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EFFECT OF INCLINATION ANGLE, DIMENSIONS OF IMPELLER BLADES, AND VELOCITY GRADIENT ON THE EFFICIENCY OF WATER FLOCCULATION

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ABSTRACT

Drinking water treatment in Mosul city needs efficient flocculation, since raw water has low turbidity formed by fine particles as it is fed from Mosul Dam Lake. This research aimed at studying the effect of mixing parameters on flocculation process in water treatment. A laboratory model was manufactured by the researchers including coagulation, flocculation and sedimentation units. The model works as a continuous flow system. The flow in the system was controlled by a valve. The coagulated water was prepared in the Jar test apparatus with alum as a coagulant according to the operational condition of the water treatment plants of Mosul city. Three flocculation parameters were studied. The velocity gradient was at three levels, the blade dimensions were at two levels and the blades inclination angle was at three levels. Turbidity was used to evaluate the efficiency of coagulation and flocculation processes. The data obtained was analyzed statistically using analysis of variance and LSD test. The studied parameters showed significant effect on turbidity removal. The higher level of velocity gradient of 60 sec^{-1} appeared more efficient for the treatment of Tigris river water in Mosul city. The increase in blades inclination angle improves effluent turbidity, while blades dimensions effect varied according to velocity gradient.

Keywords: mixing blades, velocity gradient, coagulation, flocculation, blades inclination.

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1. INTRODUCTION

Mixing is used with its all technologies in the units of drinking water treatment especially in coagulation and flocculation. Coagulation includes the rapid mixing of the chemical coagulant with raw water to provide homogeneous distribution of it in the basin. On the other hand, flocculation aimed at enhancing forming flocs by giving the chance of collision among flocs with slow mixing. This can be done by different technologies (Viessman, 1983; Steel and McGhee, 2002; Davies, 2010).

Different types of mixers are used in flocculation tanks. They are selected according to economical and designed consideration. Generally, flocculation tanks are classified according to the direction of mixing axis to: flocculation basins with horizontal mixers and with vertical mixers (Keily, 2002; Metcalf and Eddy, 2003). The first type is used in big water treatment plants as it need large space, while the second type is used in the plants with clariflocculators, small treatment plants and compact units.

In Iraq, the second type of flocculators with vertical mixers is widely applied as most of the treatments plants used the combined flocculation and clarification. Additionally, there is a focus toward using compact units in the country.

Vertical mixers are classified into many types according to the shape of impeller and the type of flow resulting from impeller: radial flow impeller and axial flow impeller (AWWA, 1991). The radial flow impellers have the ability to change the pitched angle to get different modes of flow which can effect on the efficiency of flocculation.

This research aimed at studying the effect of blades dimensions ratio of the impeller, the pitched angle of impeller and velocity gradient (shear rate) on the efficiency of the removal of low turbidity of Tigris river water.

2. LITERATURE REVIEW

Although the type of impellers and the modes of flow formed, due to their rotation, have high effect on the efficiency of flocculation basins, however, little studies have investigated such effect.

Oldshue and Mady (1978) studied the effect of impellers type and the volume of flocculation basin on the efficiency of turbidity removal on water treatment plant. They found that the efficiency removal varied with the type of impellers at the same velocity gradient.

Glasgow (1990) compared the behavior of water movement and flocculation efficiency for two types of impellers. The first one made of plastic with four blades and the second impeller covered with cloth. The researcher had not found any significant effect of the impeller type on the volume of flocs.

Spicer et al. (1996) studies the effect of impeller type and the mean shear force resulted on the speed of flocs formation and the structure formed due to the treatment of polystyrene flocs with alum using finite photography technique. They used radial turbine with six blades, axial impeller with three blades and axial impeller with four blades of 45^{o} inclination. They found that the impellers of turbine type generated larger flocs followed by axial flow with four blades and then with three blades at same velocity gradient. They also found that velocity gradient did not have clear effect on the volume and the distribution of flocs by analyzing the finite photos of the flocculation boundary when reaching the steady state condition.

