are driven toward each other by the hydraulic shear force in the rapid mix and flocculation basin. It agglomerates of a few colloids then quickly bridge together to form micro flocs, which is turned into visible floc masses [7]. Figure (1) illustrates the diagram of elementary reactions and processes that occur during coagulation, flocculation, and sedimentation.

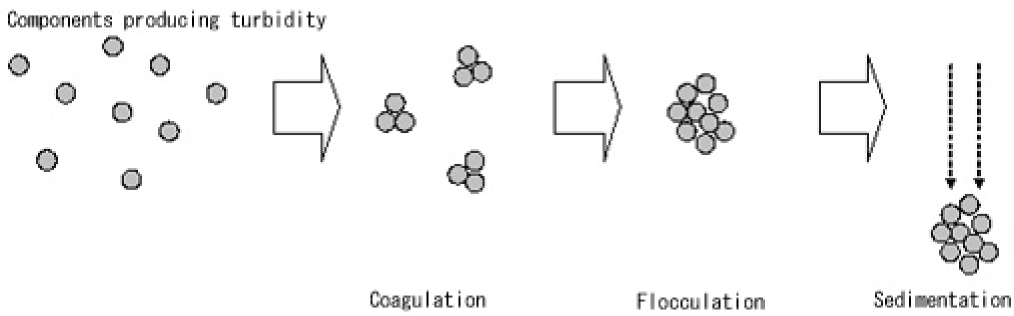

Figure (1): Process of Coagulation, Flocculation and Sedimentation

This method induces the most suitable environment that should influence coagulation/flocculation mechanisms and subsequent floc formation. It can be achieved by adding a suitable reagent as coagulant/flocculant, under vigorous stirring conditions aiming at a uniform dispersion of the reagent, the destabilization of the colloid micelles and the formation of small aggregates [8]. The growth of the aggregates towards larger and heavier flocs of appropriate size, which are then removed by precipitation, is achieved by slow agitation that enhances the movement of the aggregates and their attenuation in small distances [9]. There are numerous papers about turbidity removal from wastewater by coagulation/flocculation, among them are:

(Mirzaiy et al, 2012) studied the removal of turbidity, organic matter, coliform and heterotrophic bacteria by coagulants poly aluminum chloride from Karoon River water in Iran. The results showed that the most optimal conditions for turbidity removal and microbial parameters efficiency by poly aluminum chloride were pH = 8, flash mixing =100 rpm and the optimal doses of poly aluminum chloride were obtained as 10 and 30 ppm. The turbidity, total coliform, fecal coliform and heterotrophic bacteria removal efficiency under optimum condition of poly aluminum chloride application for dose 10 ppm were, respectively, 96.59, 90, 82.75, 84.17 %.

(Moniruzzaman et al, 2012) investigated the performance of different coagulants for turbidity and color removal. The results illustrated that among four different coagulants (aluminum sulphate, ferrous sulphate, ferric chloride and PG-M); the lowest optimum dose was found for ferric chloride as 28.0 mg/L for turbidity and 24.0 mg/L for color removal. The highest removal performance was obtained for a slow mixing period of 20.0 to 25.0 minutes.

Materials and Methods

In the current study, turbid samples with (100NTU) were prepared by mixing well an amount of kaolin powder in 6 liters of tap water. Turbidity of water was measured as Nephelometric Turbidity Units (NTU) by using the turbidimetre ((Hanna turbidity meter HI93703). Calibration has been done for the turbidity meter according to the standard methods before measurement of turbid water samples. Tap water was used in this study to notice the probable interference of any elements in its quality on turbidity removal efficiency. The characteristics of the tap water used in the experiments are taken from laboratory of sulaimani water directorate and listed in Table (2). A useful laboratory experiment for the evaluation of coagulation/flocculation of an untreated water is the jar test. It is often used for the design of treatment facilities and in the routine operation of treatment. It is also useful to reach and predict the optimum operating conditions such as pH and coagulant dosage.

