A NOVEL COMPACT COAGULATION-FLOCCULATION-SEDIMENTATION SYSTEM

Abdel Monem A. El-Bassioni[*], Ibrahim G. Rashed[**], Ahmed A. Al-sarawy[**], and Mohamed M. El-Halwany[**]

[*] Faculty of Engineering, Minia University, El-Minia, Egypt
[**] Faculty of Engineering, Mansoura University, El-Mansoura, Egypt

ABSTRACT

Coagulation-flocculation followed by sedimentation, filtration and disinfection, often by chlorine, is used worldwide in the water treatment technology before distributing treated water to consumers. The aim of the present work is to study the parameters affecting on the coagulation, flocculation and sedimentation by a non-traditional technology. Synthetic turbid water was treated with alum [$Al_2(SO_4)_3.18H_2O$], Ferric Chloride [$FeCl_3.6H_2O$], Ferric sulfate [$Fe_2(SO_4)_3.9H_2O$] and cationic polyelectrolyte (C-492 HMW) in the jar test to determine the critical dosage of the coagulant before applying in the proposed system. The proposed system is based on inline mixing and exploiting the feed pump to perform the rapid mix. Feed inters tangentially to a cylindrical tank where the circular motion facilitates the slow mix in an annular space between the wall of the tank and an inside jacket. The flow is reversed inside the jacket upward where sedimentation occurs. The clarified water passes over a weir to a filtration unit. An experimental program were conducted at various turbidity levels, retention time, slope of feed angle, slope of inner jacket, coagulant injection point from the mixing pump, flow rate and slow mixing (flocculation) time. The results obtained showed that the proposed system reduces turbidity to about 3.2, 2.5 and 2 NTU for retention times 120, 150 and 160 minutes respectively, where in the conventional technology the retention time is about 210 minute.

Kay Words: Hydraulic flocculation, Water treatment, Coagulants, Coagulant aids

INTRODUCTION

The resource of raw water to most water treatment plants in Egypt is the Nile River and its distributaries and canals, till its end at the Mediterranean Sea. The problem of potable water supply in Egypt has many different interacted aspects: hygienic, socioeconomic and technical [1]. Impurities in water could be classified according to the size of the individual particles into suspended solids, colloidal particles and dissolved substances. Dissolved substances have a molecular size lesser than 10-6 mm. Colloidal particles are smaller than 10-3 mm while the suspended solids have a larger particles than 10-3 mm. Both suspended solids and colloidal particles have the same origin. They may be mineral in origin like sand, silt and clays. Alternatively, they may be organic resulting from the decomposition of plant or animal matter. In addition, microorganisms as bacteria, plankton and viruses could form a part of the colloidal matter in water [2].

Removal of suspended solids from water could be accomplished by settling. Colloidal particles are so small that their removability from water by settling alone may require several years. Moreover, these colloidal particles are stable in water, being able to remain as independent entities within dispersion. Therefore, they are not able to aggregate spontaneously into larger particles that settle down more rapidly [3]. Hydraulic flocculators have been used for water treatment in many countries design based on intensity of energy distribution in the system usually related to ensuring that a particular value of average shear rate of velocity gradient, G, or the product of velocity gradient and retention time, Gt, is attained [4-5].

The conventional treatment process, Figure (1), as reported by Tebbutt [6] consists of the following consecutive steps:

1. Screening

The first stage in preliminary treatment usually involves a simple screening or straining operation to remove large solids. In the case of water treatment some form of protective boom or coarse screen with openings of about 75 mm is used to prevent large objects reaching the intake. The main screens are usually provided in the form of a mesh with openings of 5 to 20 mm and arranged as a continuous belt, a disc or a drum through which the flow must pass. The screening mesh is usually slowly rotated so that the material collected can be removed before an excessive head loss is reached.

2. Coagulation

Flocculation of dilute colloidal suspension provides only infrequent collisions and agglomeration does not occur to any marked extent. In such circumstances clarification is best achieved using a chemical coagulant followed by flocculation and sedimentation. Before flocculation can take place it is essential to disperse the coagulant, usually required in doses of 30-100 mg/l, throughout the body of water. This is carried out in a rapid- mixing chamber with a high-speed turbine or by adding the coagulant at a point of hydraulic turbulence, e.g. at a hydraulic pump in a measuring flume. The coagulant is a metal salt, which reacts with alkalinity in the water to produce insoluble metal hydroxide flocs, which incorporate the colloidal particles. This fine precipitate is then flocculated to produce settleable solids.

The most popular coagulant for water treatment is aluminium sulfate (alum)$Al_2(S0_4)_3$ [7]and the complex reactions which take place following its addition to water are often simplified as [8]:

$$Al_2(S0_4)_3 + 6\,H_2O \longrightarrow 2\,Al(OH)_3 + 3\,H_2SO_4$$
$$3\,H_2SO_4 + 3Ca(HCO_3)_2 \longrightarrow 3CaSO_4 + 6\,H_2CO_3$$
$$6\,H_2CO_3 \longrightarrow 6\,CO_2 + 6\,H_2O$$

Overall

$$Al_2(S0_4)_3 + 3Ca(HCO_3)_2 \longrightarrow 2\,Al(OH)_3 + 3CaSO_4 + 6\,CO_2$$

The solubility of $Al(OH)_3$ is pH dependent and is low between pH 5 and 7.5; outside this range coagulation with aluminum salts is not successful. Other coagulants sometimes used are ferrous sulfate (copperas) $FeSO_4.7H_20$, ferric sulfate $Fe_2(SO_4)_3$ and ferric chloride $FeCl_3$ [9]. With very low concentrations of colloidal matter floc formation is difficult and coagulant aids may be required. These may be simple additives like clay particles, which form nuclei for precipitation of hydroxide or polyelectrolyte which are heavy long chain synthetic polymers, when added in small amounts (< 1 mg/l) promote agglomeration and toughen the floc. Because of the spongy nature of floc particles they have a very large surface area and are thus capable of adsorbing of dissolved matter from solution.

3. Flocculation

Agitation of water by hydraulic or mechanical mixing causes velocity gradient the intensity of which controls the degree of flocculation produced. The number of collisions between particles is directly related to the velocity gradient and it is possible to determine the power input required to give a particular degree of flocculation as specified by the velocity gradient. Considering an element of fluid undergoing flocculation the element will be in shear and thus mechanical flocculators provide more control over the process than hydraulic flocculators but require more maintenance.

4. Sedimentation

Sedimentation is the gravitational separation of suspended and flocculated matter from water. In dilute suspension under quiescent hydraulic conditions, small discrete particles settle independent on the other particles. However, in concentrated suspensions with variable particle size, larger particles settle at faster rates thus take finer particles in there descend. When particle aggregation is extensive; forming a mass as in flocculated suspensions, the aggregates settle down as a blanket forming zone settling the upper most layer of which is a zone of hindered settling followed by a lower zone of transition then the compression zone which forms the lower-most layer. When dealing with flocculent suspensions, the agglomeration of floc particles results in increased settling velocity with depth due to the formation of larger and heavier particles; this feature illustrated in Figure (2), [10].

5. Filtration

Filtration of suspension through porous media, usually sand, is an important stage of the treatment of potable water to achieve final clarification. Although about 90% of the turbidity is removed in sedimentation a certain amount of floc is carried over from settling tanks and requires removal.

6. Disinfection

Because of the small size of many microorganisms it is not possible to guarantee their complete removal from water by such forms of treatment coagulation and filtration. Some form of disinfections, by chlorine or its compounds, is therefore necessary to ensure the elimination of potentially harmful microorganisms from potable waters [11].

The aim of the present work is to study the parameters affecting on the coagulation, flocculation and sedimentation by a non-traditional technology.

MATERIAL AND METHODS

1. Synthetic Turbid Water

Coagulation experiments were conducted on synthetic turbid water, prepared on the basis of tap water. The tap water was first collected in a plastic tank of 200 liters and kept for at least three days before use in order to obtain a uniform quality throughout the experimental study [12].

The synthetic turbid water was prepared by adding clay particles, which was grinded to very fine particles, to the tap water, [13-15]. Clay was added to ten liters of water and the suspension was stirred for 30 min using magnetic stirrer and then allowed settling for 24 hr. The supernatant was then carefully removed and stored in a plastic bottle.