Bouyer et al. (2004) investigated the relationship between the volume of flocs and the dynamic characteristics of the flow in flocculation tank. The first set of experiments included the comparison between Rushton turbine and Lightenin A310 impeller with same energy mean. The results showed that the type of impeller had no effect on the volume of flocs, but it affected on the distribution of flocs. The second set of experiments included the effect of flocculation stages on the volume and the distribution of the flocs.

Jarvis et al. (2005) made a review of floc strength and breakage. They concluded that flocs strength is a difficult parameter to measure. Most researchers focused on exposing flocs to increased shear rate in a containing vessel by stirring. More recent studies developed microscopic techniques that connect the energy required to pull apart or compress individual flocs until breakage.

3. MATERIALS AND METHODS

3.1. Raw water

Raw water in this research was supplied from the old left bank water treatment plant. The samples were taken from the distribution room which received the raw water directly from the river by the low lift pumps. Raw water was supplied at 100 liter per week or according to the need of the research.

3.2. Laboratory Model

A laboratory model was manufactured by the researchers for the purpose of this research. A sketch of units included in the model is shown in figure (1), with sectional and top views in figure (2). The units includes: coagulation, flocculation and sedimentation units. A photograph of model manufactured for the study is shown in figure (3).

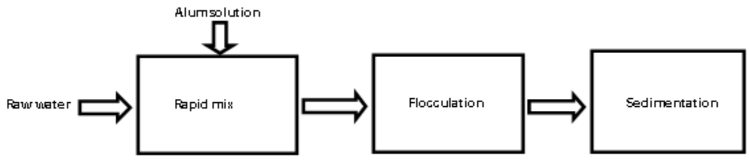

Figure 1 Sketch for the model units used in this study.

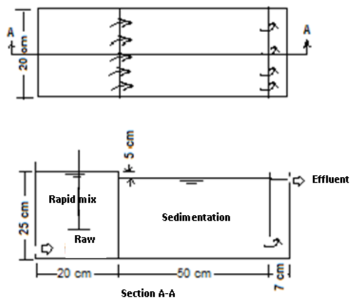

Figure 2 Section and top views of the study model.

Figure 3 A photograph for the laboratory model used in the study.

3.3. Rapid mix unit

Jar test apparatus model ET 740 was used for rapid mix process (Fig. 4). Alum as a coagulant was mixed with raw water at a dosage of 20 mg/l. This dosage was selected according to previous study and to experience with this type of raw water. The rapid mix process was conducted according to the operational conditions in the treatments plants of Mosul city.

Figure 4 A photograph for the Jar test apparatus used in the study type Lovibond model MT 740.

3.4. Slow Mix Unit

The unit included squared flocculation tanks with mixer. The mixer was provided with a blade. The blade was manufactured from thin plate, though it has the ability to arrange for different shapes. The mixer was rotated with a different speed motor to obtain the required velocity gradient. The design calculations of the model as flows:

- Discharge = 20 liter/hr
- Flocculation mix time = 30 minutes
- Blade area = 10-25% of the cross sectional area of the tank (Said, 2001)
- Volume of the flocculation tank = 30 * 20/60 = 10 liter
- Tank dimensions = 25 * 20 * 20 cm
- Blade area = 0.1 * 20 * 20 = 40 cm2

If two symmetrical and centrally cohered blades were used, the area of each blade will be 20 cm^2. Different shapes of the blades were used in this research according the aims of the research to achieve the required area.

