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Effect of Temperature on Floc Formation Process Efficiency and Subsequent Removal in Sedimentation Process

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Abstract

flocs can be separated from waters depending on their stability, size, density, etc., and according to literatures the velocity gradient of the flow is the main design parameter of the flocculators, but there is a need to take into account at least the flocs age, and the effect of temperature too. This paper will study these factors. Temperature is known to affect flocculation and settling phenomena. Jar tests have been conducted in the sanitary laboratory of Almustansiriya University using square jar test apparatus to assess the effects of temperature on floc formation and settling efficiency.

For raw water turbidities of 500 and 1000 NTU, the results show that the decrease in water temperature will impair the floc strength and virtually floc formation efficiency and causing bad settling, therefore prolonged flocculation time at low temperatures will break the big formed flocs into smaller ones again and reduce settling efficiency, thus in winter care must be taken in drinking water plant to set suitable flocculation time. It was also observed that the effect of temperature on floc formation and strength becomes less effective with increase the initial turbidity. The effect of flocculation velocity gradient on floc formation and strength, at low temperature was significant, but as temperature increases the effect will be less. Better results of turbidity removal had appeared when velocity gradient was increased from 10, to 20 then to 30 and 40 S^{-1}***. At normal temperature range for water treatment, the increase in flocculation time above 40 min. shows impairment of floc formation and virtually bad selling.***

Keywords: Temperature, Flocculation, Floc formation, settling, Jar test.

تأثير درجات الحراره على كفاءة عملية تكوين اللبادات والإزالة اللاحقة في عملية الترسيب

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الخلاصة

إن الملبدات ممكن أن تفصل من الماء اعتمادا على استقراريتها، الحجم ، الكثافة ... الخ. استنادا إلى الدراسات السابقة يمكن اعتبار انحدار سرعة الجريان من أهم المحددات التصميمية للملبدات، ولكن على العاقل نحتاج أن نأخذ

بنظر الاعتبار عمر الملبدات، وتأثير درجة الحرارة أيضا. و هذا البحث يدرس تأثير هذه العوامل باستخدام فحص الجرة. وكما هو معروف فان درجة الحرارة تؤثر على ظاهرتي التلبيد والترسيب. تم العمل ألمختبري على فحص الجرة في مختبر الصحية/ الجامعة المستنصرية لمعرفة مدى تأثير درجة الحرارة على تكوين الملبد وكفاءة الترسيب.

بالنسبة للماء الخام ذو العكورة 500 و1000 NTU بينت النتائج بان النقصان في درجات الحرارة يتلف من قوة الملبد وبالتالي يؤثر على كفاءة تكوين الملبد ويسب ترسيب ردى ، لذلك فان زمن التلبيد الطويل عند درجات الحرارة الواطئة سوف يكسر الملبدات الكبيرة المتكونة إلى صغيرة الحجم ويقلل من كفاءة الترسيب، ففي فصل الشتاء يجب ان يؤخذ الحذر في محطات معالجة المياه لاختيار زمن التلبيد المناسب. من الاستنتاجات الأخرى هو تأثير درجة الحرارة على تكوين الملبد وقوته أصبحت اقل فعالية مع الزيادة في العكورة البدائية للماء الخام. من العوامل الأخرى هو تأثير انحدار سرعة التلبيد على تكوين الملبد وقوته، ففي درجات الحرارة الواطئة كان التأثير واضحا ولكن عندما تزداد درجه الحرارة يصبح التأثير اقل. تم الحصول على النتائج أفضل للعكورة المزالة عندما كان انحدار السرعة بين 10 و20/ثا ومن ثم بين 30 و40 /ثا. عند مدى طبيعي لدرجات الحرارة لمعالجة المياه، فان الزيادة في زمن التلبيد فوق 40 دقيقة سوف يؤدي إلى تلف في تكوين الملبدات وبالتالي الترسيب الردى.

