Experimental Works on Advanced Wastewater Treatment

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Abstract

This paper develops and demonstrates the solution for advanced wastewater treatment plant design by using Experimental laboratory works. The experimental part includes the build and operation of a pilot plant for chemical clarification unit composed of rapid mix, flocculation tanks and settling column.All the experiments were performed using secondary treated effluent from Hamdan Sewage Treatment Plant, which is the central sewage treatment plant in Basrah city.The results obtained of the experimental work includes the establishment of mathematical expression that relates water turbidity to the concentration of suspended solids and mathematical expressions relating the detention time of flocculation unit to that of sedimentation unit for different values of alum dose.

Keywords: keywords, advanced wastewater treatment, Environmental, waterresource.

1.Introduction

Water is the first element of sustaining life on earth. In addition, it is crucial for the economy. Virtually every industry agriculture, electric power and industrial manufacturing to beverage, apparel, and tourism relies on it to grow and ultimately sustain their business (Lin S. D. 2007).

In the last years, water drought occurred due to the shortage in rainfall. This is a problem in arid and semi-arid countries such as Iraq (Morrison and et al 2009).

Treated wastewater is now being considered and used in many countries throughout the world, as a new additional, renewable and reliable source of water, which can be used for agricultural production. By releasing freshwater sources of potable water supply and other priority uses, treated wastewater reuse makes a contribution of water conservation and expansion of irrigated agriculture, taking on an economic dimension. It also solves disposal problems aimed at protecting the environment and public health and prevents surfaces water pollution by the direct discharge of pollutants into inland and coastal waters. This increases the need of water reuse and converts the reuse wastewater management from conventional disposal strategy into value added product (Metcalf & Eddy**,** I 2003).

2.Review of Previous Studies

During the last thirty years, research works were extensively focused on technical barriers and health risks associated with water reclamation using advanced wastewater treatment. At the same time some earlier optimization models were developed for treatment and water reuse planning. Technically speaking, modern wastewater treatment facilities are able to treat wastewater to the quality levels eligible for various purposes (Chang et al 1985). The water quality levels required by the specific water reuse applications and the water available for reuse determine the feasibility of the specific water reuse practice.

(Dharampa et al. 1994) presented optimum design of water treatment plant for turbidity removal with considering of particles size distribution (PSD). The plant includes rapid mixing, flocculation, sedimentation, filtration, and sludge treatment processes. The authors incorporated four design criteria in the optimization; (1) Annualized capital cost; (2) Operation and maintenance cost; (3) Energy cost; and (4) Land requirement. They applied empirical relationships for the four design criteria which were selected from the literature. The results of this study indicated to the importance of incorporating PSD into the design of water treatment processes and suggested the best type of treatment configuration for a given influent PSD.

(Ebeling et al. 2003)[6] evaluated two commonly used coagulation-flocculation aids (alum and ferric chloride) for the supernatant overflow from settling cone used to treat the effluent from microscreen filters in an intensive recirculating aquaculture system. They determined the effectiveness of these aids in removing both suspended solid and phosphorus. The authors performed a systematic testing of the variables normally encountered in the coagulation-flocculation process to evaluate the dosages and conditions (mixing and flocculation stirring speeds, durations, and settling times) required to achieve optimum waste capture. They found that; (1) the orthophosphate removal efficiency for alum and ferric chloride 89 and 93%, respectively, at a dosage of 90 mg/l, (2) the optimum turbidity removal can be achieved with a 60 mg/l dosage for both alum and ferric chloride, (3) flocculation and mixing speed played only a minor role in the removal efficiencies for both orthophosphates and suspended solids, and (4) the majority of the floc quickly settling out in the first 5 min for both coagulation-flocculation.

