

ENHANCED COAGULATION USING A SPIRAL CLARI-FLOCCULATOR

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ABSTRACT

Natural surface waters contain particulates of organic and inorganic origin. Inorganic particulate constituents, including clay, silt, and mineral oxides. Organic particulates include algae, bacteria, and fine colloidal and dissolved organic constituents such as humic acids, and fulvic acids. This study focuses on the coagulation, flocculation, and sedimentation processes ability to remove or reduce these particulates. The efficiency of these processes could be discussed through the removal of turbidity and natural organic matter (NOM) characteristics. Enhanced coagulation could achieve better removal efficiency of NOM because it depends on higher coagulant dose and adjusted pH. A spiral hydraulic flocculation system has been studied, and it gives a very smooth tapered flocculation with differential decreasing of velocity gradient. The efficiency of this system was discussed with all varying parameters. Enhanced coagulation was applied in order to achieve the best removal efficiency of NOM. The results show that the system performance is moderately in accordance with the mathematical model developed by Edwards (1997), which determine the theoretical amount of dissolved organic carbon after coagulation, flocculation and sedimentation processes.

Keywords: Natural organic matter (NOM), Enhanced coagulation, Hydraulic flocculation.

1. INTRODUCTION

Coagulation, flocculation, and sedimentation have become important unit processes in the treatment of water and wastewater in conjunction with conventional mechanical, biological and physico-chemical plants(Liu et al, 2003[1]; Yang et al, 2010[2]; Thiruvengkatachari, et al, 2002[3]). The first step in the coagulation process is dominated by a rapid initial growth rate in the mean diameter of the particles. During this initial time period, if particles are fully destabilized they aggregate as soon as they come into contact. As coagulation continues, aggregates become larger and have more tenuous and fragile structures that are susceptible to breakup by fluid shear. In this stage of the process, there are now fewer but larger particles, and the growth rate of particle size slows. Finally, the particle size distribution reaches a pseudo-

steady state, where breakup balances aggregation, and size spectra is essentially constant. (Serra et al, 2007[4]). Subsequently, the water is allowed to become quiescent so that settling can take place.

The usual method of agitating the water is in a mechanical stirred flocculation. However, in less developed economies this method is not particularly suitable, since mechanical flocculation depend upon the availability of an energy supply to drive them and upon regular maintenance and replacement of parts to keep them operating. An alternative to the mechanical flocculation is the hydraulic flocculation, in which rather than using mechanical energy, the water is agitated by being routed round a complex geometry. This process induces the turbulence that leads to the primary particles being brought into close enough proximity to facilitate coagulation (Liu et al, 2003[1]).

The need for better quality drinking water has encouraged improvement in the operation of water treatment processes. The application of enhanced coagulation at existing coagulation plants is one of the most practical and cost effective options available to minimize formation of disinfection by-products and improve disinfectant residual maintenance. The term “enhanced coagulation” refers to the modification of the coagulation process to achieve greater or maximum natural organic matter (NOM) removal where higher doses of coagulant are used and the pH may be controlled during the coagulation/flocculation steps. The control of pH during coagulation is one of the most important factors controlling NOM removal (Chow et al, 2008[5]. Natural organic matter (NOM) originating from natural sources that are present in all water bodies are caused by break down of vegetation that finds its way in water bodies. Usually NOM concentration increases when runoff occurs. NOM could be expressed as total organic carbon (TOC), dissolved organic carbon (DOC), UV absorbance at wavelength of 254 nm (UV254) absorption, and specific UV absorbance (SUVA) (Wang and Hsieh, 2000[6]; Egeberg et al., 2002[7]; Kim and Yu, 2005[8]). Dissolved organic carbon, (DOC), is a fraction of total organic carbon and has the operational definition of milligrams per liter of carbon remaining in the liquid after filtration through a 0.45- μm filter (Hendricks, 2006[9]; Kim and Yu, 2005[8]; Rizzo et al., 2004[10]). The NOM is comprised of humic substance that are categorized as fulvic acids and humic acids (Bose and Reckhow, 2006[11]). Concentrations in surface water range from about 1 to 75 mg/L as dissolved organic carbon. Color is another indicator of humic matter with range 10 to 50 cobalt color units (Hendricks, 2006[9]). Another surrogate of organic matter is UV254 which is the easiest analysis technique. The problems of NOM may be identified as its responsibility for color, certain organic compounds contribute to taste and odor in drinking water, organic matter acts as a substrate for bacteria in distribution systems, anion exchange resins may become fouled by NOM, organic compounds may interfere with oxidation and removal of iron and manganese, and finally disinfection by-products are formed as a result of chlorine demand by organic matter. (O'Melia et al., 1999; [12] Wang and Hsieh, 2000[6]; Korbutowicz, 2004[13]; Bond et al, 2010[14]; Leeuwen et al., 2005 [15]; Yan et al., 2008[16]).

The aim of this work is to study the efficiency of water treatment by a new system combining coagulation, flocculation, and sedimentation in a compact unit, as well as study the enhanced coagulation for improvement the removal of NOM through this system.

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Organic compound

For simulating the NOM in natural water, commercial compound of humic and fulvic acids supplied from Eden Co for Production of Fertilizers was used. The compound is composed of 68% humic acid, 17% fulvic acid, 15% different materials. It is in the form of granular material.

2.1.2. Turbidity material

Synthetic turbid waters were prepared by using kaolinite particles, with a chemical structure $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$, as supplied from Al- Gomhoria Co for Chemicals (Egypt).

2.1.3. Coagulant

Aluminum sulfate stock solution 1000 mg/L was prepared to develop different alum dose for coagulation process, as supplied from Al- Gomhuria Co for Chemicals (Egypt) with a chemical structure $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$.

2.1.4 pH adjustment:

To develop different pH in acidic zone a stock solution of (27% by weight) hydrochloric acid (HCl) was used. In order to develop different pH in alkaline zone a stock solution of (40 mg/l) sodium hydroxide was used, (as supplied from Al- Gomhuria Co for Chemicals, Egypt).

2.2 Laboratory equipments

2.2.1. Spectrophotometer

UV absorbance at wavelength 254 nm (UV_{254}) was measured by digital spectrophotometer (Unico 2100) with Single Beam, Grating System 1200 lines/mm and 10 mm quartz cell.

2.2.2. Turbiditymeter:

(Hanna turbiditymeter HI93703) was used with 10 ml cell.

2.2.3. Jar test

A six paddle (Phipps& Bird PB-700) standard jar test with variable rotational speed and six 1000 ml jars was used. Every jar loaded with 500 ml sample.

2.2.4. TOC Analyzer

TOC was determined by subtracting the TIC (total inorganic carbon) from the TC (total carbon) using a Multi N/C-3100 analyzer at a burning temperature of 850°C (combustion-supporting gas: oxygen; catalyst: cerium oxide) in conjunction with NDIR (Non-dispersive

infrared) detector (Analytik Jena AG Co., Germany), using NPOC mode. Potassium hydrogen phthalate was used as external standards for TOC quantification with relative standard deviations (SD) of TOC 1%. DOC was determined by TOC analyzer after 0.45 μm Millipore filtration.

