Increasing the phosphorus removal in rotating biological contactors treatment plant by chemical precipitation

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Study of nutrient removal involved the addition of metallic salts as coagulants to determine their effectiveness in removal of phosphorus through chemical precipitation. Our objective was to reduce the influent phosphorus concentration of 7.5 mg/l in the Kilo 26 Treatment Plant (K26TP) to an effluent concentration less than 1.0 mg/l. We hypothesized that the removal of phosphorus would increase with increasing metallic salts concentrations, to a certain limit. An initial test (in the influent) was done to compare the effect of alum, lime, and ferric chloride for removal of phosphorus (P), COD, SS and pH as well as the effect of reaction products on their removal. The study results showed that alum removes phosphorus more effectively than lime and ferric chloride. In the experimental work, we tested the amount of phosphorus , COD, SS and pH using five different concentrations of alum, lime (150, 200, 250, 300 and 350)mg/l, respectively, And another five different concentrations of ferric chloride (50, 60, 70, 80 and 90) mg/l, respectively. We found that as the concentration of these salts increased, the phosphorus, COD and SS removal also increased. With the concentrations that we used, by addition of alum and ferric chloride we were able to reach our goal of 1.0 mg/l phosphorus in the effluent, but by addition lime we were unable to reach our target.

النيتروجين والفسفور أهم المغذيات بالنسبة للنمو العشبي الزائد [Eutrophication] ونمو المغذيات يسبب مشكلة خطيرة في البحيرات والمسطحات المائية الأخرى. و يعد الفسفور، أحد أهم المغذيات ويوجد في المخلفات السائلة في صورة أملاح الفوسفات من مصادر متعددة تشمل المنظفات الصناعية والمخلفات الآدمية والحيوانية والصناعية والأسمدة ومخلفات الطعام والمنظفات المنزلية. ويوجد الفسفور في المخلفات السائلة في ثلاثة صور رئيسية: أورثوفوسفات ، و بولي فوسفات ، و فسفور عضوي. والمواد الكيميائية المستخدمة لإزالة الفسفور من المخلفات السائلة تشمل الشبه والجير و كلوريد الحديديك. وتضاف هذه الكيماويات للمخلفات السائلة للوصول إلى إزالة الفسفور إما أثناء المعالجة أو كخطوه منفصلة بعد المعالجة الثانوية. وتتم إزالة الفسفور من المخلفات السائلة بتحويل الفسفور الموجود في المخلفات السائلة في صورة عالقة أو ذائبة إلى صورة غير ذائبة. وذلك بإضافة بعض الكيماويات التي ترسب الفسفور وتحوله إلى صورة غير ذائبة تترسب وتنخفض بهذا نسبة الفسفور الناتجة في المخلفات السائلة. وقد عنيت الدراسة الحالية بمحطة معالجة الصرف الصحي (كيلو ٢٦) بمدينة الإسكندرية . وتجري حاليا بالمحطة مرحلة المعالجة الثانوية باستخدام المصافي وأحواض حجز الرمال وأحواض التهوية عن طريق الأقراص البيولوجية الدوارة (RBC) ويتبعها أحواض ترسيب مستطيلة . وهذه المعالجة غير كافية للحصول على التركيز الأمثل للملوثات المختلفة مما يؤدي إلى تلوث المسطحات المائية التي يتم الصرف فيها بعد المعالجة (بحيرة مريوط). والبديل الاقتصادي هو المعالجة الكيميائية ، ولذلك يمكن استخدام المعالجة الكيميائية إما قبل المعالجة الابتدائية أو في أثناء المعالجة الثانوية أو بعد المعالجة الثانوية في محطات معالجة المخلفات السائلة . ويمكن تلخيص أهداف البحث كما يلي: تحديد كفاءة المعالجة الابتدائية والثانوية لمحطة المعالجة كيلو ٢٦ في إزالة الفسفور) (وكذلك COD و SS. دراسة تأثير إضافة المرسبات الكيميائية مثل الشبه (Alum)والجير (Lime) وكلوريد الحديديك (Fecl3) على كفاءة المعالجة على تركيز الفسفور المتبقي (P) في المخلفات السائلة وكذلك إزالة كل من COD , SS.تحديد أفضل جرعه يمكن استخدامها لكل من Fecl3, Lime, Alum وتحديد الكفاءة المتوقعة في كل حالة وتحديد أفضل مكان لإضافة هذه الجرعة.

