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Design of dissolved air flotation (DAF) process for treating dyes-contaminated wastewater

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ABSTRACT

The effect of using natural coagulant Aloe Vera with alum $Al_2(SO_4)_3$ was examined to remove three reactive dyes: Reactive Blue (RB), Reactive Red (RR) and Reactive Yellow (RY) from simulated textile wastewater in single and blended (ternary) systems by utilizing dissolved air flotation system (DAF) combined with the coagulation + flocculation + flotation in continuous system. This combining process showed excellent removal efficiency. The process was operated under flow rate of, 100 L h^{-1} and duration of 30 min at 15 mg L^{-1} dye concentrations; pH value was fixed at 8, and the dose of alum + AV was fixed at 10 mg L^{-1}. DAF system was operated once using alum + AV and then using Poly aluminium chloride (PAC; $AlCl_3.6H_2O$) with dose of 10 mg L^{-1} as flocculant in combination with coagulant. The removal efficiency reached to 95, 93 and 92% for RR, RB and RY respectively for single system without flocculant. By using flocculant with coagulant, the removal efficiency was excellent and was 97, 96 and 95% for RR, RB and RY, respectively. Thus, combined treatment processes offer many advantages for potential treatment of sewage and industrial wastewater such as flexibility, time and coagulant/flocculant savings as well as high quality treated water.

Keyword: Dyes, Coagulant, Flocculent Dissolved Air Flotation, Wastewater.
Article type: Research Article.

INTRODUCTION

Numerous industries utilize dyes to color their items, e.g., textiles, elastic, paper, plastics, lacing, beautifiers, nourishment and mineral processing industries. The textile completing industry has a particular amount of water utilization (approx. 1 L per kg of item), some portion of which is because of dying and rinsing operations (Garg et al. 2004). The world production of dyestuffs of ≈10 million kg $year^{-1}$ in the range of 1 and 2 million kg of active dye which enter the biosphere as resolved, or a few dyes are hurmful to aquatic life in rivers where they are released. Dyes can lessen light infiltration into the water and diminishing the competence of photosynthesis in aquatic plants, hence subsequently having adverse effect on their development (Yu-li *et al.* 2003). Kadirvelu et al. (2007) concluded that dyes additionally can cause extreme harm to people, dysfunction of kidney, genital systems, liver and central neural system. The vocational exposure of workers in the textile industry is connected to a higher bladder cancer chance. Utilizes of hair colouring item and breast cancer have also been correlated. Subsequently decolourisation of dye house profluent by means of the abstraction of dye has become a significant part of textile wastewater treatment. On the other hand, the use of combined processes has been growing to overcome the disadvantages of individual treatment processes, such as high operating costs, sludge handling problems, and especially lack of effective dye treatment. The combination of coagulation and flotation is the most promising process as these steps have high individual treatment efficiencies, low costs, and ease of operation. There are many studies about removal of dyes from aqueous solutions (Olasehinde *et al.* 2020; Alshamri *et al.* 2021; Aljeboree *et al.* 2021; Jasim & Aljeboree 2021). In this work, the removal efficiencies of three dyes

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including Reactive Blue (RB), Reactive Red (RR) and Reactive Yellow (RY) were examined utilizing alum mixed with aloe vera. Dissolved air flotation (DAF) system were employed and installed all the parameters including pH, coagulants dose, and initial concentration of dyes. The best values of these parameters were obtained from the batch experiments.

MATERIALS AND METHODS

Reactive dyes: Three dyes were used including Reactive Blue (RB), Reactive Red (RR) and Reactive Yellow (RY) received from AL-Kut Textile Factory, south of Baghdad (Department of Dying and Printing, Table 1).

Table 1. Main features of reactive dyes.

Item	Reactive blue RB	Reactive Red RR	Reactive Yellow RY
Trade name	Ciba cron Blue FNR	Ciba cron Red FN-R	Ciba cron Yellow FN-2R
Phase	Solid/ Powder Package 25 kg	Solid/Powder Package 25kg	Solid/ Powder Package 25 kg
Wave length (nm)	609	540	501
Origin	Swiss	Swiss	Swiss
pH	5.5-6	5.5-6	5.5-6
Molecular formula	$C_{29}H_{23}Cu\ FN_9O_{12}S_3.3Na$	$C_{29}H_{15}CIFN_7O_{13}S_4Na_4$	$C_9H_{12}N_2O_3$
Molecular weight g/mol	936.45	944.2	176
Solubility g L^{-1} at 25 ºC	95	110	130
Chemical structure		Not disclosed by the manufacturer	

Preparation of DAF pilot scale solutions

Simulated wastewater:

Dyes stock solution was prepared by adding 10 g of dye powder to 1 L of distilled water to get concentration of 10000 g L^{-1} followed by adding 375 mL of stock solution to 250 L of water in the Raw water tank (**A**) in the supply unit to get concentration of 15 mg L^{-1} (Fig. 1F).