Jar test experiments were conducted within a pH range of 3-8 for water samples to find the optimum pH operational condition for each coagulant. A six paddle (Model/ PHIPPS&BIRDTM /Richmond Virginia 23230) standard jar test apparatus with variable rotational speed and six jars were used. Four different inorganic coagulant salts including: Aluminum sulfate (Al_2 $(SO_4)_3.18H_2O$), copper sulphate hydrate ($CuSO_4$.5H2O), ferric sulphate [$Fe_2(SO_4)_3$], , and ferrous sulphate hydrate ($FeSO_4.7H_2O$) were used in the current study. Table (3) and (4) show physical and chemical properties of the coagulants.

Table 2: Tap water quality characteristics used for water experiments

No.	Parameter	Concentration
1	pH	7.66
2	Turbidity (NTU)	0.46
3	Alkalinity (mg/l)	186
4	Chloride, Cl^- (mg/l)	22.1
5	Nitrate , NO_4^{-2} (mg/l)	3
6	Sulphate, SO_4^{-2}, (mg/l)	11.84
7	Iron, Fe, (mg/l)	0.0
8	Calcium, Ca (mg/l)	56.37
9	Magnesium, Mg^{+2} (mg/l)	29.5
10	Sodium, Na^+(mg/l)	5.53
11	Conductivity (µs/cm)	320
12	Potassium, K^+ (mg/)	0.94
13	Dissolved oxygen (mg/l)	5.12

Table 3: physical and chemical properties of Alum and ferric sulphate [10]

No.	Physical & chemical properties	Aluminum sulphate hydrate	Ferric sulphate
1	Chemical formula	$Al_2(SO_4)_3.18H_2O$	$Fe_2(SO_4)_3$
2	Molar mass(g/mole)	666.42	562
3	Appearance	white crystalline solid	grayish-white crystals
4	Density (g/cm3)	2.672	1.898
5	Melting Point (°C)	770	175
6	Solubility in water	31.2g/100ml (0°C), 36.4g/100ml(20°C), 89.0g/100ml(100°C)	Moderately soluble

Table 4: physical and chemical properties of copper sulphate and ferrous sulphate hydrate [10]

No.	Physical & chemical properties	Copper Sulphate	Ferrous sulphate hydrate
1	Chemical formula	$CuSO_4.5H_2O$	$FeSO_4.7H_2O$
2	Molar mass(g/mole)	249.685	259.99
3	Appearance	Blue	White-yellow crystals
4	Density (g/cm3)	3.6	3
5	Melting Point (°C)	<560	60-64
6	Solubility in water	1.055 molal (10 °C) 1.26 molal(20°C) 1.502 molal (30°C)	15.65g/100ml (0°C), 20.5g/100ml(20°C), 29.51g/100ml(100°C)

Sulfuric acid, sodium hydroxide and pH meter were used to adjust the pH value of water. Water temperature was averagely 30°C. The six clear jars or beakers of jar test apparatus are filled with prepared samples (1000 ml) water sample to be tested. The stock solutions of the coagulants (10,000 mg/L) were prepared by dissolving 2.5 grams of each in 250ml of distilled water in such away each ml of stock solution contains 10mg of coagulant. Make a series of coagulant concentrations ranging 10-60 mg/L at 10mg/L concentration intervals by adding stock solution (1 mL stock solution = 10 mg/l coagulant) to the jars. Different dosages (10-60mg/l) are used starting from lowest one to obtain optimum dosage required for maximum turbidity removal. After the addition of coagulant to each beaker, the samples in jar apparatus underwent rapid mixing with speed of 100rpm for 1 min and slow mixing speed of 25rpm for 25 min, and then allow the samples in the beakers to settle for 25 minutes. Water samples were taken from 20 mm below the water surface (to avoid capturing non-settleable colloidal) of each beaker for turbidity measurements. Figure (2) shows schematic diagram of processing the procedure of jar test experiment.