Keywords: Wastewater Treatment, Chemical Phosphorus Removal, Chemical Sedimentation, Control of water bodies' pollution

1. Introduction

The Kelo 26 Treatment Plant (K26TP) treats at present approximately 4000 m^3/day of the kelo 26 zone of Alexandria city. The wastewater is collected at the pump station and rise wastewater to the K26TP and at the end the final effluent is discharged to 7000 faddan basin the clean part of the Maryout lake.

Many wastewater treatment plants that are required to remove phosphorus do so by adding chemicals to precipitate the phosphate that present in the wastewater. Chemicals may be added to primary, secondary, or tertiary processes, or at multiple locations in the plant. Coagulants used for phosphorus precipitation include metal salts such as ferric chloride, aluminum sulfate (alum), and calcium hydroxide (lime) [1-7].

Phosphorus (P) occurs in natural waters and in wastewaters almost solely as phosphates. These phosphates include organic *phosphate, polyphosphate* Particulate (P) and *orthophosphate* (inorganic P). Orthophosphates are readily utilized by aquatic organisms. Some organisms may store excess phosphorus in the form of polyphosphates for future use. At the same time, some phosphate is continually lost in the sediments where it is locked up in insoluble precipitates [8-13].

As a result, there is a continuing effort to control the amount of P compounds that enter surface waters in domestic and industrial discharges. With respect to domestic wastewater, there are two means by which P is removed; chemical precipitation and the use of various biological treatment processes.

The main objectives of the present work are:

1. Provide information on the current efficiency of the primary and secondary sedimentation tanks, of the K26TP at Alexandria city to decrease Phosphorus (P) as well as Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD_5) and Total Suspended Solids (TSS).
2. Study the efficiency of different chemical flocculants or precipitants by using Alum, Lime and Ferric Chloride salts on reducing phosphorus, COD, BOD_5, and TSS for wastewater.
3. Identify the quantity and quantity of the effluent that discharges to the surface water to determine the better salt treatment with optimum dosages to meet the international standard criteria and also to meet the economical considerations, consequently, obtain a good environmental conditions in Maryout lake.

2. Materials and methods

2.1. Sample collection

Two sample collection point in K26TP were used:

1- The first sampling point was at the influent of the primary sedimentation tanks, (raw sewage).

2- The second sampling point was at the effluent of the secondary sedimentation tanks.

These experiments were done in the department of the sanitary engineering laboratory, faculty of engineering, Alexandria University during June, July, and August 2008.

2.2. Chemicals used for precipitation

The colloids in wastewater usually carry high negative charge. Coagulation, by the use of hydrolyzed coagulants such as lime, alum or ferric chloride, occurs when hydrolysable species e.g., ($CaOH^{2+}$, $AlOH^{2+}$, $FeOH^{2+}$) or solid hydroxide [$Ca(OH)_2$, $Al(OH)_3$, $Fe(OH)_3$] interact with colloidal particles Table 1 shows the used coagulants and dosages..

2.3. Experimental work

The current study investigated the chemical precipitation method simultaneous with the primary and secondary treatment to investigate the removal efficiency of the COD, the BOD_5, The Suspended Solids (SS) and the total phosphorus P in the effluent of the (K26TP), Alexandria city.

This was performed by applying chemical flocculants or precipitants such as lime, Fe^{3+}, or Al^{3+} salts to the influent and effluent of the sedimentation tanks.

2.4. Characteristics of raw and treated (ww)

Tables 2 and 3 show the characteristics of raw and treated (ww). The P-total for influent samples measured by colorimetric method using spectrophotometer, for use at 400 to 490 nm. Use a wavelength of 470 nm for concentration ranges (4.0-18 mg/l).

Table 1
The used coagulants and dosages

Chemicals		Dosage range (mg/l)
Common name	Chemical formula	
Alum (Aluminum Sulfate)	Al2 $(SO_4)_3, 18H_2O$	150-350
Ferric chloride (as Fe)	$FeCl_3$	50-90
Lime (Calcium Hydroxide)	$Ca(OH)_2$	150-350

Table 2
The measured characteristics of the (K26TP) raw sewage

No. of samples	Date	P (mg/l)	pH	COD (mg/l)	BOD_5 (mg/l)	SS (mg/l)	TDS (mg/l)
1	28-6-2008	7.5	7.54	169	98	140	370
2	14-7-2008	5.5	7.5	185	122	113	350
3	21-7-2008	5.2	7.56	173	132	91	360
4	28-7-2008	11.1	7.51	251	164	187	350
5	11-8-2008	8.1	7.57	136	109	108	330

