

# Phosphate Removal from Sewage by Chemical Precipitation and its Effect on Other Characteristics

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## Abstract

It is observed that Phosphate is seen in the sewage samples in the industry and reduction of it is required. Removing Phosphate (P) from domestic wastewater is largely done to reduce the risk of eutrophication in any water that the wastewater will be released into. Phosphorous being a nutrient can be recovered from the waste water and put to good use like in fertilizers. There are different technologies that are being used to achieve the removal of P-content from sewage like – Physical, Chemical, Biological and Ion Exchange amongst others. The main objective of our research study is to find out suitable chemical for removal of Phosphate from sewage using chemical precipitation as removal mechanism. In the current study, selection of suitable chemical for chemical precipitation amongst Alum and  $\text{FeCl}_3$  is done to reduce the P-content in the sewage up to 0.2 mg/L. Using lab trials, dosage for the same is calculated and accordingly the on-field trials were carried out to check the efficacy of the method. The study also included the study the influence of chemical addition onto the various characteristics of the sewage. The on-field trials gave an idea about the working of chemical precipitation in the current system and how it affects entire wastewater treatment system.

**Keywords:** Precipitation, Coagulation, Sewage, Phosphate Removal.

## 1. Introduction

Phosphorous is found in the sewage samples at varied concentrations and in different forms like orthophosphate, polyphosphate, organic phosphate, etc. It is introduced in the sewage streams from sources like human excreta, food waste from canteens, detergents, soaps and hand wash used in bathrooms. Excessive amount of Phosphate in treated sewage may lead to Eutrophication which is a serious concern in the ecology. Strict measures must be taken at source level to reduce the introduction of Phosphorous in the sewage system. By combining all the source control measures by adapting to the conditions, it is possible to reduce the load of Phosphorous. Phosphorous can be removed from the sewage using different techniques like chemical precipitation, biological removal technique, etc. Out of which the biological method has less efficiency of removal as compared to chemical precipitation. Various chemical agents like Alum, PAC,  $\text{FeCl}_3$ , etc. are being practiced on a wider range. The removal of Phosphorous can be carried out by chemical or biological method or by combining both of them to

achieve maximum removal efficiency. Different studies nationally and internationally have been carried out to remove the Phosphorous element from the sewage water using chemical precipitation. Ion exchange has proven to be highly efficient in P-removal but in turn is cost extensive. Even different studies have been carried out related to the Biological Phosphorous Removal (BPR) where Phosphate Accumulation Organisms (PAO) is employed to do the job.

In the current research study, removal of P-content is done on the existing Sewage Treatment Plant as shown in the plant layout below. The existing treatment method does not meet the disposal standards for Phosphate content at the outlet. Selection of suitable chemical is to be done for chemical precipitation amongst options like Alum, PAC and  $FeCl_3$  to reduce the P-content in the sewage up to 0.2 mg/L. The chemicals were introduced at different stages in the cycle and various permutations were carried out.

