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By

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Phosphorus removal from wastewaters: A cost analysis

By Inder Jit Kumar and Nicholas L. Clesceri*

The concentration of phosphorus in our wastewaters has more than doubled during the last two decades and has been cited by some writers as the leading cause for excessive enrichment of the Nation's lakes and streams. Various methods have been proposed to tackle the problems of this cultural eutrophication; one often suggested is to ban the use of phosphate-based synthetic detergents. However, the phosphorus remaining in effluents obtained from treating wastewaters with "no-phosphate" detergents may still be sufficient for algal growth.

An average concentration of total phosphorus in sewage at present is about 10 mg P/l.[1] Estimates of the contribution of phosphorus from detergents vary from 40 to 60 percent. The phosphorus requirement of algae is believed to be in the order of a few micrograms per liter.

However, there is no agreement as to the amount of phosphorus in lake waters which would be limiting to the growth of algae. According to Culp,[2] algal growth is not possible if phosphorus concentrations in water are between 0.01 to 0.03 mg P/l or less and even at 0.3 to 0.5 mg P/l the growth is minimal. On the contrary, Sawyer,[3] summarizing observations made on some Wisconsin lakes, noted that lakes that had an inorganic phosphorus concentration of 0.01 mg P/l or less at the time of Spring turnover did not exhibit algal nuisance problems in the summer season.

Unfortunately, many authors have misinterpreted Sawyer's work; they state Sawyer concluded that a concentration of 0.01 mg P/l or less **at any season of the year** would insure against any nuisance algal situations throughout the growing season. Sawyer felt that phosphorus concentrations in the sewage effluent should be comparable to those of the natural drainage waters of the area. To achieve this goal for lakes and streams almost all phosphorus must be removed from wastewaters.

Removal methods

Phosphorus can be removed from wastewaters by biological, chemical and chemical-biological methods. Assimilation of phosphorus into new cell material generally results in about 20 percent reduction of influent phosphorus at conventional biological treatment plants. Chemical-biological methods which involve the precipitation ("precipitation" used here also includes the removal of phosphorus by adsorption and complex formation) of phosphorus from wastewaters by the addition of chemicals can remove more than 90 percent of influent phosphorus.

All forms of phosphorus, orthophosphates and complex phosphates, both organic and inorganic, are amenable to removal by the addition of chemicals. Chemical treatment can also result in significant reductions in turbidity, BOD, COD and suspended solids and removal to some extent of trace elements, toxic heavy metals and proteinaceous nitrogen. In addition chemical methods afford close control in actual plant operation and give improved purification as regards virus, bacteria and intestinal worms.[4] However, the reductions obtainable are dependent upon the chemical used, the point of application of the chemical and the particular composition of the wastewater.

Chemical precipitants

The choice of chemical precipitant at present is limited to lime and a few salts of aluminum and iron. The specific choice for a particular wastewater will depend on such factors as the cost at the plant site, the quantity required, the availability of handling, storing and feeding equipment, the percent removal desired and the amount and type of sludge produced.

Lime. Lime is considered an inexpensive chemical, but, as reported in the literature, the dosage required is usually high. Its advantage, reportedly, over other chemicals is easy reclamation from sludge by recalcination. Another advantage attributed to the use of lime is that the high pH attained, i.e. about 11 (in tertiary treatment only), may be utilized for nitrogen removal by ammonia stripping if conditions permit. The high pH also helps reduce corrosion of sludge pipes. It has been reported that lime combined with 1 or 2 ppm of $FeCl_3$ yields a readily settleable sludge.[5] The amount of lime required is independent of initial phosphorus concentrations and does not increase, as in the case of other chemicals, when the phosphorus concentration is increased.[6]

Disadvantages attributed to the use of lime include the requirement of above pH 9.5 for phosphorus precipitation, necessitating effluent neutralization

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with CO_2 or an acid before it is discharged into a stream, high dosage requirements and increased amounts of sludge produced. Also, direct dosing into an aeration basin is not possible because of interference with biological activity at high pH.