Table 3
The measured characteristics of the (K26TP) effluent

No. of samples	Date	P	pH	COD (mg/l)	BOD (mg/l)	SS (mg/l)	TDS (mg/l)
1	28-6-2008	2.6	7.48	38	19	38	320
2	14-7-2008	2.5	7.55	36	23	29	320
3	21-7-2008	2.3	7.61	20	8	15	340
4	28-7-2008	2.1	7.52	29	13.26	41	340
5	11-8-2008	1.8	7.53	38	20.5	24	370

The P-total for effluent samples measured by colorimetric method using spectrophotometer (DR 2010 Colorimeter Hack, USA made). Use PhosVer 3 Method, Test'N Tube Procedure for concentration ranges (0.00 to 5.00 mg/l PO_4^3).

3. Results and discussion

Experiments were carried out in five runs to determine the optimum dosages of the lime (Calcium hydroxide), alum (Aluminum sulfate, $Al_2(SO_4)_3$) salt dosages 150, 200, 250, 300 and 350 mg/l, respectively, and optimum dosages of ferric chloride dosages 50, 60, 70, 80 and 90 mg/l. The salts dosages addition on the working properties P, COD and SS are shown in tables 4-6, figs. 1, 2 and 3 shows the relation between these salts dosages application on the average value of P, COD and SS of 5 samples of influent and effluent of experimental wastewater.

Table 4
Effect of alum on average % P removal at 30 min. Settling (raw sewage and effluent)

Sampling No.	Initial	Alum dosage (mg/l)									
	Conc.	150		200		250		300		350	
	Conc.	Conc.	% RE	Conc.	% RE	Conc.	% RE	Conc.	% RE	Conc.	% RE
P conc., mg/1 (Raw sewage)	7.5	4.8	36.3	3.4	54.3	2.5	66.2	2.1	72.0	1.7	76.3
P conc., mg/1 (Effluent)	2.3	1.7	25.7	1.4	38.0	1.1	52.2	0.9	61.5	0.8	65.0
COD conc., mg/1 (Raw sewage)	182.8	136.9	25.2	106.2	42.2	83.5	54.0	69.7	61.6	57.2	68.4
COD conc., mg/1 (Effluent)	32.2	24.6	23.4	19.1	40.8	15.4	51.8	13.9	56.4	13.0	59.2
SS conc., mg/1 (Raw sewage)	127.8	93.0	27.0	68.0	46.6	52.9	58.3	43.8	65.7	37.7	70.5
SS conc., mg/1 (Effluent)	29.4	22.2	24.9	17.0	42.4	14.1	52.7	12.7	56.7	11.9	59.7

Table 5
Effect of Ferric chloride on average % P removal at 30 min. Settling (raw sewage and effluent)

Sampling No.	Initial	Alum dosage (mg/l)									
	Conc.	50		60		70		80		90	
	Conc.	Conc.	% RE	Conc.	% RE	Conc.	% RE	Conc.	% RE	Conc.	% RE
P conc., mg/1 (Raw sewage)	7.5	4.8	36.3	4.0	45.2	3.0	58.9	2.4	67.0	2.2	69.9
P conc., mg/1 (Effluent)	2.3	1.7	25.7	1.4	37.4	1.1	53.0	1.0	56.0	0.9	59.0
COD conc., mg/1 (Raw sewage)	182.8	136.9	25.2	106.7	41.9	88.6	51.6	73.9	59.6	65.3	64.1
COD conc., mg/1 (Effluent)	32.2	24.6	23.4	20.8	35.1	18.4	42.3	17.0	46.9	16.1	49.5
SS conc., mg/1 (Raw sewage)	127.8	93.0	27.0	74.9	41.4	62.1	51.1	53.1	58.3	47.1	62.7
SS conc., mg/1 (Effluent)	29.4	22.2	24.9	18.1	39.3	15.4	48.7	13.9	53.9	12.6	57.9

Table 6
Effect of lime on average % P removal at 30 min. settling (raw sewage and effluent)