2.3 System components

The main objective of the clarifying system is to deliver the synthetic turbid water to the clari-flocculation basin after rapid mixing with coagulant solution. A combination of mechanical and hydraulic equipments was used to deliver turbid water and coagulant solution and drive it to the treating basin as shown in Fig (1). This system is composed of the following component:

Feeding tank A 200-liter plastic tank used to store the synthetic turbid water equipped with a mechanical stirrer to prevent sedimentation and changing of initial properties of raw water. The feeding tank is provided with a volumetric scale and a valve to control the discharge to the treating basin.

Coagulant feed tank A 20 liter plastic tank contains the coagulant solution. This tank is directly connected to the drag side of a dosing pump.

Dosing pump A pump with a variable speed to control the coagulant dose delivered to the clari-flocculator basin. The drag side is submerged into the coagulant feed tank, while the outlet side is connected to an injection port in the path of the raw water came from the feeding tank and placed previous to the lifting pump.

Lifting pump it is a centrifugal pump in which turbid water and coagulant are strongly mixed, and it is responsible for lifting and delivering the synthetic water mixed with coagulant solution to the treating basin.

Hydraulic clari-flocculation basin The Clari-flocculator is hydraulic, and the outer structure is a stainless steel cylinder with diameter 600 mm, and the bottom is a cone with 150 mm height as shown in Fig (2). The inner structure is composed of stainless steel removable frustum of cone. In order to investigate the effect of shape and volumetric changes of different treating processes including in this basin two frustums of cones are provided with different configuration as shown in table (1).

The water gets into the basin through a copper jet parallel to the tangent at the inlet point. The jet provides high tangential water speed at the inlet which generate helical (spiral) path for the water in the space outer the cone. This spiral path of water around the inner cone constitutes the flocculation process. The velocity path could be analyzed in two derivatives downwards vertical vector and tangential vector. In both vectors the velocity is decreases uniformly. The downwards vertical velocity comes out from the overall discharge divided on the horizontal cross-area, which equal the horizontal cross-area of cone at certain level subtracted from the horizontal cross-area of the outer body of the basin. The horizontal cross-area of cone decreases uniformly so the net horizontal cross area increases, and while the discharge is fixed the vertical velocity decreases uniformly. The tangential path comes out from the water tangential speed at the inlet jet. The tangential water velocity decreases uniformly due to the friction with the walls of the basin and cone, and the friction between water layers.

Because of the decreasing velocity of vertical and tangential water paths, the velocity gradient of water at the flocculation zone is considered to be a very differential uniform velocity gradient. This gives a suitable condition for flocculation process if it takes its preferred retention time. The inner cone is the major space of sedimentation zone. It delivers the water from the lower part of flocculation zone then the water go upwards through the cone while the flocs formed during the flocculation process are settled by gravity, and small particles may induce a blanket clarification process. V notch weirs of the collector plate collect the clarified water at the upper level of cone and transfer it to the outlet pipe.

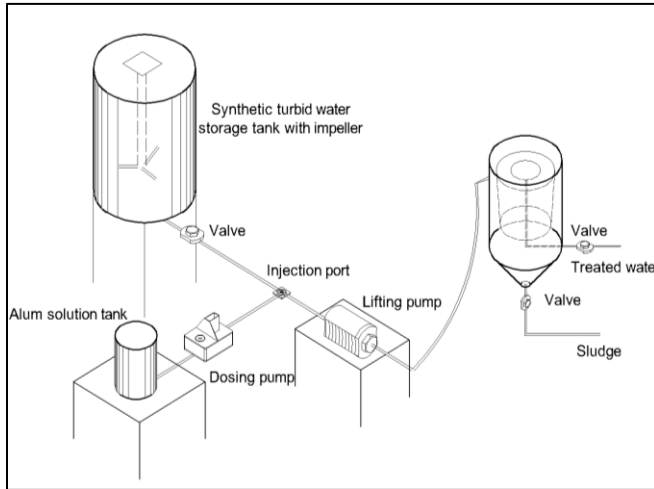


Fig (1) Schematic sheet for the water

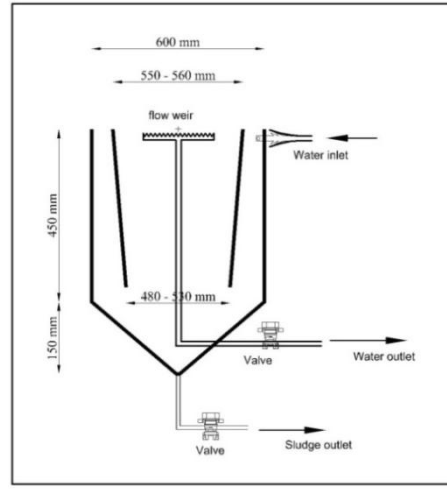


Fig (2) water treatment basin

2.4 Experimental procedure

The synthetic water is prepared in the feeding tank. The impeller is to be turned on during the addition of the kaolin or the organic material until the values of turbidity and UV_{254} maintain fixed and get matching values between the samples taken from the surface of the water and the samples taken from the bottom outlet of the feeding tank in order to ensure the homogeneity for the raw water properties during the operation run time of the clari-flocculation basin. The dosing pump is calibrated to deliver a certain amount of coagulant solution in order to achieve the targeted coagulant dose, and turned on after stabilizing the synthetic water in feed tank. The lift pump is turned on in the same time of turning on the dosing pump. The discharge of raw water is controlled by a valve at the outlet of the feed tank and computed on the basis of the retention time of the flocculation and sedimentation process and the volume of the flocculation zone and sedimentation zone as illustrated in table (1) and table (2).

Table (1) The Dimensions of the basin

	cone 1	cone 2
Dimensions (mm) $D_1 \times D_2 \times h$	560 x 530 x 450	550 x 480 x 450
Flocculation zone (Lit)	22.23	33.35
Sedimentation Zone (Lit)	120.15	109.03
Total Volume (Lit)	142.38	142.38

Table (2) The operations discharges of the system

	Flocculation time (minute)	Sedimentation time (minute)	Total retention time (minute)	Discharge (Lit/minute)
cone 1	15	81	96	1.48
	20	108	128	1.11
	25	135	160	0.89
	30	162	192	0.74
cone 2	15	49	64	2.22
	20	66	86	1.67
	25	82	107	1.33
	30	98	128	1.11

The samples were taken for measuring the parameters of turbidity and the NOM parameters such as DOC, UV_{254} , and SUVA by using equation (1).

