Settling of high concentrations of clay suspended in water by nonionic polyacrylamide flocculants

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The settling efficiency of prepared polyacrylamide flocculant showed high promising results compared to the commercial one. Different parameters such as flocculant dose, end-over-end inversions of the cylinder, pH and temperature at different concentrations of clay suspensions were studied. The effective flocculant dose that fulfilled fast settling rate was determined. It was found that, increasing the number of end-over-end inversions of the cylinder showed a reduction effect on both of settling rate and percentage turbidity removal, also increasing pH decreased both of them. Finally it was observed that as temperature increased the settling rate increased but the residual turbidity decreased.

بمقارنة المادة المجمعة المحضرة معمليا مع نظيرتها التجارية وجد أن كفاءة ترسيبها أعلى. حيث تم دراسة بعض العوامل التي تؤثر في عملية الترسيب مثل جرعة المادة المجمعه و عدد مرات الانقلاب للمخبار المدرج و درجة حموضة الوسط و درجة الحراره وذلك لتركيزات مختلفه من الطفلة المعلقه. تم تحديد كمية المادة المجمعة الفعالة و التي تعطى أسرع معدل ترسيب. اتضح أن زيادة عدد مرات الانقلاب للمخبار المدرج تقلل من معدل الترسيب و النسبة المئوية لإزالة العكاره. ايضا زيادة درجة الحموضة تقلل كلا منهما . أيضا تم ملاحظة أن زيادة درجة الحرارة تزيد معدل الترسيب ولكن تقلل العكاره.

Keywords: Settling phenomena, Flocculation, Polyacrylamide flocculant, Colloidal suspensions, Wastewater

1. Introduction

The general term settling is used to describe all type of particles falling through a liquid under the force of gravity and settling phenomena in which the particles or colloids are suspended by hydrodynamic forces. At high particle concentrations, individual particle behavior is influenced, or hindered, by the presence of other particles, and the flow characteristics of the bulk suspension can be affected. With increased particle concentration, the free area between particles is reduced causing greater interparticle fluid velocities and alteration of flow patterns around particles. Consequently, the average settling velocity of the particles in a concentrated suspension is generally less than that of a discrete particle of similar size [1].

Colloidal species encountered in raw water and wastewaters include clay, silica, iron and other heavy metals, color and organic solids. Colloids may also be produced in precipitation processes such as lime softening. Colloids always require coagulation to achieve an effective size and settling rate; but even larger particles, which are not truly colloidal and would settle if given enough time, may require coagulation to form larger, faster settling floc. When insufficient settling time is available in a treatment plant to remove suspended solids, coagulation and flocculation may cause them to grow in size and settle rapidly enough to overcome the physical limitation of the plant design. Flocculation has played an important role in domestic and industrial wastewater treatment, mineral beneficiation etc. The flocculation is caused by addition of a minute quantity of chemicals termed as flocculants. The flocculants can be inorganic or organic in nature. Among the inorganic flocculants the salts of multivalent metals such as aluminum and iron are mostly used. The organic flocculants may be synthetic or natural. Synthetic flocculants are mostly water-soluble linear polymers like polyacrylamide and polyacrylic acid. Natural polymers such as starch, cellulose, and alginic acid are very often used as flocculants or retention aids. Previous research in flocculation shows that when using inorganic flocculants large volumes of inorganic salts are required to obtain similar results to those obtained with a very small amount of polymeric flocculants. Also the use of large amounts of inorganic materials produces a lot of sludge unlike polymeric flocculants. The inorganic salts are effective over a particular pH. Therefore there is frequent need for pH adjustment this is not a factor when using polymeric materials [2].

There is a wide range of flocculants available from a number of commercial suppliers. These vary in chemistry, ionic charge, molecular weight, branching, and physical form (e.g. emulsion, powder, gel or bead). Because of this diversity, the selection of a flocculant for particular industrial application is not based upon their specific chemical and physical composition. Instead, performance parameters (e.g. settling rate, residual turbidity, sediment volume of flocculant consumption) are used to characterize the quality or extent of flocculation achieved with a given flocculant. The traditional laboratory procedure for assessing flocculants is the batch cylinder test, in which a suspension is flocculated within a measuring cylinder and the settling rate determined from the rate of fall of the "mud line", also the residual turbidity of the supernatant was measured after two different intervals (10min & 60min). This procedure is used by all commercial flocculant suppliers in the evaluation of their products, and is also widely used by a lot of researchers [3].

The performance of a flocculant in any application is decided by the complex interplay between a numbers of factors. Many of these factors flocculant dosages, number of inversions for cylinder, pH of clay suspensions, and temperature of clay suspension have been reviewed in this paper to flocculate the synthetic clay suspension using two different nonionic polyacrylamide flocculants, one of them is the previously laboratory prepared, and the other is the available commercial (Magnafloc7025) one. A comparison between the two nonionic flocculants was made at various studied conditions.

2. Materials and experiments

2.1. Materials

1. Acrylamide was supplied by Fluka chemicals Co. Ltd. (Switzerland), assay ≥ 99%. Potassium persulphate [$K_2S_2O_4$] supplied by S.D.S. FINE-CHEM Ltd. (England), min assay 98%, chloride not more than 0.04%.
2. Clay powder, Egyptian highly refined Ball clay (smectite- vermiculite) powder of very fine particle size, used mainly for manufacturing refractory bricks and mortar, was obtained directly from Alexandria for Refractories Company. The physical and chemical characteristics of the material (data provided by the manufacturer) are as shown in table 1.
3. MAGNAFLOC7025, is a high molecular weight nonionic polyacrylamide flocculant (Ciba Specialty Chemicals, U.K) is supplied as a free flowing granular powder, its properties as follow: (physical form: white granular powder, particle size: 98% < 1000μm, bulk density: 0.8g/cm3, pH of 1% solution at 25°C: 5.5, viscosity at 25°C of 0.5% solution at shear rate 5.11: 50 cP, relative viscosity at 25°C: 4.1)

2.2. Preparation of polyacrylamide

The preparation conditions were 6% monomer concentration, 0.001M potassium persulphate, and polymerization time 55min at 50°C using solution polymerization technique. The yield of acrylamide monomer converted to polyacrylamide flocculant was 71.5%. The produced flocculant has relative viscosity at 25°C; 45.

The procedure of polymerization is conducting as follow:

1. Dissolve the monomer acrylamide in distilled water to prepare acrylamide solution

Table 1
Characterization of clay powder

Particles size	- 325 mesh
Moisture	1% maximum
Silica	51.4%
Alumina	32%
Ferric oxide	2.6%
Titania	2%
Calcium oxide	0.3%
Sodium oxide	0.1%
Magnesium oxide	0.12%
Potassium oxide	0.08%
Loss on ignition	11%.

of the desired concentration and then the solution is purged with nitrogen gas for 30min at the selected temperature.