كلمات مفتاحيه: درجة الحرارة، التلبيد، تكوين الملبدات، الترسيب، فحص الجرة.

Introduction

In surface water, there are different constituents that must be removed in water supply system. These constituents can be subdivided into: settleable suspended solids, colloidal solids, and dissolved solids.

Drinking water treatment is mostly consisting of: coagulation, flocculation, sedimentation, filtration, and disinfection processes. The coagulation process is the dosing of a coagulant in water, which results in destabilization of negatively charged particles, and then these destabilized particles must be incorporated into bigger flocs through flocculation. In Iraq, the alum ($Al_2 (SO4)_3.18H_2O$) is frequently used as the coagulation agent because it is locally available in good quality, and cheaper than other polyelectrolytes imported from abroad. Rapid mixing after coagulant addition is applied so the coagulant must be uniformly and efficiently dispersed in the raw water. In case mixing is poor, or local under and overdosing occurs, bad performance of this process will appear.

The parameter expressing mixing intensity in rapid mixing and flocculation processes is called the velocity gradient(G-value). The velocity gradient is defined mathematically as follows:

$$G = \sqrt{P/\mu V} \qquad \text{............} \ (1)$$

in which:

G = average velocity gradient for mixing, s^{-1}

P = dissipated power in water, W

μ = dynamic water viscosity, $N \cdot s/m^2$

V = volume of mixing tank, m^3

The influence of the velocity gradient can be determined by Jar-test experiments. When the velocity gradient is low (less intensive mixing), the residual turbidity after sedimentation process will differ than that in situations where the velocity gradient is high. In practice, the recommended Gt value for rapid mixing is in the range of 30000~60000, for flocculation process G in the range 25~65 s^{-1} (Steel and McGhee, 1979) **[8]**. Two different mixing systems can be applied: mechanical mixing, static mixing. In the first system mechanical mixers dissipate the power in the raw water, while in the second system gravity forces cause the mixing effect.

Here, the dissipated power is defined mathematically as follows: (MWH, 2005) **[7]**.

$$\mathbf{P = Np\ \rho\ n^3\ D^5} \qquad \ldots\ldots\ \ldots\ldots(2)$$

in which:

P = power input, W ($kg/.m^2/s^3$)
ρ = density of water, kg/m^3
Np = power number for impeller, dimensionless (3.5- 4)
n = Number of revolutions per second of stirrer (rps)
D = Diameter of impeller, m

Temperature significantly affects coagulation operations, particularly for low turbidity waters, by shifting the optimum pH. This can be mitigated by operating at an optimum pOH as given by (Bratby, 2006) **[2]:**

$pH + pOH = pK_W$; where $pK_W = 0.01706 \times T + 4470.99/T - 6.0875$
T = temperature in °K, = 273.15 + °C.

After coagulation and the resulting destabilization of particles, the particles must gently collide to form big floc. The collision of particles can take place under natural circumstances or by dissipation of mixing energy (MWH, 2005) **[7]**.

Efficient flocculation is a process of gentle water movement that promotes the gathering together of the small floc particles (micro flocs) produced by coagulation into larger masses better suited for removal by clarification process and finally by filtration. These contacts or collisions between particles result from gentle stirring created by a mechanical or other means of mixing, at a rate much slower than the mixing rate in coagulation, sometimes in dedicated flocculation basins. In hopper-bottomed upward-flow basins which utilize the sludge blanket affect these contacts or collisions between particles result from hydraulic mixing. Floc formation is controlled by the rate at which collisions occur between particles and by the effectiveness of these collisions in promoting attachment between particles. The purpose of flocculation is to create a floc of a suitable size, density, and toughness for later removal in the sedimentation and filtration processes. The best floc size ranges from 0.1 mm to about 3 mm, depending on the type of removal processes used, the smaller floc size being best suited to direct filtration and the larger to removal by clarification. While detention time is not usually a critical factor in the coagulation or flash-mixing process, but in the flocculation process detention (stirring) time is *very* important. (water treatment manuals, 2002) **[10].**

Required detention time for adequate flocculation is a variable depending on the water temperature and the type of downstream processes. When sedimentation is included, detention times of 25 to 30 minutes are usually sufficient in summer.