Coagulant:

Tank for coagulant (**J**; Fig. 1F) was filled with alum + aloe vera at dose 10 mg L^{-1}. The alum + aloe vera dose was kept in flotation tank at best value using the Eq. 1 (as below):

$$C_{mix} = \frac{Q_1 * C_1 + Q_2 * C_2}{Q_1 + Q_2} \qquad \textbf{(1)}$$

where Q_1: dyes flow rate (100 L h^{-1})

Q_2: Coagulant flow rate (1 L h^{-1})

C_1: Dose of coagulant in feeding wastewater (0 mg L^{-1})

C_2: Dose of coagulant in feeding wastewater (unknown mg L^{-1})

C_{mix}: Required coagulant dose at flotation tank (10 mg L^{-1})

$$10\frac{mg}{L} = \frac{100\frac{L}{h} * 0 + 1\frac{L}{h} * C_2}{100\frac{L}{h} + 1\frac{L}{h}}$$

Thus, a concentration of 10 mg L^{-1} was prepared in the coagulant tank.

Flocculant:

Tank for flocculant (**K**; Fig. 1F) was filled with flocculant solution prepared by adding 50 g of poly aluminum chloride ($AlCl_3.6H_2O$) to 2-L distilled water to get the concentration of 1000 mg L^{-1} in the flocculation tank.

Caustic soda (NaOH):

To obtain maximum removal efficiency at best pH (8), NaoH was used. The use of acid is not suitable, since all coagulants works better at alkaline environment. 35 g caustic soda is added to 2 L distilled water in the tank to be used in different experiments (**L;** Fig. 1F).

Prepared materials and dissolved air flotation (DAF) system: (Fig. 1)

fundamental precept in quantitative UV-visible spectrophotometer method is linear relation between absorbance A and concentration of disbanded sample C (mg L^{-1}) which is given by Beer–Lambert law (Eq. 2; Ekrami & Okazi 2010, AL-Degs *et al.* 2008).

$$A = KC + E \qquad \textbf{(2)}$$

where A is absorbance of light at wavelength

K is absorbance coefficient (slant of linear relation).

C is concentration of dye in solution (mg L^{-1}).

E is opposing of linear relation.

For multi-ingredients solution, the absorptive absorbance coefficient for each dye is determined from absorbance estimation of dye at certain dye concentration at the point when absorbance linear relation is built by plotting absorbance of each single dye against dye concentration at its wavelength and re-plots at wavelengths of other dyes in the blend of dye solution. These decided coefficients are then used to determine the value of obscure dye concentration by Eq. 3 which can be resolved at the same time by forming matrix called multiple linear regression analysis (De-Alba *et al.* 1997; Kang *et al.* 2003).

$$\begin{bmatrix} A_1 \\ A_2 \\ . \\ . \\ A_n \end{bmatrix} = \begin{bmatrix} K_{11} & K_{12} & . & . & K_{1m} \\ K_{21} & K_{22} & . & . & K_{2m} \\ . & . & . & . & . \\ . & . & . & . & . \\ K_{n1} & K_{n2} & . & . & K_{nm} \end{bmatrix} \begin{bmatrix} C_1 \\ C_2 \\ . \\ . \\ C^m \end{bmatrix} \oplus \begin{bmatrix} E_1 \\ E_2 \\ . \\ . \\ E_n \end{bmatrix}$$

where: A_i is the absorbance at wavelength. K_{ij} is absorbance coefficient of component (i) at wavelength of component (j). C_j Concentration of j^{th} component. E_I is error of measurement (intercept value of linear relation) which can be ignored.

Analytical methods (Calibration curves for analyses single and multi-dyes):

Seven solutions of each dye RB, RR and RY with concentration of 5, 10, 25, 50, 75, 100 and 150 mg L^{-1}) were prepared from the mitigation of the stock solution. Absorption was estimated utilizing UV-spectrophotometer (thermo-genesys 10 UV, USA) for wavelengths of 609, 540 and 501 nm for RB, RR and RY respectively. A linear relationship was drawn between the absorption and concentration of each dye at every wavelength and the procedure was reduplicated for each dye respectively to acquire the adsorption coefficients for computing the concentrations of the obscure dyes (Fig. 2.)