2. Predetermined weight of potassium persulphate is added to the monomer solution with continuous bubbling of nitrogen gas for 10 minutes.

3. Temperature of the reaction medium is adjusted to start the polymerization reaction.

4. After 30 minutes, the stirring is stopped but the nitrogen gas continues to pass through the polymerization vessel atmosphere.

After completion of the desired polymerization time the reaction medium is diluted with distilled water to give the selected flocculant concentration (0.5%) and the medium stirred gently with mechanical stirring until a homogeneous solution is obtained.

2.3. Preparation of clay suspension

Clay suspensions were prepared from clay powder immediately before each set of experiments, through mixing accurate weight of clay powder with certain volume of tap water. Tap water used for preparing clay suspensions has the following properties (data obtained from Alexandria water company): pH 6.5-8, turbidity<1 NTU, total hardness 500 mg/L and total dissolved solids 1200 mg/L.

2.4. Preparation of flocculant solution

A concentrated flocculant solution was prepared by first wetting the surface of the flocculant (0.5g) with 3ml of ethanol, and complete until 100ml with distilled water. The sample then was stirred for 2 hours to have a homogeneous 0.5%(w/v) solution that stored as stock solution.

2.5. Clay settling test (cylinder test)

1. Fill on liter standard stoppered glass-measuring cylinders with the prepared clay suspensions (prepared using tap water).

2. Close the cylinder and invert it five times then the cylinder is set upright and the height of the solid phase was measured at regular time intervals.

3. Plot the curve of height against time to determine the settling rate.

4. The sample for turbidity measurement was withdrawn after 10 min & 60min from the previous inverted cylinder using automatic pipette from a height of 3.5 cm below the surface of suspension. The turbidity of these samples was measured using 2100 p Turbidimeter (Hach Co.) calibrated using standard suspensions.

5. The samples that withdrawn after 10 min represent the initial turbidity (To), and the others measured samples after 60min are the residual turbidity ($T1$).

6. For both prepared and commercial nonionic flocculants add the requisite amount of 0.5% solution of previously prepared stock solutions.

7. Repeat both steps 2 & 3.

8. The residual turbidity (T) of the supernatant liquid was measured after 10min as described previously and another measurement of the supernatants turbidity take place after 60min ($T2$).

9. The percentage removal of turbidity was calculated according to the following equation, where $T = T$, $T1$ or $T2$.

$$\%\text{Turbidity removal}=[(T_o-T)/T_o] * 100, \qquad (1)$$

10. Flocculation efficiency using both flocculants (prepared & commercial) was compared.

3. Results and discussion

Hindered settling rates, measured from the rate of descend of the mud line, provides a qualitative indication of the aggregate dimensions, and serve as a guide to the throughput of gravity thickeners. They are normally obtained from cylinder tests, where dilute polymer is dosed into a standard cylinder of slurry and mixed by inversion. A comparative study was made to investigate the effect of various parameters on the settling rate using both prepared and commercial (Magnafloc7025) nonionic flocculants.

3.1. Effect of flocculant dosages

The effect of both prepared and commercial (Magnafloc7025) nonionic flocculants dosages of 0.5% stock solution on the settling rate and the percentage turbidity removal was studied using different clay concentrations (3-9%).

Fig. 1 illustrates the settling rate of 9% clay concentration using both nonionic flocculants. It is clear that settling of clay suspensions without using flocculant (blanks) is generally slow compared to the settling using any of the previously mentioned flocculants because flocculant materials adsorb on different clay particles and help particles to aggregate into clusters, which settle faster than the discrete clay particles.

By comparing settling of clay suspension with and without using flocculants, it is observed that at the beginning the height of interface decreased with time, and as settling time increased the sedimentation becomes lower for both cases. This may be due to the consolidation of the sediment, liquid is forced upward around the solid particles forming a loose bed with the particles in contact with one another, also the flow area is gradually being reduced, hence the resistance to the flow progressively increases [4]. But when settling occurs using flocculant, a sharp decrease in settling rate is noticed. Also the beginning settling period is very short using flocculant compared with its counterpart without flocculant, where the settling period reduced from two hours in case of settling the 9% clay suspension without using flocculants to about 10min when using 1ml of prepared flocculants and about 30min using 1ml of commercial flocculants. Moreover increase in flocculant dose from 0.1 to 1.5ml shows an appreciable increase in settling rate but has a little effect on the percentage removal of clay turbidity as illustrated in fig. 2. This may be related to the high initial turbidity of the initial clay concentration that shows a slight difference in decreasing residual turbidity (T_o- T) with increasing flocculant dose and this by its role shows a slight decrease in percentage turbidity removal with increasing flocculant dose.
Furthermore from the percentage removal of clay turbidity vision, it is noticed that settling of clay suspension without using flocculant required one hour to obtain a clear supernatant but this time decreased to 10min to acquire the same supernatant clarity or better by using a flocculant. Also it is remarkable from these curves that when clay settled using flocculant there is no appreciable improvement in percentage of turbidity removal after 60min as compared to that after 10min. So the flocculation of clay suspension using any flocculant dose not require more than 10min to gain a clear supernatant liquid. Chan W., and Chiang C., [5] supports these results, they decided that the value of residual turbidity decreased rapidly at the initial settling time (about 10min), and then almost remained constant.

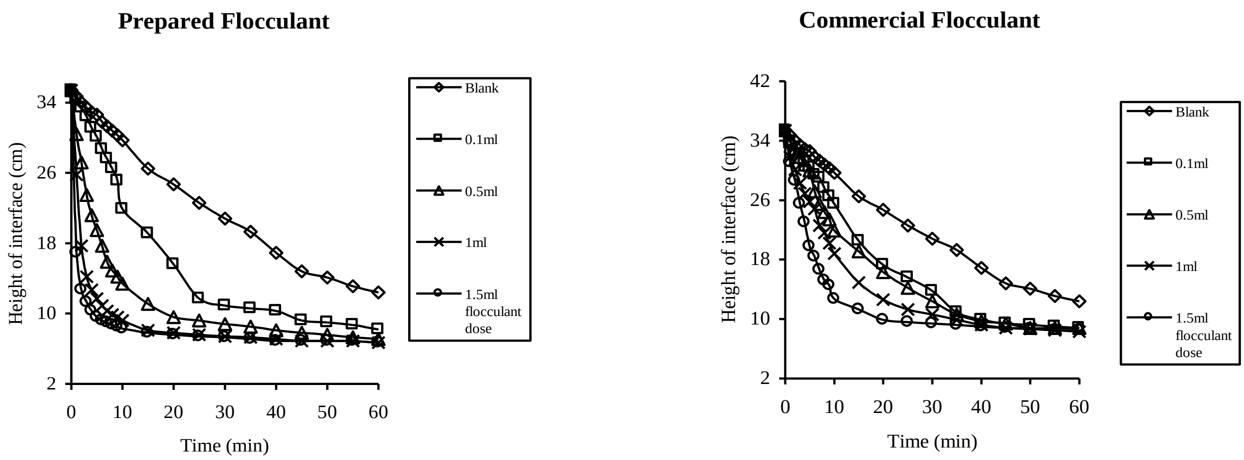

Fig. 1. Effect of flocculant dose on settling rate for 9% clay concentration using 5 numbers of inversions at room temperature.