Parameters that are important to the design of a floc formation installation are the following (Masschelein W., 1992) **[6]:**

- residence time, t
- residence time distribution
- velocity gradient for floc formation, G, s^{-1}
- floc volume concentration, c

The efficiency of flocculation could be deteriorated when (i) Insufficient residence time and mixing conditions, or (ii) Inadequate coagulation process. The latter one process is supposed to take place in a few moments if there is a possibility to meet the particles with the coagulants, and at least $Gt = 20000$ is ensured (AWWA, 1969) **[1].**

Materials and Methods

The standard apparatus now uses square Jars that are fabricated by cementing together sheets of acrylic plastic, with dimensions of 11.5 cm x 11.5 cm x 21 cm deep, and inserting sampling tap at 10 cm below the required water level that engraved on jar wall to give 2 L volume of water, as shown in **Figure(2).** After 2 L of water had been added to the Jar to the level graved on the container, at each test run, an opening fitted with tube of the container at a distance 10 cm below the surface of the water was used to get the samples. Samples were taken after 2 min. following the termination of the flocculation period and start of sedimentation process; this corresponds to a settling velocity of 5 cm/min. This value is in the range of 2~8 cm/min which is commonly adopted in most treatment plants.

The square plastic Jars have the following advantages over the normal rounded glass beakers or glass used in Jar test: 1- The plastic Jars are less fragile, 2- Rotational velocity stops quickly upon the termination of stirring, 3- No siphon or pipette is needed for sampling and the sample is withdrawn without disturbing the settling water and, 4- The acrylic plastic walls are less heat–conductive than the glass walls of other jars. The plastic has lower thermo conductivity than glass, and the wall thickness in the plastic units is about fourfold that of glass beakers. Plastic units can therefore be used in the laboratory without a water bath. No material change in temperature of the water occurs during testing, a water bath is recommended when cold water (<10 °C) is to be evaluated (Hudson, 1976) **[5].**

Figure.(1) shows the jar testing setup used in this research work, the coagulation-flocculation were carried out according to the standard methods for coagulation-flocculation (Water treatment manual, 2002) **[10].** Each Jar was filled with 2 L raw water of 500 or 1000

NTU turbidity poured to the engraved level on container wall. Four-paddle stirrer was operated in each Jar container during these tests to impart the required mixing energy for coagulation and flocculation process, and four square Jars were used. The four flat paddles are all driven to provide a constant velocity gradient (G) of 700 s^{-1} for coagulation process for 1min detention period and using optimum alum dosages, at the tests temperature of 4, 10, 15, 20, & 25 ^{o}C. Samples were collected after sedimentation process for different flocculation times of 10, 20, 30, 40, & 50 min at the temperature range and turbidities mentioned above, and flocculation velocity gradient values were varied as 20 s^{-1}, 30 s^{-1} and 40 s^{-1} in different test runs. An illuminated base helps observation of the floc formation and settling characteristics. A small portion of each sample was bled to waste to flush out the sampling tube, and a sample large enough for turbidity measurement was taken after a sedimentation time of 2 min. following the termination of flocculation and start of sedimentation, and the remaining turbidities were measured, recorded and analyzed.