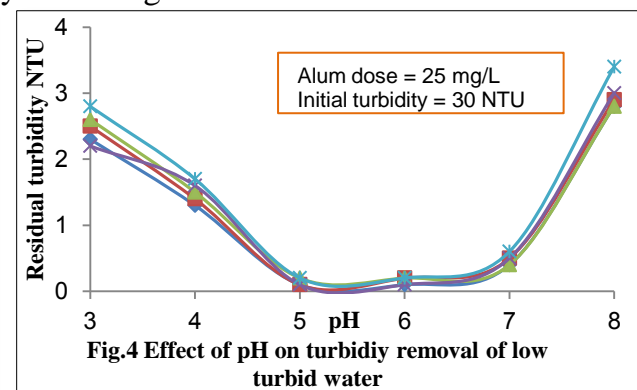
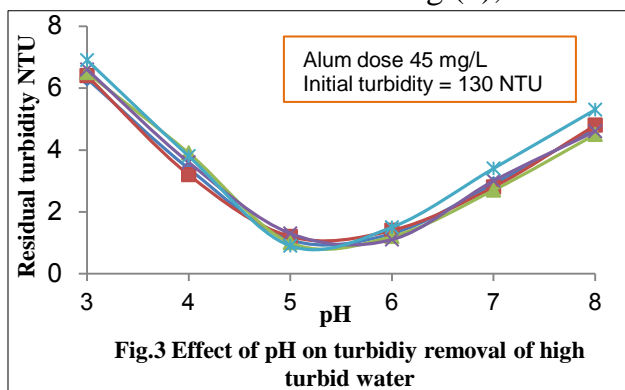
$$SUVA_{raw\ water} = \frac{UV_{254}}{DOC} \times 100 \quad (1)$$

3. RESULTS AND DISCUSSION

3.1 Jar tests

3.1.1 Optimum conditions for turbid water

The effect of coagulant dose and pH control was investigated by using a synthetic turbid water with initial turbidity of 30 NTU and 130 NTU. For each type of water five repeated jar tests were performed to determine the optimum dose for this synthetic turbid water at pH 7, and ten jar tests were performed with synthetic turbid water at pH 5 and pH 6 five for each and the average value was considered. The average value of the optimum dose for high turbid water was found to be 45 mg/L arriving an average minimum residual turbidity of 2.9 NTU for water with pH 7, 1.1 for water with pH 5, and 1.3 for water with pH6. The effect of varying the pH from 3 to 8 on the turbidity removal is shown on Fig. (3) indicating that the best turbidity removal efficiency was between pH 5 and pH 6. The difference between turbidity removal of neutral water and water at optimum pH is considerable. For the 30 NTU turbid water the optimum dose was 25 mg/L. The difference between residual turbidity at optimum pH and at neutral water was about 0.3 NTU as shown in Fig (4), which may be not significant.



3.1.2 Optimum conditions for NOM removal efficiency

The removal of NOM was studied on a raw water with 30 mg/L of the organic compound mentioned in section 2.1.1 which cause a DOC equal 11.53 mg/L and UV_{254} equal 0.535. The optimum alum dose was determined by fifteen jar tests, five on neutral water with pH approximately ≈ 7 , five on synthetic water with pH 5, and five on synthetic water with pH 6, and it was 100 mg/L. The effect of the raw water pH on the removal of natural organic matter during coagulation and flocculation was studied on water at pH values of 3.0, 4.0, 5.0, 6.0, 7.0, and 8.0, and the relation between pH and NOM removal was investigated by five jar tests and measuring the UV_{254} and DOC as shown in Figs (5) and (6). The results clarify that the best removal efficiency occurred when adjusting the pH down between 5 and 6 prior to alum coagulant addition which allows the formation of soluble NOM-aluminum complexes that link to each other, thereby forming large insoluble bridged complexes (micro-flocs) that also act as nuclei for macro-floc development (flocculation). However, qualitatively, as pH increases, humic substances will become more ionized because the carboxyl groups will loss protons, and the positive charge on metal coagulants will decrease. Consequently, higher coagulant dosages will be required at higher pH values.

In order to pinpoint the optimum pH removal five jar tests were performed with different pH ranged from 4.5 to 5.75 with interval of 0.25. The results shown on Figs (7), and (8) show that the optimum pH for the removal of NOM from water is about 5.5.