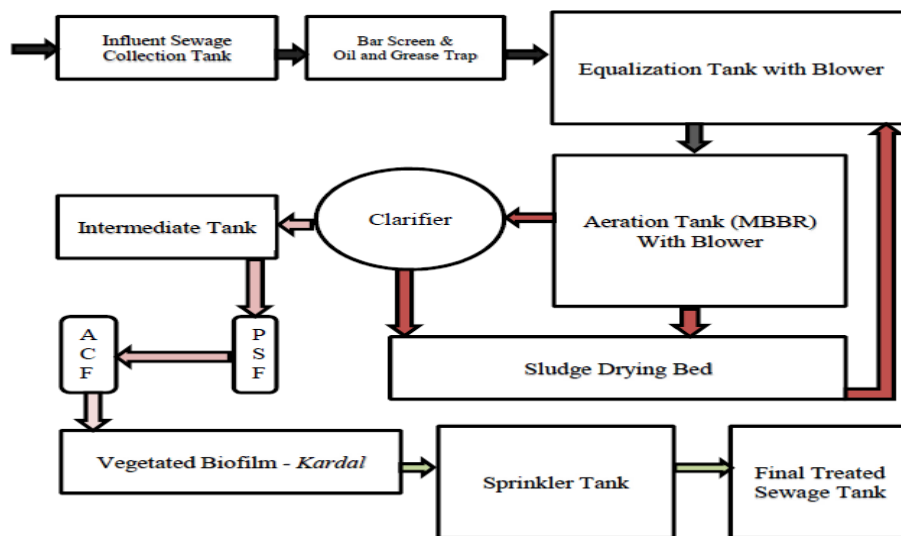


Figure 1. Sewage Treatment Plant Layout

### 3. LITERATURE REVIEW

Sawsan A. M. Mohammed et. al. (2009)[1] have carried out a study for removal of Phosphorous from waste water using coagulation. They carried out a series of Jar tests using different coagulants at studied their effects on the concentration of Phosphorous and its effect on pH. They also tried variations in the mixing speed and concluded that mixing speed is not relevant to the efficiency of Phosphorous removal. They have concluded that Phosphorous removal was found to be highly dependent on pH of the waste water. Through their tests and analysis, it can be seen that Phosphorous removal for highest (83%) for dosage of Alum (80mg/L) as compared to (60%) for dosage of Calcium Chloride (60mg/L). Finally they concluded that Alum proved to be more efficient in Phosphorous removal than Calcium Chloride.

Jong-Oh Kim et. al. (2013)[2] carried out a study to find out the factors that affect the removal of Phosphorous as pre-treatment for MBR (Membrane Bio-Reactor) based waste water treatment. For this study, waste water from 5 different treatment plants in Japan was collected. Coagulation experiments were carried out using a Jar Test Apparatus with two coagulants namely PAC (Poly Aluminum Chloride) and  $FeCl_3$ (Ferric Chloride). Parameters like pH, Alkalinity, Suspended Solids, Total Phosphorous, Total Organic Carbon, Total Nitrogen, Color, Turbidity, Zeta Potential and Metal ions were analyzed for raw waste water as well as filtered waste water. They studied the effect of dosage of PAC and  $FeCl_3$  on coagulation, relation between Total Phosphorous removal and other characteristics of

the waste water. They concluded that Total Phosphorous removal from raw waste water was seen more as compared to  $\text{FeCl}_3$  than PAC, whereas, for filtered waste water, PAC was more effective. Finally, they concluded that chemical coagulation can be used as a pretreatment to remove the Total Phosphorous for MBR based treatment.

G. K. Luk (1999)[3] in his study has defined the objective of solving the problem of complex metal-phosphorous reactions and hydroxide reactions occurring in the coagulation process by carrying out standard jar tests. The chemicals chosen for study are Ferric Chloride ( $\text{FeCl}_3$ ) and Alum ( $\text{Al}_2(\text{SO}_4)_3$ ). He has also considered the effects of different field conditions, initial Phosphorous level, pH of waste water, dosage & removal efficiency. A series of Jar tests were carried out for known concentration of Phosphorous in the waste water using different dosages of coagulant. After the study, he has concluded that due to the presence of alkalinity in the sample, removal efficacy of Phosphorous is varied. He also concluded that Alum is more effective in Phosphorous removal than Ferric Chloride. But Ferric Chloride functions better in lower pH waste water.

Mina Nejad et. al. (2013)[4] carried out research to achieve the prescribed concentration limit for Phosphorous in treated municipal waste water. A combination of PAC and Bentonite Clay was used for coagulation. Samples were collected from different locations within the same waste water treatment plant like inlet, before primary and before secondary treatment. Along with the main objective of finding the best possible combination dosage and its efficiency, study of pH on removal efficiency of Orthophosphate was also carried out. Upon analysis, it was found that with increase in pH, the removal efficiency of Orthophosphate increased. Highest efficiency was observed at pH=10. Variation in coagulant performance can be seen due to other contaminants present in waste water. Increase in contaminant concentration resulted in decrease in removal efficiency of Orthophosphate.

Joshua T. Bunce et. al. (2018)[5] have carried out a comprehensive review of Phosphorous removal technologies and tried to find out their applicability to small scale domestic waste water treatment plants. They have stated that most of the technologies that are present right now cater only to the large scale waste water treatment plants and not for the small ones. They have explained different methods that are used presently for removal of Phosphorous like Physico-Chemical process; Adsorption through media, Ion exchange, Biological method like EBPR (Enhanced Biological Phosphorous Removal), Algae based hybrid systems, etc. In all of this, it is not feasible to apply the existing systems for small scale treatment plants and requires further research along the lines. The possible technology must satisfy two basic requirements of affordability and appropriateness. They have concluded that there is need for more research in this area and technologies which are reliable and have minimal operation and maintenance must be developed.