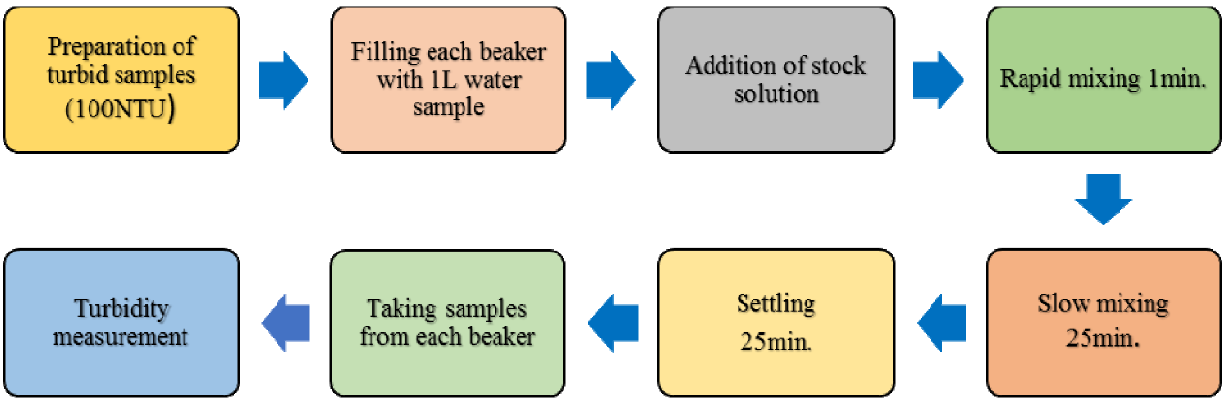

Figure 2: schematic diagram of processing the jar test experiments

The lowest residual turbidity was used as the indicator of high performance. Later, the optimum amount of chemical dose for all the four inorganic coagulants were also attained depending on optimum pH resulted in the experiments. Finally, the performance efficiency of turbidity removal of each coagulant was determined by the following equation:

$$\% \text{ Performance efficiency} = \frac{\text{Initial turbidity(NTU)} - \text{Residual turbidity(NTU)}}{\text{Initial turbidity(NTU)}} * 100$$

Experimental characteristics for the jar test experiments in this research were summarized in table (5). Summary the effect of variation of both pH and dosages for all the coagulant salts to reach maximum turbidity removal efficiency has been shown in table (6, 7)

Table 5: Experimental Characteristics carried out in jar test of this work

No.	Characteristics	Descriptions
1	Coagulant	Alum, Copper sulphate, Ferric sulphate, Ferrous sulphate
2	Coagulant dosage	(10-60mg/l) except for Copper sulphate (30-80 mg/l)
3	pH range	3-8
4	Initial Turbidity	100NTU
5	Rapid mixing	1 min.
6	slow mixing	25 min.
7	Settling	25 min.

Table 6: the effect of variation of pH on turbidity removal efficiency for each coagulant salts

Alum	$Al_2(SO_4)_3.18H2O$		Copper sulphate anhydrate		$CuSO_4.5H_2O$
Initial turbidity	100 NTU		Initial turbidity		100 NTU
Each Beaker contains 30mg/l of Alum			Each Beaker contains 30mg/l of CuSO4		
PH	Residual Turbidity (NTU)	Turbidity removal efficiency (%)	PH	Residual Turbidity (NTU)	Turbidity removal efficiency (%)
3	44.2	55.8	3	58.5	41.5
4	35.3	64.7	4	57.7	42.3
5	8.8	91.2	5	52.9	47.1
6	4.5	95.5	6	38	62
7	4.4	95.6	7	27	73
8	14.8	85.2	8	44	56

Ferric sulphate	$Fe_2(SO_4)_3$		Ferrous sulphate anhydrate		$FeSO_4.7H_2O$
Initial turbidity	100 NTU		Initial Turbidity		100 NTU
Each Beaker has 30mg/l of $Fe_2(SO_4)_3$			Each Beaker has 30mg/l of $FeSO_4.5H_2O$		
PH	Residual Turbidity (NTU)	Turbidity removal efficiency (%)	PH	Residual Turbidity (NTU)	Turbidity removal efficiency (%)
3	30	70	3	32	68
4	12	88	4	28	72
5	12.6	87.4	5	31.6	68.4
6	14	86	6	38.3	61.7
7	15.6	84.4	7	43.6	56.4
8	15.4	84.6	8	48.2	51.8

Table 7: the effect of variation of dosage on turbidity removal efficiency for each coagulant salts

