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Full Length Article

Effect of settling time, velocity gradient, and camp number on turbidity removal for oilfield produced water ☆

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ABSTRACT

This paper studies the effect of settling time, velocity gradient, and camp number on turbidity removal for oilfield produced water from Degasing station1 (DS1)/North Rumaila oilfield/Southern Oil Company in Basrah Province/Iraq during 2013. Physico-chemical tests were carried out on sample with the different dosage of three types of coagulants and flocculants; poly-aluminum chloride, ferric chloride, and cationic polyelectrolyte individually and in combination. From experiments, it was found the removal of residual turbidity increases as the settling time increases. The rotation speed of 45–55 rpm, (G of 54.5–78.5 s^{-1}) was the most favourable speed of mixing of flocculation. The effect of camp number on the residual turbidity was done at time range of (10–30 min) and velocity gradient (G) of 50 s^{-1}. The residual turbidity initially decreases with increasing camp number; it reaches a minimum value, and then starts increasing again with further increases in camp number. The experimental results of this study are used to develop an empirical correlation for turbidity removal efficiency as a function of multi variables poly-aluminum chloride dosage; polyelectrolyte dosage; and Ferric chloride dosage.

1. Introduction

Turbidity in water is caused by suspended matter, such as clay, silt, finely divided organic and inorganic matter, soluble colored organic compounds, planktons and other micro and macroscopic organisms [1]. Turbidity particles range from about 0.01 to 100 μm in size. The larger fraction is relatively easy to settle or filter. The smaller, colloidal fraction, (from 0.01 to 5 μm), presents the real challenge. Their settling times are intolerably slow and they easily escape filtration [2,3]. The removal of turbidity in water would be extremely beneficial as it would alleviate the majority of problems associated with turbidity [4,5]. Turbidity can be used to measure the performance of individual treatment processes as well as the performance of an overall water treatment system. Common water treatment processes like screening, Pre-sedimentation, Coagulation- Flocculation and Filtration intended to remove suspended solids and reduce turbidity [6]. One of the most commonly used methods for the removal of turbidity in the form of suspended and colloidal material in water is the addition of coagulants and flocculants, such as alum, ferric chloride, and long-chain polymers [7]. Coagulation technology is one of the important ways and the most popular process to deal with water and wastewater treatment [8,9]. It is effective in removing particles as well as organic matter [10]. The separation of particulate matter from the liquid phase is one of the important steps in most wastewater treatment processes. All waters contain both dissolved and suspended particles. Coagulation and flocculation processes are used to separate the suspended solids portion from the water [11,12]. it is an advanced method and may be categorically defined as treatment for the removal of pollutants include suspended solids, BOD, nutrients, nitrogen and phosphors, heavy metals and colors [13]. This paper studies the effect of settling time, Velocity Gradient, and Camp Number on turbidity removal for oilfield produced water using coagulation-flocculation with different dosages of poly-aluminum chloride, ferric chloride, and poly-electrolyte.

2. Experimental work

2.1. Produced water characteristics

Oilfield produced water used in the present study was from Degasing station1(DS1)/North Rumaila oilfield/Southern Oil Company which is situated at coordinates: 30°34′40.88″N, 47°20′18.78″E in Basrah Province/Iraq during 2013. The characteristics

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of produced water was analyzed according to [14], Table 1. The site of produced water sample is shown in (Fig. 1).

2.2. Experimental procedure

The process of treating oilfield produced water was coagulation-flocculation process using bench scale Jar test apparatus (Flocculator/SW6). Six (1000 mL) volume samples of the produced water were introduced into the six beakers of the jar test. Appropriate quantities of coagulant added and the multiple stirrer was first agitated quickly at the speed of 150 rpm ($G = 273\ s^{-1}$) for 1 min, then reduce the speed to 50 rpm ($G = 52\ s^{-1}$) for 20 min. After 20 min of settling, withdraw a sample volume of supernatant liquor at a point 5 cm from the surface of the sample, to conduct the required analyses. Turbidity of the supernatant liquors was measured by (TURB model 3551, WTW, Germany) and expressed in nephelometric turbidity unit (NTU) within the range (0.00–1000) NTU. The procedure for measurement was conformed to that described in Standard Methods for the Examination of Water and Wastewater [14]. The efficiency of turbidity removal, R% was calculated using the formula given:

$$R\% = \frac{(C_o - C)}{C_o} * 100 \quad (1)$$

where
Co: initial turbidity, NTU.
C: final turbidity, NTU.