Fig .(1) Jar test apparatus

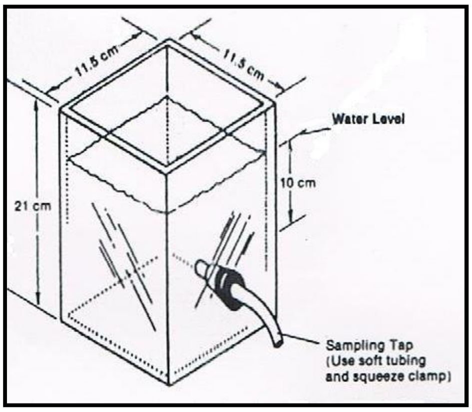

Fig .(2) 2L Diagram of Jar test

The stirrers used in the jar test apparatus have; a certain shape, paddle number and dimensions of their impellers; therefore equation-1 and equation-2 were used to calculate the required number of revolution per minute of the impellers to give the specified velocity gradients in the tests, according to water viscosity variation in the test temperature range and characteristics of the impellers. These rotation speeds ensure the impartment of the needed energy in water to give the required velocity gradients which represent the intensity of collisions between particles**. Figure(3), Tables (2** and **3)** were prepared during conducting the experiments. The physical properties of the impeller were measured and used in equations as power number, number of paddles, and diameter, etc.

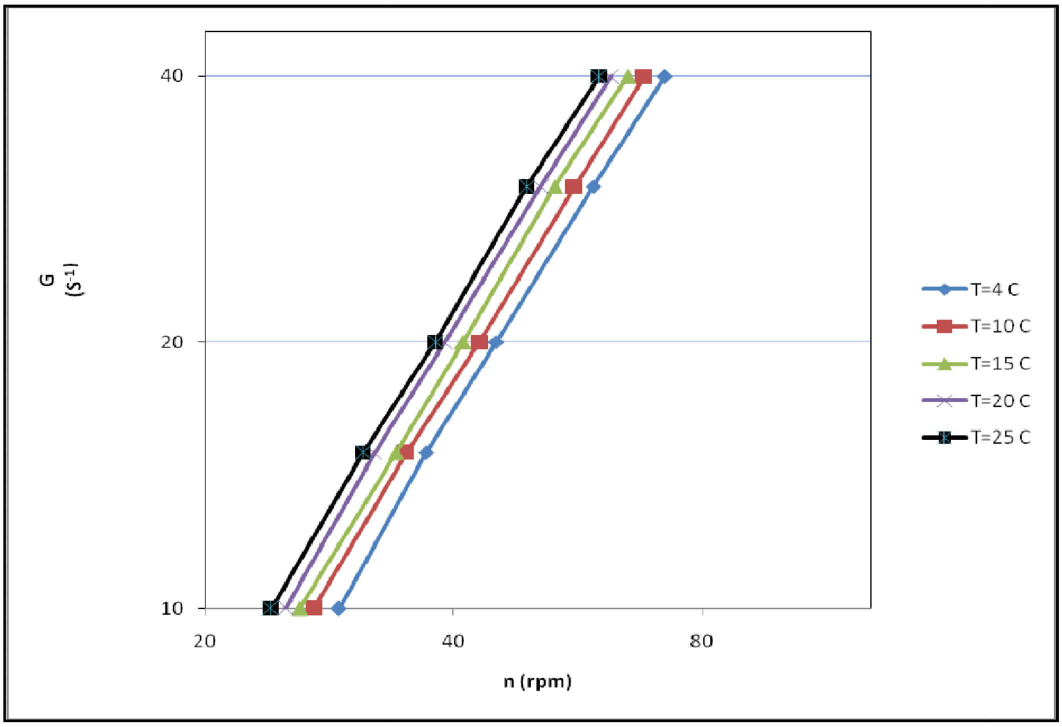

Fig . (3) Velocity gradient versus stirrer rpm at different water temperatures in the Jar test container

Table .(2) Power and rotational speed of stirrer to be imparted to raw water according to G and temperature during coagulation process.

G constant (700 S^{-1})				
Temp. (^oC)	**P(W)**	**n (rpm)**	**ρ (kg/m^{3})**	**μ(N.s/m^2)**
4	1536	485	1	$1.5676 * 10^{-3}$
10	1284	456	0.99973	$1.3097* 10^{-3}$
15	1122	436	0.99912	$1.1452* 10^{-3}$
20	989	418	0.99823	$1.0087* 10^{-3}$
25	877	402	0.99941	$0.89535* 10^{-3}$

Table .(3) Power and rotational speed of stirrer to be imparted to raw water according to G and temperature during flocculation process.