The clay suspension was diluted using tap water to produce an initial turbidity of about 25 NTU in 200 liters tank. The synthetic turbid water was agitated continuously to prevent sedimentation and change of initial turbidity. Table (1) indicates the main characteristics of the tap water and synthetic turbid water. All these parameters were measured following the standard methods outlined in the standard methods for the examination of water and wastewater [16]. Turbidity was determined using HACH model 2100A turbidimeter (0-1000 NTU), USA. Electrical Conductivity (EC) was measured by Corning checkmate 90 with cond/TDS sensor, USA. Total Phosphorus (PO_4^{-3}) was measured by using Per-sulfate Digestion method. Nitrate (NO_3^-) was measured by using Brucine-Sulfate method. Sulfate Anion (SO_4^{2-}) was measured by using Turbidimetric method. Total Hardness was measured by using EDTA method. Residual Chlorine was measured by using DR colorimeter (HACH).

Table (1): Main characteristics of tap water and Synthetic turbid water

Parameter		Tap water	Synthetic turbid water
pH		7.52	7.02
Turbidity	NTU	1.07	25
Conductivity	μ mho/cm	425	459
Total Hardness	mg/l as $CaCO_3$	122	122
Cl^-	mg/l	27.8	31.76
SO_4^{2-}	mg/l	23.8	30.8
NO_3^-	mg/l	< 0.5	< 0.5
PO_4^{3-}	mg/l	0.01	0.1

2. Preparation of Coagulants Solution

Commercial grade alum, ferric chloride and ferric sulfate ware dissolved in a tap water gradually to obtain a concentration of 1gm/l. The solution of cationic polyelectrolyte (p.e.) C^+492 HMW [17] was prepared by dissolving them in cold or hot water to obtain a final concentration of 2 mg/l.

3. Prediction of Critical Coagulant Dose

Because the processes of water treatment are mostly of a physiochemical nature, bench-scale testing often gives meaningful insight to full-scale results. The jar test as outlined in Bhaskar and Gupta [18] was carried out.

The data obtained from the jar test, Figures (3, 4, and 5), indicate that the critical dose of alum about 25 mg/l, the critical dose of polyelectrolyte about 0.2 mg/l, the critical dose of ferric chloride about 20 mg/l, the critical dose of ferric sulfate about 20 mg/l and for mixed coagulant required 15mg/l of alum with 0.1 mg/l polyelectrolyte, to obtain a minimum critical turbidity.

4. Pilot Studies (Proposed System)

The system proposed for coagulation, flocculation and sedimentation is presented in Fig. (6), which consists of:

1. Feed basin, is a 200-liter plastic tank equipped with a mechanical stirrer to prevent sedimentation and change of initial turbidity.
2. Treatment basin is the core of the proposed system. The main features of this basin are shown in Fig. (7). It consists of a cylindrical tank with a conical bottom. It is

provided with an inner jacket, which may be cylindrical or conical with the main parameters as displayed in Table (2). The inner jacket divides the basin into two separates regions:

- The outer region is the annulus between the inner cylinder and the outer body of the basin, slow mixing in these regions occurs where the flocculation takes place.
- The inner region is the space enclosed with inner cylinder, where in this region sedimentation occurs.

Four sampling ports are located at different height on the outer cylindrical wall. There are also four input tubes on the outer surface of the cylindrical basin, which have different slope angles (θ) and different flows area. The features of these entrance tubes on the wall of the outer cylinder are displayed in Figure (8).

3. Coagulant feed tank**,** which is a 20-liter plastic tank connected to a dosing pump with a variable speed to control the dose of coagulant used.
4. Feed pump**,** it is a centrifugal pump equipped with an impeller in which turbid water and coagulants are vigorously mixed through it.

Table (2): Geometrical shape and dimensions of inner jacket

Type	Upper radius R_1 (cm)	Lower radius R_2 (cm)	Height H (cm)	Annulus (cm)	Slop θ (°)
Cylinder	20	20	50	5	90
Cone 1	22.5	12.5	50	2.5	85
Cone 2	20	12.5	50	5	80
Cone 3	17.5	12.5	50	7.5	75

RESULTS AND DISCUSSION

Standard jar test study, for raw water with turbidity of 23-25 NTU, indicated that:

1. The critical dose of alum is 25 mg/l,
2. The critical dose of polyelectrolyte alone is 0.2 mg/l,
3. For a mixed coagulant is 15 mg/l alum and 0.1 mg/l polyelectrolyte,
4. For ferric chloride is 20 mg/l and
5. For ferric sulfate is 20 mg/l.

Investigation of the effects of operational and geometrical parameters on the treatment process is presented herein, with the above coagulant doses.

1. Effect of Flow Rate (Retention Time) on Turbidity Removal

Setting the coagulant injection port at 1 m from the feed pump, using the inner jacket of the cylindrical shape and feed-tube angle 45^o. The effect of flow rate on the turbidity of the treated water was investigated as displayed in Figure (9). Results indicate that the turbidity is a function of the retention time (T) and fits a quadratic equation of the form ($a\ T^2 + b\ T + c$), giving the capability of predicting the appropriate treatment level with retention time.

2. Effect of Feed Angle on Turbidity Removal

Setting the operating condition as (1) above, in addition to adjusting the retention time at 85 min with varying the feed angle between 45°, 60°, 75° and 90°. The effects of variation of the feed angle on the turbidity of the treated water displayed in Figure (10). Results indicate that the feed angle is critical for turbidity removal. Feed angle of 60° produces water with turbidity of 7.5 NTU. Generally feed angle is critical and have to be considered.

3. Effect of Initial Turbidity on the Turbidity Removal

Setting the operating condition as (2) above, in addition to adjusting the feed angle between at 45°. The effects of variation of initial turbidity on the turbidity of the treated water are displayed in Figure (11). Results indicate that the initial turbidity is critical for turbidity removal and a critical value of 39.5 NTU feed water turbidity produces water with turbidity of 9.9 NTU. Even though the turbidity may reach to 3.6 NTU with initial turbidity but by using feed water of 7.6 NTU.

4. Effect of Coagulant Injection Distance on the Turbidity Removal

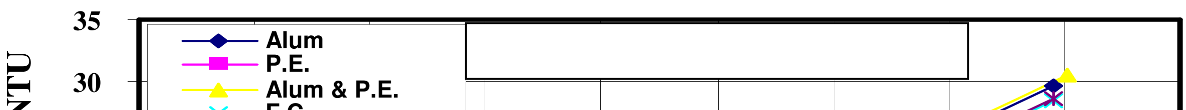
Setting the operating condition as (3) above. The effect of the coagulant injection port, from the pump, on the turbidity of treated water is displayed in Figure (12). Results indicate that the coagulant feed distance has no significant effect for turbidity removal.

5. Effect of Geometrical Shape of the Inner Jacket on the Turbidity Removal

For studying the effect of geometry of the system on the turbidity of treated water, the following conditions were set:

Retention time was 160 min.
Feed water turbidity was 23-25 NTU.
Point of injection of coagulant in the feed line was at 0.1 m.
Feed pipe angle was 60°.

The effects of geometry of the system on the turbidity of the treated water are displayed in Figure (13). Results indicate that, as by using different geometrical shape with dimensions as indicated in Table (2). The more favorable shape is a shape, cone (1). The results concerning the geometrical shape and dimension of the inner jacket indicate that the tapering in the path of water downward in the annular space and upward in the inner jacket affect on the produced velocity gradient (g), which enhance the coagulation,



where the upward flow in the inverted tapering in cross sectional area of the path in the inner jacket enhance the settling and creates a blanket zone. The result may be explained from the theoretical point of view as illustrated below.

The slope angles of the cones cause variation of the velocity, in Z direction, of the turbid water in the annulus (Fig. 14). This variation can be put in an empirical equation as follows:

For annulus

$$A_{annulus} = A_{outer} - A_{inner} \quad \text{.................................... (1)}$$

$$A_{outer} = \pi R^2 \quad \text{and} \quad A_{inner} = \pi r^2$$

$$r = R + (R_1 - R_2)(h/H), \text{ From the figure}$$

$$\therefore A_{annulus} = \pi R^2 - \pi \left[R + (R_1 - R_2)(h/H)\right]^2 \quad \text{............... (2)}$$

$$\because v = \frac{Q}{A_{annulus}}$$

$$\therefore v_{(h)} = \frac{Q}{\pi R^2 - \pi\left[R_2 - \left(\frac{R_1 - R_2}{H}\right)h\right]^2}$$

$$\therefore v_{(h)} = \frac{Q}{\pi\left(R^2 - \left[R_2 - \left(\frac{R_1 - R_2}{H}\right)h\right]^2\right)} \quad \text{.................. (3)}$$

Equation (3) shows the relation between the velocity in the vertical direction (Z direction) and height (h) at known flow rate and height (H), H = 50 cm, for different cones with different slope angles. Table (3) indicates the relation for each conical shape used in the experiments. The function in the table indicates that as of (h) value decrease velocity will decrease, which enhance flocculation. The data obtained was plotted in Figure (15).