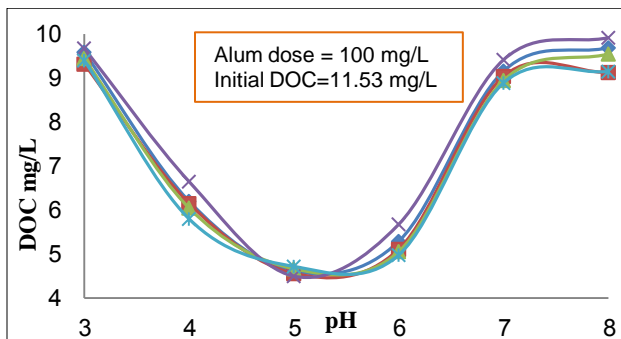


Fig 5 Effect of pH on DOC removal

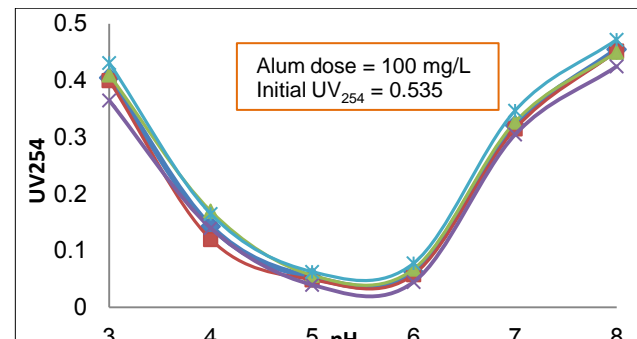


Fig 6 Effect of pH on UV₂₅₄ removal

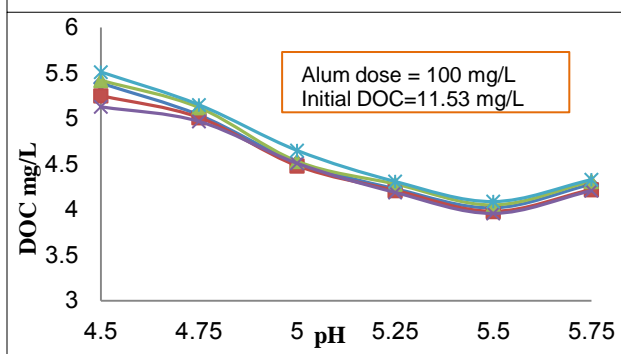


Fig. 7 Effect of pH on DOC removal

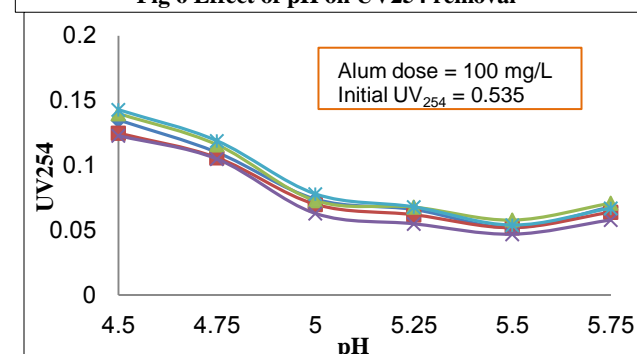


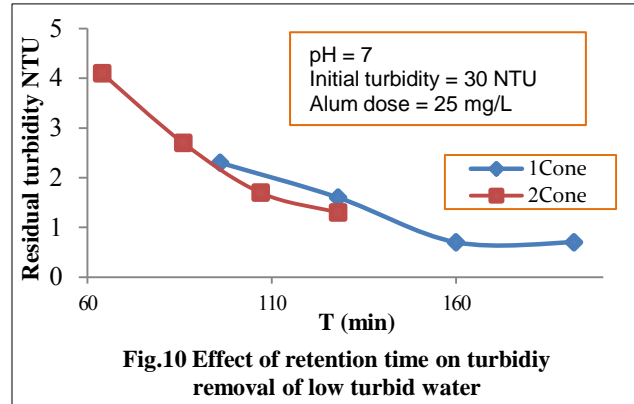
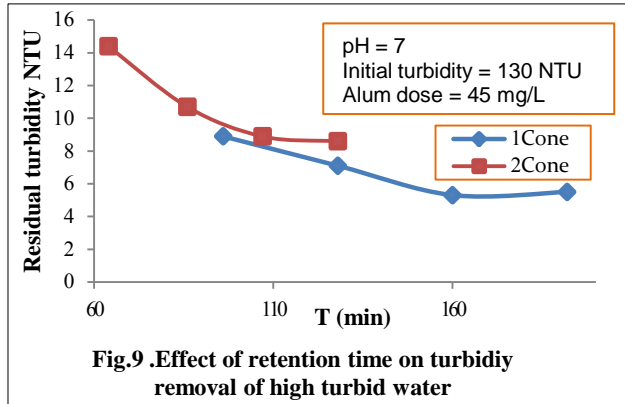
Fig.8 Effect of pH on UV₂₅₄ removal

3.2 Hydraulic clari-flocculator system studies

3.2.1 Turbidity removal efficiency

3.2.1.1 Effect of retention time

The effect of the retention times of flocculation and sedimentation processes was investigated by using two different synthetic turbid water with about 30 NTU for the lower turbidity water and 130 NTU for the higher one. The pH of both synthetic turbid waters was about 7. The tests were performed by using the two cones to separate and form the flocculation and sedimentation zones as calculated in table (1).



As illustrated in Fig (9) the best turbidity removal by cone 1 was at overall retention time of 160 minute composed of 25 minute for flocculation process and 135 minute for sedimentation process leaving out about 5.3 NTU as remaining turbidity on average. When retention time was raised to 192 minute composed of 30 minute for flocculation process and 162 minute for sedimentation process the remaining turbidity measured was not significantly changed and it was 5.5 NTU on average. For cone 2 it was investigated that best removal efficiency was indicated when the retention time was about 128 minute composed of 30 minute for flocculation process and 98 minute for sedimentation process leaving out about 8.6 NTU as remaining turbidity on average. For any runs on cone 2 the longer retention time the better removal was indicated as shown in Fig (9).

For low turbidity water, the best turbidity removal when using cone 1 was indicated at overall retention time of 160 minute composed of 25 minute for flocculation process and 135 minute for sedimentation process as shown in Fig (10) leaving out about 0.7 NTU as remaining turbidity on average. Rising the overall retention time to 192 minute composed of 30 minute for flocculation process and 162 minute for sedimentation process did not give significant change in the remaining turbidity as it was about 0.7 NTU on average. For cone 2 the longer retention time the better removal was indicated as shown in Fig (10), so the best removal was indicated when the retention time was 128 minute composed of 30 minute for flocculation process and 98 minute for sedimentation process leaving out about 1.3 NTU as remaining turbidity on average.

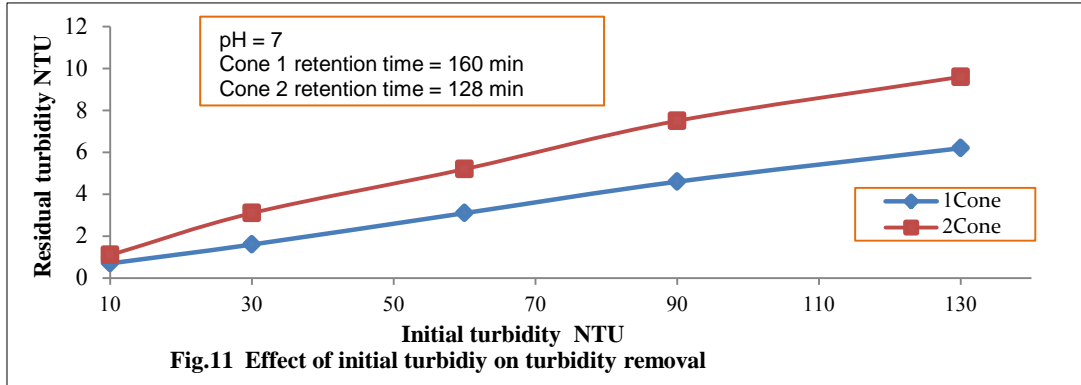
The obtained results clarify that the configuration of the clarifier model when using cone 1 is more better than the configuration when using cone 2. better turbidity. The geometric configuration of the model when using cone 1 gives the opportunity to suitable retention times of both flocculation and sedimentation process.

3.2.1.2 Effect of velocity gradient

As clarified in the last section the removal efficiency is not always improved by increasing the retention time, because the parameter of velocity gradient is highly affected by changing the discharge and retention time of flocculation process. On the other hand, it was not acceptable to study the velocity gradient as an individual parameter because the conditions of experiments such as retention time cannot be fixed with changing the velocity gradient.

3.2.1.3 Effect of initial turbidity

The effect of initial turbidity was investigated by using five different synthetic turbid waters with different turbidity varying from 10 to 130 NTU. The pH value of these waters was 7.0, while the coagulant dose for each water was chosen according to a jar test under the same conditions of this synthetic water. The retention times for the operations using cone 1 were about 160 minute composed of 25 minute for flocculation and 135 minute for sedimentation. For operations using cone 2 the retention time was about 128 minute composed of 30 minute for flocculation and 98 minute for sedimentation.



The results shown in Fig (11) clarify that for the turbidity removal by this clari-flocculator system is acceptable in wide range of initial turbidity. The results also emphasizes that the configuration of cone 1 is better than cone 2 especially in higher turbidity waters.