Temperature ^oC	G (s^{-1})	P (w)	n (rpm)	ρ (kg/m^3)	μ ($N.s/m^2$)
4	20	1254	45	1	$1.5676 * 10^{-3}$
	40	5016	72	1	$1.5676 * 10^{-3}$
10	20	1048	43	0.99973	$1.3097* 10^{-3}$
	40	4191	68	0.99973	$1.3097* 10^{-3}$
15	20	916	41	0.99912	$1.1452* 10^{-3}$
	40	3665	65	0.99912	$1.1452* 10^{-3}$
20	20	807	39	0.99823	$1.0087* 10^{-3}$
	40	3228	62	0.99823	$1.0087* 10^{-3}$
25	20	716	37	0.99941	$0.8953* 10^{-3}$
	40	2865	60	0.99941	$0.8953* 10^{-3}$

Results and Discussion

Floc size may be considered to be a balance between the hydrodynamic forces exerted on a floc and the strength of the floc. Where the floc strength is resistant to the hydrodynamic forces, one would expect floc size either to remain constant. Consequently, the conceptual growth/breakage mechanism may be expressed as follows: B = [hydrodynamic forces/ floc strength] = F/J, where F represents the hydrodynamic forces exerted by the flow, and J represents strength of the floc. It is clear from equation that breakage will occur when B>1, and floc size will be maintained or increased when B< 1. Floc strength, J is a function of the physic-chemical conditions (raw water type, coagulant type and dose) and the floc structure (Bridgman, 2009) [3].

Experimental data resulting from the flocculation and sedimentation tests in the Jars are shown in **Figures (4 - 14).** Time is needed for the formation of removable flocs in flocculation process, and the best average residence time is ranged from 20 to 40 min. depending on the temperature effect and other mixing conditions. The average residence time for floc formation is about 30 minutes. To determine the required residence time, Jar-test experiments were carried out.

As shown in **Figures (4 - 8),** at raw water turbidity of 500 NTU, and flocculation velocity gradient of 40 s^{-1} the remaining turbidity after flocculation and subsequent sedimentation, decreased as flocculation time decreased at low temperature, i.e., at temperature of 4 ^oC, the best flocculation time is 20 min, and increasing this time will cause deterioration in turbidity removal, while at higher temperature such as 10 ^{o}C , the best time is 31 min., and so on as temperature increases (10,15, 20, 25 ^{o}C) the best flocculation time required increases (31, 33, 34, 36 min.) respectively. It means high flocculation time will impair the floc strength and virtually floc formation efficiency and causing bad settling as this prolonged flocculation time would break the big formed flocs into smaller ones more easily at low temperature raw waters and because of increased shear stress due to higher water viscosity. (Wahlberg et. al., 1994) **[9]** conducted that the greatest decrease in turbidity typically occurred within 2 minutes of flocculation at room temperature. (Wahlberg et al., 1994) **[9]** and (Chang, 2008) **[4]** predicted that turbidity decreased with increasing flocculation time at room temperature.

Figures (9 - 13) show the results when raw water initial turbidity was high; 1000 NTU, at flocculation velocity gradient of 40 s^{-1} , the same trend obtained previously is valid here, but the effect of temperature on the best flocculation time required is less significant than at raw water turbidity of 500 NTU, as the temperature increased (4, 10, 15, 20, 25 ^{o}C) the best flocculation time required increased (25, 33, 35, 40, 40 min.) respectively, therefore a conclusion could be made that, effect of temperature on floc formation and strength becomes less pronounced with increasing in raw water initial turbidities, however, the results also show that, the effect of temperature on optimum flocculation time required for efficient sedimentation becomes less when temperature increases and reaches 25 ^{o}C, and little difference in flocculation times at temperature range from 10 to 25 ^{o}C, while much higher differences at temperatures less than 10 ^{o}C.