Table (3): The relation between velocity of water in the annulus and height

Type	R_{out}(cm)	R_1(cm)	R_2(cm)	θ	Velocity (cm/min)
Cylinder	25	20	20	90	$v(h)=\frac{q}{706.56}$
Cone 1	25	22.5	12.5	75	$v(h)=\frac{q}{1472.62-15.71h-0.126h^2}$
Cone 2	25	20	12.5	80	$v(h)=\frac{q}{1472.62-11.781h-0.071h^2}$
Cone 3	25	17.5	12.5	85	$v(h)=\frac{q}{1472.62-7.854h-0.01h^2}$

Variation of Average Velocity Gradient (G) with Height in the System

The relation between the velocities of water in the direction (θ) was obtained by applying the experimental data obtained in the Least Square Method to obtain the relation in the following form:

$$V_{(\theta)} = d\,(R_{out} - R_{in})^a\,H^b\,Q^c$$

where: a, b, c, d are constants.

The final result of calculation indicates that: a = -0.762, b = 0.979, c = 0.121 and d = 3.98 so the final form of velocity is:

$$V_{(\theta)} = 3.98\,(R_{out} - R_{in})^{-0.762}\,H^{0.979}\,Q^{0.121} \qquad (4)$$

Camp and Stein defined G value commonly used in theories on the coagulation flocculation of (waste) water in a stirred vessel:

$$G = \left(\frac{\varepsilon}{\eta}\right)^{1/2}$$

where: G: angular velocity value (sec^{-1}).
ε: dissipated power per volume ($Nms^{-1}\,m^{-3}$).
η: dynamic viscosity (Nsm^{-2})

The average velocity gradient (G) was calculated by using the relation used by Leentvaar and Ywema [20], which derived from Camp and Stein relationship.

$$G = \frac{2\tau R_{in} R_{out}}{R_{out}^2 - R_{in}^2} \qquad (5)$$

$$\tau = V/r \qquad (6)$$

where: τ: is the angular velocity value (sec^{-1}).
r: is the mean radius (cm), $r = (R_{out} + R_{in})/2$

R_{in} can be put in a form of height (h), the relations obtained for different types of annulus were:

For cylinder	R_{in} = 20 cm
For cone 1	R_{in} = (h+50)/4
For cone 2	R_{in} = (h+66.67)/5.33
For cone 3	R_{in} = (h+100)/8

These relations can be used in Equations (4), (5) and (6) to obtain relations between the average velocity gradient (G) and height (h), Table (4) shows the relation obtained which plotted in Figure (16).

The critical data obtained were used at different retention time for alum and polyelectrolyte, the data showed that the retention time reduced to about 150 min with turbidity 2.9 and 2.5 respectively, the data obtained was illustrated in Figure (17).

Table (4): The relation between average velocity gradient and height

Type	Average velocity gradient (G) (sec^{-1})
Cylinder	$G = 0.231 Q^{0.121} h^{0.979}$
Cone 1	$G = \frac{1.831(10^4)(h+50)(50-h)^{-0.762} Q^{0.121} h^{0.979}}{1.125(10^6) - h^3 - 250h^2 - 7500h}$
Cone 2	$G = \frac{4.047(10^4)(h+66.67)(66.6-h)^{-0.762} Q^{0.121} h^{0.979}}{2.661(10^6) - h^3 - 333.12h^2 - 13319.34h}$
Cone 3	$G = \frac{1.242(10^5)(h+100)(100-h)^{-0.762} Q^{0.121} h^{0.979}}{9(10^6) - h^3 - 500h^2 - 3E^4 h}$

CONCLUSION

This article includes coagulation, flocculation and sedimentation in one unit by utilizing hydraulic mixing instead of mechanical mixing. The following conclusions were obtained:

1. The proposed system produced water with turbidity to about 2 NTU, with 75% of the retention time, compared with the conventional technology used in the potable water treatment units.
2. Turbidity of the treated water by the aid of cationic polyelectrolyte, C-492 HMW, alone reached to about 6.5 NTU, which is cooperatively high.
3. Alum aided with Polyelectrolyte, C-492 HMW, has no significant of turbidity removal compared with alum alone.
4. Ferric chloride and ferric sulfate has no significant of turbidity removal compared with alum alone.
5. The geometrical shape of the inner jacket, of the proposed system, has a significant effect on turbidity removal.
6. The inclination of the entrance, tangential angle, to the main tank is critical and the optimum angle is 60^o.
7. The effect of the coagulant injection port has no significant for turbidity removal.
8. The efficiency of proposed system is increased with the increase of initial turbidity of raw water.

REFERENCES

1. Rashed, I. G.; El-Bindary, A. A.; Abdalla, E. A. M. and Hamza, A. M.; "Removal of Some Heavy Metal from Water by Coagulation", *Third International Water Technology Conference*, Alexandria, Egypt, Feb. 20-23, (1998).
2. O'Mielia, C. R.; "Coagulation and Flocculation, In: Weber WJ, Ed. Physicochemical Processes for Water Quality Control", New York: Wiely Inter-Science, 61-109, (1972).
3. Benschoten, J. E.; Edzwald, J. K.; "Chemical Aspect of Coagulation Using Aluminum Salts, Hydrolytic Reaction of Alum and Poly-Aluminum Chloride", *Water Research*, 24 (12), 1519-1526, (1990).
4. McConnachie, G. L.; Liu, J.; "Design of Baffled Hydrolytic Channels for Turbulence-Induced Flocculation", *Water Research*, 34 (6), 1886-1896, (2000).
5. Bhargava, D. S.; Ojha, C. S.; "Model for Design of Flocculation Baffled Channels", *Water Research*, 27 (3), 465-475, (1993).
6. Tebbutt, T. H. Y.; *Principles of Water Quality Control*, Third Edition, The Pergamon Textbook, Inspection Copy Service, (1983).
7. Ndabigengesere, A. and Narasiah, K. S.; "Influence of Operating Parameters on Turbidity Removal by Coagulation Using Moringa Oleifera Seeds", Env. Tech., 17, 1103-1112, (1996).
8. Metcalf & Eddy, Inc.; *Wastewater Engineering: Treatment, Disposal, Reuse*, Third Edition, McGraw-Hill, Inc, (1991).
9. Adin, A.; Soffer, Y. and Ben Aim; "Effluent Pretreatment by Iron Coagulation Appling Various Dose-pH Combination for Optimum Particle Separation", Water Science Technology, 38 (6), 27-34, (1998).

10. Sanks, R. L.; *Water Treatment Plant Design*, Forth Edition, Ann Arbor Science Publishers, (1982).
11. Letterman, R. D. and Pero, R. W.; "Contaminant in Polyelectrolytes Used in Water treatment", J. Am. Wat. Wks Ass., 82, 87-97, (1990).
12. Olsen, A.; "low Technology Water Purification by Bintonite Clay and Moringa Oleifera Seeds Flocculation as Preformed in Sudance Villages". *Water Research*, 21, 517-522, (1987).
13. Ndabigengesere, A. and Narasiah, K. S.; "Quality of Water Treated by Coagulation Using Moringa Oleifera Seeds", *Water Research*, 32 (3), 781-791, (1998).
14. Ndabigengesere, A.; Narasiah, K. S. and Talbot B. G.; "Active Agent and Mechanism of Coagulation of Turbid Water Using Moringa Oleifera", Water Research, 29, 703-710, (1995).
15. Gregor, J. E.; Nokes C. J. and Fenton, E.; "Optimising Natural Organic Matter Removal from Low Turbidity Waters by Controlled pH Adjustment of Aluminium Coagulation", *Water Research*, 31 (12), 2949-2958, (1997).
16. APHA. Standard Methods for the Examination of Water and Wastewater, 20th Edn.; American Public Health Association, Water Environmental Federation; Washington, Dc, (1998)
17. Al-Sarawy, A. A.; El-Sherbiny, M. F. and Mels, A. R.; "Coagulation Flocculation of domestic Sewage with organic poly electrolyte", *Alexandria Engineering Journal*, Vol. 40, No. 5, 777-782, (2001).
18. Bhaskar, G. U. and Gupta, S. K.; "Syntheses and Application of Anionic Polyelectrolyte in Water and Wastewater Treatment", *Water, Air and Soil Pollution*, 35, 251-260, (1987).
19. Leentvaar, J. and Ywema, T. S. J.; "Some Dimension Parameters of Impeller Power in Coagulation-Flocculation Processes", *Water Research*, 14, 135-140, (1980).