Aluminum salts. The aluminum salts generally employed in phosphorus removal are aluminum sulfate (alum) and sodium aluminate. Phosphorus removal by alum is optimal at pH 6. Unlike lime, it does not appear to retard biological activity when added directly into the aeration basin. The dosage, directly related to the phosphorus content of wastewater, is usually lower than for lime, and comparatively less sludge is produced. The cost per ton of alum is higher than that for lime, but since the dosages required are normally lower, the cost for removal may be comparable. Though processes for alum recovery are still in the research stage, a feasible system, when found, may reduce the cost of phosphorus removal by alum. Also, alum can be solution-fed.

Iron salts. Iron salts are also used for the removal of phosphorus. Primary consideration has been given to ferric chloride and Fe^{2+} salts. Addition of a small quantity of calcium enhances the removal of phosphate with Fe^{3+} salts.[7]

The chemical dosage in the case of iron salts is low, and the sludge produced is readily settleable, especially when a suitable polymer is used. Fe^{2+} salts require the addition of a small quantity of lime or sodium hydroxide for efficient removal of phosphorus, except where these are added directly into the aeration basin. Availability of waste pickle liquor in steel-producing areas may provide a most economical method to remove phosphorus.

Treatment methods

An extensive review of the methods employed for phosphorus removal is given by Clesceri,[8] Nesbitt,[9] Jenkins et al.,[1] Shindala [10] and Minton and Carlson.[11] However, a brief description of the methods most commonly used is provided below.

Chemical treatment of raw sewage. Often classed as pre-precipitation, this process involves the addition of chemicals to the influent of the primary clarifier. At places where waste treatment is limited to primary treatment only, and in the case of trickling filters, addition of chemicals to the raw sewage is an effective method of removing phosphorus. The only additional facilities required are for chemical storage, feeding and control equipment. Some modifications to sludge handling equipment may be necessary.

The amount of chemicals required, in general, increases exponentially with decreasing phosphorus residual. One recent approach is to decrease the phosphorus concentration in wastewater only to 1 to 2 mg P/l to minimize chemical costs. Theoretically, further reduction in phosphorus concentration is possible with subsequent biological treatment, especially activated sludge; the microorganisms presumably would remove that fraction of phosphorus which requires large chemical dosages for removal, making the process more economical. Schmid and McKinney[6] investigated this process using a complete mixing activated sludge system and obtained 90 percent removal with lime dosage of 150 mg/l. They report that since lower lime dosages are used, the CO_2 produced in the subsequent aeration tanks by microbial action is able to keep the pH near neutral. Recent full scale plant studies conducted for over one year in Ontario, Canada, have confirmed this point and have also shown that the solids can be successfully handled in anaerobic digesters.[12]

Also, a number of laboratory feasibility studies and full scale plant trials have been conducted using iron and aluminum salts. Phosphorus removal of more than 80 percent was achieved with ferric chloride at approximately 14-20 mg Fe/l (42-60 mg of $FeCl_3$ per liter) at several plants. A number of plants in Sweden, Finland, Switzerland and the United States are using alum for pre-precipitation, and dosages are in the range of 7-10 mg Al/l (80-110 mg of $Al_2(SO_4)_3.14\ H_2O$ per liter).

The advantages claimed for pre-precipitation include:

1. Increase in hydraulic and organic capacity
2. Increased efficiency in BOD, COD and suspended solids removal
3. Reduced cost of aeration
4. Better oil, grease and scum removal in primary clarifiers
5. Reduction of corrosion in sludge pipes, when

Table 1. Chemical dosages.

Dosage for 10 mg P/l for 80-90 percent overall removal
Assumption: chemical 70 percent and existing processes 10-20 percent

	Alum $Al_2(SO4) \cdot 14H_20$	Ferric Chloride $FeCl_3$	Lime Ca O
Stoichiometric			
Molar basis	1Al:1P	1 Fe: 1P	—
Weight Basis	0.88 Al:1P	1.8 Fe: 1 P	—
Actual Use			
Molar Basis	1.1 Al to 2.0 Al:1P	1.1 Fe to 2.0 Fe: 1P	—
Weight Basis	0.97 Al to 1.76 Al:1P	1.98 Fe to 3.6 Fe: 1P	—
For 7 mg P/l Metal Ion Required (mg/l)	6.8 Al to 12.3 Al	13.8 Fe to 25 Fe	—
Chemical (mg/l)	75 to 135 as Alum	40 to 73 as $FeCl_3$	150 to 200* as Ca 0

*Lime doses are determined by the amount required to raise the pH to 9.5 or higher and are not related to P concentartion.