Sampling No.	Initial	Alum dosage (mg/l)									
	Conc.	150		200		250		300		350	
	Conc.	Conc.	%RE	Conc.	% RE	Conc.	% RE	Conc.	% RE	Conc.	% RE
P conc., mg/1 (Raw sewage)	7.5	5.9	21.1	4.6	37.1	4.0	45.2	3.5	51.4	3.2	55.3
P conc., mg/1 (Effluent)	2.3	1.8	19.0	1.6	30.0	1.4	36.7	1.3	41.1	1.3	43.3
COD conc., mg/1 (Raw sewage)	182.8	137.7	24.8	110.2	39.9	94.4	48.1	87.2	51.7	80.9	55.1
COD conc., mg/1 (Effluent)	32.2	23.9	25.4	19.7	38.5	16.9	47.7	16.8	47.8	16.6	47.6
SS conc., mg/1 (Raw sewage)	127.8	94.5	25.9	77.5	40.0	64.2	50.7	56.7	57.0	50.8	61.1
SS conc., mg/1 (Effluent)	29.4	22.1	25.6	18.2	39.8	15.2	49.9	13.7	54.0	13.4	55.2

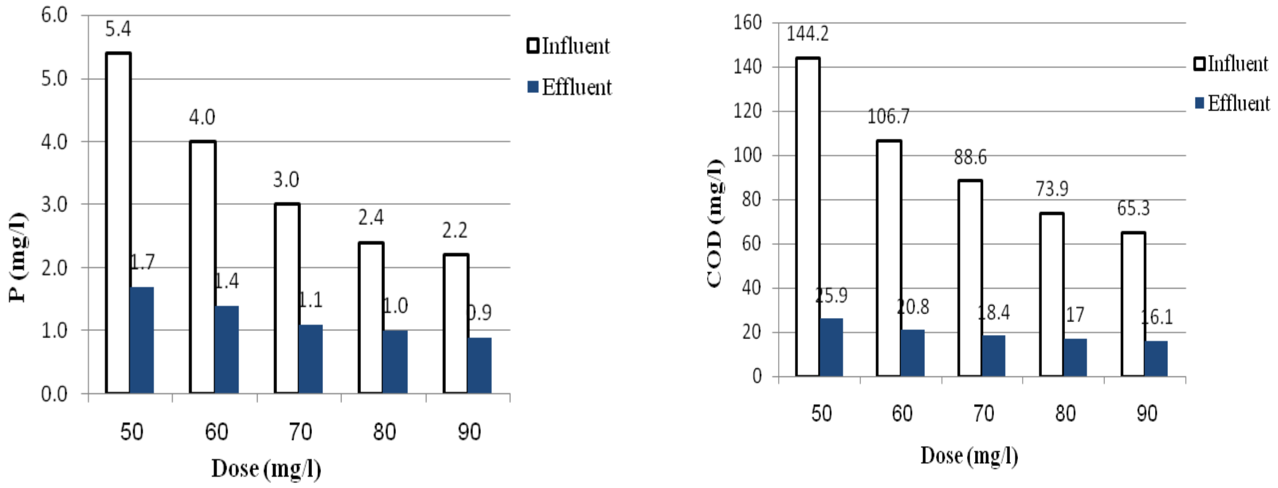

Fig. 1. Relation between Alum doses (mg/l) on the average of (P, COD) of raw sewage and effluent.

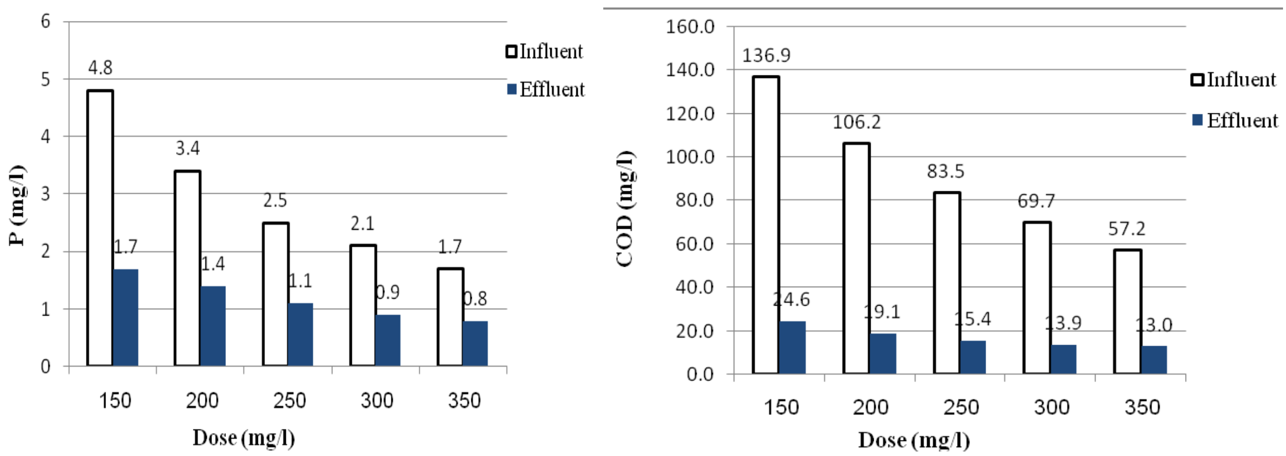

Fig. 2. Relation between Lime doses (mg/l) on the average of (P, COD) of raw sewage and effluent.