3.5. Sedimentation Unit

It comprised a rectangular tank with a baffle at the last part to increase efficiency of sedimentation. The design calculations are as follows:

- Discharge = 20 l/hr
- Average surface flow = 20 m3/m2/day (Steel and McGee, 2001)
- Tank depth = 20 cm (as streamlined flow occurs by gravity)
- Surface area of the tank = 20 * 24/20/1000 = 0.024 m2 = 240 cm2
- If a width equal to that of the slow mix was used = 20 cm
- Tank length = 240/20 = 12 cm
- As the depth of the tank did not approximate the actual one
- A tank length = 50 cm was used to obtain minimal sedimentation time
- Sedimentation time = (0.5 * 0.2 * 0.2 / 0.02) * 60 = 60 minute

This time is near the lower limit of designated time of sedimentation (1 hr) (Viessman, 1983)

3.6. Methods

The prepared model works as a continuous flow system. The coagulated water was prepared in the Jar test apparatus with alum as a coagulant according to the operational conditions of the water treatment plants of Mosul city. The coagulated water was then taken to the feeding tank of the system which was fixed at a higher level of the system to obtain a continuous flow. A valve was used to control the flow in the system which was measured by a flow meter. The coagulated water enters the flocculation tank from an orifice at the bottom of the tank. Then after the formation of the flocs in the tank, the flocculated water with surface overflow entered the sedimentation tank. The clarified water leave the sedimentation tank after the settling of the flocs.

Samples were taken from the raw water and the clarified water and tested for the specific quality (ASTM, 1998). The shape of the blades was changed with same surface designed area. Turbidity was used to evaluate the efficiency of coagulation and flocculation processes.

The rectangular shape was used with different dimensions and inclination angles as stated in the references to obtain six sets of the blades (table 1). The data obtained was statistically analyzed using analysis of variance and LSD test.

Table 1 The dimensions and inclination angles of the blades used in the research.

Sets	Dimensions (cm x cm)	Inclination angle (degree)
1	2 x 10	0
2	2 x 10	10
3	2 x 10	20
4	3 x 6.65	0
5	3 x 3.65	10
6	3 x 6.65	20

4. RESULTS AND DISCUSSION

The analysis of the results obtained showed a significant effect of velocity gradient, blades dimensions and inclination angle on the efficiency of the flocculation process at $p<0.001$ (table 2). The interactions between the studied variables were also significant (G x Dimensions, $p = 0.003$ and $p<0.001$ for others). Velocity gradient and area of blades were studied by many authors and found effective on coagulation and flocculation (Serra et al., 2008; Mohammad and Shakir, 2018).

Table 2 Analysis of variance of sedimentation tank output turbidity including the studied variables: velocity gradient (G), dimensions of the blades and inclination angle.

SOV	SS	df	MS	F	p-value
G	1.323	2	0.661	21.774	<0.001
Dimensions	1.070	1	1.070	35.220	<0.001
Angle	10.363	2	5.181	170.604	<0.001
G x Dimensions	0.429	2	0.215	7.067	0.003
G x Angle	1.481	4	0.370	12.189	<0.001
Dimensions x Angle	3.983	2	1.991	65.567	<0.001
G x Dimensions x Angle	1.485	4	0.371	12.226	<0.001
Error	1.093	36	0.0304		
Total	21.226	53			

Velocity gradient of 45 sec^{-1} and blade dimensions of 2 x 10 cm gave the best results of effluent turbidity (table 3 and fig. 5). Effluent turbidity decreased with velocity gradient increase from 30 to 45 sec^{-1} especially in case of blade dimensions 2 x 10 cm. When velocity gradient increased over 45 to 60 sec^{-1}, effluent turbidity increased significantly for blade dimensions of 2 x 10 cm. This can be attributed to the breakup of flocs with velocity gradient increase. The flocs may breakup at different velocity gradient. In the experiments conducted by Marques and Filho (2017) the breakup of flocs occurred at a velocity gradient over 20 sec^{-1}. The breakup of flocs may depend on initial turbidity, nature of turbidity and type of coagulant. Figure (5) shows deterioration in mean effluent turbidity from 1.92 to 2.37 ntu with the change in blade dimensions from 2 x 10 cm to 3 x 6.65 cm, without significant difference. This may be attributed to increase in flocs breakage versus aggregations with the change in the velocity gradient distribution due to blade dimensions change.

Table 3 The effect of the interaction between blade area and velocity gradient on the sedimentation tank effluent turbidity.