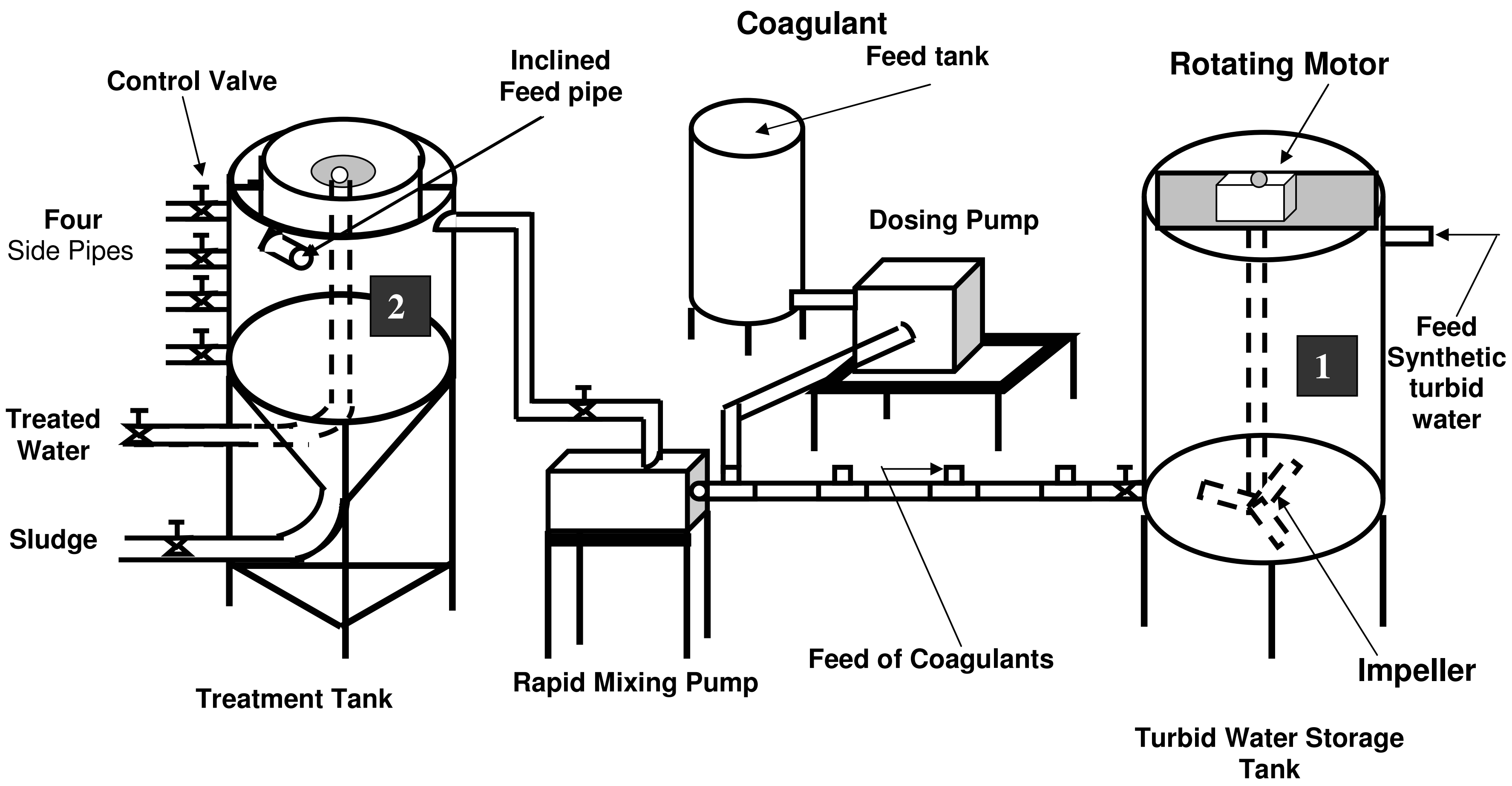


Fig (6):schematic sheet for the proposed system used for Chemical treatment of water

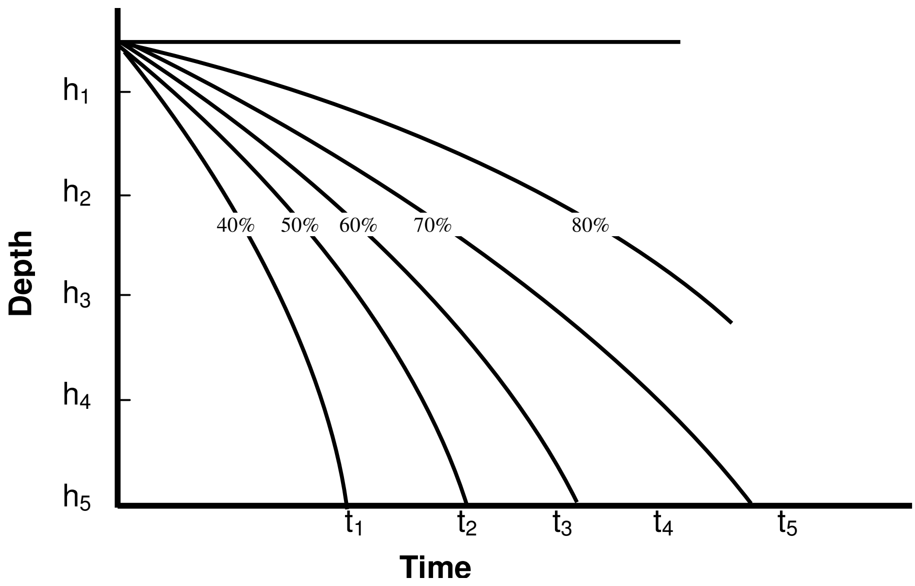


Fig. (2): Settling curves for flocculent particles

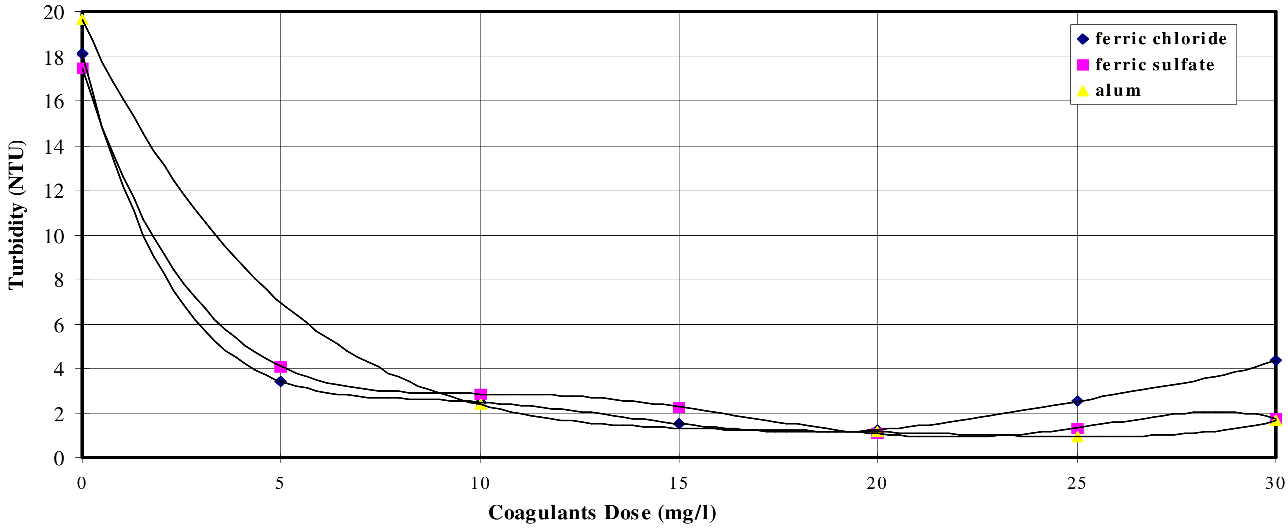


Fig. (3) Determination of optimum dosage of alum, ferric sulfate and ferric chloride