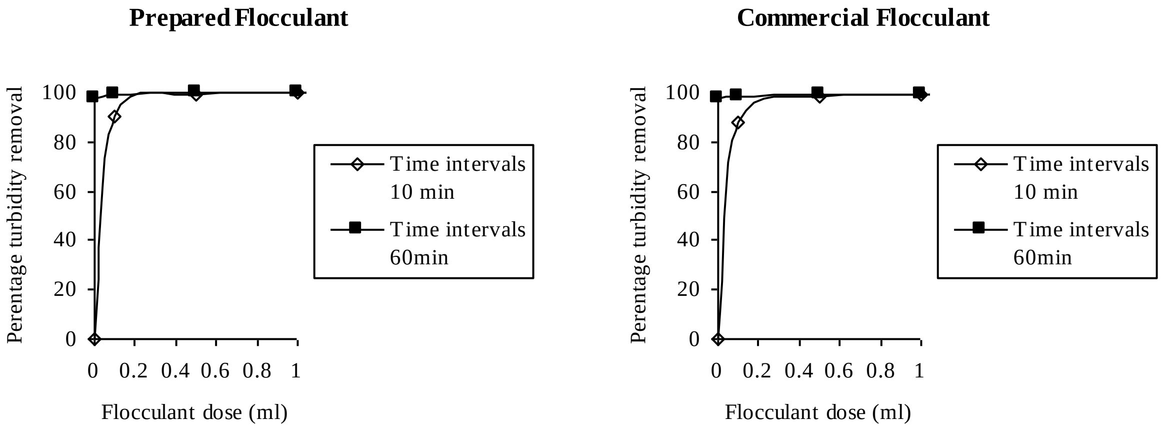

Fig. 2. Effect of flocculant dosages on percentage turbidity removal for 9% clay concentrations using 5 numbers of inversions at room temperature.

It is interesting to note that for both prepared and commercial nonionic flocculants, faster settling rates and lower residual turbidities may be achieved by using 1 ml of flocculant for all concentrations of clay studied. It can be seen that the addition of flocculant has effectively little impact on the settling rate for doses in excess of 1 ml especially for smaller concentrations of clay. This may explained by, when 1ml flocculant dosage used, all added polymer is adsorbed on the solid and clusters formed. The point beyond which, the added polymer is not completely adsorbed and lead to waste of polymer. This suggestion is harmonious with Farrow J.B., and Warren L.J. [6], they suggest that the initial stages of flocculation may progress through a fines capture process, forming small, slow settling aggregates. Further addition of flocculant may lead to "cluster" flocculation of such aggregates into larger bodies, which are settled faster. This suggestion is compatible with the previously stated mechanism of bridging flocculation [2]. Also, Owen A.T., et al. [7], mentioned that as the external surface area of these aggregates is low relative to their volume, the formation of cluster aggregates with much higher settling rates may only require a small increase in flocculant dosage.

The effect of prepared and commercial flocculant dosages on the obtained $\%H/H_o$; where $\%H/H_o$ is the percentage between the heights of interface at certain time (5min) and the initial slurry height; using different clay concentrations are represented in fig. 3.

From the obtained data, it can be noticed that for clay concentrations (3, 5%) there is a sharp decrease in $\%H/H_o$ when flocculant dose varied from 0 to 0.1 ml and as flocculant dose increased from 0.1 to 1.5 ml the decrease in $\%H/H_o$ become scanty. Although for concentrated clay suspensions (7, 9%) there is a gradual decrease in $\%H/H_o$ with increasing flocculant dose. These results are coincident with what should be expected, because at low clay concentrations the minimum flocculant dose is sufficient to get all clay particles in large clusters that settle faster than the clay particles. As clay concentration is increased this minimum dose is capable of aggregating some of clay particles in clusters and leave the others not aggregated. Further addition of flocculant more clusters are formed until the optimum flocculant dose is reached which at this point all clay particles aggregate into clusters, so $\%H/H_o$ decreased. When comparing the settling performance of both prepared and commercial flocculants at the selected optimum dosage (1ml), it can be realized that the prepared flocculant gave a higher decrease in $\%H/H_o$ than the commercial one at the same dose & time. This is by its role give indication that the effect of the prepared flocculant on settling rate is higher than the commercial one. Also the percentage of removing clay turbidity using prepared flocculant is slightly larger than the case of the commercial flocculant.

3.2. Effect of number of inversions

The effect of the number of end-over-end inversions of the cylinder using the predetermined optimum flocculant dosage (1 ml) on both the settling rate and the percentage turbidity removal for different clay concentrations (3-9%) was studied using both prepared and commercial (Magnafloc7025) flocculants. The results of settling rate for 9% clay concentration were investigated in fig. 4.

From the latter it is clear that the settling rate achieved is slightly affected with the number of inversions. It can be seen a little tangible increase in the interface height with increasing the inversion numbers from five to fifteen. Also in imputation to the percentage removal of clay turbidity presented in fig. 5. It shows a slight decrease with increasing the number of inversions. These results are in agreement with Farrow J.B., and Swift J.D. [8], they found that the residual turbidity increased with increasing number of inversions when a mixture of quartz, feldspar, hematite, montmorittonite and other minor components is flocculated using polyacrylamide flocculant. They concluded that the efficient mixing of the flocculant and the suspension in the cylinder requires about four to five inversions, thereafter with additional inversions the aggregates start to break-up, resulting in higher residual turbidities. This commentary is compatible with interparticle collision theory of flocculation [9], which illustrate that excessive agitation will cause floc breakdown since bonding forces are relatively weak, so a compromise on the extent of agitation is necessary.

On the other hand, the effect of inversion number on $\%H/H_o$ using different clay concentrations is illustrated in fig. 6.

