

IMPACT OF CHEMICALS ADDITION IN WATER/WASTEWATER TREATMENT ON TDS CONCENTRATION AND SLUDGE GENERATION

Jurek Patoczka, PhD, PE
Hatch Mott MacDonald
27 Bleeker Str., Millburn, NJ 07041
(973) 912 2541
jurek.patoczka@hatchmott.com

INTRODUCTION

With progressively more stringent limits and expanding list of controlled parameters wastewater treatment plants increase their dependency on treatment chemicals. Chemicals are used to precipitate phosphorus and heavy metals, to improve flocculation/settling, for disinfection and for pH control, among others. At the same time, in some states (such as New Jersey) regulators are beginning to enforce effluent TDS limits based on the 500 mg/L in-stream freshwater quality criterion. For plants with limited dilution in the receiving stream, use of chemicals places additional strain on the ability of the plant to meet its existing or future TDS limit. In some other systems, typically industrial, which rely on reused water, use of chemicals contributes to build-up of the inert dissolved solids.

The paper analyses theoretically expected TDS changes resulting from use of typical chemicals and from biological treatment. This is compared with the experimental data from full-scale facilities and from bench tests. Sludge generation effects are also discussed with supporting data.

THEORETICAL EFFECT OF CHEMICALS ON TDS

The expected impact on TDS from the addition of various chemicals is derived from underlying stoichiometry. These effects range from straightforward, as is the case of chlorination/dechlorination chemicals and neutralization with caustic or acid, to more complex, when the effect of alum or ferric salts addition on TDS depends upon the stoichiometric excess ratio in relation to orthophosphates. Similarly, use of bicarbonate could have varied impacts depending upon alkalinity, hardness and pH. The impact of aluminum or ferric salts and chlorination/dechlorination chemicals will be also affected by a desired neutralization level. The theoretical conversion factors developed for most common chemical addition cases are summarized in Table 1.

Table 1. Conversion factors for TDS increase from Chemical Addition

Chemical/Process	TDS increase mg/L per mg/L of chemical added
pH adjustment with Caustic	0.575
pH adjustment with Sulfuric Acid	0.980
Alum ⁽¹⁾ for stoichiometric phosphorus precipitation (as alum orthophosphate), w/o neutralization	0.165
Excess alum (precipitating as aluminum hydroxide), w/o neutralization	0.485
Typical alum application for chemical P removal (at 3:1 excess alum to phosphorus stoichiometric rate), w/o neutralization	0.378
Typical alum application for chemical P removal (at 3:1 excess), with full neutralization with caustic	0.533
Chlorine w/o neutralization	1.00
Sulfur Dioxide Dechlorination w/o neutralization	1.50
Neutralization with Sodium Bicarbonate (pH in 4.6 to 8.3 range, hardness > alkalinity)	0.631
Neutralization with Sodium Bicarbonate (pH < 4.3)	0.274
Neutralization with Sodium Bicarbonate (pH >8.3)	0.476
Neutralization with Lime (pH 4.6 - 8.3)	1.35
Neutralization with Lime (pH < 4.6)	0.540
Neutralization with Lime (pH >8.3, alkalinity > hardness)	-1.35 ⁽²⁾
Neutralization with Lime (pH >8.3, hardness removed)	1.00

NOTE: TDS impacts from neutralization with lime and bicarbonate include effect of bicarbonate breakdown during TDS analysis

(1) - Alum dose expressed as $\text{Al}_2(\text{SO}_4)_3 \cdot 14\text{H}_2\text{O}$

(2) - Lowering of TDS due to lime softening

TDS IMPACTS DURING CHEMICAL PHOSPHORUS REMOVAL

Of particular interest for many dischargers is the impact on TDS from the addition of large doses of aluminum or ferric salts needed for phosphorus reduction to low levels. Table 2 compares the expected TDS impact in a range of alum doses (and the resulting residual phosphorus concentrations) with the experimental data, indicating a good agreement. This is also illustrated on Figures 1 and 2. Use of chemicals such as polyaluminum chloride and polyaluminum hydroxychloride could result in a smaller or even negligible increase in TDS, partially due to the smaller (or none) need for neutralization, with, however, a premium chemical cost.