G (sec-1)	Dimensions (cm x cm)	Mean	SD	SE	Range
30	2 x 10	2.156ab	0.391	0.130	1.6-2.6
45	2 x 10	1.922a	0.342	0.114	1.6-2.5
60	2 x 10	2.511b	0.948	0.316	1.3-3.6
30	3 x 6.65	2.522b	0.755	0.252	1.9-3.8
45	3 x 6.65	2.367ab	0.529	0.176	1.7-3.1
60	3 x 6.65	2.544b	0.532	0.177	1.9-3.6

Different letters vertically mean significant difference at $p<0.05$ according to LSD test.

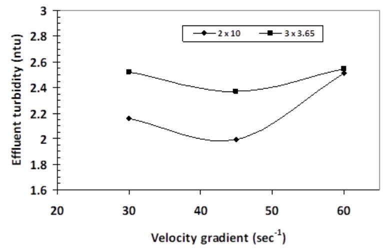

Figure 5 Effect of velocity gradient and blade dimensions on effluent turbidity.

Table (4) and figure (6) show that best flocculation efficiency was recorded with the highest blade inclination angle included in the study of 20 degree for all studied levels of velocity gradient. The lowest effluent turbidity was recorded at 45 sec^{-1} velocity gradient with mean of 1.68 ntu and range of 1.6-1.8 ntu. When inclination angle decreased to 10 degree, the mean effluent turbidity increased to 2.30 ntu with 30 sec^{-1} velocity gradient. For blades without inclination, the mean effluent turbidity increased to 2.35 ntu at 45 sec^{-1} velocity gradient. The increase in blade inclination angle may cause a more suitable velocity gradient distribution, homogeneity and increases the chances for flocs formation versus flocs breakage.

Table 4 The effect of the interaction between blade inclination angle and velocity gradient on the sedimentation tank effluent turbidity.

G (sec^{-1})	Angle (degree)	Mean	SD	SE	Range
30	0	2.92^{c}	0.67	0.28	2.2-3.8
45	0	2.35^{b}	0.64	0.26	1.6-3.1
60	0	2.95^{c}	0.36	0.15	2.5-3.6
30	10	2.30^{b}	0.21	0.09	2.1-2.6
45	10	2.40^{b}	0.13	0.05	2.2-2.5
60	10	2.93^{c}	0.60	0.24	2.3-3.6
30	20	1.80^{a}	0.17	0.07	1.6-2.0
45	20	1.68^{a}	0.08	0.03	1.6-1.8
60	20	1.70^{a}	0.41	0.17	1.3-2.2

Different letters vertically mean significant difference at $p<0.05$ according to LSD test.

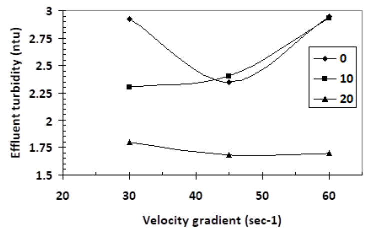

Figure 6 Effect of velocity gradient and blade inclination angle on effluent turbidity.

The effect of the interaction between blade inclination angle and dimensions on water flocculation is illustrated in table (5) and figure (7). For the wider blades (3 x 6.65 cm), effluent turbidity improved with the increase in blade inclination angle. On the other hand, the narrower blades (2 x 10 cm) showed non-smooth variation with blade inclination angle. Effluent turbidity increased to a peak value as inclination angle increased to 10 degrees, then decreased as the angle increased to 20 degrees. The best effluent was recorded with narrower blades and 20 degrees inclination angle. This result indicates that lower breakage of flocs occurred with the narrower blades. This result coincided with the results of Ahangari et al. (2016), who found that the increase in blade length decrease the ability of breakage.

Table 5 The effect of the interaction between blade inclination angle and blade dimensions on the sedimentation tank effluent turbidity.

