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Process Optimization of Chemical Phosphorus Removal in Wastewater Treatment Facilities

Jega Jeganathan, Ph.D., P.Eng., R.V. Anderson Associates Limited

Phosphorus, one of the nutrients in municipal wastewater, needs to be removed because high concentrations of phosphorus lead to eutrophication in receiving water of phosphorus lead to eutrophication in receiving waters. Human excreta, food additives, detergents, corrosion inhibitors, and industrial discharges are the main sources of phosphorus compounds in sewage. Typical phosphorus concentrations in raw sewage are provided in Table 1.

The removal of phosphorus in conventional secondary sewage treatment can be accomplished through biological uptake and sedimentation. However, removal efficiencies by these processes are fairly low. In general, primary sedimentation removes about 10% of the phosphorus content of raw wastewater. Conventional secondary treatment further reduces about 10-20% by biological uptake. If the treatment facility includes anaerobic digestion process for sludge handling, phosphorus would be returned in recycle streams, which limit overall phosphorus removal through the secondary treatment. Accordingly, conventional secondary effluent will

have phosphorus content of 3-15 mg/L. Additional phosphorus reductions can be achieved by chemical precipitation, enhanced biological phosphorus removal filtration, or a combination of these technologies. Based on the methodology selected, nominal reduction to almost complete removal of phosphorus is possible.

Chemical precipitation is a well-known technology for phosphorus removal from municipal sewage. Chemical precipitation is a two-step process: 1) adsorption of soluble (ortho) phosphate from the sewage into metal hydroxide floc, and 2) separation of the metal hydroxide/phosphate floc from the liquid phase by settling/clarification or by filtration. A variety of metal salts are being used for the adsorption of soluble phosphate; however, the common chemicals are aluminum sulphate (alum), ferric chloride, and ferrous chloride (pickle liquor). The theoretical stoichiometric ratios necessary for phosphorus removal using the above-mentioned chemicals are presented in Table 2. The choice and type of chemical selection depends on various factors, including the sewage characteristics, location of facility,

chemical form and cost, facility's preference, chemical availability, and delivery method.

Chemical precipitation process configuration is divided by groups according to dosage point and way of precipitation. Basic process configurations (WEAO, 2010) are as follows:

- i) Pre-precipitation
- ii) Co-precipitation
- iii) Post-precipitation
- iv) Multiple points

Pre-precipitation process provides phosphorus removal in the primary clarifiers, which is beneficial for reducing organic loading to the secondary treatment. However, too much reduction in phosphorus in the primary treatment may lead to nutrient deficiency in the subsequent biological process. Co-precipitation process, a common method in Ontario, provides phosphorus removal in the secondary clarifiers, where chemical is added directly to the bioreactor or to the inlet/outlet of the bioreactor. This method provides sufficient contact time for the reaction. Post-precipitation process provides phosphorus removal in the tertiary treatment processes, though it is usually combined with other process configurations. Multiple points configuration combines two or more of the aforesaid processes to provide flexibility and control of the process, as well as to produce an optimal operating point with respect to chemical dosages and sludge production (WEAO, 2010).

Metal salt addition at multiple points is expected to be the best overall phosphorus removal mode, however, a single point may be sufficient for lower phosphorus reduction. The added advantage of multiple points configuration is that phosphorus removal may be accomplished with as much as 20% less chemical (WEF 2005). In addition, the treated

TABLE 1 – Typical phosphorus content of raw sewage (adapted from WPCF, 1983)

	Concentration as P (mg/L)	Phosphorus generation (kg/cap/yr)
Organic	2-5	0.3-0.6
Inorganic	4-15	0.5-1.2
Total	6-20	0.8-1.8

TABLE 2 – Stoichiometric ratios for metal salts (adapted from WEF, 2005)

Chemical name	Chemical formula	Molecular weight (g)	Stoichiometric ratio (chemical:P)
Aluminum Sulphate	$Al_2(SO_4)_3 \cdot 14H_2O$	594	10:1
Ferric Chloride	$FeCl_3$	162	5:1
Ferrous Chloride	$FeCl_2$	127	6:1