3.2.1.4 Effect of pH

The effect of pH control was investigated on bench studies scale under the same synthetic waters conditions, and the results show that the pH range which may enhance the coagulation and flocculation process was between 4.0 and 7.0, while when the pH below 4.0 or higher than 7.0 the efficiency of turbidity removal was reduced. In consequence of that, the runs on the clari-flocculator system were carried out on pH ranges from 4.0 to 7.0. The effect of pH was studied on both of high and low turbidity water. The coagulant dose used was the optimum dose determined according to the jar tests carried out as shown in bench scale studies which was 45 mg/l for high turbidity water and 25 mg/l for low turbidity water. The operations were carried out using both of the two cones. The retention times for the operations using cone 1 were about 160 minute composed of 25 minute for flocculation and 135 minute for sedimentation. For operations using cone 2 the retention time was about 128 minute composed of 30 minute for flocculation and 98 minute for sedimentation.

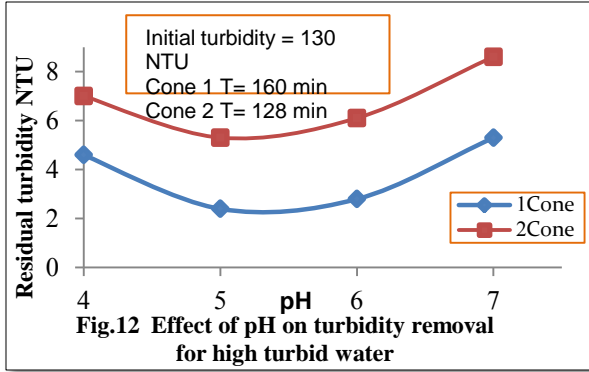


Fig.12 Effect of pH on turbidity removal for high turbid water

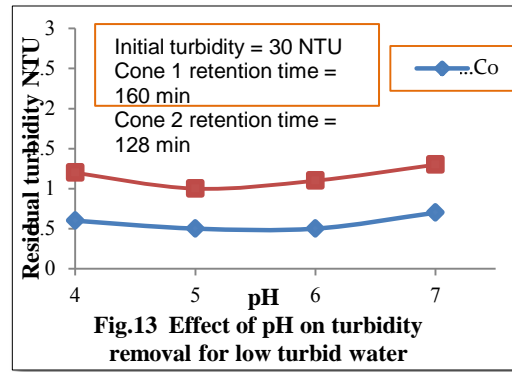


Fig.13 Effect of pH on turbidity removal for low turbid water

As shown in Fig (12), the adjustment of pH for high turbidity water increases the turbidity removal efficiency with clear difference whether using cone 1 or cone 2. And the best removal efficiency was at pH nearly 5.0 for both cones. For the low turbidity water the effect of adjusting the pH as shown in Fig (13) was not significant as the difference between best conditioned water and neutral water was 0.2 NTU for cone 1 and 0.3 NTU for cone 2 which could be considered as a neglected difference compared to the efforts of controlling the pH.

3.2.2 NOM Removal Efficiency.

As discussed before the removal of natural organic matter (NOM) could be achieved by coagulation and flocculation followed by settling process. The parameters that measure the NOM presence in water in this section were the dissolved organic carbon (DOC), and UV absorbance at wavelength 254 (UV_{254}), and specific UV absorbance (SUVA) which computed from the equation (1).

Many parameters may affected the efficiency of removal of NOM such as coagulant dose, retention times of various processes, velocity gradient, pH, initial concentration of NOM, and presence of other non-organic particles. The effect of coagulant dose was checked in jar test studies to obtain optimum dose for treatment process, while the other parameters were experimented using the clari-flocculation system as discussed in the following sections.

3.2.2.1 Effect of retention time

The effect of retention time of flocculation and sedimentation processes were investigated according to various runs using four different discharge values for each of the two cones as illustrated in table (2).

The coagulant dose for these runs was specified according to jar test studies and it was 100 mg/L for alum coagulation. 30 mg/L of organic material was added to produce NOM in water with approximately dissolved organic carbon 11.53 mg/L, and $UV_{254} = 0.535$. The runs were first carried out using water with no pH adjustment at pH=7.0, then water with adjusted pH to 5.5.

The measured values for UV_{254} , DOC, and calculated values of SUVA are shown in table (3). For cone 1 the best removal efficiency was observed when the retention time was 160 minute for both waters. When the retention time was 96 and 128 minute the removal efficiency was comparatively poor even though the average velocity gradient in flocculation process was relatively high but the time of settling process might be not enough. When the retention time was raised to be 192 minute the removal efficiency was moderately decreased as shown in Figs (14),(15),and (16) even though the time of both flocculation and settling was fair enough but the velocity gradient in this run was relatively low.

Table 3 Results of UV₂₅₄, DOC, and SUVA

Retention time min	UV ₂₅₄ pH=7.0	DOC mg/L pH=7.0	SUVA pH=7.0	UV ₂₅₄ pH=5.5	DOC mg/L pH=5.5	SUVA pH=5.5
Cone 1						
96	0.475	10.59	4.485	0.21	8.15	2.577
128	0.412	10.13	4.067	0.145	7.24	2.003
160	0.351	9.46	3.710	0.073	4.91	1.487
192	0.364	9.75	3.733	0.078	4.96	1.573
Cone 2						
64	0.493	10.91	4.519	0.248	9.23	2.687
86	0.448	10.43	4.295	0.164	7.47	2.195
107	0.391	9.95	3.930	0.098	6.24	1.571
128	0.396	10.04	3.944	0.096	6.2	1.548

As shown in Figs (14),(15),and (16) when the retention time was 64 and 86 minute using cone 2, the removal efficiency was relatively bad especially if the pH was 7.0. This attribute to the low retention time which might be not sufficient for settling. The removal efficiency at retention time 107 and 128 minute was relatively high especially if the pH was 5.5 with no significant difference between them. This because the velocity gradient at retention time 107 minute was more fair than the velocity gradient at retention time 128 minute, while the runs of retention time 128 minute have a sufficient time for settling.