Table 2. TDS Impacts from Alum Use for Phosphorus Removal

Parameter	Sample 1				Sample 2			
	0	30	60	120	0	30	60	120
Alum Dose, mg/L	0	30	60	120	0	30	60	120
Stoichiometric ratio Al:P (applied)	-	3.2	6.4	12.8	-	1.1	2.2	4.4
Residual Total Phosphorus, mg/L	0.978	0.098	0.126	0.036	2.87 ⁽¹⁾	0.307	0.079	0.018
pH after Alum Addition	7.27	7.04	6.64	5.35	6.76	6.43	5.7	4.91
TDS (after adjustment to original pH with caustic), mg/L ⁽²⁾	466	480	497	535	431	440	455	495
Measured TDS Increase (TDS/Alum Dose)	-	0.47	0.52	0.58	-	0.29	0.41	0.53
Theoretically Expected TDS Increase (TDS/Alum Dose)	-	0.50	0.52	0.53	-	0.41	0.48	0.51

(1) - Filtered

(2) - Measured by a conductivity meter calibrated with gravimetric TDS for this specific wastewater

TDS Changes During Biological Treatment

- Soluble organics (measured as TDS in raw wastewater) are mostly degraded, incorporated into biomass or converted into CO₂.
- Generated CO₂ could be stripped, captured as alkalinity or assimilated by nitrifiers.
- Inorganic salts will be released during degradation of organic matter in dissolved and particulate form, which contain inorganic molecules.
- Released metabolic bacterial byproducts will contribute to TDS.

Figure 1. Expected and Measured TDS Changes during Phosphorus Precipitation, Wastewater Sample A

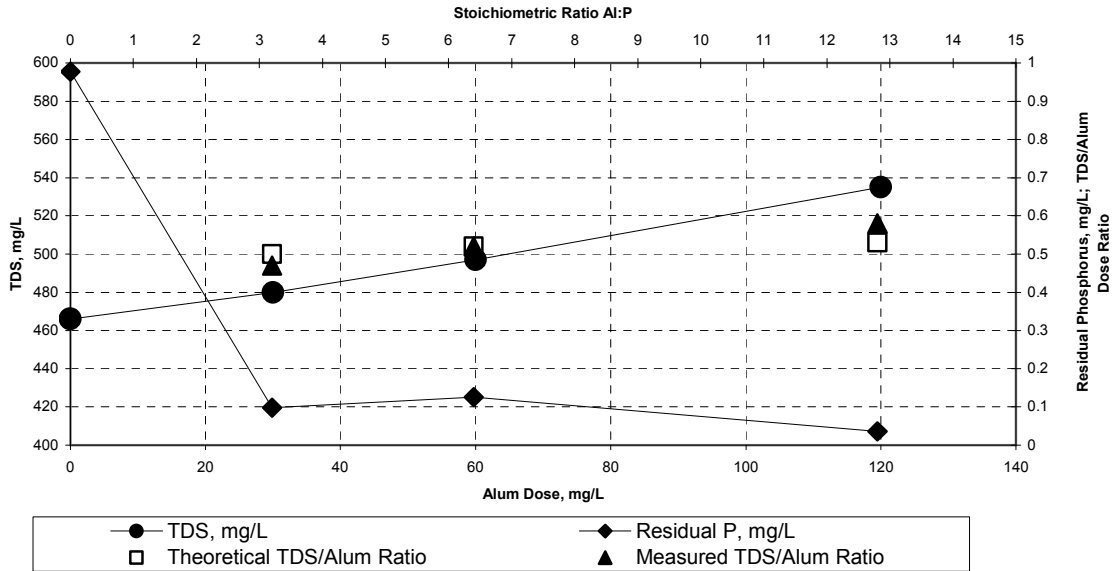
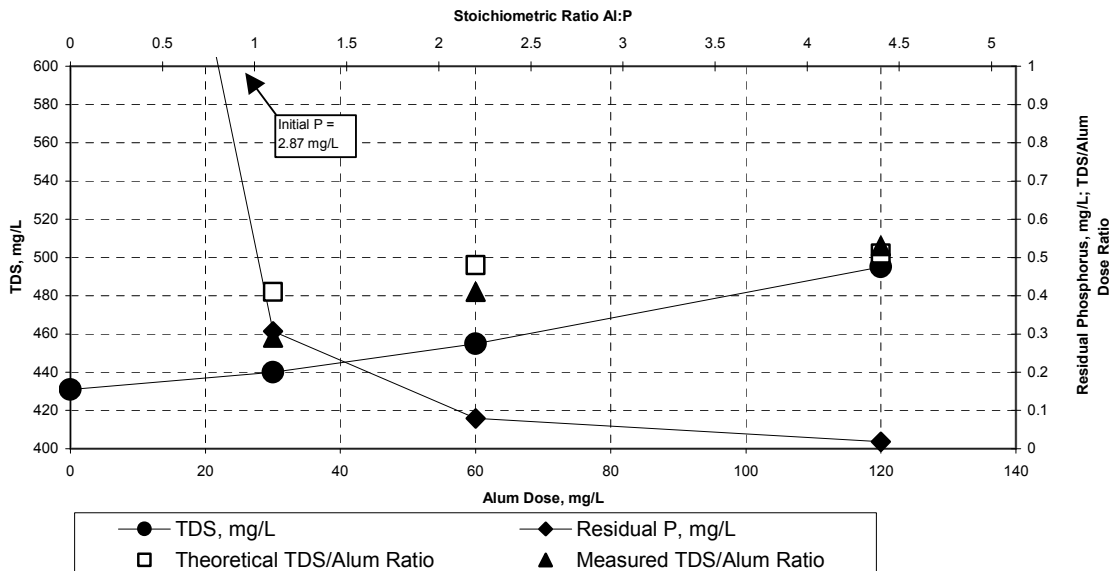