(Hamedany et al. 2012**)** applied Genetic Algorithm (GA) method to minimize the sum of iron and manganese in the output of Ekbatan dam water treatment plant, Iran. They calculated the relation between the concentration of iron and manganese in the water treatment plant output and electrical conductivity and turbidity in the plant input using Multiple Stepwise Regression. The authors showed that the effective processes in decreasing the concentration of iron were axilator and gravity sand filter, while, only gravity rapid sand filter have had significant effect on decreasing of manganese.

The previous literatures review reflects the following points:

Little attention has been given to the experimental design of advanced wastewater treatment plants.

The aim of this study to Developing and building a pilot plant of water treatment system to establish mathematical expressions to be used in relating the design criteria of flocculation and sedimentation units (which are mostly applied in AWWT plants).

3. Experimental works

Chemical Clarification Experiments

A series of experiments on a chemical clarification unit were conducted during the period extended from 25 Sep./2011 to 15 Feb./2012. In these experiments, the effluent of Hamdan Sewage Treatment Plant (HSTP) which is secondary treated by activated sludge system was used as an influent to the chemical clarification unit. Characteristics of Hamdan Sewage Treatment Plant is shown in **Table** 1.

Table (1) Effluent characteristics of HSTP

Date		BOD (mg/l)	COD (mg/l)	SS (mg/l)	TDS (mg/l)	Cl (mg/l)	PO_4 (mg/l)	NO_3 (mg/l)
Year	Month							
2010	Jan.	176	403	382	4358	1739	3.78	*
	Feb.	135	411	720	5211	2043	4.96	*
	Mar.	242	360	360	5550	1606	6.39	*
	Apr.	240	440	326	4714	1615	2.82	*
	May	156	419	330	4104	1568	1.7	*
	June	200	300	195	4170	1083	4.67	*
	Oct.	200	402	178	4114	1092	1.7	*
	Nov.	48	*	246	*	*	*	*
	Dec.	76	143	276	4276	1358	7.8	*
2011	Jan.	100	153	212	4854	1320	2.609	*
	Mar.	60	225	268	4804	1691	4.2	*
	Apr.	60	160	274	4236	*	3.6	*
	May	60	190	40	4860	1910	2.9	9.8
	June	35	71	100	3620	1365	5.57	20
	July	*	65	100	3525	1321	.4	16
	Sep.	60	136	80	3330	1476	2	36
	Oct.	70	133	90	3260	1400	5.8	7.5
	Nov.	57.05	115.06	96	4360	1570	1.2	7
	Dec.	68	124	80	3440	1142	1.6	12.5

- not measured

Description of Experimental Rig

Chemical clarification experiments were conducted in a lab scale chemical clarification unit constructed in this study. A schematic diagram of this unit are presented in Fig. (1). From this figure, it can be shown that the unit is composed of rapid mix tank, slow mix tank, and settling column completed with pumps and piping works.

A- Rapid mix tank

This tank was made of a plastic. It has dimensions of 91cm length, 55cm width, and 50cm depth with a total capacity of 250 liter. It was provided with electrical mixer of 3.3kW power. In this tank alum ($Al_2(SO_4)_3 .18H_2O$) was added as a coagulant (Culp et al 1978).].

B- Slow mix tank

This tank was made of steel. It has a length of 60cm, a width of 45cm and a depth of 45 cm. At one of its wall, five valves were fixed at a vertical spacing of 10 cm. These valves were used to control the detention time of flocculation process (t_f). The tank was supplied with electrical mixer of 0.18 kW power (**Culp** et al 1978) and (Bhuni 1986) .

C- Settling Column

The setting column was made of steel with dimensions of 25cm×25cm×300cm. Along this column five taps were fixed at a vertical spacing of 60 cm. These taps were used for withdrawing water samples to measure the turbidity of water at different water depths and times (Dharmapa et al 1994) .