Ying Zhao et. al.(2014)[6] have carried out a study wherein they recycled the chemical sludge along with fresh coagulant to improve the removal efficiency of Phosphate. They carried out a pilot lab test to study different parameters like ration of recycled sludge, operating conditions and removal mechanism. The idea for this study has been attributed to the fresh chemical costs and problems raised due to disposal of chemical sludge generated. They have created synthetic waste water containing known concentration of Phosphate. Ratio of chemical and recycled sludge is considered to be important. From the analysis results, it was found that removal efficiency increase when the ratio of recycled sludge was between 15-20%. Also mixing and aging time of the recycled sludge has a significant effect on removal of Phosphate.

Stainslaw M. Rybicki et. al. (2022)[7] has reviewed various Phosphorous removal technologies from municipal waste water. He has also discussed history of Phosphorous removal technologies and the difficulties and operating problems faced by the same. He has also briefly explained the electrolytic method of Phosphorous removal where electricity is used for coagulation. Other methods like Crystallization, Magnetic Separation and Adsorption is also explained in short. Along with those, few methods of Biological nature like Multiphase Biological reactors and Sequential Batch Reactor has been explained. Finally he has concluded that in future the technology used for Phosphorous should be such that, the Phosphorous can be used as a fertilizer.

C. Kazadi Mbamba et. al. (2019)[8] carried out a research study which focused on optimizing the operational aspects of a MBR pilot plant using Iron based chemical dosing for Phosphorous removal. The pilot plant operates on the mechanism of precipitation, adsorption and co-precipitation. The study also showed that environmental factors such as pH as well as operational conditions such as Fe/P molar ratios contributed to the variation in Phosphate concentration. Dosing at 3 different points in the plant was carried out – at pre-aeration tank before primary clarifier, in aerobic tank and before membrane tanks. The research study had good results which depicted closer to 5-10% relevancy in pilot plant and reality.. The study demonstrated that the integrated model was suitable enough for biological nutrient and Phosphorous removal through Iron precipitation. They also concluded that the reaction showed a slow dynamic response which may be likely due to factors like dissolution, Oxidation of Iron, Precipitation of Fe-P compounds, adsorption and co-precipitation processes.

Viola Somogyi et. al. (2022) [9] have carried out an experimental research for recovery of Phosphorous from waste water using Red Mud. The researchers have created a synthetic waste water of known Phosphorous concentration. A highly alkaline Red Mud, treated with gypsum and Carbon Dioxide was used for experiments. Red Mud treatment was carried out on different waste waters like synthetic waste water, poultry effluent, spiked effluent from Municipal waste water treatment plant and leachate generated from Landfill. The Red Mud dosages for given concentration of synthetic waste water were found to achieve 90% removal efficiency (at alkaline pH). A relationship between Red Mud, HCL, Conductivity and remaining Phosphate was established. Similar experiments were carried out with remaining waste water and leachate and their respective results were discussed. They have concluded their research by stating the importance of finding the optimal dosage of alkaline adsorbent (Red Mud) and neutralizing agent (HCL) to achieve optimal pH for Phosphorous removal. Applied dosages were capable enough to remove all the Phosphorous from waste water and achieve stricter limiting values. Increase in Red Mud dosages does not equate to increase in cost but pH setting would increase the cost significantly.

Mahamalage Kusumitha Pereraa et. al. (2019) [10] have carried out a review on technologies that are used for recovering nutrients from waste water. Available technologies are reviewed by them on basis of waste water characteristics, effluent discharge limits, recovery goals, constraints on chemical dosage, scale and size of treatment plants, operational ease and applicability along with the energy requirements for per unit nutrient recovery. Methods like Ion exchange, magnetic micro-absorption, reactive filtration, urine separation, Struvite precipitation, Electro-dialysis, chemical precipitation, biological P-recovery, algae harvesting and electrochemical P-recovery have been discussed in detail. They have also summarized pros and cons of all P-recovery technologies. Finally they have concluded their review by saying that Struvite and Electrochemical precipitation can be used for production of Fertilizers which require minimal post-processing. Also, processes like electrochemical precipitation, chemical

precipitation and ion-exchange have relatively low maintenance and chemical requirements and are suitable for on-site applications. Only the adsorption technologies are capable enough to achieve the stringent requirements of Phosphorous concentration from effluent discharge.