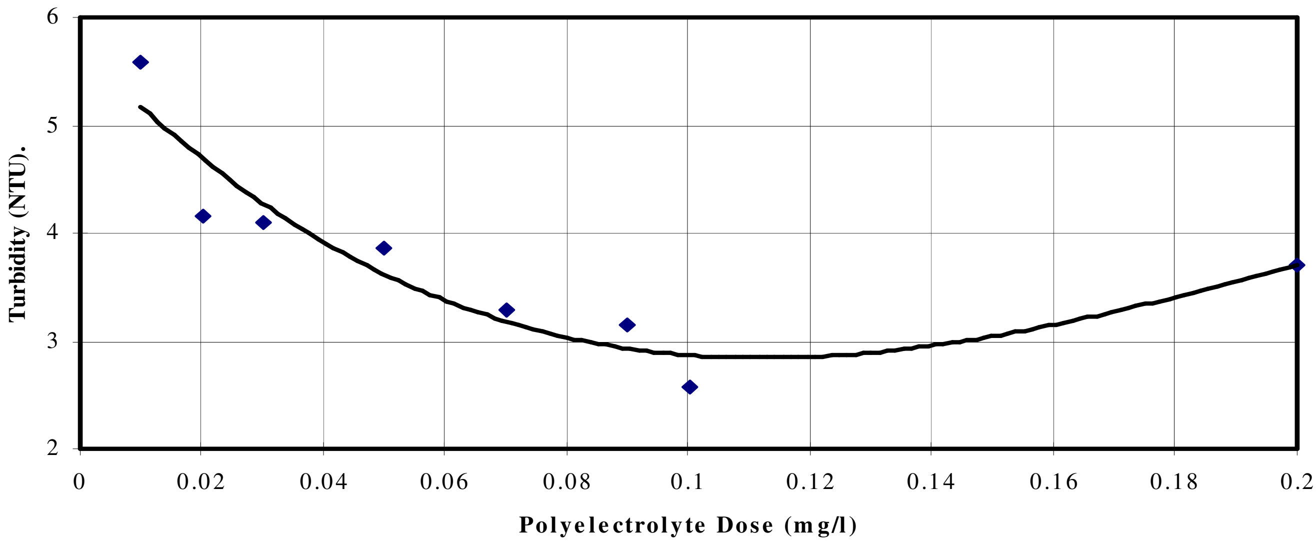


Fig. (4) Determination of optimum dosage of polyelectrolyte

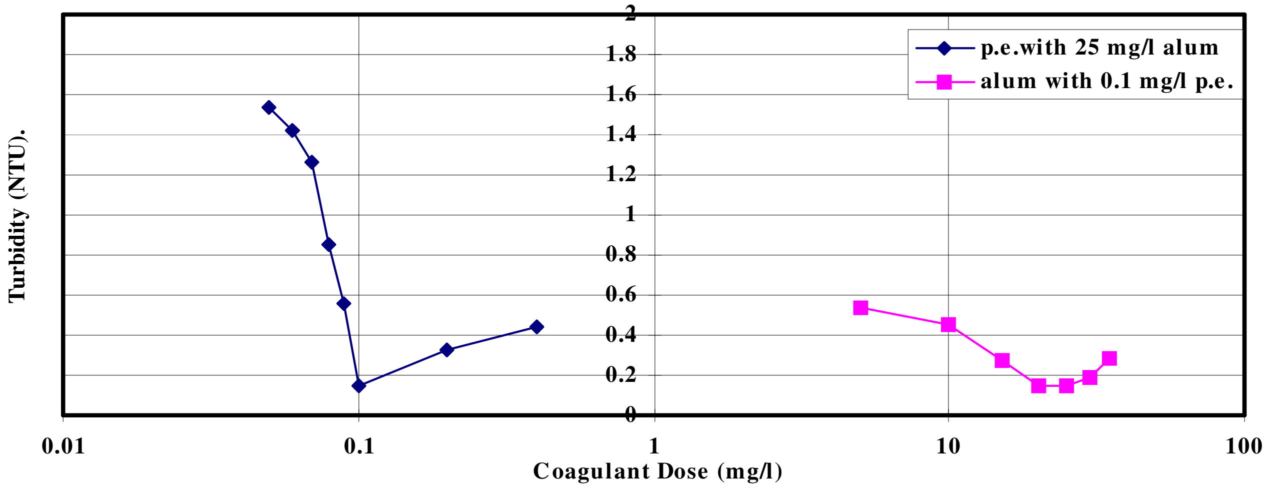


Fig. (5) Determination of optimum dosage of polyelectrolyte with alum

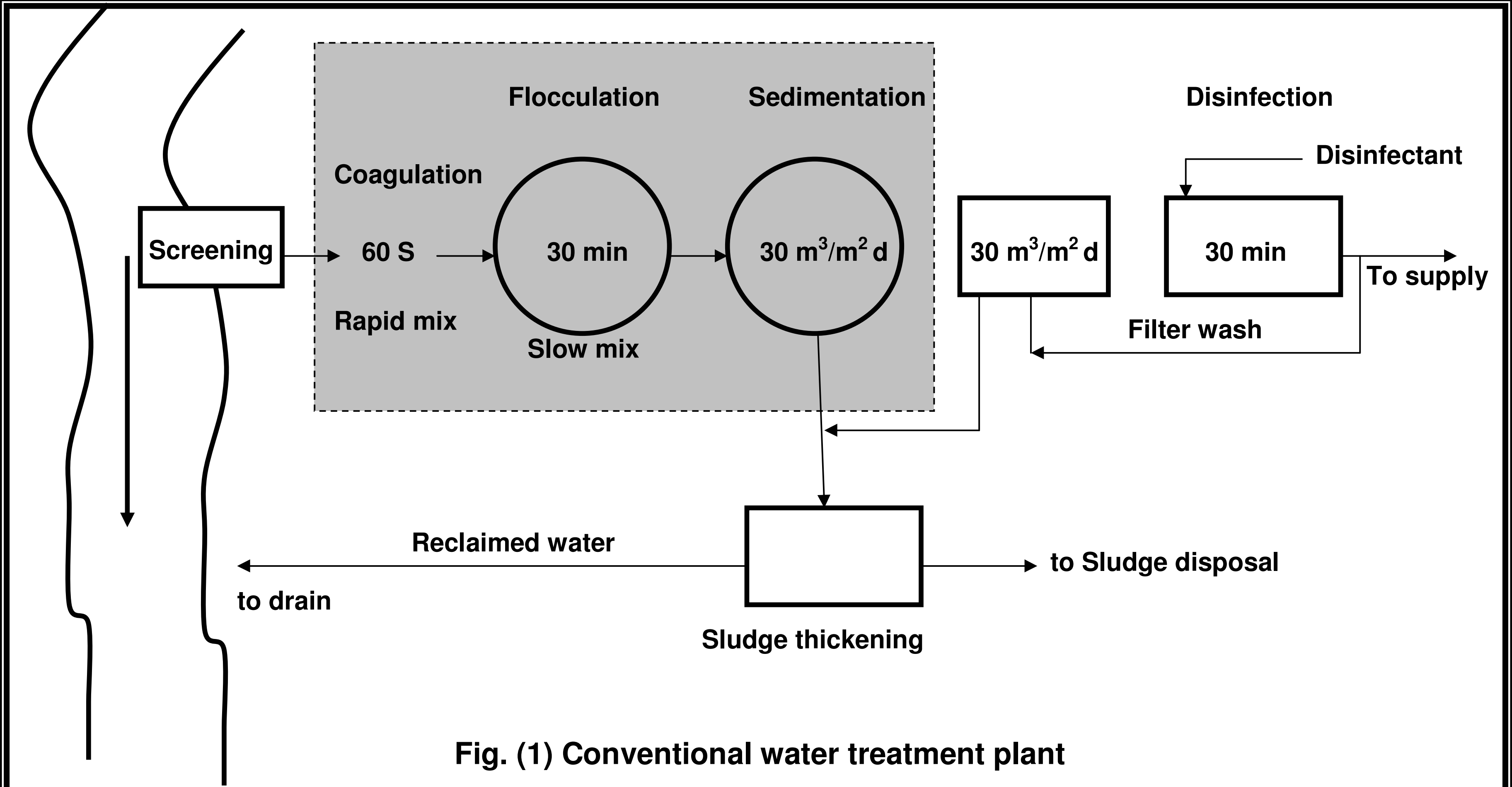


Fig. (1) Conventional water treatment plant

The proposed system replaced the enclosed consecutive steps

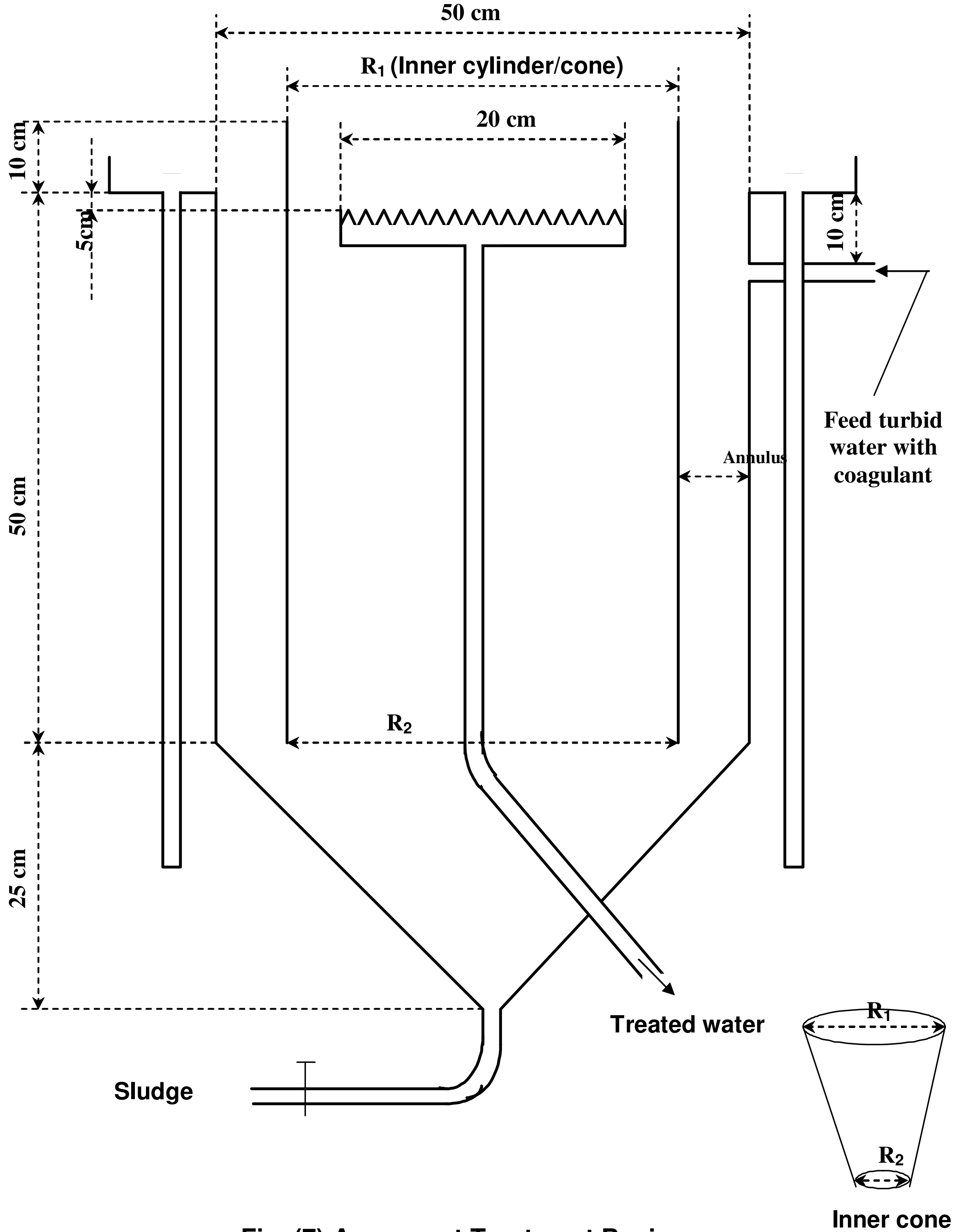


Fig. (7) A compact Treatment Basin