Procedure

A series of chemical clarification experiments have been conducted at different alum doses and different flocculation times. For each series of experiments, 250 liter of HSTP secondary effluent was used. This water was pumped to the rapid mix tank (coagulation unit) where alum was added to accomplish coagulation, Alum doses of (10mg/l-50mg/l) were used as concentrations to be added to the rapid mix tank. During each experiment, the following steps were conducted:

1. Adding of alum at a dose of 10mg/l to the rapid mix tank and mixing for a period of about 45sec.
2. Discharging the coagulated water to the slow mix (flocculation) tank with measuring the water flowrate using a container of specific volume and a stop watch.
3. Controlling the detention time of flocculation tank by opening one of the valves.
4. Pumping the flocculated water to fill the settling column at a depth of 3m.
5. Measuring the initial turbidity of water directly after filling the settling column.
6. Withdrawing of water samples from the five taps of the settling columns.
7. Measuring the turbidity of the withdrawn samples.
8. Repeating steps 6 and 7 at different settling times (t_s).
9. Repeating steps 1 through8 at different flocculation times.
10. Repeating steps 1 through 9 with different alum doses (20, 30, 40, and 50 mg/l).

Concentrations above these values were found to UN sensitive.

Measurement of Water Turbidity

Turbidity of water was measured using a turbidity meter; model LP2000-11 Precision Bench, see Fig.(2). The meter covers turbidity readings range of (0.0-5000) NTU in two scales; (0.0 to 50.0) NTU and (50.0 to 5000.0) NTU.

Measurements of Suspended Solids

During the chemical clarification experiments, water turbidity was measured. But since the results are required to be interms of suspended solids concentration, it is required to transform turbidity readings to suspended solids concentrations. For this purposes a number of suspension samples were prepared using fine clay (kaolinite). In these samples, turbidity and suspended solids concentration were measured. The concentration of suspended solids was measured using gravimetric method in accordance to the standard methods, section 2540 D (APHA, AWWA, and WEF (1998) .

Experimental Results

he results of settling column analysis performed at specific values of alum dose and flocculation time (t_f), as shown in Table (2).

Relation between SS and Turbidity

As was mentioned in procedure above, SS and turbidity were measured in suspension samples to develop an expression that can be used to transform turbidity readings into SS values. From Table (3), the readings of SS were plotted verses those of turbidity as shown in Fig.(3). Based on curve fitting, the relation between SS and turbidity can be defined as;