Figure 2. Expected and Measured TDS Changes during Phosphorus Precipitation, Wastewater Sample B



The typical ratio of BOD₅ to concentration of soluble, organic matter (which is causing the biological oxygen demand) is in the range 1.0 to 2.5, with an approximate average of 1.75. The soluble BOD₅ reduction during domestic wastewater treatment is typically in the 60 to 100 mg/L range, with 80 mg/L average. Consequently, this should result in a TDS reduction of approximately 35 to 60 mg/L. Nitrification and conversion of organic phosphorus into orthophosphates could increase TDS by 40 to 60 mg/L. However, alkalinity (bicarbonate) consumption during nitrification will lower TDS. Denitrification, due to the release of alkalinity will have a minor effect on the effluent TDS. In summary, the net reduction of TDS during conventional biological treatment (with nitrification) of domestic wastewater without chemical addition is estimated to be in 10 to 40 mg/L range.

Table 3 provides data from several full scale facilities, where the calculated and measured changes in TDS resulting from biological treatment and addition of chemicals are compared. A satisfactory agreement is seen indicating that the TDS impacts of combined biological treatment and chemical addition could be reliably predicated.

Table 3. Comparison of Measured and Calculated TDS Changes During Treatment

Wastewater Treatment Plant	1 ⁽¹⁾	2	3
Parameter, mg/L			
Potable Water TDS	234	198	-
Raw Wastewater TDS	474	457	410
TDS Increase From Potable Water Use	237	259	-
Final Effluent TDS	434	501	517
Measured TDS Increase During Wastewater Treatment	-31 ⁽¹⁾	44	107
Chemical dose added:			
Alum	-	86	130
Caustic	-	44	40
Lime	-	-	41
Cl ₂	2	-	1
SO ₂	1	-	0.5
TDS Increase Expected from Chemical Addition	3.5	51	113
TDS Increase Expected from Biological Treatment (estimated)	-20	-20	-20
Combined, Expected TDS Increase During Wastewater Treatment	-17	31	93

1) Median values

SOURCE WATER EFFECTS

Long term data from two different service areas indicated that an increase in TDS during potable water use was in 230 to 260 mg/L range, which is consistent with literature sources. For one of the plants, the most significant problem in evaluating its ability to meet future TDS permit limit was a significant variability in potable water TDS, which originated from a large public supplier with varying water sources.

Discrete sampling of the selected sewer lines revealed that significant spikes in TDS concentration were common, typically at night. Ion speciation indicated that the increase was due to sodium chloride, which is consistent with the suspected source, namely residential and institutional water softeners. These softeners typically operate on timers with a periodical regeneration cycle set at night and the regeneration brines contribute an estimated 30 mg/l of additional TDS to raw wastewater at the location investigated.

INERT SLUDGE GENERATION AND ITS PROCESS IMPACTS

Addition of chemicals for flocculation or removal of phosphorus will result in the generation of additional, inert sludge, which will get incorporated into the overall waste sludge from the facility. Table 4 presents theoretical TSS generation coefficients (lb of extra dry solids per lb of applied chemical) based on the simplifying assumption of straight metal hydroxides and phosphates precipitation.