## 2. Methodology

The research consisted of analysis of sewage water before addition of Coagulation chemical, Jar Tests consisting of 2 chemicals viz. Alum and Ferric Chloride and on-field trials based on the dosages determined by the Jar tests.

### 2.1 Current Scenario

Sewage samples were collected before the chemical trials for getting an idea about the current status of the treatment cycle. Analysis of raw sewage water and treated sewage was carried out over a period of 20 days. The samples were analyzed for parameters like pH, Alkalinity, Biological Oxygen Demand (BOD) at 27°C for 3-Days, Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Total Kjeldahl Nitrogen (TKN) and Phosphate. Obtained analysis results are shown below:

**Table 1. Analysis results for raw sewage collected at STP Inlet.**

Sr. No.	Parameter	Minimum	Maximum	Average	Unit
1	pH	6.48	6.81	6.64	--
2	Alkalinity	203	268	235.85	mg/L
3	Phosphate	16.9	20.86	18.73	mg/L
4	BOD at 27°C for 3-Days	104	320	199.15	mg/L
5	COD	681	916	832.15	mg/L
6	TSS	115	195	142.5	mg/L
7	TKN	65	82	73.25	mg/L

**Table 2. Analysis results for raw sewage collected at STP Outlet.**

Sr. No.	Parameter	Minimum	Maximum	Average	Unit
1	pH	6.46	6.9	6.67	--
2	Alkalinity	28	95.5	59.9	mg/L
3	Phosphate	6.59	8.21	7.75	mg/L
4	BOD at 27°C for 3-Days	16.6	35.4	23.5	mg/L
5	COD	44	109	71.7	mg/L
6	TSS	1.5	13.8	9.6	mg/L
7	TKN	3.22	7.15	5.81	mg/L

### 2.2 Chemical Trials

Two chemicals namely Alum and Ferric Chloride were identified for the study. For better understanding the dosages, Jar tests were performed in the laboratory. The main purpose of the Jar tests was to identify the right amount of dosages for required results. Samples at 3 different locations were collected from the Sewage Treatment Plant namely – Equalization Tank (S2), Aeration Tank (S3) and Intermediate Tank (S4). Tests were carried out on Jar Test Apparatus as shown below:

Figure 2. Jar Test Apparatus



Alum and FeCl<sub>3</sub> were added to the samples at different dosages like 0.2, 0.4, 0.6, 0.8 and 1.0 mg/L. Obtained test results for addition of chemicals is shown below for samples collected at Equalization Tank (S2). The mentioned values are average values of 7 days. Along with it percent changes in waste water parameters is shown.

Table 3. Analysis results for chemical addition at Equalization Tank (S2).

Chemical used	Initial Values	Alum						Ferric Chloride					
		0.1	0.2	0.4	0.6	0.8	1.0	0.1	0.2	0.4	0.6	0.8	1.0
Dosage in ml	--	0.1	0.2	0.4	0.6	0.8	1.0	0.1	0.2	0.4	0.6	0.8	1.0
Dosage in mg/L	--	20	40	80	120	160	200	20	40	80	120	160	200
pH	7.08	7.04	6.94	6.87	6.77	6.64	6.55	6.95	6.76	6.60	6.07	5.75	5.38
Alkalinity (mg/l)	308.0	245.00	230.71	215.00	185.00	153.57	101.43	215.71	162.14	130.71	14.29	0.00	0.00
Phosphate (mg/l)	19.5	17.93	17.22	15.18	13.80	9.84	7.06	12.01	3.72	1.62	0.79	0.30	0.12
BOD (mg/l)	179.7	142.39	116.09	93.29	77.89	54.70	48.10	139.49	122.27	99.63	74.81	63.49	46.31
COD (mg/l)	447.3	335.67	290.64	231.90	200.34	159.21	143.00	318.87	258.76	218.96	166.49	147.27	115.04
TSS (mg/l)	87.2	84.52	76.27	63.99	50.19	42.06	35.31	72.50	57.29	46.01	37.91	34.91	31.84
TKN (mg/l)	72.1	60.56	48.96	42.46	34.74	30.02	24.21	58.16	51.61	43.00	38.13	34.86	30.84