Alum	$Al_2(SO_4)_3.18H2O$		Copper sulphate anhydrate		$CuSO_4.5H_2O$
Initial Turbidity	100 NTU		Initial Turbidity		100 NTU
PH	6.5		pH		7
Dosage (mg/l)	**Residual Turbidity (NTU)**	**Turbidity removal efficiency (%)**	**Dosage (mg/l)**	**Residual Turbidity (NTU)**	**Turbidity removal efficiency (%)**
10	17.1	82.9	30	22.2	77.8
20	11.4	88.6	40	17.7	82.3
30	8.2	91.8	50	13.3	86.7
40	2.1	97.9	60	10.3	89.7
50	2.4	97.6	70	9.2	90.8
60	5.6	94.4	80	16.3	83.7

Ferric sulphate	$Fe_2(SO_4)_3$		Ferrous sulphate anhydrate	$FeSO_4.7H2O$	
Initial Turbidity	100 NTU		Initial Turbidity	100 NTU	
PH	7		pH	4	
Dosage (mg/l)	**Residual Turbidity (NTU)**	**Turbidity removal efficiency (%)**	**Dosage (mg/l)**	**Residual Turbidity (NTU)**	**Turbidity removal efficiency (%)**
10	30	70	10	32	68
20	18.5	81.5	20	28	72
30	13	87	30	31.6	68.4
40	14.7	85.3	40	38.3	61.7
50	16.9	83.1	50	43.6	56.4
60	16.8	83.2	60	48.2	51.8