**Polymer doses are related to volume of sewage and *not* to P concentration.

Table 2. Buildings and structures.

	Cost in dollars for plant size		
	1 mgd	10 mgd	100 mgd
Soil investigation and site preparations	—	1,000	2,500
Roads and sidewalks	—	1,000	3,500
Process building	—	20,000	40,000
Building fixtures (lighting, heating ventilation, etc. (20 percent of building cost)	—	4,000	8,000
Building equipment (office, lab, etc.)	—	6,000	10,000
Equipment foundations and structures	—	3,000	10,000
	$13,500*	$35,000	$74,000

*Estimated costs for this size plant are to small to be detailed by specific categories.

Table 3. Process Equipment.

Description of item	Basis	1 mgd cost in dollars	Basis	10 mgd Cost in dollars	Basis	100 mgd Cost in dollars
Lime						
Storage silo(s) or tank(s)	30 tons	6,000	150 tons	20,000	2 at 500 tons each	80,000
Belt conveyor 30 in. wide	manual/ mechanical	2,000	30 tph*	5,000	2 at 50 tph each	14,000
Bucket elevator	—	—	30 tph	5,000	2 at 50 tph each	14,000
Screw conveyor 50-100 ft long	0.5 tph	1,000	6 tph	4,000	2 at 12 tph each	10,000
Lime slaker	0.5 tph	1,500	6 tph	6,000	2 at 12 tph each	16,000
Feed bins 2 no.	0.5 ton each	1,000	2 tons each	3,000	5 tons each	5,000
Lime feeder	0.1 tph	800	0.5 tph	2,000	5 tph	6,000
		12,300		45,000		145,000
Alum**						
Storage tank(s)	6,000 gal	3,000	2/16,000 gal each	8,000	250,000 gal	58,000
Insulation or heating arrangement	—	800	—	2,000	—	10,000
Metering and feed pumps	0.5 gpm	600	5 gpm	2,000	40 gpm	8,000
		4,400		12,000		76,000
Ferric Chloride**						
Storage tank(s)	6,000 gal	3,000	2/8,000 gal each	6,000	120,000 gal	45,000
Insulation or heating arrangement	—	800	—	1,500	—	8,000
Metering & feed pumps	0.5 gpm	600	2 gpm	2,000	15 gpm	6,000
		4,400		9,500		59,000
Polymers						
Polymer dispenser	manual	1,000	1 no. automatic polymer dispenser unit	6,000	2 no. automatic polymer dispenser unit	12,000
Transfer pump	2 gpm	200				
Feed tanks	200 gal each	600	2 at 400 gal each	1,500	2 at 2,000 gal each	6,000
Lightning mixer	0.5 hp	400	1 hp	600	2 hp	1,000
Metering and feed pumps	0.1 gpm	300	0.5 gpm	500	5 gpm	1,000
		2,500		8,600		20,000

*tph is tons per hour.

**In actual practice, consulting engineers are usually required to design process equipment to handle either of the two metal salts (alum or ferric chloride).

lime is used as the precipitant

6. No additional structures required, resulting in low capital cost.

Simultaneous precipitation. Phosphorus can be precipitated during biological treatment by adding metal salts directly into the aeration basin of an activated sludge plant. The combined phosphate precipitate and activiated sludge floc is then separated from the effluent in the secondary clarifier. Additional equipment requirements are minimal.

Advantages claimed for this process are:

1. The wastewater has the advantage of some equalization in phosphorus concentration by passage through the primary stage.
2. During biological treatment, polyphosphates are converted to the more easily precipitated orthophosphate form.
3. Seattleability of the activated sludge is improved.
4. Only a small increase in total volume of sludge is produced.
5. No additional structures are required: therefore, capital cost is very low.

Chemical treatment of secondary clarifier effluent. In this process phosphorus is precipitated in a separate operation following conventional biolo-

Table 4. Total capital cost in dollars.