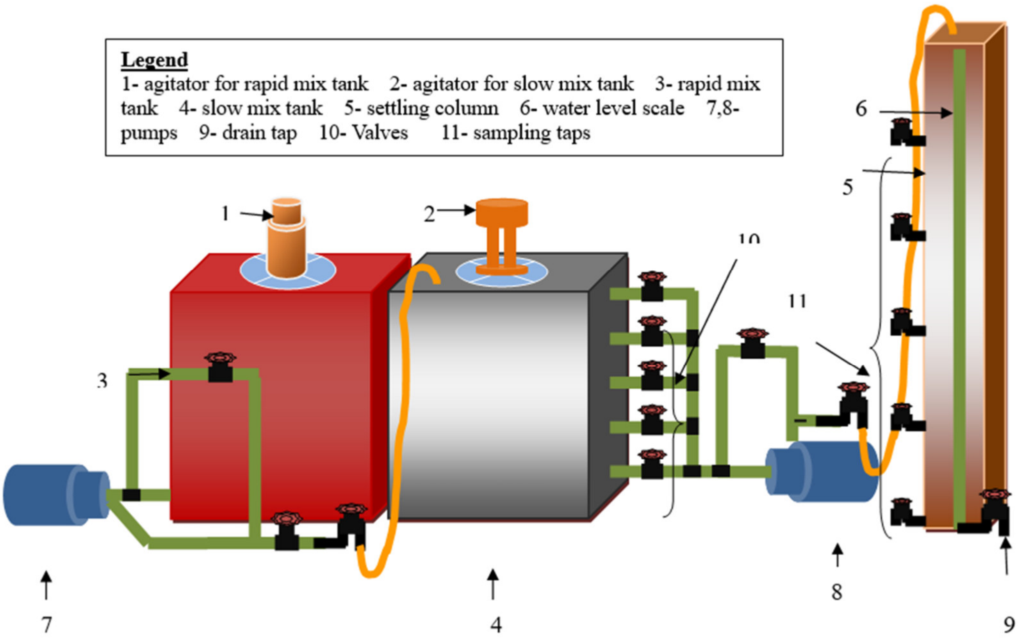

Fig (1) Experimental rig. of chemical clarification unit

Fig.(2) Turbidity meter

Table (2)A dopted alum doses and flocculation times.

Table No.	Alum dose (mg/l)	t_f (min)
1	10	25.8
2		21
3		15
4		12.5
5	20	25.8
6		21
7		15
8		12.5
9	30	25.8
10		21
11		15
12		12.5
13	40	25.8
14		21
15		15
16		12.5
17	50	25.8
18		21
19		15
20		12.5

Table (3) Results of SS and turbidity measurements

Sample No.	Turbidity (NTU)	SS (mg/l)
1	0	0
2	363	512
3	458	576
4	660	698
5	827	893
6	973	1013
7	993	1100

$$SS = -0.00026Tur^2 + 1.3587\,Tur \qquad (1)$$

where; SS is the concentration of suspended solids (mg/l) and Tur is the turbidity (NTU).

The Relation Between SS Removal Efficiency and t_s/t_f

The results of settling columns analyses were used to develop expressions defining the relation between SS removal efficiency and the ratio of settling time to flocculation time (t_s/t_f). At first all turbidity readings were transformed into SS values using Eq.(1). After that, the % of SS removal was calculated for each depth and time using the following equation;

$$\%\boldsymbol{SS\ removal} = \frac{SS_0 - SS_t}{SS_0} \times 100 \qquad (2)$$

where; SS_0 and SS_t are values of SS at time=0 and time=t, respectively.

As an example, the data of Table (3) were transformed into SS values and percents of SS removal as shown in Tables (4) and (5), respectively.

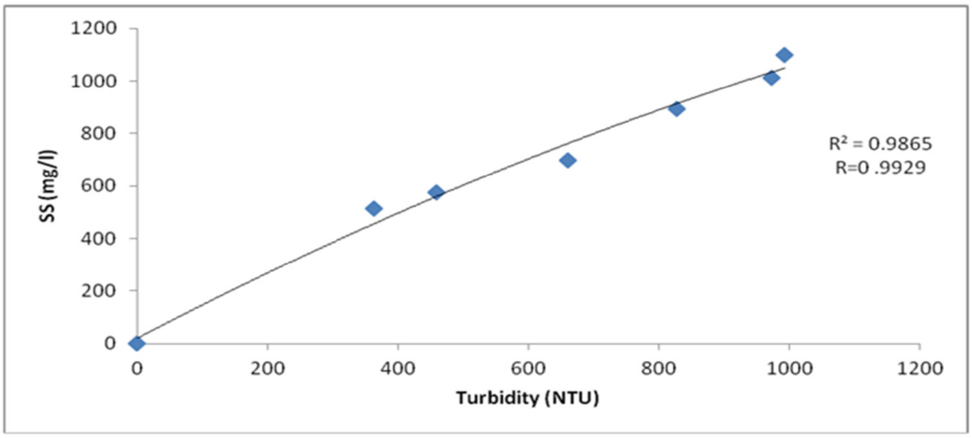

Fig.(3) The relation between SS and turbidity

Table (3) Values of SS for alum dose = 10mg/l and t_f = 25.8 min

Time (min)	SS at indicated depths				
	10 cm	70cm	130cm	190cm	250cm
0	101.8	101.8	101.8	101.8	101.8
5	40.5	45.9	52.6	53.9	56.6
10	37.8	44.6	52.6	52.6	55.3
20	32.5	40.5	51.3	52.6	52.6
40	31.1	36.5	49.9	51.3	52.6
60	27.1	35.2	45.9	47.2	51.3