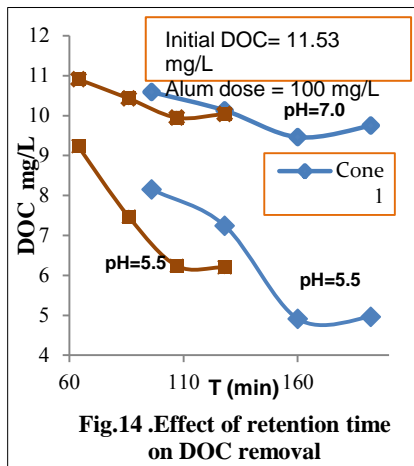


Fig.14 .Effect of retention time on DOC removal

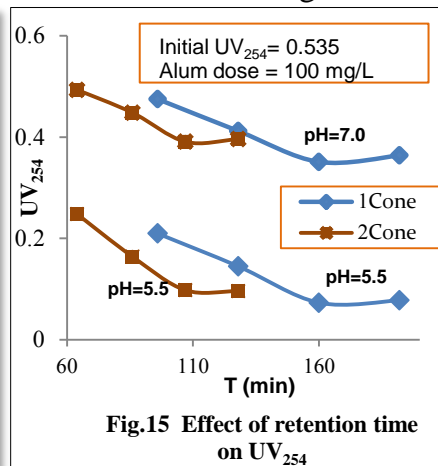


Fig.15 Effect of retention time on UV₂₅₄

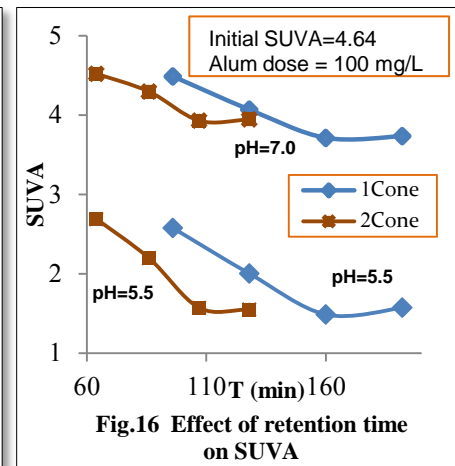


Fig.16 Effect of retention time on SUVA

The best removal efficiency was observed when using cone 1 at retention time 160 minute, and it was 13.64% on the basis of UV₂₅₄, 42.58% on the basis of DOC, and on the basis of SUVA it was 32.05%.

3.2.2.2 Effect of initial NOM concentration.

The effect of initial NOM concentration was studied using five synthetic waters with different dose of organic material. The doses used were 5, 10, 20, 30, and 40 mg/L and the effect of removal was observed using UV₂₅₄, DOC, and SUVA under pH 7.0 and pH5.5 as shown in tables (4) and (5).

Table 4 Effect of initial organic dose on removal efficiency for cone 1

Initial organic dose mg/L	pH = 7.0			pH = 5.5		
	Initial UV ₂₅₄	Initial DOC	Initial SUVA	Initial UV ₂₅₄	Initial DOC	Initial SUVA
	Residual UV ₂₅₄	Residual DOC	Residual SUVA	Residual UV ₂₅₄	Residual DOC	Residual SUVA
	Removal%	Removal%	Removal%	Removal%	Removal%	Removal%
5	0.114	5.67	2.01	0.114	5.67	2.01
	0.096	5.24	1.84	0.072	4.56	1.58
	15.53	7.54	8.62	36.74	19.54	21.35
10	0.198	6.80	2.91	0.198	6.80	2.91
	0.155	6.11	2.54	0.090	4.77	1.88
	21.54	10.12	12.71	54.60	29.86	35.23
20	0.360	9.17	3.93	0.360	9.17	3.93
	0.258	7.90	3.26	0.098	5.11	1.93
	28.47	13.87	16.95	72.64	44.27	50.96
30	0.535	11.53	4.64	0.535	11.53	4.64
	0.351	9.46	3.71	0.073	4.91	1.49
	34.39	17.95	20.04	86.36	57.42	67.95
40	0.702	13.94	5.04	0.702	13.94	5.04
	0.424	11.13	3.81	0.071	4.94	1.44
	39.61	20.19	24.33	89.86	64.58	71.40

Table 5 Effect of initial organic dose on removal efficiency for cone 2

Initial organic dose mg/L	pH = 7.0			pH = 5.5		
	Initial UV ₂₅₄	Initial DOC	Initial SUVA	Initial UV ₂₅₄	Initial DOC	Initial SUVA
	Residual UV ₂₅₄	Residual DOC	Residual SUVA	Residual UV ₂₅₄	Residual DOC	Residual SUVA
	Removal%	Removal%	Removal%	Removal%	Removal%	Removal%
5	0.114	5.67	2.01	0.114	5.67	2.01
	0.101	5.39	1.88	0.093	5.18	1.80
	11.05	4.86	6.48	18.09	8.68	10.28
10	0.198	6.80	2.91	0.198	6.80	2.91
	0.166	6.30	2.63	0.114	5.47	2.09
	16.32	7.31	9.72	42.36	19.56	28.30
20	0.360	9.17	3.93	0.360	9.17	3.93
	0.281	8.21	3.43	0.127	6.26	2.03
	21.86	10.44	12.75	64.68	31.68	48.36
30	0.535	11.53	4.64	0.535	11.53	4.64
	0.391	9.95	3.93	0.098	6.24	1.571
	26.92	13.70	15.30	81.68	45.88	66.14
40	0.702	13.94	5.04	0.702	13.94	5.04
	0.491	11.82	4.16	0.103	6.95	1.48
	30.04	15.23	17.47	85.32	50.15	70.58

For cone 1 all the runs were performed in the same conditions of coagulant dose and retention time using 100 mg/L alum and under discharge of 0.89 Liter per minute which give 160 minute as a total retention time.

The relationship between the initial value and removal efficiency of each parameter is shown in Figs (17), (19), and (21) using cone 1 and Figs (18), (20), (22) using cone 2. For all parameters the removal efficiency is more better when the initial value is higher. That because in higher concentrations the interparticle bridging between colloids will be more effective.