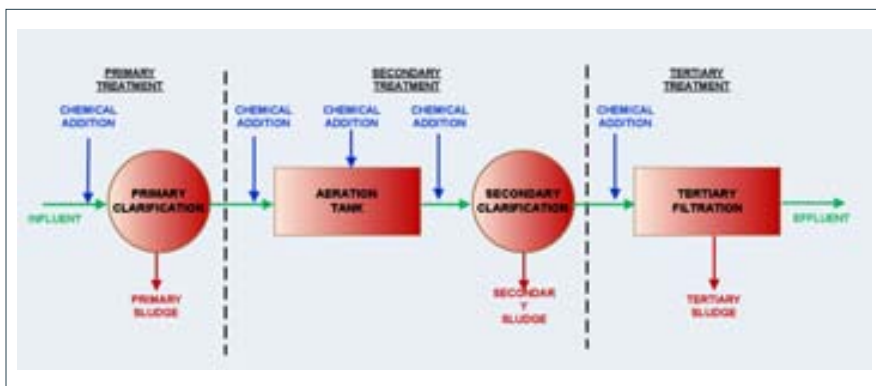


FIGURE 1: Alternative locations for chemical addition in sewage treatment facilities

effluent will have lower phosphorus concentration, as some of the phosphorus has been removed prior to the secondary treatment.

Figure 1 illustrates various locations for chemical addition in sewage treatment facilities. Generally, the location of dosing point(s) is determined by bench/pilot/full-scale studies, past experience, or the facility's preference. Moreover, the optimum point(s) for chemical addition is facility-specific because it depends on the characteristics of the raw sewage, type of biological treatment process employed, physical structure, and mechanical equipment used in the facility. Alkalinity, pH, trace elements, and ligands in the sewage (Metcalf & Eddy, 2003) may also affect the dosage requirements.

Process optimization can provide

sufficient information needed to conduct cost estimation and impact evaluation of sludge production on sludge handling and disposal processes. Jar tests are normally used as an optimization tool to identify the suitable metal salt, optimum chemical dosage, contact time, and intensity of mixing (WEAO, 2010). Conducting a jar test is always advisable when the effluent phosphorus limit is 0.5 mg/l or less. The possible variables for optimization of chemical phosphorus removal are provided in Table 3.

The performance data to achieve chemical phosphorus removal from selected wastewater treatment plants in Ontario is shown in Table 4. As seen from the table, most of the treatment facilities have achieved phosphorus removal of 80-99%.

The Duffin Creek Wastewater

Pollution Control Plant (WPCP) undertook a process optimization program for the expansion project (Jeganathan *et al.*, 2008). The existing rated capacity of the facility is 420 MLD and will be upgraded to 630 MLD during the Stage 3 expansion. The existing plant is required to meet an annual average phosphorus compliance limit of 1.0 mg/L. The new limits established through an EA process reduce this value to 0.8 mg/L on a monthly basis and, ultimately, to 0.5 mg/L on an annual average basis. The existing plant employs ferrous sulphate as a single-point dosage in the aeration tank at a rate of about 10 mg/L as Fe. As part of the optimization program, a study was conducted to evaluate the feasibility of using dual-point additions with ferric chloride to improve phosphorus removal performance. This study was conducted in two stages: (1) field bench-scale treatability study to establish design parameters including a range of iron dosage requirements and removal efficiencies, and (2) process modelling to determine the optimal iron dosages and overall plant performance.