From this figure, it can be seen that for all clay concentrations the $\%H/H_o$ increased with increasing inversion numbers from five to fifteen for both nonionic flocculants. This gives an indication that for both nonionic flocculants large flocs which give fast settling rate and high percentage turbidity removal are formed at 5 end-over-end inversions of the cylinder, and as the number of inversions increased these formed aggregates are broken into fine ones with smaller settling rates and larger residual turbidity. This indication is compatible with Pearse M.J., et al. [10], they mentioned that a lower sediment volume was achieved by using low mixing (I.e. between 2

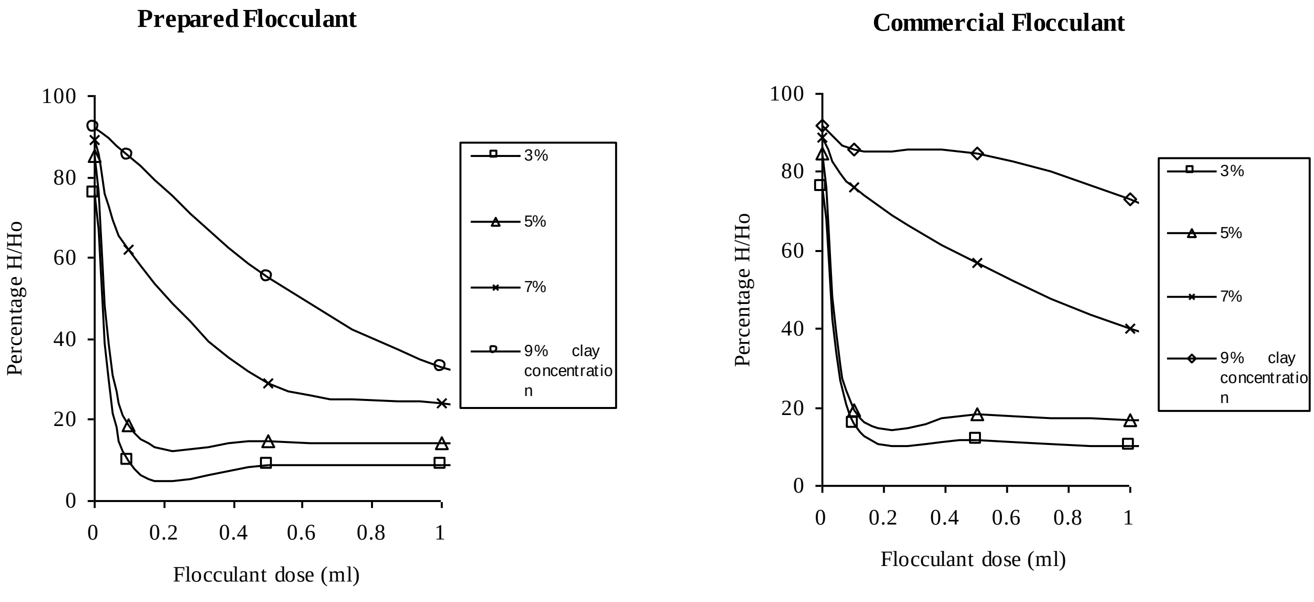

Fig. 3. Effect of flocculant dose on $\%H/H_o$ for different clay concentrations using 5 numbers of inversions at room temperature.

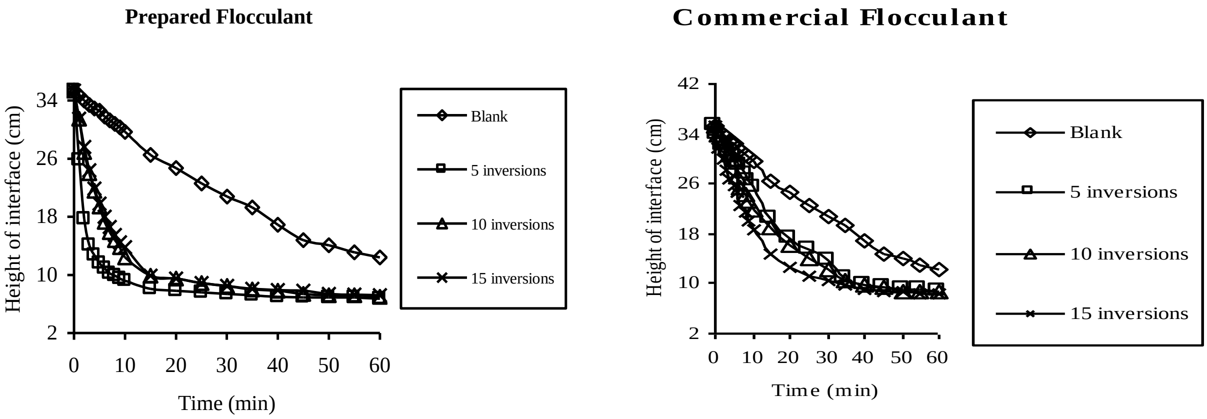

Fig. 4. Effect of number of inversions on settling rate for 9% clay concentration using 1ml flocculant dose at room temperature.

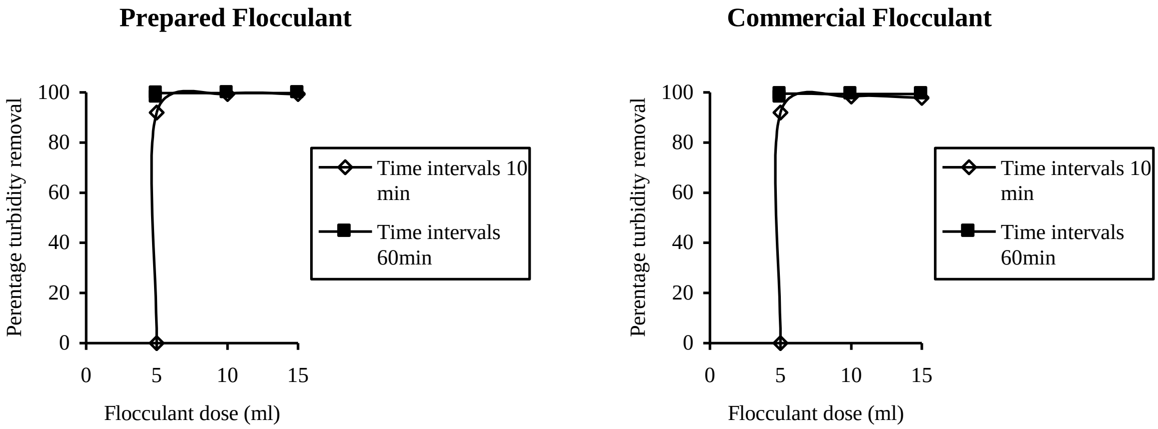

Fig. 5. Effect of number of inversions on percentage turbidity removal for 9% clay concentrations using 1ml flocculant dose at room temperature.