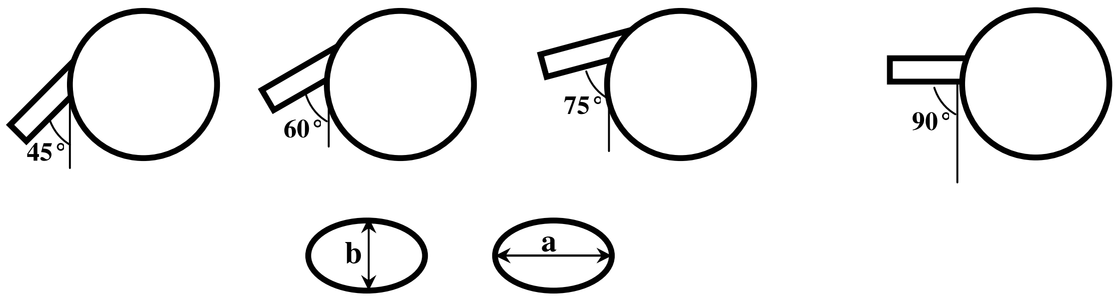


Fig (8): Different feed input pipe angles and the ellipse shape of the feed

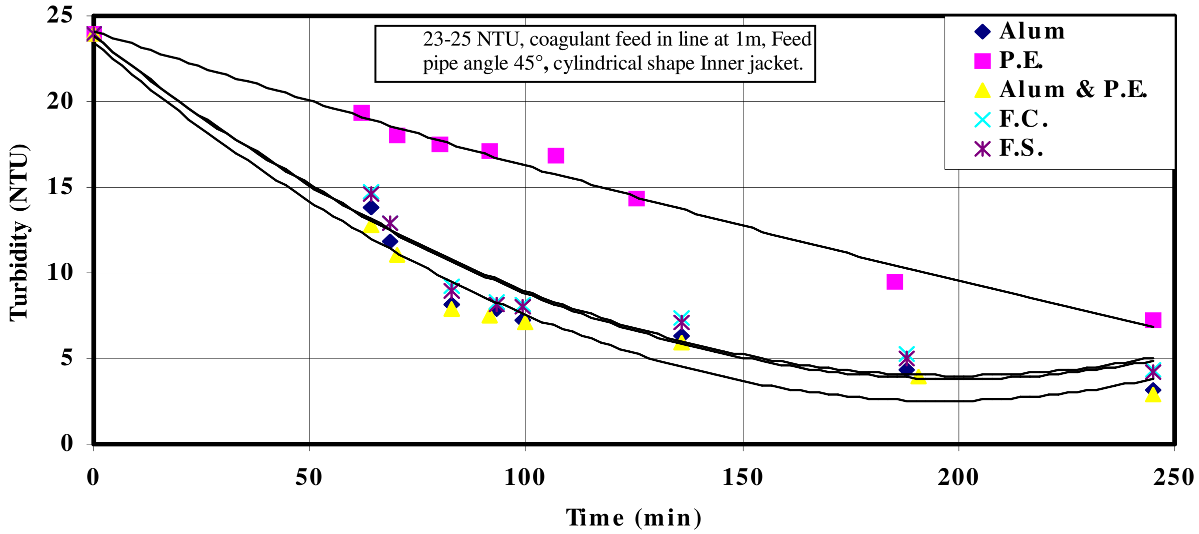


Fig. (9): Effect of the retention time on the output turbidity

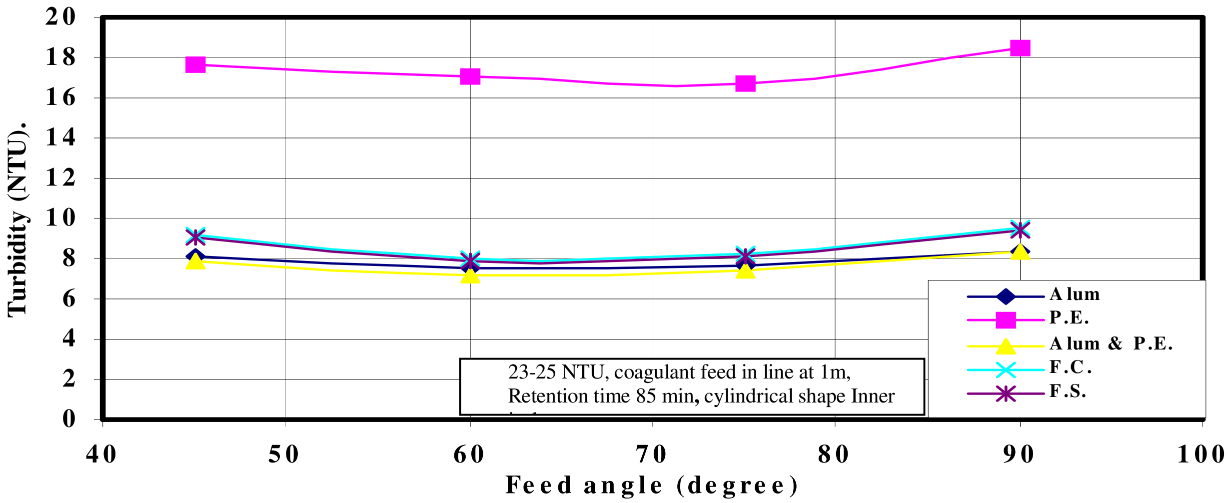


Fig. (10): Effect of the feed angle on the output turbidity

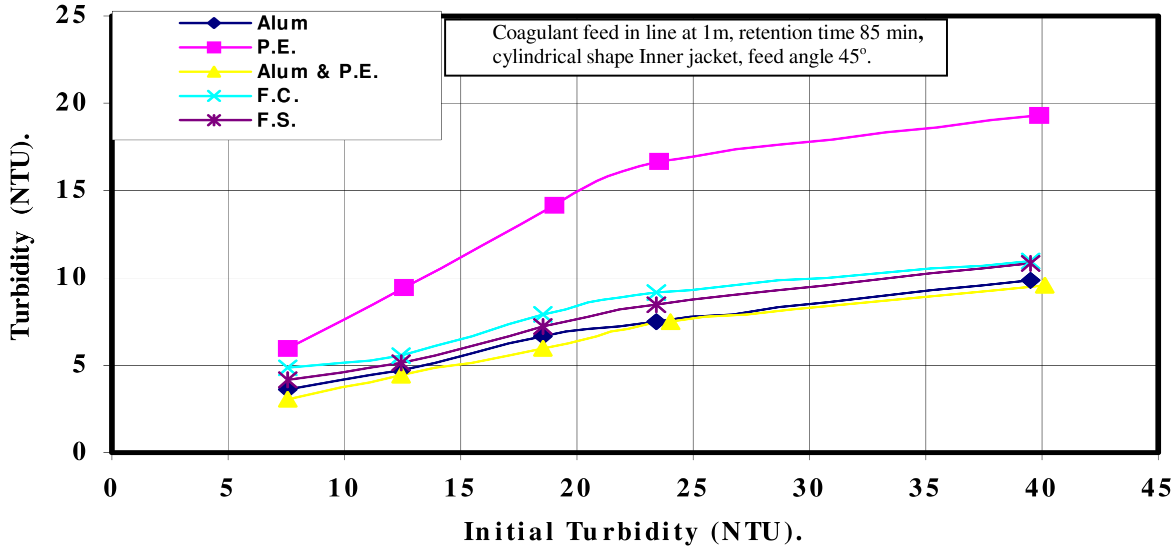


Fig. (11): Effect of the initial turbidity of raw water on the output turbidity of treated water