Some experiments in this research were conducted to investigate the effect of flocculation process velocity gradient on the relation between raw water temperature and efficiency of floc formation in size and strength reflected by the settling efficiency measured as remaining turbidity at constant flocculation time for test runs. The results are shown in Fig.14, they indicate that, at low temperature the effect is significant, but as temperature increases the effect of flocculation process velocity gradient will be less. Better results of turbidity removal had been gotten when the velocity gradient was increased from 10, to 20 then to 30 and finally 40 s^{-1}. The results also show that at normal temperature range for water treatment plant, the increase in flocculation time above 40 min. would cause impairment of floc formation and virtually bad selling.

Until recently, it was thought that floc strength could be determined only by observing whether a terminal breakthrough occurred in the filtering process. Recent experiences in the conduct of jar testing under winter and summer conditions showed that floc breakage can happen during flocculation process that adversely affect the following sedimentation process efficiency as shown in **Figures (4 - 14).**

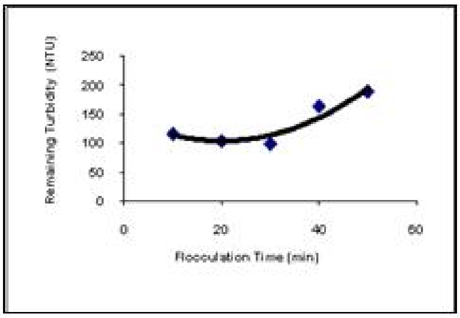

Fig .(4) Remaining turbidity as a function of flocculation time at G = 40 s^{-1} initial turbidity= 500 NTU, T=4°C

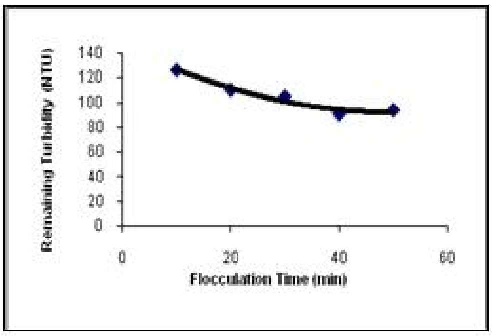

Fig .(5)Remaining turbidity as a function of flocculation time at G = 40 s^{-1} initial turbidity= 500 NTU, T=10°C

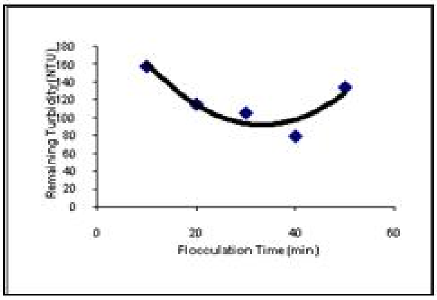

Fig .(6) Remaining turbidity as a function of flocculation time at G = 40 s^{-1} initial turbidity= 500 NTU, T=15°C

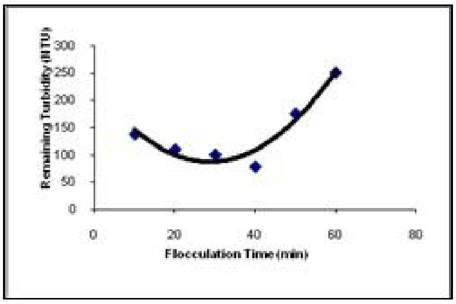

Fig .(7) Remaining turbidity as a function of flocculation time at G = 40 s^{-1} initial turbidity= 500 NTU, T=20°C