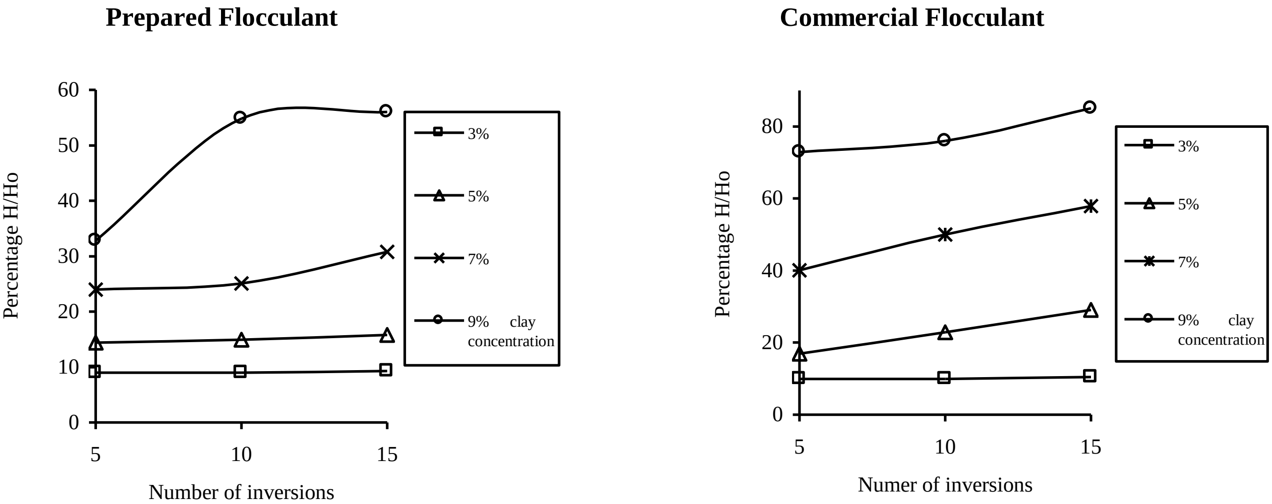

Fig. 6. Effect of number of inversions on %H/H$_o$ for different clay concentrations using 1ml flocculant dose at room temperature.

and 3 cylinder inversions). Also, this determined optimum inversion number (5-inversions) as applicable by both Henderson J.M., and Wheatley A.D. [11], who used polyacrylamide as flocculant and Chandra W.A., et al. [12], where in this study cationic flocculant is used to flocculate kaolinite suspensions. Finally when comparing settling rate for different clay concentrations using prepared flocculant with the other comparable commercial one at the optimum inversion number (5inversions), this confirms that the performance of prepared flocculant in sedimentation is better than the commercial one.

3.3. Comparison between prepared and commercial flocculants

Figs. 7 and 8 represent the comparative study in both settling rate and percentage removal of clay turbidity between prepared and commercial flocculants for different clay concentrations (3- 9%) using the previously determined optimum conditions.

It is observed from fig. 7 that for both prepared and commercial nonionic flocculants, as the concentration of clay increased from 3 to 9% the optimum time required increased. This may be attributed to the fact [4] that at high concentrations of clay the suspension becomes denser and the large particles are settling relative to a suspension of smaller ones so that the effective density and viscosity of the fluid are increased. Hence the resistance of particles to flow increased this by its role increase the required settling time. Moreover, it is noticed from the same figure that for both nonionic flocculants as clay concentration increased the $\%H_{op}/H_o$ increased; where $\%H_{op}/H_o$ represent percentage between the height of interface at the optimum settling time and the initial slurry height. It is considerable from this figure that the sedimentation with prepared flocculant is much better than commercial flocculant, because both the required optimum settling time and $\%H_{op}/H_o$ are smaller than those using commercial flocculants.

Further fig. 7 show for prepared flocculant, as clay concentration increased from 3 to 9% there is a negligible increase in percentage turbidity removal (up to 95% turbidity removal). But for commercial one the percentage turbidity removal increased from 85% to 99%. These indicate that the efficiency of prepared flocculant in removal of clay turbidity is not affected with clay concentration, but the efficiency of commercial one increased with increasing clay concentrations. It is also noticed that even the percentage removal of clay turbidity using commercial flocculant after 60min is lower than that after 10min when prepared flocculant used.

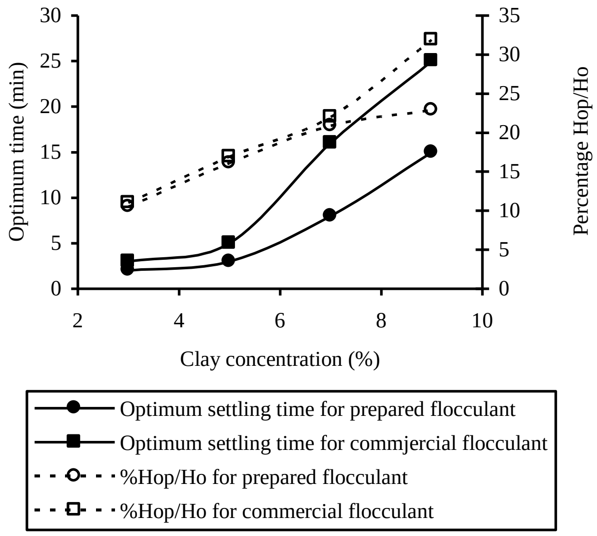

Fig. 7. Comparison between prepared & commercial flocculants on settling rate using different clay concentrations using optimum flocculant doses 1ml and 5 numbers of inversions.

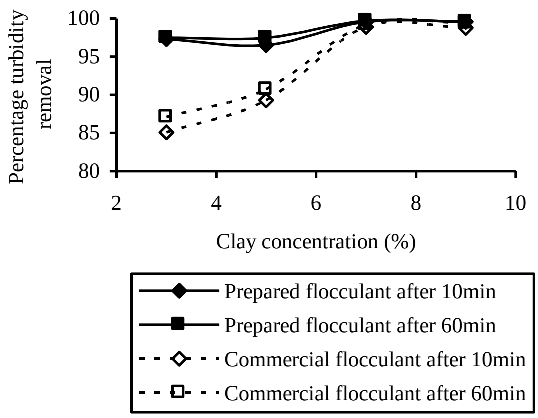

Fig. 8. Comparison between prepared & commercial flocculants on % turbidity removal using different clay concentrations using optimum flocculant doses 1ml and 5 numbers of inversions.

3.4. Effect of suspension pH

The studied variation range of pH values 3-9 was coverage the basic three media (acidic, alkaline and neutral) at optimum predetermined flocculant dose and inversion number, using both prepared and commercial nonionic flocculants for the studied clay concentrations 3-9%. From the obtained settling rate data for 9% clay concentration which plotted in fig. 9. It is deduced for clay suspensions, which settled without using flocculant (blanks) that after 5-end-to-end inversions, the movement of the sedimentation boundary shows a continuous decrease in the height of interface with time. This indicate that 60min is not sufficient for settling these suspensions completely without flocculant for all pH. However respecting to the flocculated suspensions it is noticed fast decrease in the interface height at the beginning and then the settling rate become slowly. It is noticed for commercial flocculant that the beginning settling period is ranged between 20min for acidic and neutral media (pH 3,5,7) and this time increase to 30min for alkaline suspension (pH 9), this give indication that as pH of the clay suspension increased the stability of the suspension increased. This is returned to the fact of the natural surface of clay that [13] increasing pH results in increasing the charge on the edges of clay layers so the magnitude of the repulsive force between clay particles increased that is increase the stability of clay suspension and more settling time required. But this effect of pH is not appreciable for suspensions flocculated using prepared flocculant. This may return to its higher flocculation efficiency than the commercial one, because its relative viscosity is 45 compared to 4.1 for commercial flocculant.