	Basis	Lime			Alum			Ferric chloride		
		1 mgd	10 mgd	100 mgd	1 mgd	10 mgd	100 mgd	1 mgd	10 mgd	100 mgd
Building & structures costs	Table 2	13,000	35,000	74,000	13,500	35,000	74,000	13,500	35,000	74,000
Process equipment Costs for chemical addition	Table 3	12,300	45,000	145,000	4,400	12,000	76,000	4,400	9,500	59,000
Polymer addition	Table 3	2,500	8,600	20,000	2,500	8,600	20,000	2,500	8,600	20,000
Plant piping	10-30 percent of equipment	1,500	5,000	16,000	2,000	6,000	20,000	2,000	6,000	20,000
Plant electrics	15-20 percent of equipment	2,000	8,000	20,000	1,500	4,000	12,000	1,500	4,000	12,000
Instrumentation	15-30 percent of equipment	2,500	7,500	25,000	2,500	7,500	25,000	2,500	7,500	25,000
Sub total (Net capital)		34,300	109,100	300,000	26,400	73,100	227,000	26,400	70,600	210,000
Engineering & construction	25-40 percent of net capital	12,000	30,000	75,000	9,000	21,000	57,000	9,000	20,000	54,000
Modification & start up	5-10 percent of net capital	2,500	8,000	18,000	2,000	6,000	15,000	2,000	6,000	15,000
Spare parts	5-10 percent of equipment	1,000	2,000	10,000	1,000	2,000	7,000	1,000	2,000	7,000
Contingencies		6,000	15,000	35,000	5,000	11,000	30,000	5,000	11,000	30,000
		55,800	164,100	438,000	43,400	113,100	336,000	43,400	109,600	316,000
Consultant's fee	7-12 percent of gross capital	6,700	16,000	36,000	5,500	13,000	31,000	5,500	12,500	29,000
Total capital costs		62,500	180,000	477,000	48,900	126,100	367,000	48,900	121,100	345,000
Capital cost per person (100 gal per capita per day)		6.25	1.80	0.48	4.89	1.26	0.37	4.89	1.21	0.35

gical treatment. Some earlier investigations of phosphorus removal have dealt with this process. It has been found effective and reliable. Removals of over 90 percent are possible and residual phosphorus concentration lower than 1.0 mg P/l can be achieved. Several installations, ranging in capacity from less than 0.3 mgd to greater than 7.5 mgd, are presently in operation in the United States and other countries.

Post-precipitation of phosphorus, as this method is generally called, is accomplished with lime, with iron salts or aluminum salts, or with combinations of these salts. Additional facilities required include flocculation and sedimentation basins, chemical storage and feeding and control equipment.

Cost analysis

Cost figures for phosphorus removal in the literature vary from $2.50 to $110.00 per mil gal (0.25 to 11 cents per 1000 gal). Most of these cost figures are reported in insufficient detail for analysis. In some cases, only the cost of chemicals employed is given; in other cases the labor costs involved are included, and in still others capital and operating costs are taken into account. Another disparity in the reported cost figures is the different degrees of phosphorus removal and the different methods employed. In many cases the disposal costs, if any, for the additional sludge produced have not been considered.

Cost analysis of phosphorus removal must consider capital costs and operating costs: the capital costs should include the cost of additional structures and equipment, and the operating costs should include the debt service, the process and maintenance labor, the chemical costs and the excess sludge disposal. Considerable savings would result from increased hydraulic and organic removal capacities effected by chemical treatment. However, due to lack of any pertinent data in the literature and due to complexity of the calculations, this has not been taken into account in this paper.

Table 5. Chemical and sludge disposal costs (dollars per day).

	Lime			Alum/Ferric chloride*		
	1 mgd	10 mgd	100 mgd	1 mgd	10 mgd	100 mgd
Cost of chemicals @ 80 percent P removal	19.40	187.50	1812.50	23.00	220.00	200.00
Cost of polymers	6.50	60.50	542.10	6.50	60.50	542.10
Excess sludge disposal costs	10.00	100.00	1000.00	5.00	50.00	500.00
(Hauling to land fill, 25 miles one-way trip):	7.30	73.00	730.00	3.65	36.50	365.00
Total	35.90	348.00	3354.60	35.40	330.50	3142.10

*Chemical costs for alum and ferric chloride both calculated at an average cost of $22/million gallons as described on page 23.