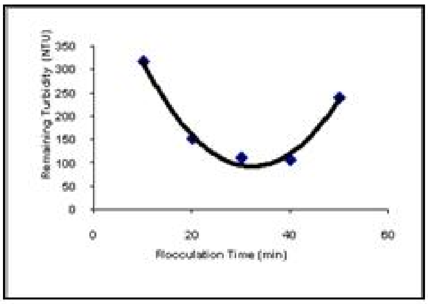

Fig .(8) Remaining turbidity as a function of flocculation time at G = 40 s^{-1} initial turbidity= 500 NTU, T=25°C

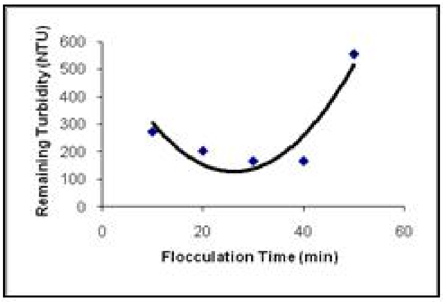

Fig .(9) Remaining turbidity as a function of flocculation time at G = 40 s^{-1} initial turbidity= 1000 NTU, T=4°C

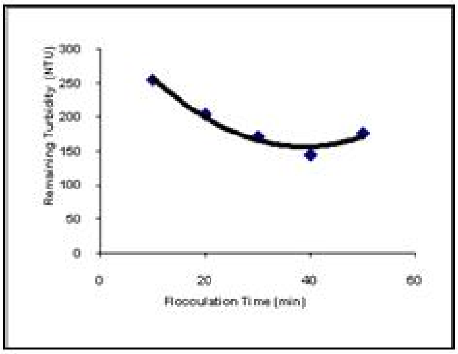

Fig .(10) Remaining turbidity as a function of flocculation time at G = 40 s^{-1} initial turbidity= 1000 NTU, T=10^{o}C

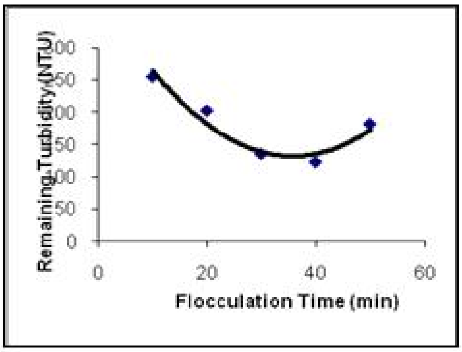

Fig .(11) Remaining turbidity as a function of flocculation time at G = 40 s^{-1} initial turbidity= 1000 NTU, T=15^{o}C

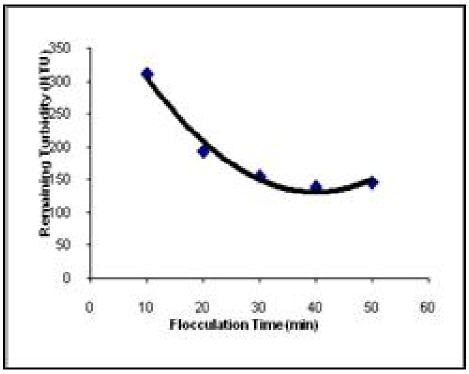

Fig .(12) Remaining turbidity as a function of flocculation time at G = 40 s^{-1} initial turbidity= 1000 NTU, T=20^{o}C

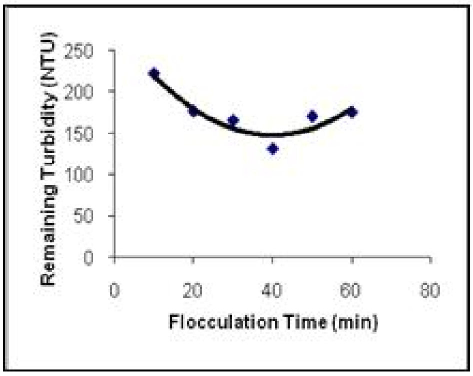

Fig .(13) Remaining turbidity as a function of flocculation time at G = 40 s^{-1} initial turbidity= 1000 NTU, T=25^{o}C