Moreover fig. 10 represent the effect of pH variations on residual turbidity for both blank suspensions, which are settled without using flocculants and the flocculated suspensions for 9% clay concentration.

From this figure it is found that the pH has a significant effect on the residual turbidity for settling blank suspensions and this effect decreased when flocculant used. It can be seen for blank suspensions that the difference between the residual turbidity after 10min

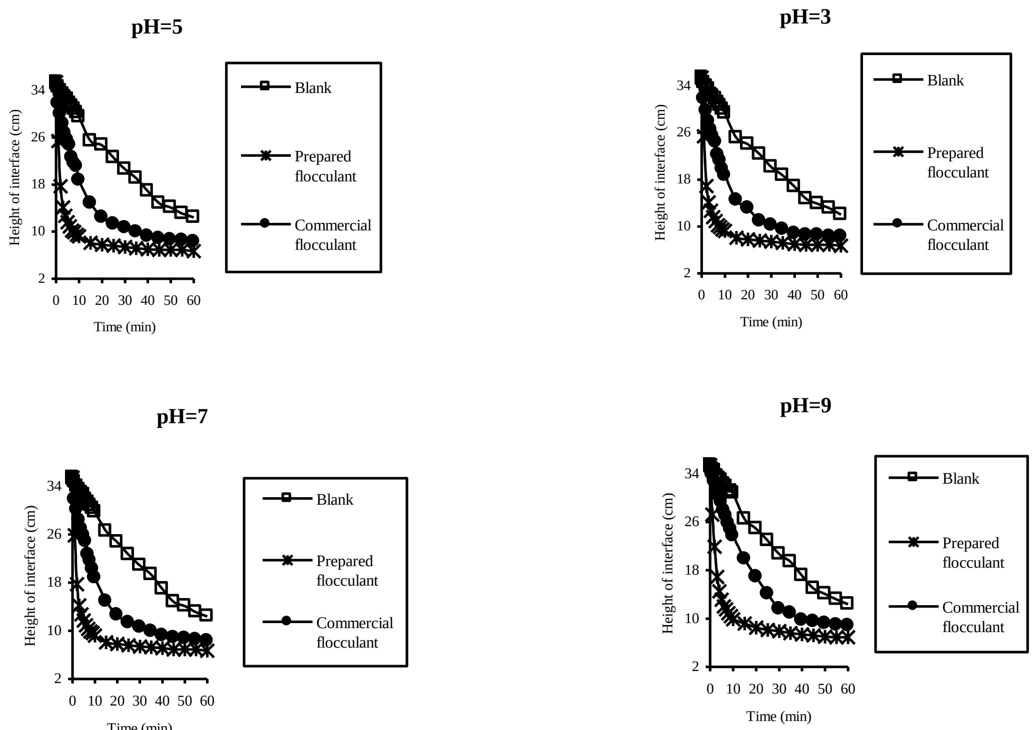

Fig. 9. Effect of pH on settling rate for 9% clay concentration using 1ml flocculant doses and 5 numbers of inversions.

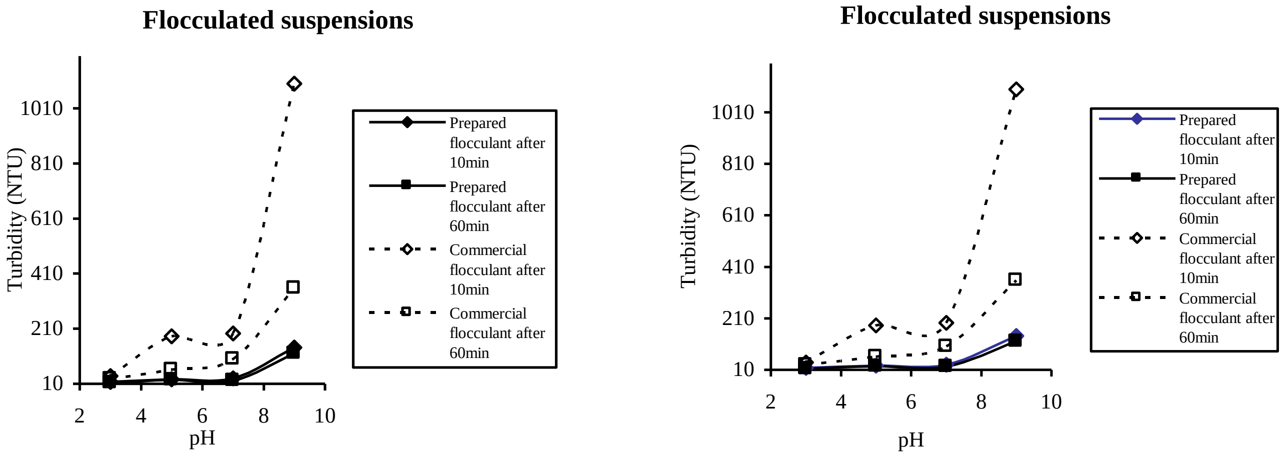

Fig.10. Effect of pH on residual turbidity for 9% clay concentration using 1ml flocculant doses and 5 numbers of inversions.

and the corresponding residual turbidity after 60min is increased as pH increased from 3 to 9. This may returned to increasing pH increasing [13] the mutual repulsion between particles due to the increase in charge density this by its rule prevent particles from coming together, also it retard settlement by keeping the particles in constant motion so residual turbidity increased with increasing pH. In looking at the residual turbidity when flocculant used, it can be seen the value of the residual turbidity decreases completely at the first 10min and then it almost remains constant. This behavior is true for both prepared and commercial nonionic flocculants at the acidic and neutral media (pH 3,5,7) but as pH increased to 9 (i.e. basic media) it is noticed a slight increment in the residual turbidity after 60min when prepared flocculant used and this increment become larger in case of using commercial flocculant. These reflect that the performance of prepared flocculant show a little effect than the commercial one as the pH increased. Furthermore the large difference between the residual turbidity after 10min and 60min in blank suspensions is nearly disappeared when prepared flocculant used, comparing with a small difference when using commercial flocculant this difference show a gradual slight increment as the pH increased.

The effect of pH on $\%H/H_o$ using different clay concentrations are presented in fig. 11 for both prepared and commercial nonionic flocculants.

Sedimentation is carried out at pH 3, 5, 7 and 9. The surface charge of the particles would be expected to increase with pH. Particles can approach each other most closely when they are not highly charged so that increasing the surface charge density on particles should cause stabilization of a suspension, this clarified by the increase in $\%H/H_o$ as pH increased at the same flocculant dose for each clay concentration. Furthermore it is noticed that when prepared flocculant used, a slight increase in $\%H/H_o$ with increasing pH for each clay concentration. But this relationship shows larger increase at high values of pH especially for concentrated suspensions (7 & 9%). This is as mentioned before confirm that for prepared flocculant the flocculation performance is not affected by pH compared with commercial one which its performance decrease as pH increased.