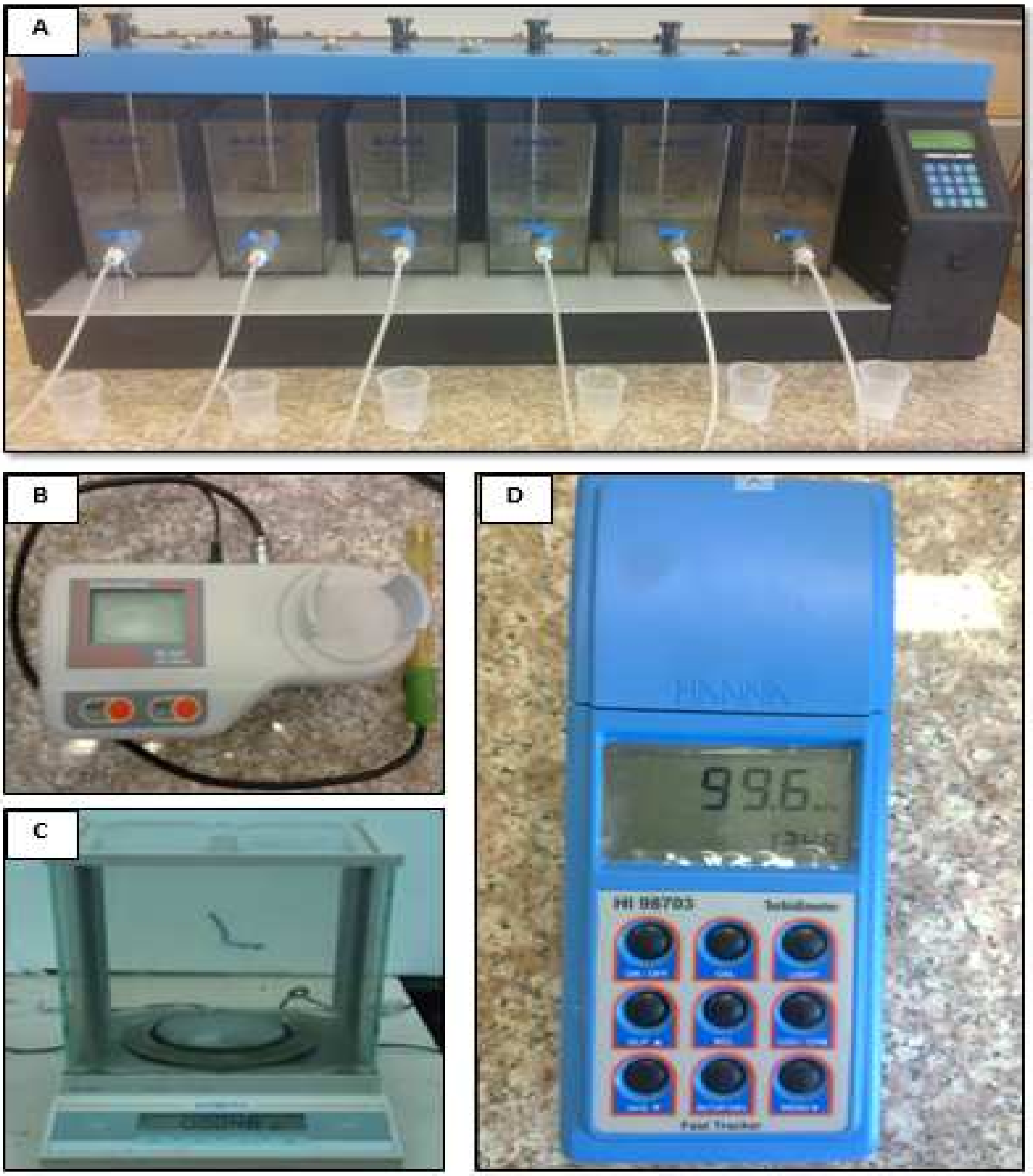

Figure 3: A) Jar test apparatus (Model/ PHIPPS&BIRD^{TM} /Richmond Virginia 23230), B) pH meter (Hana instrument, HI 207 pH meter, Romania), C) Electrical balance (Sartorius BL 210S, Germany), D) Turbidity meter (Hanna instrument turbidity meter Code: HI98703-02, Romania).

Results and Discussion

Turbidity usually results from fine colloidal particles. These particles remain in suspension, causing prolonged turbidity for three plain reasons. A water body may have enough turbulence to prevent fine particles from settling. The resuspension rate of particles may exceed the speed of sedimentation. In addition, colloidal particles settle at an exceedingly slow rate. Colloidal particles are mostly negatively charged, and mutual repulsion counteracts the tendency of particles to floc together and precipitate. The presence of cations tends to neutralize negative charges on fine elements and allow them to floc [11].

The results of this study on the performance of four coagulants (alum, copper sulphate, ferric sulphate, and ferrous sulfate) in water turbidity removal are investigated. Figures (4) represents the residual water turbidity of coagulants as a function of pH ranged from 3-8 with coagulant dose of 30mg/l of each coagulant into each six jars or beakers of jar test apparatus at different run. Results indicated that turbidity removal efficiency was varied by pH value of water samples.

The lowest water turbidity using (alum, copper sulphate, ferric sulphate, and ferrous sulfate) was observed at optimum pH value of (6.5, 7, 4, 4) respectively and minimum residual water turbidity was (4.4, 27, 12, 28,) NTU respectively. Alum among other used coagulants gives the least residual turbidity.

Various coagulant dosage at optimum pH value for each coagulant at different run were used as illustrated in figure (5), which represents the relationship between residual water turbidity and the amount of coagulant dosage. As indicated from the figure, alum has the biggest potential capability to reduce water turbidity to 2.1 NTU with 40mg/l as optimum dosage followed by copper sulphate to 9.2 NTU with 70mg/l. However, Ferric sulphate and ferrous sulphate enable to reduce water turbidity to (13, 28) NTU with (30mg/l, 20 mg/l) respectively. The results indicated that more copper sulphate dosage was used to reduce water turbidity to 9.2NTU compared with ferric sulphate which only 30mg/l was used to obtain 13NTU.

The percentage of turbidity removal efficiency for all the coagulants at different dose of coagulants was estimated dependent on optimum pH value. The results are shown in figure (6) which indicates that alum has the best performance of water turbidity removal efficiency with (97.9%) at dosage 40mg/l followed by copper sulphate with (90.8%) at dosage 70mg/l. However, ferric sulphate and ferrous sulphate have the ability to remove water turbidity with (% 87 at 30mg/l dosage and %72 at 20mg/l dosage) respectively.