Table 6. Operating and maintenance costs.

	Lime (CaO)			Alum $Al_2(SO_4)_3 14\ H_2O$			Ferric Chloride ($FeCl_3$)		
	1 mgd	10 mgd	100 mgd	1 mgd	10 mgd	100 mgd	1 mgd	10 mgd	100 mgd
Total capital costs (dollars)	$62,000	$18,000	$477,000	$48,900	$126,100	$367,000	$48,900	$121,000	$350,000
Operating & maintenance costs (dollars per day)									
Amortization, 5 percent and 20 yrs.	13.70	39.40	104.85	10.70	27.70	80.75	10.70	26.40	76.40
Operating labor $4/hr.									
2 man-hrs/day for 1 mgd	8.00			8.00			8.00		
6 man-hrs/day for 10 mgd		24.00			24.00			24.00	
12 man-hrs/day for 100 mgd			48.00			48.00			48.00
Maintenance labor $5/hr.									
2 man-hrs/day for 1 mgd	10.00			10.00			10.00		
3 man-hrs/day for 10 mgd		15.00			15.00			15.00	
10 man-hrs/day for 100 mgd			50.00			50.00			50.00
Supervision & payroll over-head									
30 percent of operating and maintenance labor	5.40	11.70	29.40	5.40	11.70	29.40	5.40	11.70	29.40
Maintenance materials @ 3 percent of capital/yr.	5.10	14.80	23.25	4.00	10.05	30.15	4.00	10.00	28.70
Electrical Power @ 1.75¢/kwh	1.30	6.30	37.80	1.90	5.60	32.70	1.90	5.00	30.20
Insurance 1 percent of capital/yr.	1.70	4.90	13.00	1.30	3.35	10.05	1.30	3.30	9.60
Total operational and maintenance cost (dollars/day)	$45.20	$116.10	$322.25	$41.30	$97.40	$281.05	$41.30	$95.40	$272.30

The cost of phosphorus removal cannot be generalized for every plant since actual chemical dosage depends not only on the amount of phosphorus in the wastewater influent but also on the characteristics of the carriage water which vary from place to place. Estimates are that chemical costs vary from 40 to 90 percent of the operating costs depending upon the size of the plant, the chemical employed, the point of addition and the concentration to which the phosphorus is to be decreased.

For the purpose of this paper, it is assumed that the influent phosphorus content is 10 mg P/1 and an 80 percent reduction is desired, the chemical removing 70 percent (7 mg P/1) and the existing treatment processes removing 10 percent. Phosphorus removal standards set by most states at present require an overall removal of 80 percent or more. The concept of probability which is often employed in sewage treatment processes is also being employed in phosphorus removal standards in Ontario. Their present standard has been set at 80 percent phosphorus removal 80 percent of the time. A range in chemical dosages is given in Table 1.

There will be locations where one or the other salt will have a geographic advantage. Since the purpose of this paper is to show order of magnitude costs, the chemical costs including some delivery charges will be generally between $18 and $26 per mil gal treated. Therefore, an average chemical cost of $22 per mil gal will be used for both metal salts in this study.

When lime is used even in a one mgd plant, the quantities are such that bulk shipment would probably be indicated. A dosage of 150 mg/1 and a bulk delivered price of $30 per ton of calcium oxide (CaO) will be used in estimatng costs. Polymer costs vary with quantity purchased from $1.30 to $1.60/lb; however, an average delivered price of $1.45 per pound will be used in the cost analysis.

The average chemical and polymer costs cited above are for a 10 mgd plant. In calculating the costs for 1 mgd and 100 mgd plants an allowance has been made for the scaling factor in the quantity of chemicals required at these plants.

While other precipitants such as sodium aluminate, ferric sulfate, ferrous chloride and ferrous sulfate could be used for phosphorus removal, this cost analysis will deal only with lime, alum and ferric chloride, and polymer, the chemicals most often used.