Table (4) Percents of SS removal for alum dose = 10mg/l and t_f = 25.8 min

Time (min)	% of SS removal at indicated depths				
	10 cm	70cm	130cm	190cm	250cm
0	100	100	100	100	100
5	60.2	54.9	48.3	47.1	44.4
10	62.9	56.2	48.3	48.	45.7
20	68.1	60.2	49.6	48.	48.3
40	69.4	64.1	50.9	49.6	48.3
60	73.3	65.4	54.9	53.6	49.6

After the calculation of % of SS solid removal at each time and depth, the percent of overall SS removal (F_o) for each time was obtained as [12];

$$F_o = \frac{100 + F_{10}}{2} \times \frac{10}{250} + \frac{F_{10} + F_{70}}{2} \times \frac{60}{250} + \frac{F_{70} + F_{130}}{2} \times \frac{60}{250} + \frac{F_{130} + F_{190}}{2} \times \frac{60}{250} + \frac{F_{190} + F_{250}}{2} \times \frac{60}{250} \quad \ldots (3)$$

Where; F_{10}, F_{70}, F_{130}, F_{190}, and F_{250} are percents of SS removal at depths of 10, 70, 130, 190, and 250cm, respectively, from the water surface, respectively. Then, the percents of overall SS removal were plotted verses t_s/t_f as shown in Figs.(4), (5), (6), (7), and (8) for alum doses of 10, 20, 30, 40, and 50, respectively. Each of these figures shows the best fitting line of the obtained data. The relationship between the percent of overall SS removal (F_o) and t_s/t_f can be described by Eqs.(4), (5), (6), (7), and (8) for alum doses of 10, 20, 30, 40, and 50, respectively.