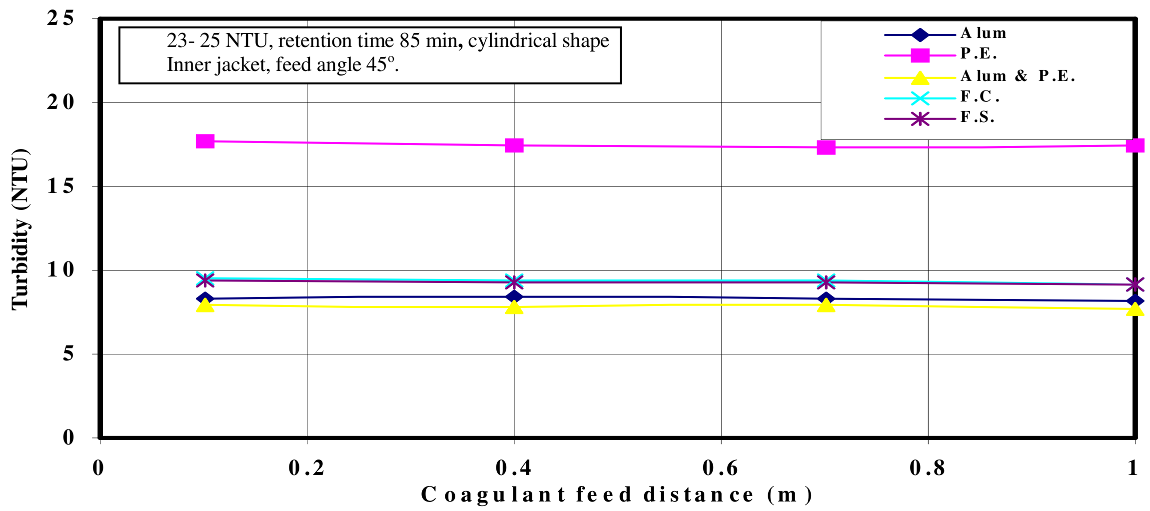


Fig. (12): Effect of the Coagulant feed distance on the output turbidity

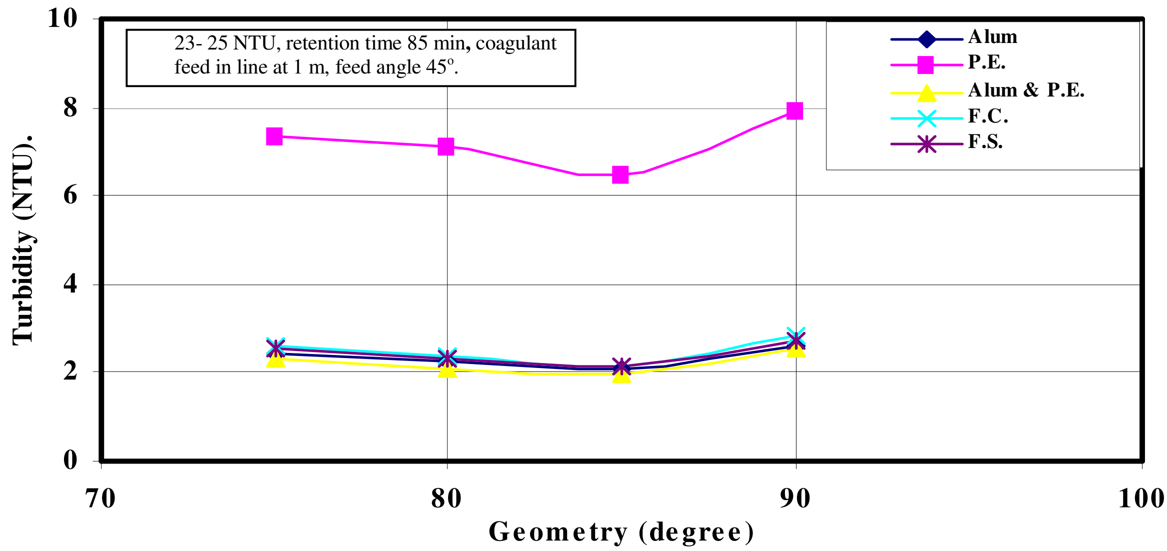


Fig. (13): Effect of the Geometry (Cone) angle on the output turbidity

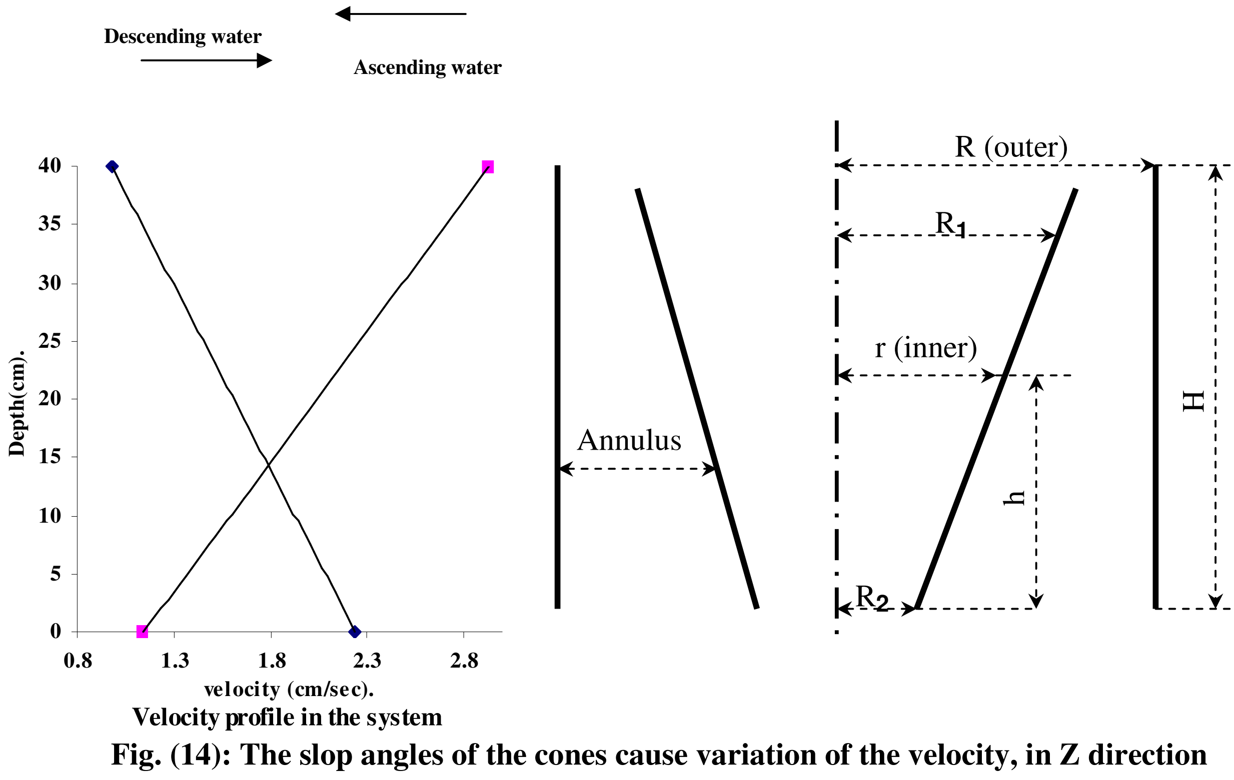


Fig. (14): The slop angles of the cones cause variation of the velocity, in Z direction