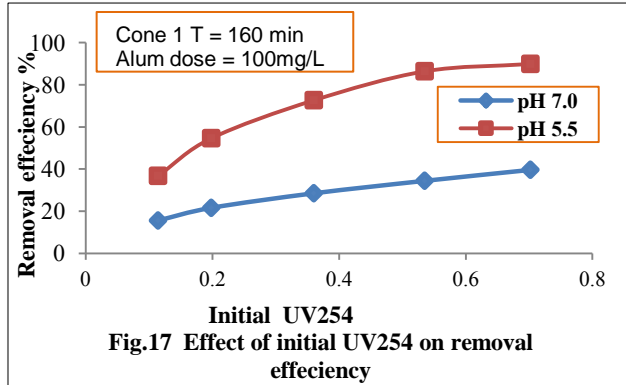


Fig.17 Effect of initial UV₂₅₄ on removal efficiency

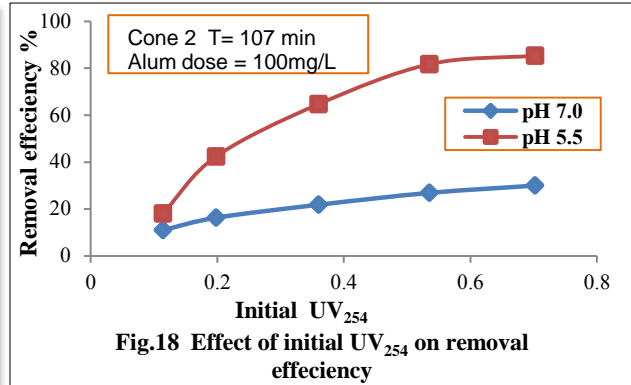


Fig.18 Effect of initial UV₂₅₄ on removal efficiency

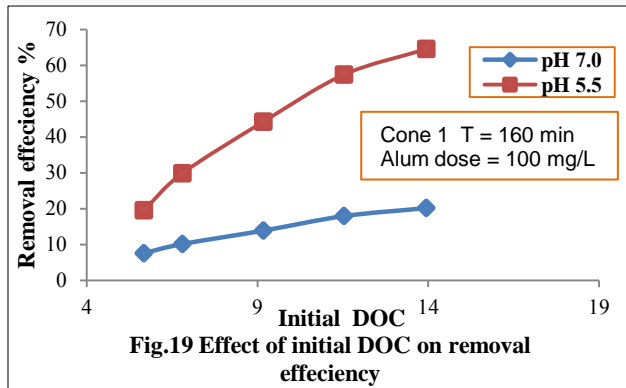


Fig.19 Effect of initial DOC on removal efficiency

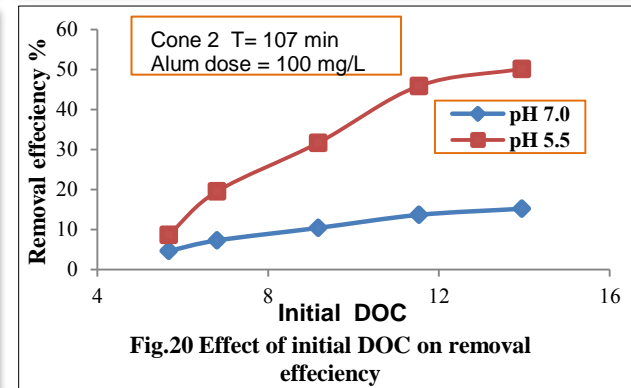


Fig.20 Effect of initial DOC on removal efficiency

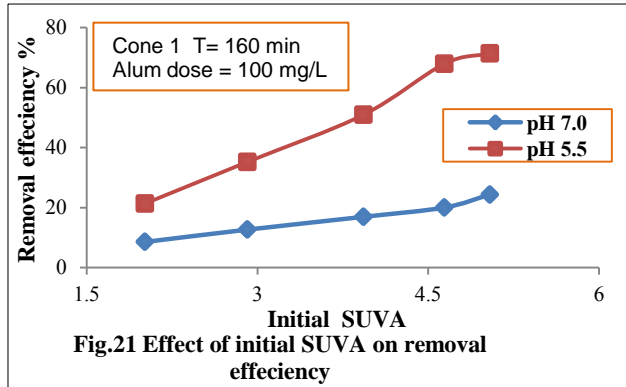


Fig.21 Effect of initial SUVA on removal efficiency

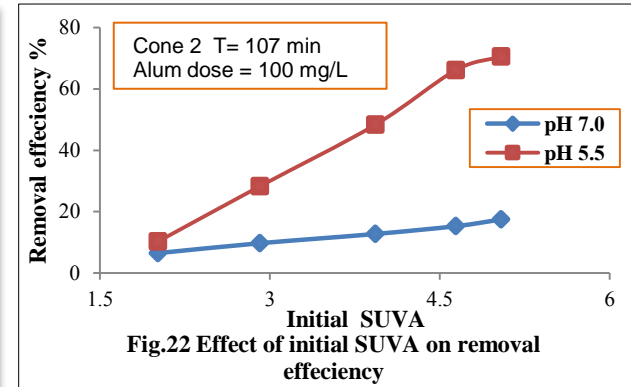
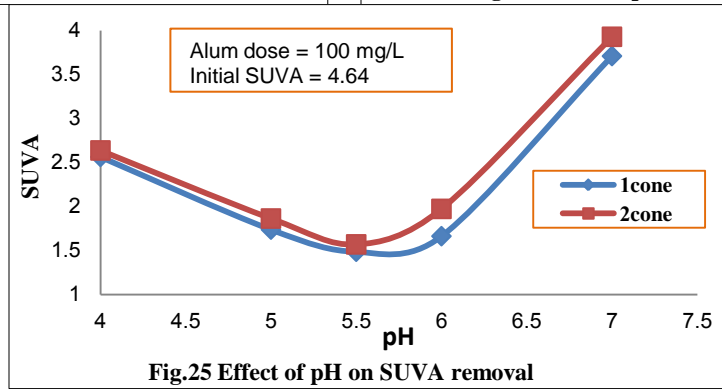
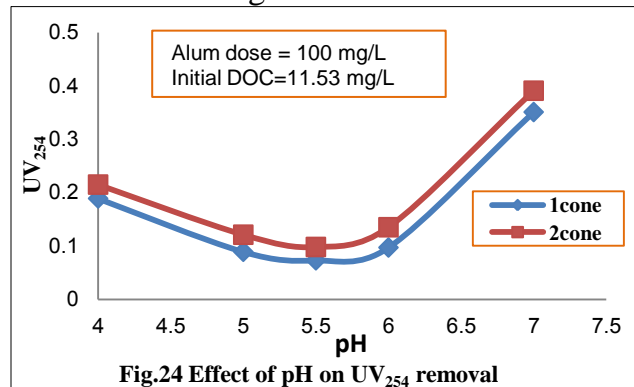
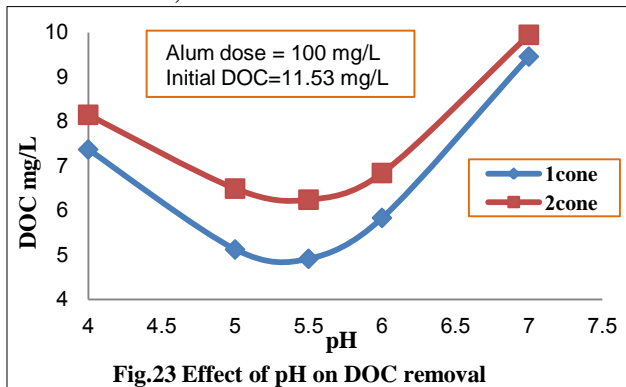


Fig.22 Effect of initial SUVA on removal efficiency

3.2.2.3 Effect of pH on NOM removal

The runs on the clari-flocculator system were carried out on pH 4.0, 5.0, 5.5, 6.0, 7.0. The effect of pH was studied using synthetic water containing 30 mg/L of organic material. The coagulant dose used was the optimum dose determined according to the jar tests carried out as shown in bench scale studies which was 100 mg/l. The operations were carried out using both of

the two cones. The retention times for the operations were about 160 minute composed of 25 minute for flocculation and 135 minute for sedimentation. For cone 2 the operation time was 107 minutes, 25 minute for flocculation and 82 minute for settling.



The relationship between the pH and NOM removal is shown in Figs (23), (24), and (25), and it performs the jar tests results that the best removal efficiency is at pH near 5.5 for both of the two cones used. The difference in removal of NOM based on the three parameters between the neutral water at pH near 7.0 and the water with adjusted pH is very significant and may deserve the costs and efforts needed to control the pH in water treatment plants. It should be refer that the treatment of water at pH near 5.5 may be not acceptable because it has harmful effect on tanks, pipe, and other devices in the treatment plants, but this effect may be controlled by using adequate materials and coating as many researchers try to go ahead in this field.