The treatability study confirmed that dual-point additions are feasible prior to the primary clarifier and secondary clarifier, predicting bench-scale phosphorus removal efficiencies from 60-80% for iron dosages from 6-10 mg/L. Further, process modelling showed that dual-point additions

TABLE 3 – Optimization of chemical phosphorus removal (adapted from WEAO, 2010)

Parameter	Methods to optimize
Chemical(s) used	Use jar testing to test a variety of metal salts and/or polymers to ensure that the most appropriate combination of chemicals are used for the process and sewage characteristics.
Chemical addition location(s)	In processes in which a single-point addition is used, adding chemicals at multiple locations could improve phosphorus removal as well as lower chemical usage. Full-scale testing is the best method to determine the appropriate locations for chemical additions. The optimum locations are dependent on the treatment plant configuration.
Chemical dosage	Jar testing should be used to predict the most appropriate chemical doses. For multi-point chemical additions, the jar testing should reflect the sewage characteristics and conditions at the chemical addition location.
Control of chemical dosing	For sewage treatment plants with high variability in flows, chemical dosing by flow-pacing can be used to ensure that the applied chemical dosages are not over or under the required amount. Flow proportioning of chemical feed rates can reduce chemical costs and sludge production significantly. In addition, online equipment can be used to continuously measure the orthophosphate concentration for process control.
Chemical contact time	Use jar testing to optimize the contact time required between the waste stream and the chemical to ensure optimal precipitation, flocculation, and settling of the precipitated solids.
Mixing	Use jar testing to test the current mixing regime to ensure that it is optimized. A high mixing intensity can result in floc destruction and a low mixing intensity can result in poor contact between the waste stream and chemicals.
pH	Adjustment of the pH could be required to ensure that the pH does not have an impact on phosphorus precipitation. The impact of pH on precipitation depends on the addition point as well as the chemicals used.

can achieve design objective of 0.35 mg/L, with 10 mg Fe/L added into the primary clarifier and 6 mg Fe/L added into the secondary clarifier. Process modelling also proved that dual-point additions improve overall plant performance, specifically, reduction in WAS production as much as 30%, may improve dewaterability as well as lower polymer consumption, and reduce in-process oxygen requirements in the aeration tanks as high as 9%.

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TABLE 4 – Chemical phosphorus removal performance of selected wastewater treatment facilities in Ontario

Treatment facility	Location	Treatment process	Chemical used	Dosing point	Rated ADF	Raw TP	CofA effluent limit (mg/L)	CofA effluent limit (kg/yr)	Removal efficiency	Source
Uxbridge Brook WPCP	Uxbridge Township	extended aeration + tertiary filtration	Alum	aeration tanks inlet	5,221	4.2	0.15	28500	96%	XCG, 2010
Beaverton WPCP	Township of Brock	extended aeration + tertiary filtration	Alum	aeration tanks inlet + upstream of tertiary filters	4,550	2.3	0.30	19000	87%	
Schomberg WPCP	Schomberg	extended aeration + tertiary filtration	Alum	aeration tanks inlet and outlet	2,055	7.3	0.10	7500	99%	
Sutton WPCP	Sutton	SBR + tertiary filtration	Alum	aeration tanks inlet + upstream of tertiary filters	3,412	3.9	0.18	22400	95%	
Mount Albert WPCP	Town of East Gwillimbury	extended aeration + tertiary filtration	Alum	aeration tanks outlet + upstream of tertiary filters	2,040	5.9	0.10	7500	98%	
Barrie WPCP	City of Barrie	UNOX + RBC + tertiary filtration	Alum	grit tank inlet + aeration tanks inlet + RBC outlet	76,000	5.5	0.18	5,00100	97%	
Bradford WPCP	Town of Bradford West Gwillimbury	extended aeration + SBR + tertiary filtration	Alum	aeration tanks inlet+ upstream of tertiary filters	17,400	3.8	0.11	74700	97%	
Innisfil WPCP	Town of Innisfil	extended aeration + tertiary filtration	Alum	aeration tanks inlet+ upstream of tertiary filters	14,370	2.5	0.30	80300	88%	
Orillia WTTC	City of Orillia	conventional activated sludge	Alum	upstream of primary clarifiers + aeration tanks	27,300	3.9	0.30	2,99300	92%	
Hespeler WWTP	Cambridge	extended aeration	Alum	upstream of secondary clarifiers	9,320	4.9	1.00	3,39450	80%	RVA, 2010
Welland WWTP	City of Welland	conventional activated sludge + tertiary filtration	Ferric Chloride	aeration tanks outlet	54,550	2.4	1.00	-	58%	RVA, 2011