Application of the study

Coagulation-flocculation is used widely during water or wastewater treatment. It is an integral treatment step in the surface or underground water treatment, indented for human consumption. Typical applications are the removal/separation of colloids and suspended particles of natural organic matter, or of metal ions. In wastewater treatment, additional applications include the removal of toxic metals, anions (i.e. phosphates), color; odor etc. [12]. The application of different salt coagulants in water treatment plants is conventional in most of large cities. The most common widespread coagulant is aluminum sulphate due to the relatively low cost, high effectiveness and the simpler application route. However, it requires several optimum operating conditions such as the need for pH adjustment before or after treatment, the sensitivity to temperature changes, the need for higher dosages because the charge neutralization is not usually sufficient, the sensitivity to sample specific characteristics and composition, and the excessive sludge production [13].

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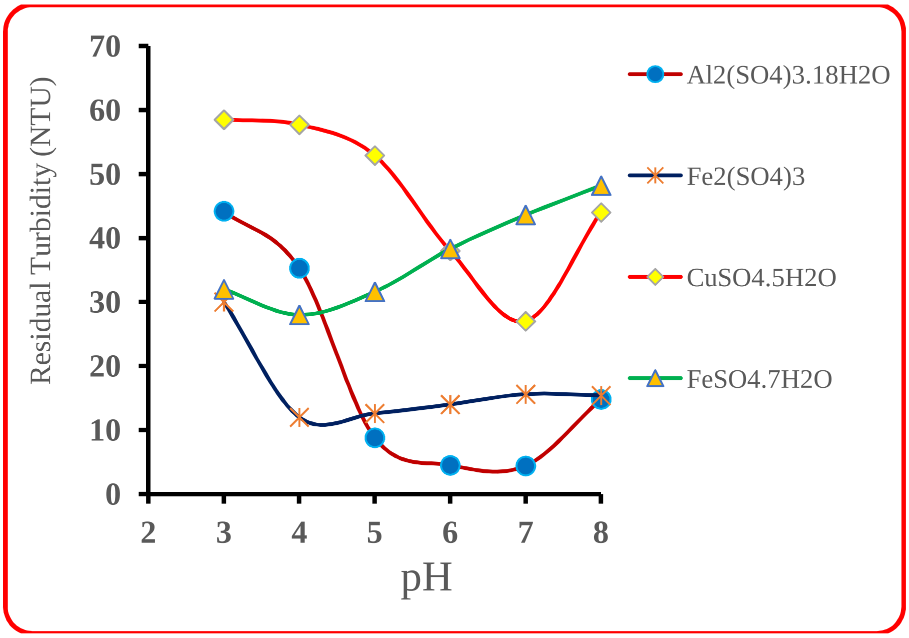
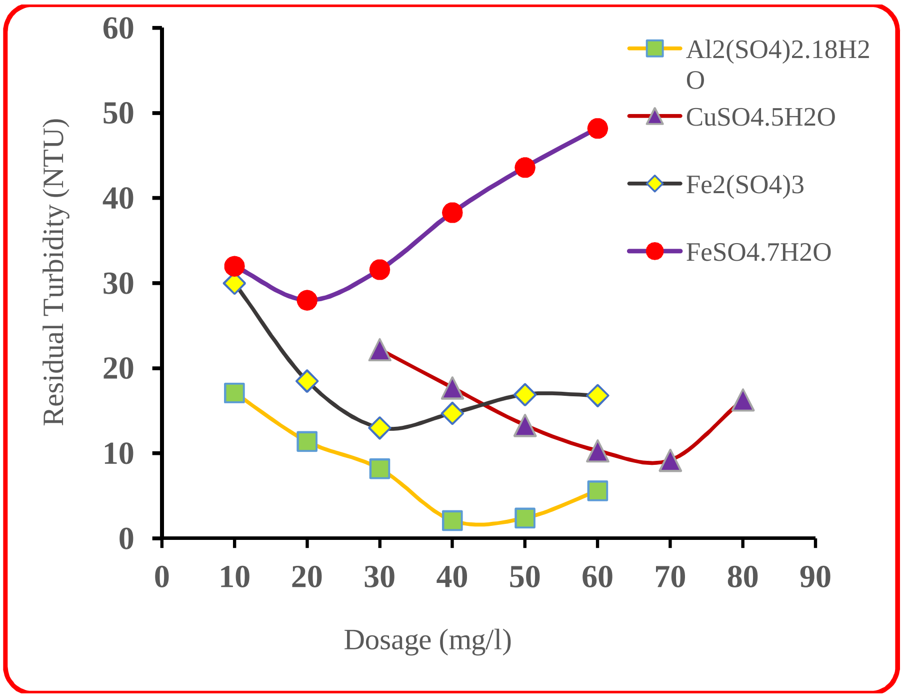
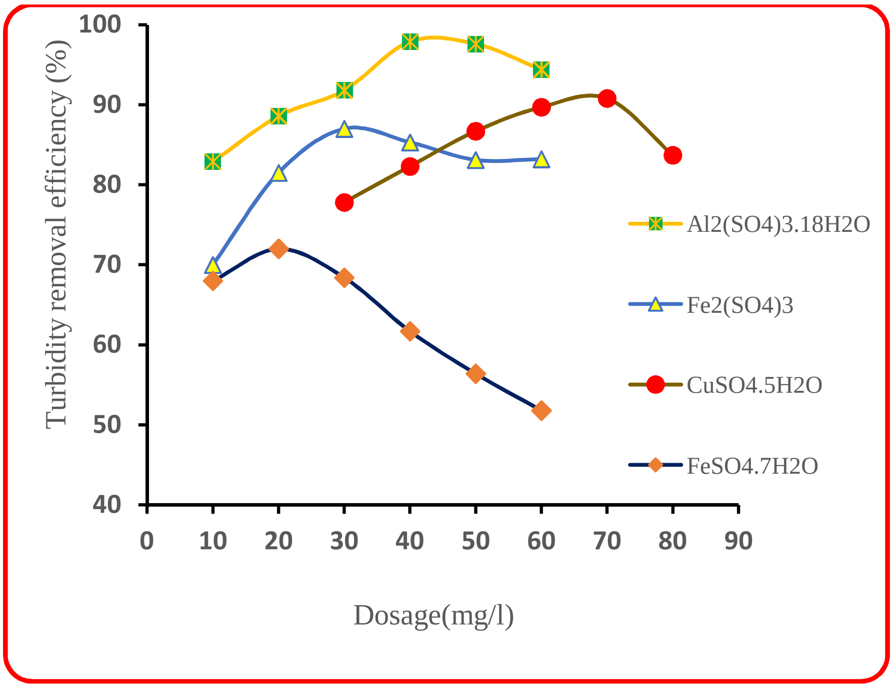