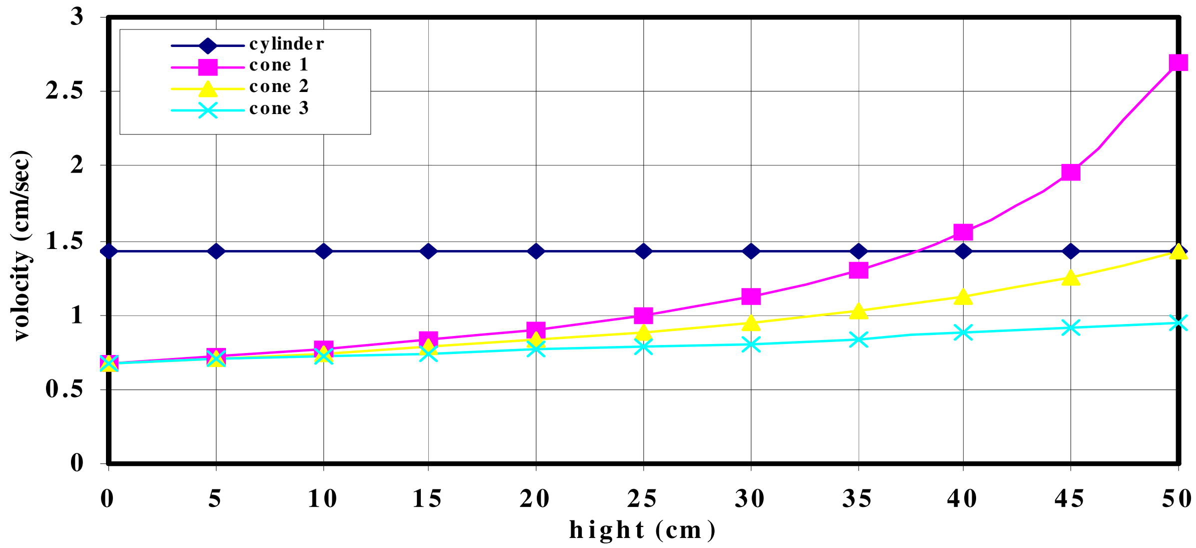


Fig. (15): Relation between height and velocity (Z direction) for different inner cylinder, cones with different slop angles

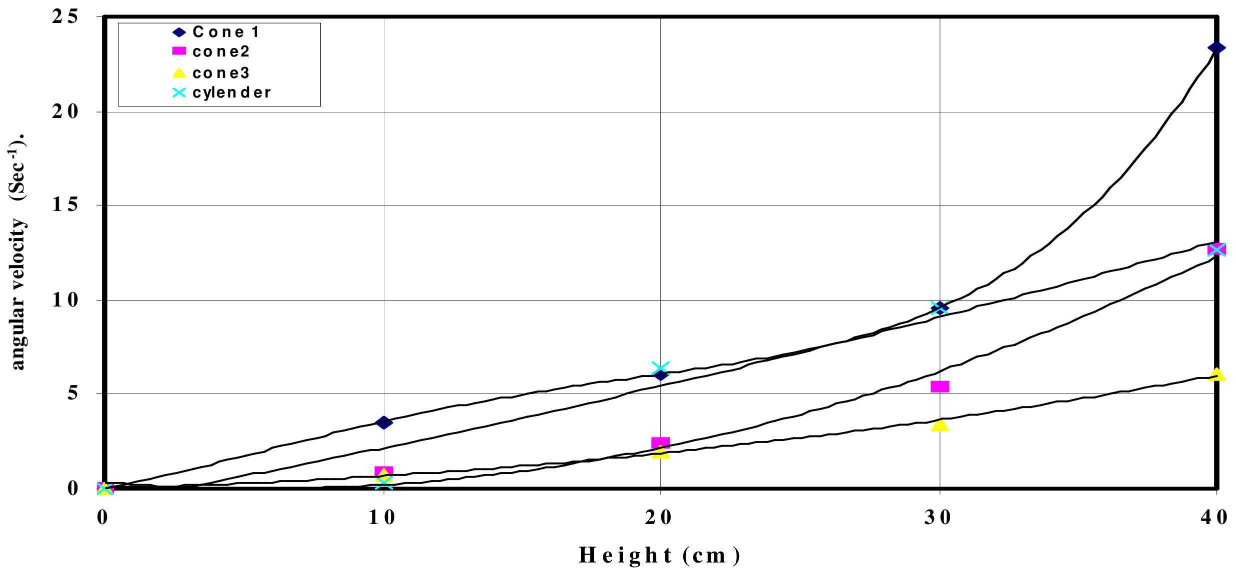


Fig. (16): Variation of angular velocity with height

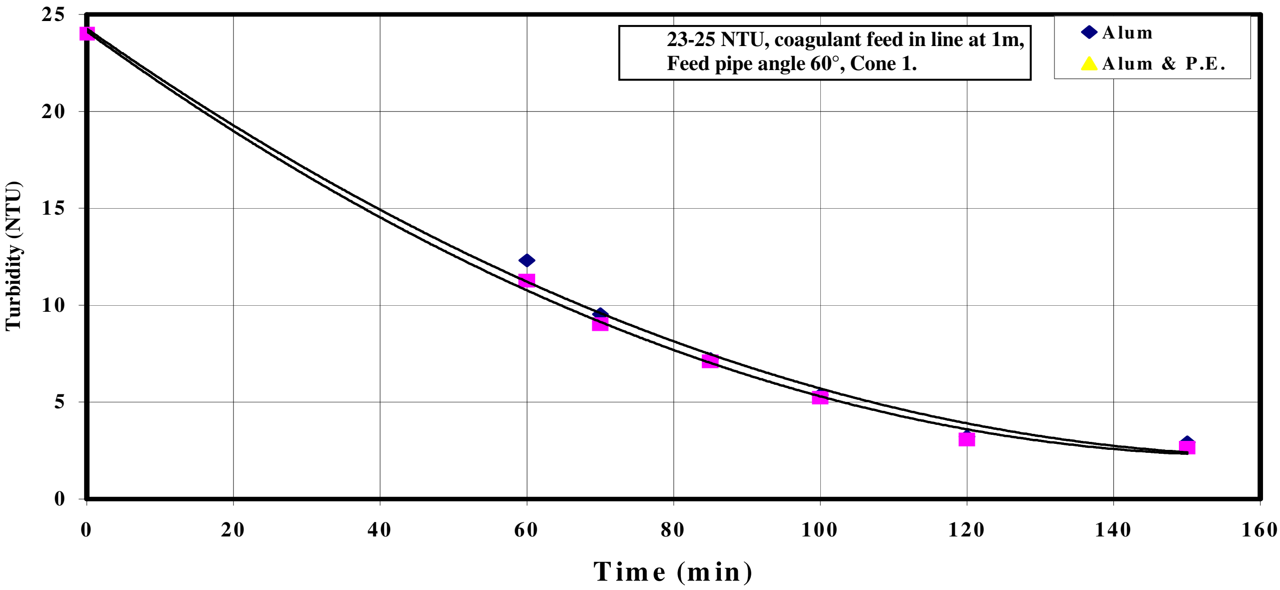


Fig. (17): Effect of the retention time on the output turbidity