**Table 4. Percent changes in parameters in Equalization Tank (S2).**

Parameter	Initial Values	Results after addition of 200mg/L Ferric Chloride	% Change
pH	7.08	5.38	-24.01
Alkalinity (mg/l)	308.0	0.00	-100
Phosphate (mg/l)	19.5	0.12	-99.38
BOD (mg/l)	179.7	46.31	-74.23
COD (mg/l)	447.3	115.04	-74.28
TSS (mg/l)	87.2	31.84	-63.49
TKN (mg/l)	72.1	30.84	-57.23

**Table 5. Analysis results for chemical addition at Aeration Tank (S3).**

Chemical used	Initial Values	Alum						Ferric Chloride					
		0.1	0.2	0.4	0.6	0.8	1.0	0.1	0.2	0.4	0.6	0.8	1.0
Dosage in ml	--	0.1	0.2	0.4	0.6	0.8	1.0	0.1	0.2	0.4	0.6	0.8	1.0
Dosage in mg/L	--	20	40	80	120	160	200	20	40	80	120	160	200
pH	6.92	6.76	6.65	6.52	6.34	6.18	5.98	6.54	6.34	5.86	5.01	4.49	3.57
Alkalinity (mg/l)	213.94	114.17	92.50	80.83	65.00	34.17	5.00	80.00	46.67	17.50	0.00	0.00	0.00
Phosphate (mg/l)	19.65	17.19	15.55	12.61	10.37	7.08	0.77	6.58	5.24	2.98	0.75	0.30	<b>0.19</b>
BOD (mg/l)	261.97	212.53	198.67	181.18	140.57	99.03	27.83	162.27	91.33	49.12	29.27	10.87	6.73
COD (mg/l)	711.14	438.75	413.95	381.53	328.97	209.08	79.07	372.53	205.32	110.98	71.93	29.45	15.60
TSS (mg/l)	456.89	185.80	158.22	137.80	111.40	63.08	75.40	149.02	104.20	70.57	20.23	21.12	31.07
TKN (mg/l)	52.36	43.80	40.12	34.35	29.93	25.02	19.46	39.78	35.53	31.70	19.53	16.58	13.87

**Table 6. Percent changes in parameters in Aeration Tank (S3).**

Parameter	Initial Values	Results after addition of 200mg/L Ferric Chloride	% Change
pH	6.92	3.57	-48.41
Alkalinity (mg/l)	213.94	0.00	-100
Phosphate (mg/l)	19.65	0.19	-99.03
BOD (mg/l)	261.97	6.73	-97.43
COD (mg/l)	711.14	15.60	-97.81
TSS (mg/l)	456.89	31.07	-93.2
TKN (mg/l)	52.36	13.87	-73.51

**Table 7. Analysis results for chemical addition at Intermediate Tank (S4).**

Chemical used	Initial Values	Alum						Ferric Chloride					
		0.1	0.2	0.4	0.6	0.8	1.0	0.1	0.2	0.4	0.6	0.8	1.0
Dosage in ml	--	0.1	0.2	0.4	0.6	0.8	1.0	0.1	0.2	0.4	0.6	0.8	1.0
Dosage in mg/L	--	20	40	80	120	160	200	20	40	80	120	160	200
pH	6.88	6.98	6.87	6.67	6.40	5.88	4.64	6.41	6.01	4.66	3.85	2.72	2.48
Alkalinity (mg/l)	131.50	89.29	71.43	57.86	30.00	2.86	1.43	24.29	12.86	0.00	0.00	0.00	0.00
Phosphate (mg/l)	13.62	11.41	5.79	2.89	0.99	0.39	0.09	5.44	1.74	1.03	3.15	7.05	10.33
BOD (mg/l)	28.76	21.81	18.95	16.61	14.01	12.04	10.67	24.12	21.29	19.69	16.06	13.79	11.27
COD (mg/l)	73.70	53.94	50.01	44.89	39.67	32.20	28.37	62.21	56.64	52.61	42.50	32.39	27.39
TSS (mg/l)	21.66	17.64	16.16	13.89	10.98	8.27	5.71	17.43	16.79	17.83	18.64	16.84	18.75
TKN (mg/l)	41.94	33.43	30.40	28.38	25.56	22.26	20.24	34.11	31.67	29.89	29.69	29.76	27.84