$$F_o = 86.00(\frac{t_s}{t_f})^{0.075} \quad \ldots (4)$$

$$F_o = 77.64(\frac{t_s}{t_f})^{0.063} \quad \ldots (5)$$

$$F_o = 54.55(\frac{t_s}{t_f})^{0.265} \quad \ldots (6)$$

$$F_o = 66.20(\frac{t_s}{t_f})^{0.133} \quad \ldots (7)$$

$$F_o = 70.17(\frac{t_s}{t_f})^{0.052} \quad \ldots (8)$$

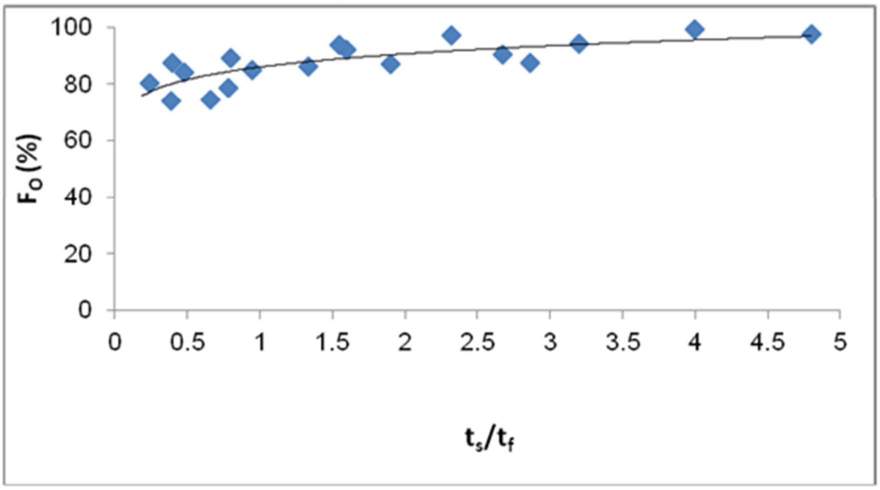

Fig. (4) Variation of F_o with t_s/t_f for alum dose =10mg/l

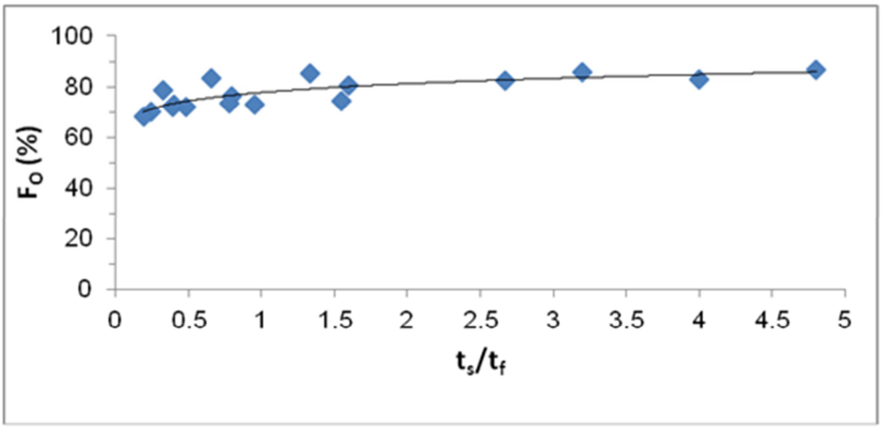

Fig. (5) Variation of F_o with t_s/t_f for alum dose = 20mg/l

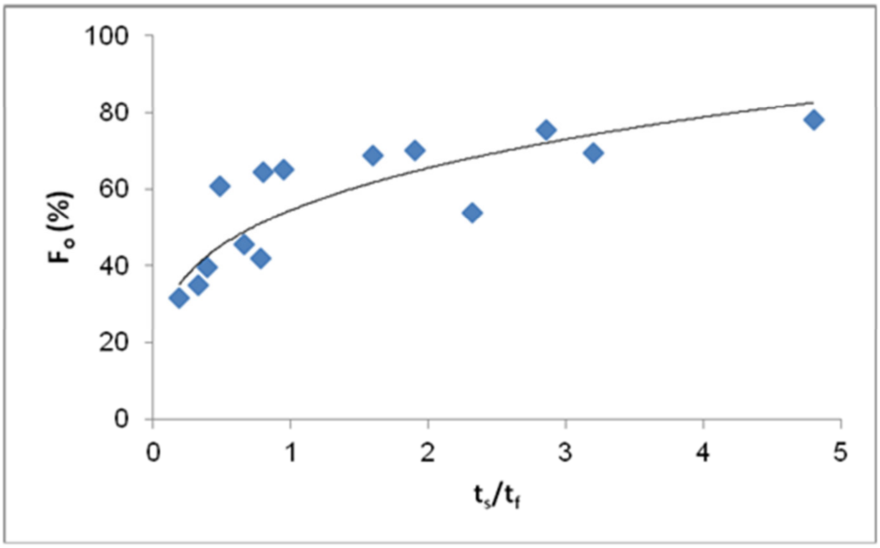

Fig. (6) Variation of F_o with t_s/t_f for alum dose = 30mg/l

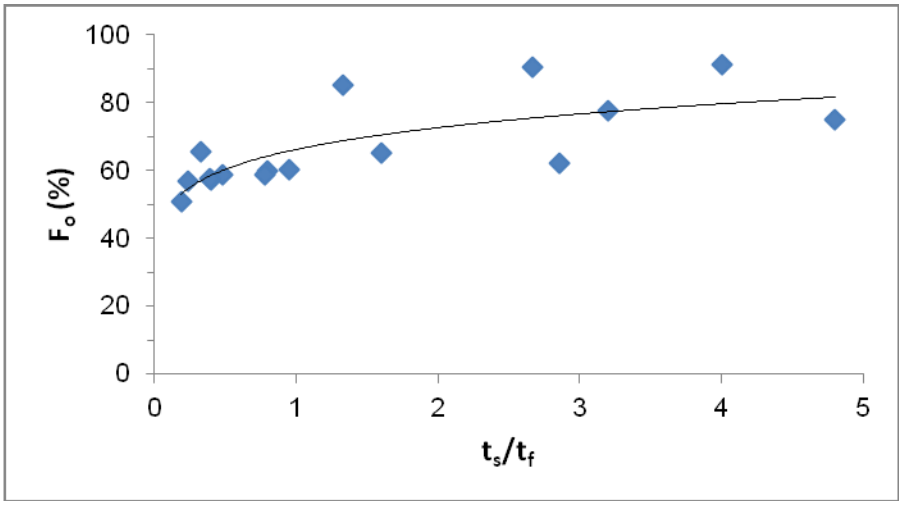

Fig. (7) Variation of F_o with t_s/t_f for alum dose = 40mg/l

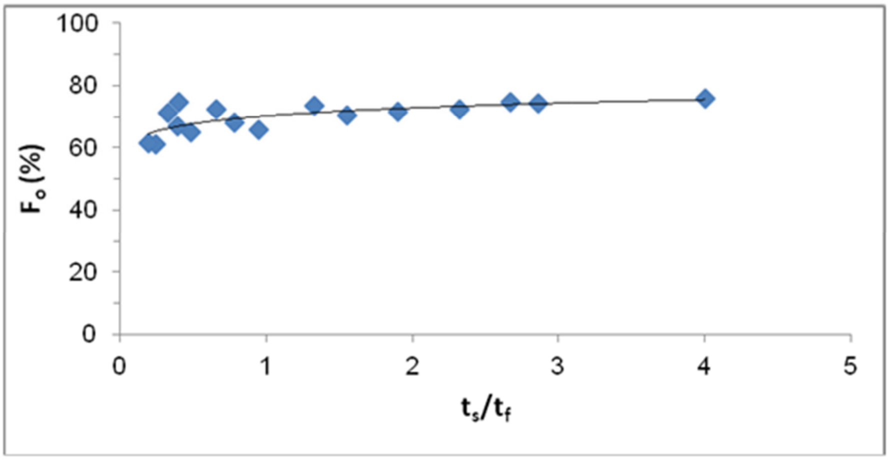

Fig. (8) Variation of F_o with t_s/t_f for alum dose = 50mg/l

CONCLUSION

Wastewater treatment plants rely on SS as one of the most important process variables to maintain optimal operation.

The chemical clarification is an important process unit in most treatment plants providing clarified effluent suspended solids concentrations, which can be used for different water reuses.

This work presented the experimental work on clarification unit, and the effect of varying the alum dose, which affects the relation between t_s and t_f, on the values of removal of the suspended solids.

Experimental work was conducted to develop the mathematical relationships which represent the various processes control advance treatment.

Based on experimental work results, the followings are concluded:

1- The relationship between concentration of suspended solids (SS) and water turbidity (Tur) can be defined as;

$$SS = -0.00026\, Tur^2 + 1.3587\, Tur$$

2. The relationship between percent of SS removal (F_o) and the ratio of settling time to flocculation time (t_s/t_f) is dependent on alum dose and can be defined as:

- For alum dose =10 mg/l,

$$F_o = 86.00(\frac{t_s}{t_f})^{0.075}$$

- For alum dose =20 mg/l,

$$F_o = 77.64(\frac{t_s}{t_f})^{0.063}$$

- For alum dose = 30 mg/l,

$$F_o = 54.55(\frac{t_s}{t_f})^{0.265}$$

- For alum dose = 40 mg/l,

$$F_o = 66.20(\frac{t_s}{t_f})^{0.133}$$

- For alum dose = 50 mg/l,

$$F_o = 70.17(\frac{t_s}{t_f})^{0.052}$$

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