3.5. Effect of suspension temperature

Figs. 12 and 13 represent the effect of variation in the temperature (25, 50, 60 °C) for 9% clay concentrations using tap water (pH~7) on both the settling rate & residual turbidity using the two nonionic flocculants (prepared and commercial) at the predetermined optimum conditions.

It is noticed for each clay concentration that the increase in temperature shows little effect on settling rate for both flocculants. On considering the residual turbidity fig. 13 the effect of this increase in temperature becomes clearer, so it is noticed residual turbidity decrease where the temperature is increased. These results correspond with those obtained by Miyata, N. [14] who studied the sedimentation rate of kaolin using polyacrylamide at different temperatures. He stated that the sedimentation rate increased with increasing temperature, and the transparency of upper layer passed through a maximum value with an increase in temperature.

On the other hand fig. 14 shows the effect of temperature on %H/H_o using two different clay concentrations (7 & 9%) for both prepared and commercial nonionic flocculants.

It is clear for each clay concentration that as temperature is increased the %H/H_o slightly decreases. This means that the settling rate increased as temperature is increased. This should be expected result since the rate of diffusion of flocculants and the rate of collision of particles increases with rise in temperature [15]. The prepared flocculant showed higher efficiency in decreasing %H/H_o as compared to the commercial one.

Finally fig. 15 summarizes most of the previously obtained results during studying the effect of pH and the temperature on the settling rate for both prepared and commercial flocculants. Through studying the effect of variation of both temperature and pH on the settling of 7% clay concentration. It can be seen that:

1. For all pH values there is a slight decrease in %H/H_o (i.e. increase in settling rate) as the temperature is raised from 25 to 60°C for both flocculants.
2. As pH is increased from 3 to 9, the %H/H_o increased. That means that increasing pH of clay suspension decrease the settling rate.
3. The performance of the prepared flocculant on settling rate is slightly affected with the increase in pH compared with the commercial flocculant, which show a large decrease on settling rate as pH is increased from 7 to 9.

4. Conclusion

The final conclusion from the previous study is that the settling rate of clay suspension without flocculants is low especially for high clay concentrations and the settling rate and percentage turbidity removal increased with increasing flocculant dose for both flocculant types. Also the optimum flocculant dose, that required for obtaining a faster settling rate and corresponding clear supernatant, is 1 ml for each clay concentration using any flocculant type. It was noticed a slight decrease in settling rate and percentage turbidity removal as the number of end-over-end inversions of the cylinder increased. The effect of pH shows that the flocculation performance of the prepared flocculant is not affected by pH compared with commercial one,

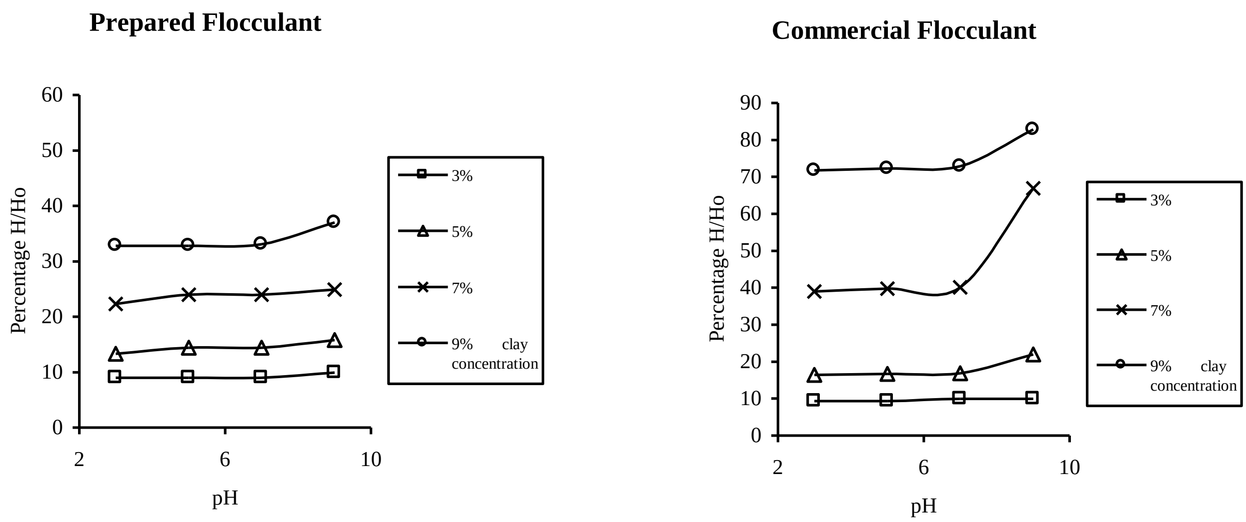

Fig. 11. Effect of pH on %H/H_o for different clay concentrations using 1ml flocculant dose and 5 numbers of inversions.

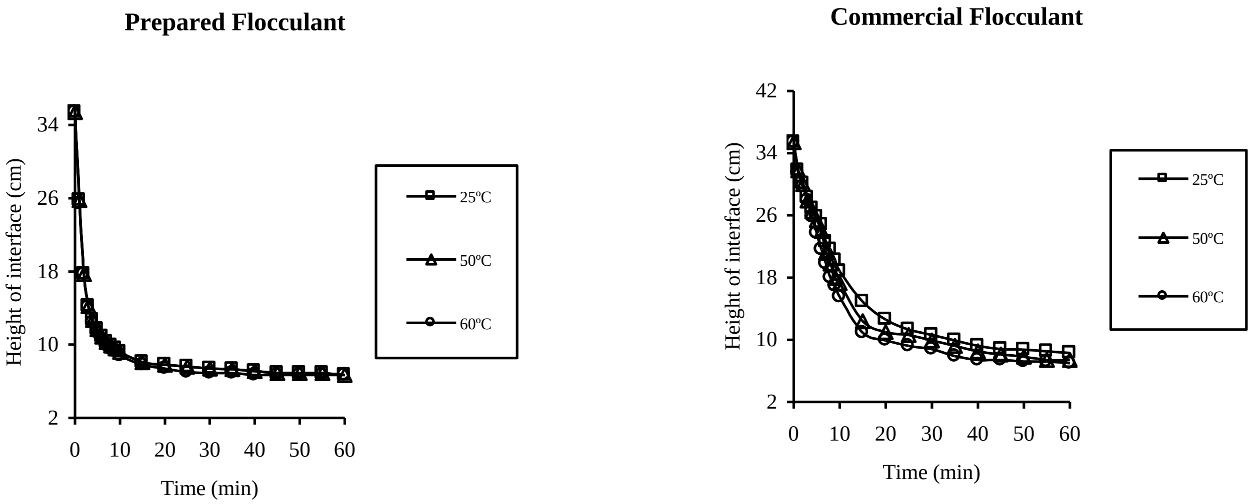

Fig. 12. Effect temperature on settling rate for 9% clay concentration using 1ml flocculant doses and 5 numbers of inversions.