Capital and operating costs calculated in this paper are mainly for pre-precipitation. Since simultaneous precipitation and subsequent precipitations differ from pre-precipitation only in the point of application of chemicals, these costs may apply to these processes also, if chemical dosages prove to be the same as assumed for pre-precipitation. Lime is usually not recommended for use in simultaneous precipitation and when it is used in subsequent precipitation its dosage may be as much as twice the amount shown in Table 1. The operating costs will, therefore, be considerably higher than those for pre-precipitation.

Capital costs have been computed in Tables 2 through 4. Table 2 lists the cost of buildings and structures. The building houses the feeding and control equipment as well as the lab facilities. Building costs have been calculated at $20/sq ft. Capital cost estimates for the 1 mgd plant were estimated by Standard Engineering costing methods. However, in actual practice, existing facilities may be used and a much lower capital expense would be required.

Table 3 lists separately the cost of process equipment required for phosphorus removal, by lime or alum or ferric chloride. The cost of storage tanks and pumps has been taken from various equipment manufacturers. The size of the storage tank depends on the maximum rate of consumption, the shipping time required for delivery and the size of the tank car or truck making deliveries. In view of efficient transport facilities and the availability of chemicals upon short notice, 10 days' storage is considered adequate especially for larger plants. Lime involves elaborate arrangements for loading the storage silos and subsequent feeding. Enclosed conveyors are provided at plants of more than 5 mgd capacity. At smaller plants manual and mechanical arrangements may have to be made for economical reasons. Feed pumps are provided to deliver at least 2 times the average chemical dosage. Equipment for polymer addition is also included in this table. In view of the small quantity of polymers required, it is assumed that the polymers would be stored in their shipping containers. Costs may vary somewhat depending on the location of the treatment plant and the market conditions.

Cost of services, such as plant piping and plant electricity, is given in Table 4. These costs have been calculated on the basis of certain percentages of the installed equipment, a procedure usually employed in preliminary estimates. The exact costs would depend on the location of the process building relative to the other structures at the plant, location of the storage tanks and nearness of the existing utilities, i.e. water and electrical lines. Other items included in Table 4 are engineering and construction,

Table 7. Total cost summary ($/day).

	Basis	Lime (CaO) 1 mgd	10 mgd	100 mgd	Alum $Al_2(SO_4)_3 \cdot 14\ H_2O$ 1 mgd	10 mgd	100 mgd	Ferric Chloride ($FeCl_3$) 1 mgd	10 mgd	100 mgd
80-90 percent P removal										
Chemical and sludge disposal costs	Table 5	35.90	348.00	3354.60	34.50	330.50	3142.10	34.50	330.50	3142.10
Operating & maintenance costs	Table 6	45.20	116.10	322.25	41.30	97.40	281.05	41.30	95.40	272.30
Total treatment costs/day		81.10	464.10	3676.85	75.80	427.90	3423.15	75.80	425.90	3414.90
Total treatment costs, cents per 1,000 gallons		8.11	4.64	3.68	7.58	4.28	3.42	7.58	4.26	3.41
Total treatment costs per person per year (100 gals. per capita per day)		2.96	1.69	1.34	2.77	1.56	1.25	2.77	1.56	1.25

modification and start up and spare parts. The consultant's fee has been calculated on the basis of percentages given by Smith,[13] namely 7 to 12 percent of gross capital costs.

The per capita capital costs decrease as plant size increases. Total capital costs (detailed in Table 4) range from a high of $6.25 per person in the case of lime treatment for a 1 mgd plant, to a low of about $0.35-0.37 per person in the case of metal salts for a 100 mgd plant. The capital costs are essentially equal in the case of alum and ferric chloride.

The costs of chemicals and excess sludge disposal are given in Table 5. Disposal costs for hauling the lime sludge produced by a lime dosage of 350 mg/1 to a landfill, 25 miles one-way, is given at 0.67 cent per 1000 gal of raw sewage (Report No. TWRC-9, June 1969, FWPCA, Cincinnati, Ohio). When updated to July 1972, using the ENR Index, sludge disposal would cost 1.0 cent per 1000 gal. This latter estimate does not appear to be excessive even for the lime dosages assumed in this cost analysis. The excess sludge disposal cost for 80 percent P removal by lime, therefore, is assumed to be 1.0

cent per 1000 gal. The amount of excess sludge produced by alum or ferric chloride is presumably about half of that produced by lime for the same percent P removal.