Table 4. Conversion factors for TSS increase from Use of Alum and Ferric

Chemical/Process	TDS increase, lb (or mg/L) per lb (or mg/L) of chemical added ⁽¹⁾
Alum precipitating as aluminum orthophosphate	0.411
Excess alum (precipitating as aluminum hydroxide)	0.263
Typical alum application for chemical P removal (at 3:1 excess alum to phosphorus stoichiometric rate)	0.312
Ferric chloride precipitating as ferric orthophosphate	0.929
Excess ferric (precipitating as ferric hydroxide)	0.658
Typical ferric application for chemical P removal (at 3:1 excess alum to phosphorus stoichiometric rate)	0.748

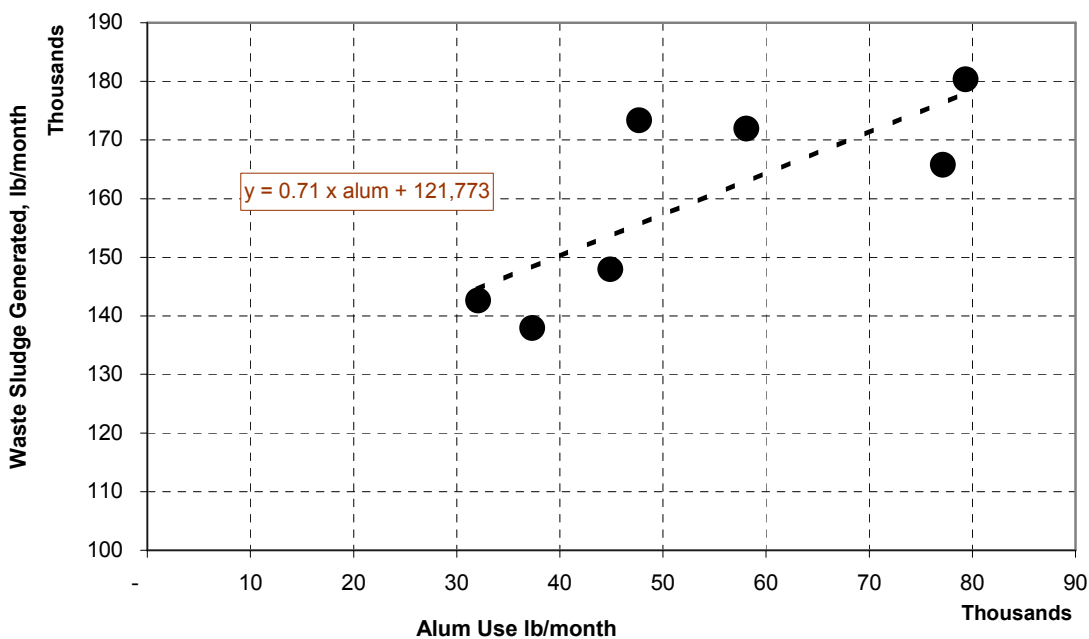
(1) – Alum dose expressed as $\text{Al}_2(\text{SO}_4)_3 \cdot 14\text{H}_2\text{O}$; ferric as FeCl_3

In reality, more complex, hydrated metal hydroxides are precipitated, which would result in somewhat higher extra sludge generation coefficients than presented in Table 4. Moreover, due to the coagulating properties of alum and ferric, additional sludge will be generated by coagulation of colloidal matter.

When evaluating relative effects of alum and ferric, the chemicals should be compared on metal equivalent basis. On such basis, ferric dose is approximately twice as effective as alum dose expressed in customary units (see Table 4 footnote). This should be factored in when comparing alum and ferric impacts on both TSS and TDS.