Experiment procedures

The following steps were followed to carry out the experiments in continuous system:

1. 250 L tap-simulated wastewater contaminated with dyes single and in combination secondly was filled into feed tank. The solutions were mixed for 2 min to achieve homogenization.
2. Flocculant tank was filled with poly aluminium chloride solution.
3. Coagulant tank was filled with best mixing coagulant solutions.

4. Caustic soda tank was filled with 0.1M NaOH solution to adjust the pH to best value.
5. The pumps were run to transfer coagulant and flocculant from the coagulant and flocculant tanks to coagulation and flocculation tanks.
6. The stirrer was switched on and the rotation speed was set to 50 rpm. The stirrer was allowed to mix the water with coagulant and flocculant for 2 min before opening contaminated water.
7. The bubble generation system is turned on so bubbles were generated in the flotation tank.
8. Pump was switched on from the switch cabinet and the flow was set to 100 L h^{-1} to transport polluted water from feed tank to coagulation and flocculation tanks, as well as the pH adjustment and flotation tanks.
9. Stopwatch started when continuous operation begun: Continuous operation begun when the water was flowing from the flotation tank into the treated water tank.
10. The device was running for half an hour and taking a sample from treated water tank every five minutes.
11. The samples of dyes then examined by spectrophotometer.

The operating conditions of DAF pilot scale is shown in Table 2.

Fig. 1A: Alum; **B**: Aloe Vera; **C**: Poly aluminium chloride (PAC); **D**: Caustic soda (NaOH); **E**: Schematic diagram of DAF; **F**: Dissolved air flotation (DAF) system.

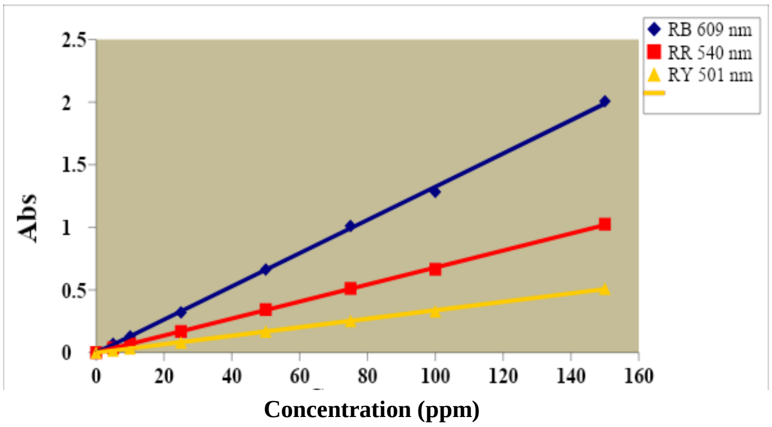

Fig. 2. Calibration curve for the three dyes at different wavelength.

RESULTS AND DISCUSSION

Experiments in single system without flocculent:

The dissolved air flotation (DAF) unit was used to assess the performance of this pilot scale. The dye solutions were prepared in the raw tank. The dyes concentration was 15 mg L^{-1}, pH value was fixed at 8, and the dose of alum + AV was fixed at 10 mg L^{-1}. pH was adjusted using 0.1 M NaOH. No acid was used in pH adjustment, since the dye solutions was above 6. pH was controlled using automated sensors to keep the pH at best value in flotation tank.

Table 2. Influencing variables on flotation process.

Items	Maximum value	The value used
Raw water pump	0-550 L h^{-1}	100 L h^{-1}
Stirrers	0-500 rpm	50 rpm
pH	0-14	Best pH obtained from a previous search
Recycle water flow rate	30-320 L h^{-1}	150 L h^{-1}
Metering pumps	0-2.1 L h^{-1}	1.0 L h^{-1}
Air flow rate	20-360 L h^{-1}	50 N L h^{-1}
Recycle water pressure	0-6 bar	4.5 bar
air pressure	0-10 bar	7 bar