Operating and maintenance costs are listed in Table 6. Debt service has been computed as 8.024 percent of the total capital cost per year. This corresponds to interest at 5 percent over a 20 year period. Operating labor is estimated at 2 man-hr/day for a 1 mgd plant, 6 man-hr/day for a 10 mgd plant and 12 man-hr/day for a 100 mgd plant. Maintenance labor is similarly estimated at 2 man-hr/day, 3 man-hr/day, and 10 man-hr/day for 1 mgd, 10 mgd and 100 mgd plants, respectively. Supervision and payroll overheads are taken as 30 percent of the operating and maintenance labor. Maintenance materials are taken as 3 percent of the capital costs per year. The cost of electrical power has been calculated at 1.75 cents/kwhr and insurance at 1 percent of the capital cost per year.

At the dosages assumed, the total operating costs (Table 7) vary from 3.4 to 8.1 cents per 1000 gal for 80 percent phosphorus removal, depending on the plant size and the method of treatment.

A comparison is made between the capital and operating costs for phosphorus removal and those of a conventional activated sludge plant (Table 8). It is seen that incorporation of phosphorus removal will increase the capital costs at a 10 mgd activated sludge plant by less than 3 percent and the operating costs by about 23 percent.

Operating costs for phosphorus removal at a 1 mgd plant are comparatively high. This is because the labor costs account for more than 30 percent of the total cost. In the case of 10 mgd and 100 mgd plants, the labor costs are less than 12 percent and 4 percent of the total cost, respectively. Automatic monitoring of phosphorus and automatic dosing of chemicals geared to the phosphorus content and changes in flow rate would reduce the operating costs especially for larger plants. Unfortunately, the monitoring instruments available at present determine only the orthophosphate content of wastewater and not total phosphate. One way of overcoming this deficiency would be to establish an appropriate relationship between ortho and total phosphates.

The per capita cost of phosphorus removal per year varies from $1.25 to $2.96 for 80 percent removal, depending upon the size of the plant. These cost figures pertain to the phosphorus removal at the existing plant by pre-precipitation and by simultaneous precipitation or subsequent precipitation if the chemical dosage is the same.

Post-precipitation of phosphorus is an advanced treatment step and requires additional clarifiers. The approximate cost of additional clarifiers will be $35,000, $180,000 and $1.1 million for 1 mgd, 10 mgd, or 100 mgd plants, increasing the capital costs per person by $3.50, $1.80, $1.10, respec-

Table 8. Cost comparison of phosphorus removal at a conventional activated sludge plant, 10 mgd.

	Capital costs	Operating costs
Activated sludge plant*	$4,500,000	18.5 cents/1000 gal
Phosphorus removal (metal salts)	125,000	4.27 cents/1000 gal
Increase in cost on additional percent P removal facilities	3 percent	23 percent

*From Smith[13] adjusted to July 1972

tively. The debt service and the operating costs will also increase. Total operating costs for post-precipitation with alum or ferric chloride are estimated at 0.75 cent/1000 gal to 1.5 cents/1000 gal, in addition to those given in Table 7, depending on the size of the plant. Lime dosages in post-precipitation, depending upon alkalinity of the wastewater, may be as much as twice the dosages shown in Table 1. The effluent also needs neutralization. The cost of treatment with lime will, therefore, be increased considerably.

For economic reasons it is suggested that post-precipitation of phosphorus should be employed only when other precipitation methods are not capable of reducing phosphorus content to the desired level. Being the last step in the treatment system, post-precipitation facilities can be added at any time if phosphorus removal laws become more stringent.

Summary

Recommendation of any specific treatment method for phosphorus removal could be done only after actual laboratory tests on the particular wastewater from which phosphorus removal is desired. The authors want only to emphasize that phosphorus is amenable to removal by chemical treatment to any degree desired and that no sophisticated plants are required for this purpose. Phosphorus can be removed at existing treatment plants by providing only the storage, feeding and control facilities for chemical addition. The approximate cost of reducing the influent phosphorus of 10 mg P/l to 2 mg P/l (80 percent removal) would range from 3.5 cents/1000 gal to 8 cents/1000 gal, depending on the plant size and the method of treatment. ■

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