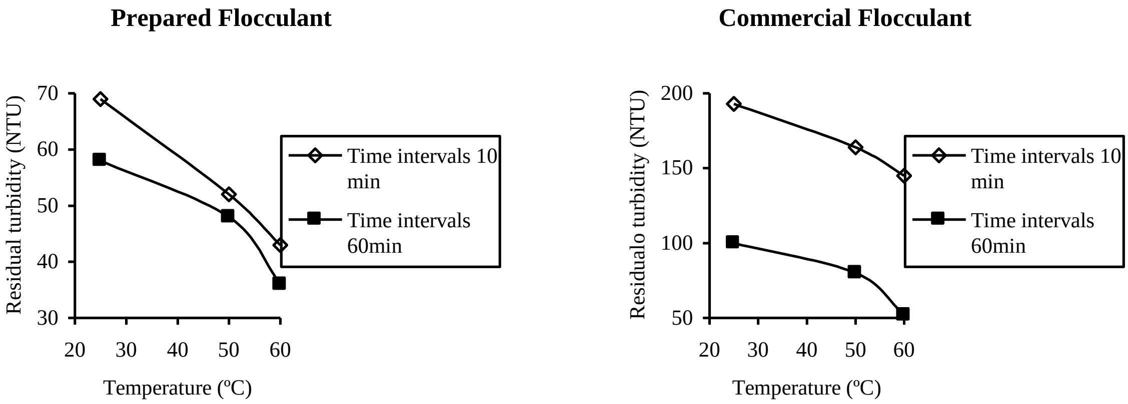

Fig. 13. Effect of temperature on percentage turbidity removal for 9% clay concentrations using1ml flocculant and 5 numbers of inversions at room temperature.

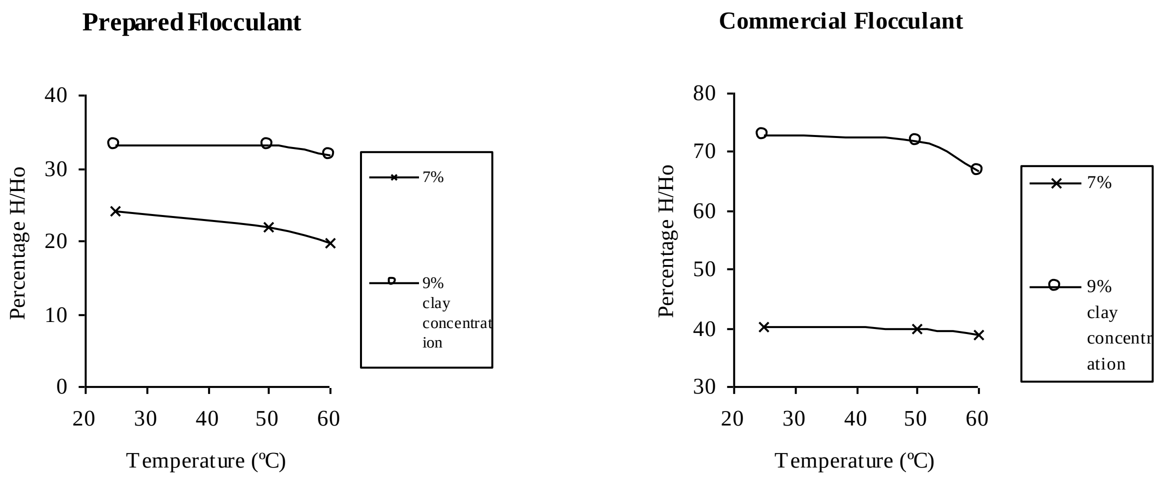

Fig. 14. Effect of temperature on %H/H$_o$ for different clay concentrations using 1ml flocculant dose and 5 numbers of inversions.

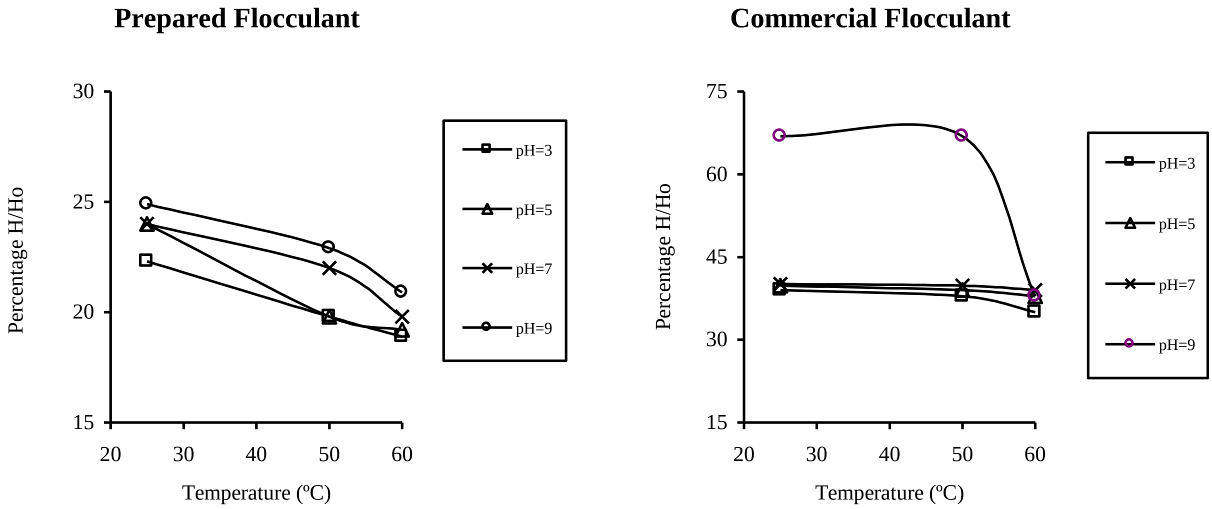

Fig. 15. Effect of temperature on %H/H$_o$ for different pH using 7% clay concentration at 1ml flocculant dose and 5 numbers of inversions.

which its performance decrease as pH increased. Because the relative viscosity of the prepared flocculant is higher than the commercial flocculant more than 10 times, so its molecular weight is much higher and makes it capable of compensation the increase in the pH. From studying the temperature effect it was concluded that the performance of the laboratory prepared flocculant shows good results in both settling rate and the clarity of the residual supernatants even if the treated waste will be at high temperatures.

At the end from all previously studied conditions it is clear that the laboratory prepared flocculant showed better performance in both the settling rate and turbidity removal than the compared commercial Magnafloc7025 flocculant, due to its higher relative viscosity and so larger molecular weight than the commercial one.

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