**Table 8. Percent changes in parameters in Intermediate Tank (S4).**

Parameter	Initial Values	Results after addition of 200mg/L Alum	% Change
pH	6.88	4.64	-32.56



<b>Alkalinity (mg/l)</b>	131.50	1.43	-98.91
<b>Phosphate (mg/l)</b>	13.62	0.09	-99.34
<b>BOD (mg/l)</b>	28.76	10.67	-62.9
<b>COD (mg/l)</b>	73.70	28.37	-61.51
<b>TSS (mg/l)</b>	21.66	5.71	-73.64
<b>TKN (mg/l)</b>	41.94	20.24	-51.74

When the chemical is added in the Equalization Tank sample, Phosphate is reduced up to 0.12 mg/L for a dosage of 200 mg/L of FeCl<sub>3</sub>. In the Aeration Tank sample, Phosphate is reduced up to 0.19 mg/L for a dosage of 200 mg/L of FeCl<sub>3</sub> but the downside being, pH is lowered to 3.57. This will harm the microbial life in the Aeration Tank and hence it is not advisable. In the Intermediate Tank sample, Phosphate is reduced up to 0.09 mg/L for a dosage of 200 mg/L of Alum. pH is reduced to 4.64. Sludge is precipitated at the bottom of the Jars after ample time is given to settle. Which is why, the chemical addition on field should be done in such a way that, the sludge can be easily removed. Also, it was observed that the pH of the samples dropped down and turned acidic. So there was need to add alkalizing agent to maintain the pH of the sewage water.

### 3. Results and Discussion

Based on the results obtained from the Jar Tests, Ferric Chloride (FeCl<sub>3</sub>) was selected to be used in the on-field trials with a dosage of 40mg/L at location Equalization Tank (S2) and 80mg/L at location Intermediate Tank (S4). Alkalizing agent Caustic Soda used for maintaining pH with a dosage of 10mg/L at the end. Obtained average results of 20 iterations are shown below:

**Table 9. Average results of On-field trials.**

Dosage Location	STP Inlet	Equalization Tank		Intermediate Tank		After Caustic Soda Addition	Unit
		0.2	% Change	0.4	% Change		
		40		80			
pH	6.64	6.83	-2.74	3.57	46.21	6.78	--
Alkalinity	235.85	198.45	15.66	0.00	100.00	76.29	mg/L
Phosphate	18.73	1.69	90.96	0.23	98.80	0.18	mg/L
BOD	199.15	95.44	49.84	29.76	83.15	25.69	mg/L
COD	832.15	239.14	71.06	83.53	89.97	72.92	mg/L
TSS	142.47	64.81	53.64	26.33	81.51	21.14	mg/L
TKN	73.25	42.12	42.38	26.84	63.30	24.69	mg/L

1. pH of the sample dropped in the acidic zone up to 3.57 resulting in alkalinity being zero.
2. Phosphate level was brought down below the required target of 0.2mg/L.
3. BOD and COD of the sample was within permissible range of disposal standards

4. TSS and TKN were reduced by more than 80% and 60% respectively.

In summary, the on-field trials were successful in replicating the results obtained in the Jar tests and achieved the target of reducing the Phosphate level below 0.2mg/L.

#### 4. Conclusion

The research study was aimed at reduction of Phosphate levels in the Sewage Treatment Plant. After the raw samples were analyzed for existing parameters, Jar tests were carried on the sewage samples using Alum and Ferric Chloride. Jar tests helped in selection of appropriate coagulating chemical and determining the amount & location of dosage. On-field trials were carried out which were successful in achieving the reduction target of Phosphate levels. Other parameters like Alkalinity, TSS, BOD and COD were also affected by addition of the chemical. Addition of coagulant chemical resulted in drop in pH of the samples and thus alkalizing agent was introduced to maintain the pH of the sewage at the disposal end.

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