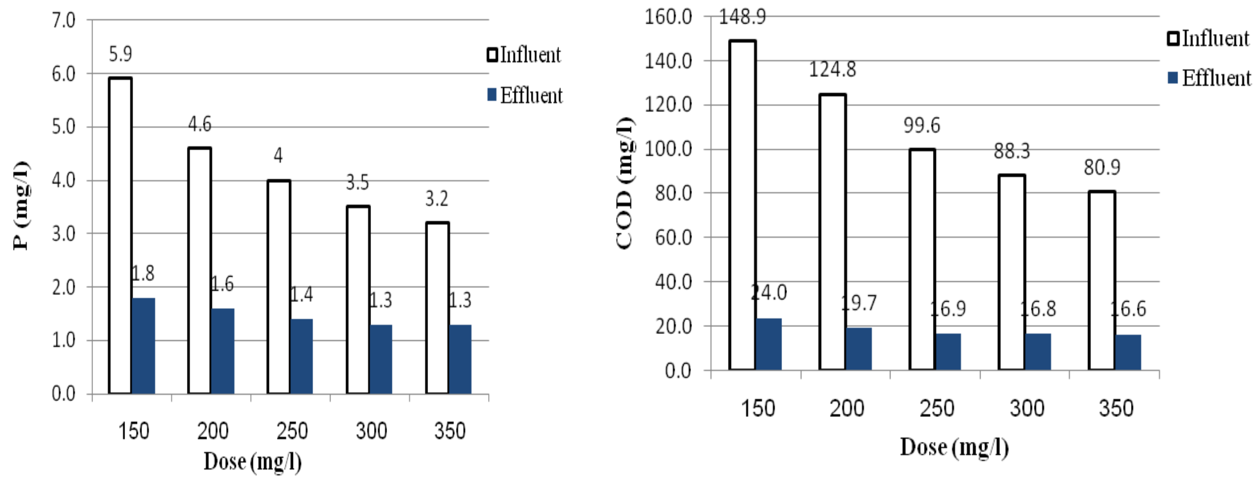

Fig. 3. Relation between Lime doses (mg/l) on the average of (P, COD) of raw sewage and effluent.

The Alum coagulant reaction occur as follows:

$$Al_2(SO_4)_3.18H_2O+3Ca(HCO_3)_2 \longleftrightarrow 3CaSO_4\downarrow + 2Al(OH)_3\downarrow + 6CO_2 + 18H_2O$$

$$6CO_2+18H_2O \longleftrightarrow H\,CO_3 \longleftrightarrow H^+ +HCO_3^- \ (pH<7)$$

The insoluble aluminum hydroxide is a gelatinous floc that settles with the suspended materials (Nemerow, 1971 and Amirtharajah and O'Melia, 1991). It occurs at alum dosage of 300 mg/l, where the removal efficiency of working properties is better in comparison to the lime coagulant at the same dosage.

The lime coagulant reaction occur as follows:

$$Ca(OH)_2 + H_2CO_3 \longleftrightarrow CaCO_3\downarrow + 2H_2O$$

$$Ca(OH)_2 + Ca\,(H_2CO_3)_2 \longleftrightarrow 2CaCO_3\downarrow + 2H_2O$$

The interpretation of the mechanisms of lime addition in removal efficiency is due to the pH effect. Where the addition of $Ca(OH)_2$ dosages increased the pH of the wastewater changes from almost (7.4) to(10.9) which indicates the formation of $Ca(OH)_2$ and $CaCO_3$ system and forms a lime gel type. These results are in accordance with results reported by (Metcalf and Eddy, 1997), (Babbitt and Baumann, 1985).
The ferric chloride coagulant reaction occur as follows:

$$FeCl_3 + H_2O \longleftrightarrow Fe(OH)_3\downarrow \ CaCL_2 + H_2CO_3$$

$$H_2CO_3 \longleftrightarrow H^+ + HCO_3^-$$

Addition of ferric chloride salt to the aerated wastewater leads to the information of insoluble ferric hydroxide as a bulky gelatinous floc, It is clear that the dominant system is bicarbonate system where pH < 6.4. The presence of $CaCl_2$ enhances the flocculation and precipitation process. It is clear that optimum dose of ferric chloride dosage is 90 mg/l for removal efficiency of P, COD, and SS where pH value is 6.4.