Angle (degree)	Dimensions (cm x cm)	Mean	SD	SE	Range
0	2 x 10	2.29c	0.44	0.15	1.6-2.9
10	2 x 10	2.76d	0.55	0.18	2.2-3.6
20	2 x 10	1.54a	0.17	0.06	1.3-1.8
0	3 x 6.65	3.19e	0.38	0.13	2.6-3.8
10	3 x 6.65	2.33c	0.17	0.06	2.1-2.5
20	3 x 6.65	1.91b	0.17	0.06	1.7-3.8

Different letters vertically mean significant difference at $p<0.05$ according to LSD test.

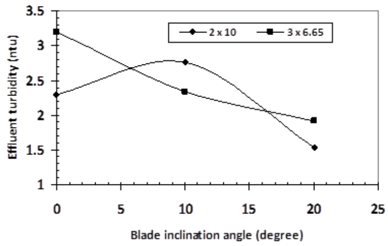

Figure 7 Effect of blade dimensions and inclination angle on effluent turbidity.

To select the best treatment configuration, table (6) shows the results of data analysis for the interactions among the studied variables. The best configuration of variables was recorded with 20 degree inclination angle, 2 x 10 cm blade dimensions and 60 sec^{-1} velocity gradient. The effluent turbidity was 1.33 ntu with 1.3 to 1.4 ntu range. The results showed that Tigris river water flocculation require a higher level of velocity gradient of 60 sec^{-1}. This may be attributed to the fine particulate in raw water which come from the middle and lower layers of Mosul dam lake. The configurations of the second level of treatment were recorded with 20 degree inclination and 2 x 10 cm dimensions at variable velocity gradient. On the other hand, the configuration of the worst treatments was recorded with 0 degree blade inclination angle, 30 sec^{-1} velocity gradient and 3 x 6.65 cm blade area. The mean effluent turbidity recorded was 3.5 ntu with a range of 3.2-3.8 ntu.

Table 6 The effect of the interaction among blade inclination angle, blade dimensions and velocity gradient on the sedimentation tank effluent turbidity.

G (sec^{-1})	Angle	Dimensions (cm x cm)	Mean	SD	SE	Range
60	20	2 x 10	1.33a	0.06	0.03	1.3-1.4
45	20	2 x 10	1.63b	0.06	0.03	1.6-1.7
30	20	2 x 10	1.67bc	0.12	0.07	1.6-1.8
45	20	3 x 6.65	1.73bc	0.06	0.03	1.7-1.8
45	0	2 x 10	1.80bcd	0.20	0.12	1.6-2.0
30	20	3 x 6.65	1.93cde	0.06	0.03	1.9-2.0
60	20	3 x 6.65	2.07def	0.15	0.09	1.9-2.2
30	10	3 x 6.65	2.13ef	0.06	0.03	2.1-2.2
30	0	2 x 10	2.33fg	0.15	0.09	2.2-2.5
45	10	2 x 10	2.33fg	0.15	0.09	2.2-2.5
60	10	3 x 6.65	2.40fg	0.10	0.06	2.3-2.5
30	10	2 x 10	2.47gh	0.15	0.09	2.3-2.6
45	10	3 x 6.65	2.47gh	0.06	0.03	2.4-2.5
60	0	2 x 10	2.73hi	0.21	0.12	2.5-2.9
45	0	3 x 6.65	2.90ij	0.26	0.15	2.6-3.1
60	0	3 x 6.65	3.17j	0.38	0.22	2.9-3.6
60	10	2 x 10	3.47k	0.15	0.09	3.3-3.6
30	0	3 x 6.65	3.50k	0.30	0.17	3.2-3.8

Different letters vertically mean significant difference at $p<0.05$ according to LSD test.

5. CONCLUSIONS

1. For Tigris river water in Mosul city, velocity gradient, blade dimensions and inclination and their interactions had significant effect on the flocculation process efficiency.
2. Turbidity effluent decreased with velocity gradient increase to 60 sec-1 or this level of velocity gradient is more suitable for Tigris river water flocculation.
3. The efficiency of flocculation process improved with increase in blade inclination angle.
4. The narrower blade at 20 degree blade inclination angle is more appropriate for water flocculation.

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