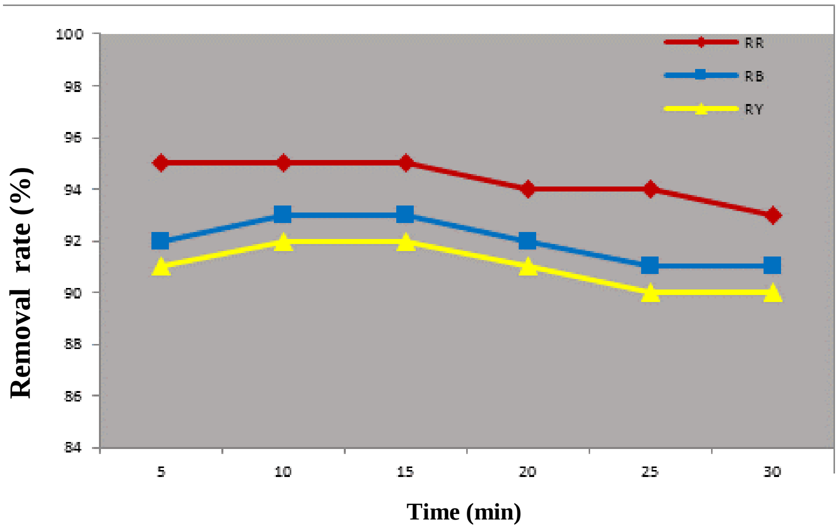

Fig. 3. Removal efficiency of RR, RB and RY with initial dye concentration of 15mg L^{-1}.

The removal efficiency for RR, RB and RY ranged from 95 to 93%, 93 to 91% and 92 to 90% respectively (Fig. 3). The running time was 30 min and samples were taken every 5 min. The small fluctuation in removal efficiency values was normal because of operation conditions. The best removal efficiencies can be obtained in 10 and 15 min, similar to results of Puganeshwary *et al.* (2010). Fig. 4 exhibits the formation of RB dye sludge, which is holding by air bubbles to the upper zone of flotation tank to be skimmed to the sludge zone.

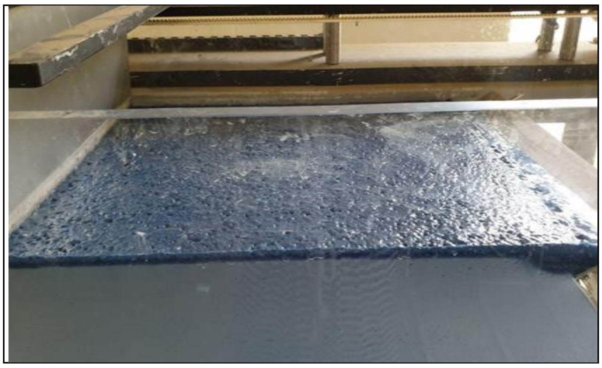

Fig. 4. Formation of RB sludge in the upper zone of the flotation tank.

Using Flocculant along with alum and aloe vera in DAF system:
The flocculent was used with alum +AV to remove the dyes. Poly aluminium chloride (PAC; $AlCl_3.6H_2O$) was used with dose of 10 mg L^{-1} in the flotation tank. The selection of this flocculant was based on high efficiency and low sludge production as reported by Ahmed *et al*. (2019).

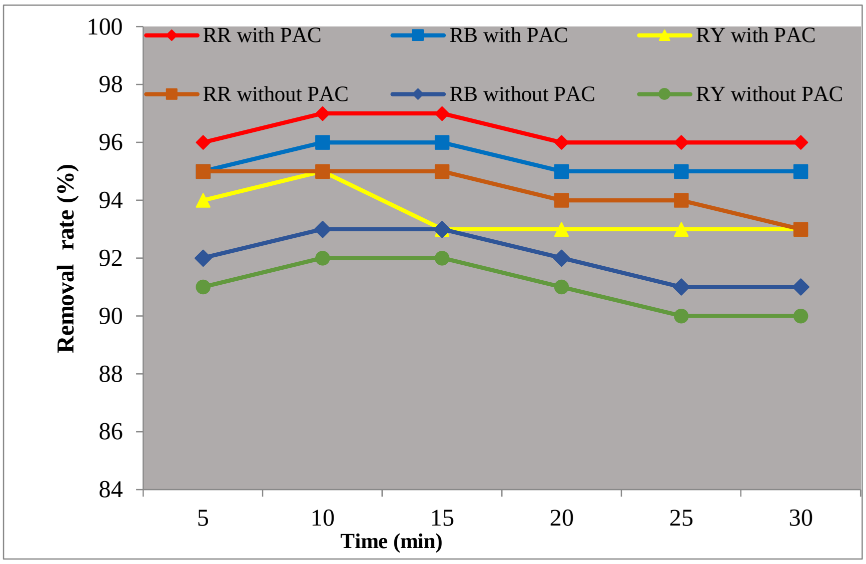

Fig. 5. Removal efficiency versus time using alum combination with AV and PAC to remove of RR, RB and RY with initial dye concentration of 15mg L^{-1}.