3.1. Relation between coagulant dose and residual phosphorus concentration

The following results are the average of the five runs obtained from sample (1), sample (2), sample (3), sample (4) and sample (5) for each coagulant:

3.1.1. Phosphorus elimination by alum coagulant

[Relation between Alum Dose and Residual Phosphorus Concentration after 30 min. Settling]. From fig. 1, it is clear that increasing alum dose improves phosphorus removal.

Fig. 1 and table 4, *[Raw Sewage***]** show that the optimum dose of alum is 350 mg/l, residual P is 1.7 mg/l.

Fig. 1 and tables 4, [*Effluent*] show that the optimum dose of alum is 300 mg/l, residual P is 0.9 mg/l.

These results assure that on using alum coagulant the preferred settling time should be 30 minutes at a dose of (350) mg/l for influent and (300) mg/l for effluent because it gives considerable results with respect to the time factor.

3.1.2. Phosphorus elimination by ferric chlorid coagulant

[Relation between Ferric Chloride Dose and Residual Phosphorus Concentration at 30 min. Settling]. From fig. 2 show that as the average dose increases the P concentration decreases.

Fig. 2 and table 5 [*Raw Sewage***]** show that the optimum dose of ferric chloride is 90 mg/l, residual P is 2.2 mg/l.

Fig. 2 and table 5 [*Effluent*] show that the optimum dose of ferric chloride is 80 mg/l, residual P is 1.0 mg/l.

These results proved that the best condition for Ferric Chloride had been obtained by using a dose of 90 mg/l for influent and 80 mg/l for effluent as ferric ion to reach the required limit.

3.1.3. Phosphorus elimination by lime coagulant

[Relation between Lime Dose and Residual Phosphorus Concentration at 30 min. Settling]. From fig. 3 it is clear that as the average dose of lime increases, the residual phosphorus (P) concentration decreases.

Fig. 3 and table 6 [*Raw Sewage*] show that the optimum dose of lime is 350 mg/l, residual P is 3.2 mg/l.

Fig. 3 and table 6 [*Effluent*] show that the optimum dose of lime is 350 mg/l, residual P is 1.3 mg/l.

The lime addition therefore increases the sludge production which might be considered as a disadvantage of using lime as a coagulant.

4. Conclusions

According to the observations and the results obtained, the following points are concluded:

1- Using coagulants increase the removal efficiency of (P), COD, BOD and SS removal efficiencies.

2- Chemical precipitation method may be used for primary and secondary treatment to improve the wastewater quality before discharging to lake Maryout to minimize Eutrophication. It should be considered as a reasonable method to decrease total phosphorus concentration in wastewater. A high quality effluent may be obtained at relatively low cost and manpower input.

3- Regarding to the objectives of this study, which was to examine if by adding chemical coagulants such as lime and alum, ferric chloride in the influent or effluent of wastewater to sedimentation tanks of the K26TP, would improve the removal efficiency of (P), COD, BOD and SS, it can be concluded that:

a) (*Raw Sewage*) Phosphorus, COD, SS removals of 76.3%, 68.4%, 70.5% respectively with alum dose of 350 mg/l. (*Effluent*) Phosphorus, COD, SS removals of 61.5%, 56.4%, 56.7% respectively with alum dose of 300 mg/l.

b) (*Raw Sewage*) Phosphorus, COD, SS removals of 69.9%, 64.1%, 62.7% respectively with ferric chloride dose of 90 mg/l. (*Effluent*) Phosphorus, COD, SS removals of 56.0%, 46.9%, 53.9% respectively with alum dose of 80 mg/l.

c) (*Raw Sewage*) Phosphorus, COD, SS removals of 55.3%, 55.1%, 61.1% respectively with lime dose of 350 mg/l. (*Effluent*) Phosphorus, COD, SS removals of 43.3%, 47.6%, 55.2% respectively with alum dose of 350 mg/l.

4- According to the results of the three coagulants tested; the use of alum and ferric chloride can be recommended, to achieve the required phosphorus concentration in the treated wastewater.

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