4.2.3.5 Theoretical assessment of DOC remaining after treatment

In this work the empirical model developed by Edwards (1997) (Edwads, 1997 [17]) will be applied to assess the DOC remaining after treatment. In the model development it was assumed that DOC is composed of adsorbable and nonadsorbable fraction. According to that, the effluent DOC after the coagulation process is the sum of the nonadsorbable DOC and the adsorbable DOC remaining at equilibrium after coagulation. The adsorbable DOC remaining after coagulation was not adsorbed during the coagulation process because it was in equilibrium with the DOC adsorbed on the flocs.

The nonadsorbable DOC is given by the equation

$$DOC_{nonadsorbable} = [K_1(SUVA)_{raw\ water} + K_2] \times DOC_{initial} \quad (2)$$

Where K_1 and K_2 are empirical fitting constants and for aluminum coagulants

$$K_1 = -0.075$$

and $K_2 = 0.56$

$$SUVA_{raw\ water} = \frac{UV_{254}}{DOC} \times 100 = \frac{0.535}{11.53} \times 100 = 4.64 \frac{L}{mg \cdot m}$$

$$DOC_{nonadsorbable} = [-0.075(4.64) + 0.56] \times 11.53 = 2.44 \text{ mg/L}$$

To compute the amount of DOC that is in equilibrium (DOC_{eq}) with the DOC adsorbed to the flocs Langmuir isotherm is used and in the final form of the model, the mass of DOC (mg) adsorbed per meq of coagulant to the amount adsorbed is equated to Langmuir isotherm as follows:

$$\frac{[1 - K_1(SUVA)_{raw\ water} + K_2]DOC_{initial} - DOC_{eq}}{M} = \frac{[x_3pH^3 + x_2pH^2 + x_1pH]b\ DOC_{eq}}{1 + b\ DOC_{eq}} \quad (3)$$

Where $x_1, x_2,$ and x_3 are unitless empirical constants and for aluminum coagulants

$x_1=284, x_2= -74.2, x_3=4.91$ (according to Edwards 1997)

$b =$ Langmuir equilibrium constant L/mg DOC, and for aluminum coagulants $b=0.147$

$M =$ the molar concentration of alum, $M=0.29 \text{ mM}$

Rearrange the last equation with substituted variable and develop an expression for DOC_{eq} :

$$\frac{A - DOC_{eq}}{M} = \frac{B\ DOC_{eq}}{1 + b\ DOC_{eq}} \quad (4)$$

$$b\ (DOC_{eq})^2 + (M\ B + 1 - A\ b)(DOC_{eq}) - A = 0 \quad (5)$$

Solving the quadratic equation and use the positive expression:

$$DOC_{eq} = \frac{-(M\ B + 1 - A\ b) + \sqrt{(M\ B + 1 - A\ b)^2 + 4A\ b}}{2\ b} \quad (6)$$

Substitute the constant values and solve for A and B:

$$A = [1 - K_1(SUVA)_{raw\ water} + K_2]DOC_{initial} = 9.086$$

$$B = [x_3pH^3 + x_2pH^2 + x_1pH]b$$

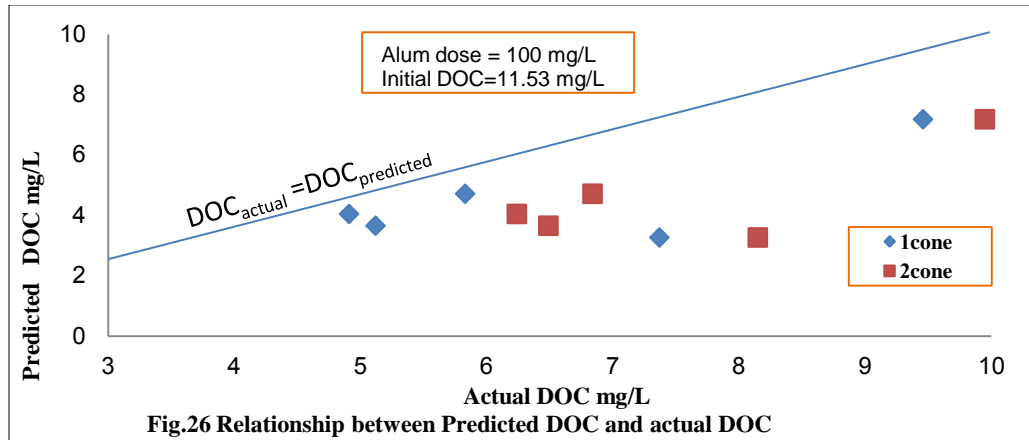
Substitute the values of A and B into the equation to get DOC_{eq} then compute the predicted remaining DOC by the following equation:

$$DOC_{remaining} = DOC_{nonadsorbable} + DOC_{eq}$$

The results of predicted remaining DOC after treatment with variant pH are illustrated in table (6) and graphed in Fig (26). The results clarify that the mathematical model is considerably to be applicable when the pH is greater than 5.0.

Table 6 relation between predicted values and actual values of DOC

<i>pH</i>	<i>DOC_{eq}</i> <i>mg/L</i>	<i>DOC_{non-adsorbable}</i> <i>Mg/L</i>	<i>DOC</i> <i>remaining mg/L</i>	<i>actual</i> <i>DOC_{remaining}</i> <i>cone 1</i> <i>mg/L</i>	<i>actual</i> <i>DOC_{remaining}</i> <i>cone 2</i> <i>mg/L</i>
4.00	0.83	2.44	3.27	7.37	8.15
5.00	1.22	2.44	3.66	5.12	6.49
5.50	1.61	2.44	4.05	4.91	6.24
6.00	2.28	2.44	4.72	5.83	6.84
7.00	4.75	2.44	7.19	9.46	9.95



5.CONCLUSION

- 1) The mixing of coagulant with raw water was carried out with high efficiency through the rising pump followed by the shooting high speed which occurs by the inlet nozzle when the water is going in the tank.
- 2) The best efficiency of turbidity removal was established when the retention time was 160 minute, 25 minute of them was for flocculation whether using high turbidity water or low turbidity water and cone 1 was inserted to the system.
- 3) The turbidity removal efficiency is acceptable in wide range of initial turbidity of raw water, and it always improved in higher turbidity water.
- 4) The optimum pH for turbidity removal in higher turbidity water was about 5.0, and there was a clear difference between the water with adjusted pH and the water treated without adjusted pH. For the low turbidity water the effect of adjusting the pH was not significant as the difference between best conditioned water and neutral water could be neglected.
- 5) The best removal efficiency of natural organic matter (NOM) based on DOC, UV254, and SUVA was observed when the retention time was 160 minute, 25 minute was for flocculation, and using cone 1.
- 6) The removal efficiency of NOM based on DOC, UV254, and SUVA is always increases when the initial concentration of organics in raw water is higher.
- 7) The pH adjustment was found to has a considerable effect on NOM removal and the best removal efficiency was observed when the pH was about 5.5.
- 8) The final lab results of NOM removal could be in accordance with the mathematical model of Edwards (1997) when the pH value is higher than 5.0.

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