Figure(4): Optimum pH value for different coagulants, Initial Turbidity=100NTU, 30mg/l coagulant dosage in each beakers of jar test apparatus



Figure(5): Optimum dosage for different coagulants at optimum pH, Initial Turbidity=100NTU



Figure(6): Turbidity removal efficiency of coagulants at different dosage and optimum pH, Initial Turbidity=100NTU

Conclusions

Based upon the experiments results in the study and limited to the conditions determined a prior, the following observations and conclusions could be drawn:

- The process of coagulation and flocculation followed by sedimentation improve turbidity removal of water caused by colloidal suspended solids.
- Four different inorganic coagulant salts [$Al_2(SO_4)_3.18H_2O$, $CuSO_4.5H_2O$, $Fe_2(SO_4)_3$, and FeSO4.7H2O] were studied by varying the reagent dosage and pH. Alum proves to be the most efficient coagulant/flocculant, resulting in almost negligible turbidity, followed in treatment performance by copper sulfate, ferric sulphate and ferrous sulphate which they have less capability potential of coagulation/flocculation to clear water turbidity compared with alum.
- The aluminum sulfate, copper sulphate and ferric sulphate proved to be efficient coagulation/flocculation reagents for treating turbid water in this study with initial turbidity 100NTU.
- Chemical coagulant dosage for (alum, copper sulphate, ferric sulphate, and ferrous sulphate) affects the process efficiency of coagulation/flocculation to some extend in most cases.
- pH plays a significant role of the process efficiency.

Recommendations for Future Study

1. Checking the performance of the same coagulant salts to remove water turbidity when coagulant aid is added such as bentonite, polymer, and gypsum.
2. Studying the change of rapid and slow mixing speed on turbidity removal efficiency. .
3. Evaluation the efficiency of coagulant salts to reduce turbidity of surface water which exceed than 100NTU (rain condition).

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