The removal efficiency was higher than previous experiments using alum + AV alone. In the case of dyes, the maximum removal efficiency for RR with and without PAC was 97 - 95%, respectively, while it was 96 - 93% for RB and also 95 - 92% for RY (Fig. 5). The addition of flocculant will accelerate formation of flocculant particles and strengthen the linking of coagulant particles, hence, subsequently this will increase the removal efficiency of turbidity and dyes. Although the removal efficiency after adding PAC was not so much, because the remaining particle concentrations concerning to the turbidity or dyes were so tiny, hence it was difficult to convert them to flocs and then settled or floated to skim (Iwuozor 2019). Nevertheless, some standards are so strict and required high effluent quality and this made the use of flocculants are so nesseccary. Many authors obtained same findings (Giwa *et al.* 2017; Rao 2015).

The sequence of the three tested pollutants as a function of removal efficiency was:

RR > RB > RY

Experiments in ternary system with and without flocculant:

DAF system was tested for dyes ternary combination. The ratio of dyes mixture was 1:1:1, where the initial concentration was 15 mg L^{-1}. In addition, the experiment was repeated, once with and once without the flocculent. The dose of alum, AV, PAC and pH remained steady as well as the remaining conditions.

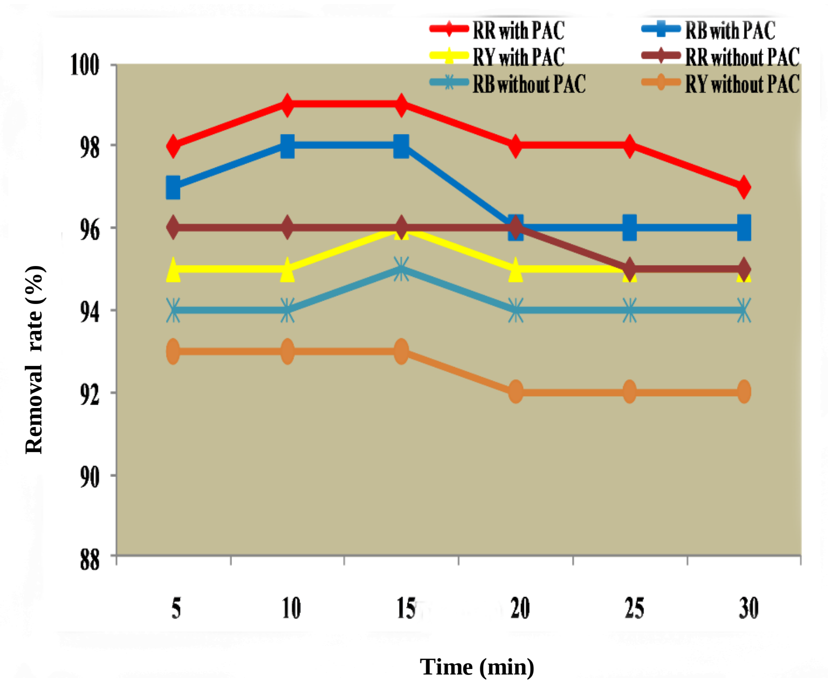

Fig. 6. Removal efficiency of RB, RR and RY in ternary system with initial dyes concentrations of 15mg L^{-1} with and without PAC.

In the single system, removal efficiencies were higher in the initial minutes and the efficiencies for removing RR were higher than those of RB and RY. Furthermore, RR still removed better than in ternary system since it has less solubility and high molecular weight than RB and RY. In general, the removal efficiency with PAC for all dyes remained very high: 99, 98 and 96 % for RR, RB and RY respectively. This indicates that the influent concentration is 0.15, 0.3 and 0.6 mg L^{-1}, respectively. Thus, it is considered as a high reduction in effluent concentration and as a consequence, will decrease the effects on receiving water bodies or subsequent wastewater treatment plants (Ahmed *et al.* 2019).

CONCLUSION

Utilizing of the dissolved air flotation (DAF) system show great capacity in the removal of dyes RB, RR and RY using alum + AV as a coagulant and excellent removal efficiency was achieved once using flocculant with coagulant. The best removal efficiencies can be obtained in 10 and 15 min. The dissolved air flotation (DAF) system gives high quality and pure water that is better than the treatment units used. The coagulant amounts used are less, therefore more economic. In addition, dyes removal were in th order of RR > RB > RY.

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