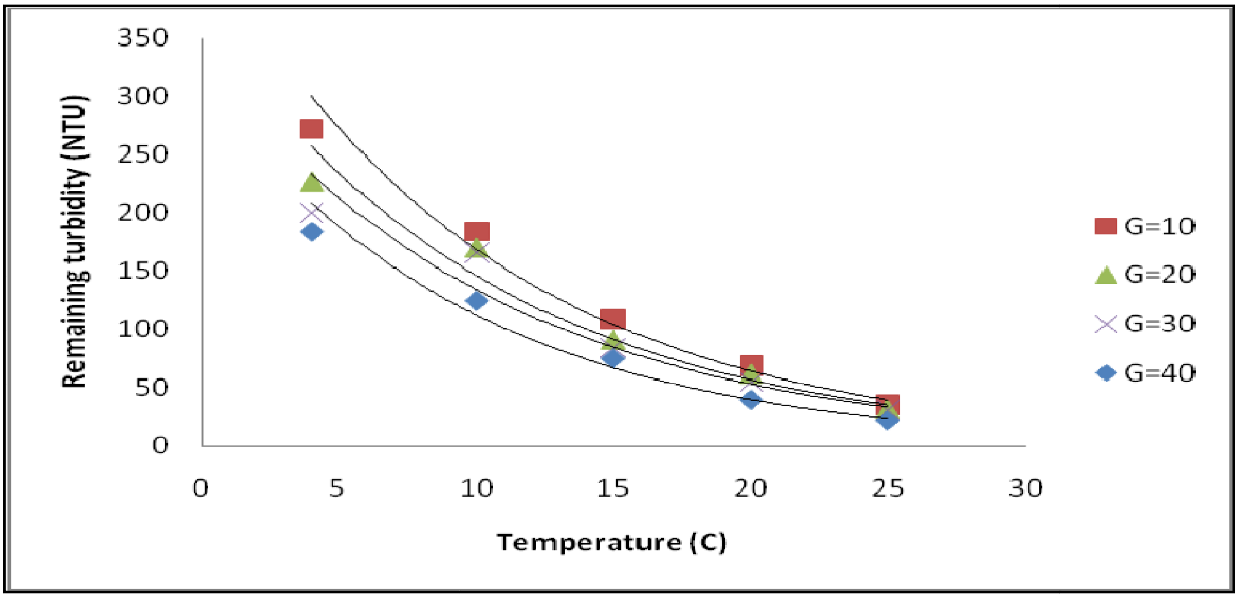

Fig .(14) Effect of flocculation velocity gradient on the relation between temperature and remaining turbidity

Conclusions

1. Time is needed for the formation of removable flocs in flocculation process, and the best average residence time ranged from 20 to 40 min. depending on the temperature effect and other mixing conditions, on average the residence time for floc formation is about 30 minutes
2. At low temperature raw waters, high flocculation time will impair the floc strength and virtually floc formation efficiency and causing bad settling as this prolonged flocculation time would break the big formed flocs into smaller ones more easily at low temperature than at higher ones because of increased shear stress due to higher water viscosity
3. The effect of temperature on floc formation and strength becomes less pronounced with increasing in raw water initial turbidities, however, the results also show that, the effect of temperature on the best flocculation time required for efficient sedimentation becomes less when temperature increases and reaches 25 ^{o}C, and little difference in flocculation times at temperature range from 10 to 25 ^{o}C, while much higher differences at temperatures less than 10 ^{o}C.
4. Flocculation velocity gradient affects the relation between temperature and the optimum required flocculation time for efficient sedimentation. At low temperature the effect is significant, but as temperature increases the effect of flocculation process velocity gradient will be less. Better results of turbidity removal had been gotten when velocity gradient was increased from 10, to 20 then to 30 and finally 40 s^{-1}.
5. Comparing results of Jar tests on raw water turbidities of 500 and 1000 NTU show that the effect of temperature on floc formation and strength becomes less pronounced with increasing in raw water initial turbidities.

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