2.3. Material used and solution preparation

Three types of coagulants and flocculants were used in this study; poly-aluminum chloride, ferric chloride, and cationic polyelectrolyte individually and in combination; poly-aluminum chloride with cationic polyelectrolyte and ferric chloride with cationic polyelectrolyte. All the coagulants used were provided by Al-Dura Refinery (Iraq).

2.3.1. Preparation of primary coagulant

Poly-aluminum chloride (PAC) ($Al_2(OH)_3Cl_3$) and Ferric Chloride ($FeCl_3{\cdot}6H_2O$) solution were prepared by dissolving 1 g of the powder in 100 ml of distilled water, stirring and mixing well to produce a solution of 10,000 ppm concentration.

2.3.2. Preparation of coagulant aid

Poly- electrolyte (PE) was used as a coagulant aid, which is a cationic polymer (CHIMEC 5268) in powder form with high molecular weight, highly cationic, completely and easily soluble in water. It is equally effective over a wide pH range, thus ensuring use at low dosages. A solution was prepared by dissolving 0.1 g of the powdered polyelectrolyte in 100 ml of distilled water, mixed, and stirred very well to produce a solution of (1000 ppm) concentration.

3. Results and discussion

3.1. Investigation of the optimum coagulants dosage

One of the most important parameters is dosage that has been considered to determine the optimum conditions of the coagulation and flocculation. It was decisive to determine the optimum dosage in order to minimize the dosing cost and obtain the optimum performance in treatment [15]. A set of experiments were conducted using jar test apparatus to investigate the effect of coagulants dosage on the produced water in term of turbidity removal efficiency (R%).

Figs. 2 and 3 show optimum dose of Poly-aluminum Chloride (PAC) and Ferric Chloride, respectively. The turbidity removal efficiency increases with PAC and Ferric Chloride dose increase until reaching the optimum dose. The optimum doses of PAC and Ferric Chloride were (80–100 mg/L) and (10–15 mg/L), respectively, then turbidity removal efficiency decreases because the over dosing causes restabilization of the colloid particles. This removal results from the effect of coagulation-flocculation, which overcomes some of the forces of repulsion between colloidal particles and reduces the distances between them, which increases the attraction forces and Vander Vaal forces and weakens the Brownian motion then weakens the value of Zeta-potential.

The results of optimum doses of PAC and Ferric Chloride, as primary coagulants, with different doses of polyelectrolyte (PE), as a coagulant aid, were shown in Figs. 4and 5. The adding of PE with PAC achieved a lower dose required for coagulation- flocculation process compared with the use of PAC alone. This is because the PAC doses not affect removal of all the colloidal particles and decrease Zeta potential to the required limit, while when combining PE with PAC will have effect on removing some of the colloidal particles, which aren't affected by PAC alone and thus, increase the removal efficiency. PAC when combined with (1.0 mg/L) PE has been seen the most effective in reducing the turbidity and providing higher removal efficiency which is increased up to more than 99.61%. Ferric chloride has been seen the most effective in reducing the turbidity and providing higher removal efficiency which increases up to more than 99.64% when combined with (0.6 mg/L) PE. This is because Polyelectrolyte which has high molecular weight and long chain branching adsorbs colloids; therefore a charge will be neutral and the floc particles grow and will be affected by the gravity force and settle at higher settling velocity.

3.2. Effect of settling time on the residual turbidity

The residual values of turbidity plotted against settling time are shown in Figs. 6–8. The removal of residual turbidity increases as the settling time increases. That is due to the settling behavior of suspended particles and other floc particles which are collected during their movement in the bulk of the solution forming settled particles [16]. From results shown when the settling time was 20 min, the optimum dose of Ferric Chloride (15 mg/L) gives the lower residual turbidity than the optimum doses of PAC and PE doses, and when the dose of PE is 0.8 mg/L combined with PAC dose of 20 mg/L and Ferric Chloride dose of 10 mg/L, gives lower residual turbidity than used PE doses 0.4 and 0.6 mg/L.

3.3. Effect of velocity gradient (G) on the residual turbidity

The velocity gradient is a very important factor when it comes to determining the probability of the particles coming together, as shown in Eq. (2).

$$G = \sqrt{\frac{P}{\mu V}} \quad (2)$$

Table 1
Oilfield produced water characteristics.

pH	Electrical Conductivity (EC), μ s/cm	Turbidity, NTU	Total Dissolved Solid (TDS), mg/l	Total Suspended Solid (TSS), mg/l
Around (7)	94900	410.3	85410	333.2

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