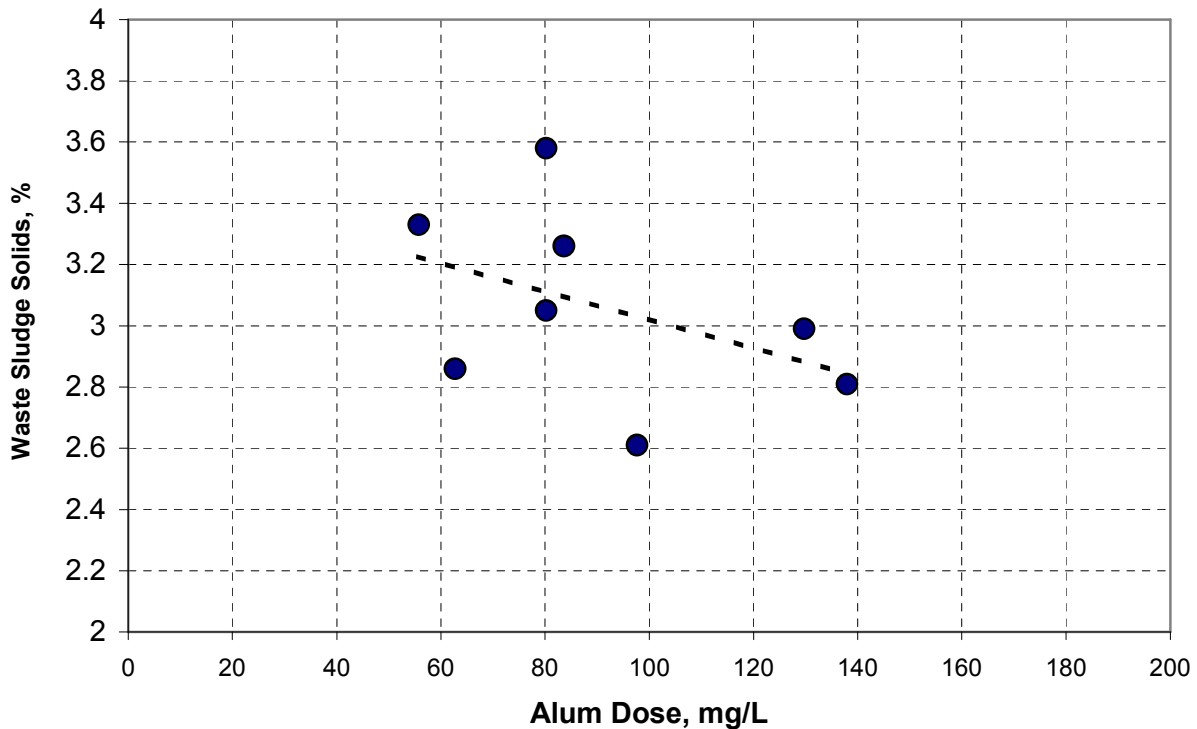
Figure 3 presents waste sludge generation data from a full scale plant as a function of alum addition. The correlation indicates the sludge generation coefficient to be approximately 0.7, which is consistent with the discussion above.

Figure 3. Correlation between alum addition and waste sludge generation at an activated sludge plant.



In addition to generating additional waste sludge in terms of dry mass, chemical sludge can change thickening properties of the commingled sludge. At one NJ facility (no primary clarifiers), use of alum to meet 1 mg/L phosphorus limit caused a decrease of percent solids from gravity belt thickener from 6% to 4% and decreased the acceptable sludge loading to the belt thickener. Use of two different polymers only partially improved the situation. At another, similar facility in the same township, such detrimental effects from alum were not observed. Figure 4 presents data from yet another facility, where an increased alum addition caused lowering of percent solids in the underflow from gravity thickener.

Figure 4. Correlation between Alum Dose and Percent Solids in Gravity Thickener



The average lowering of percent solids was from 3.2 % to 2.8 % (combined primary and secondary sludge), when alum addition was increased from 60 to 120 mg/L.

Yet another consideration is potential impact of inert, chemical sludge on plant's nitrification performance. When alum is added to the aeration basin effluent, as is commonly practiced, the precipitated phosphorus is incorporated into the biomass and gets recycled to the aeration basin with the clarifier underflow. Consequently, the inert, chemical sludge resides in the aeration tankage for the period commensurable with the system's sludge age. This accumulation increases the inert fraction of the mixed liquor and leaves less room for the active biomass, in particular for nitrifiers. A simple mass balance confirmed by BioWin simulations indicates that alum addition required to achieve 0.2 mg/L phosphorus limit may require a 40% or more increase in MLSS concentration in order to maintain the same sludge age. If final clarifiers cannot reliably accept the increased MLSS levels (solids loading), a commensurable lowering of the sludge age to maintain the same MLSS levels may be necessary. While some extended aeration facilities, such as most oxidation ditches, could usually accommodate the described MLSS impacts, other plants, with limited hydraulic retention time, may have a problem, particularly in winter.

Conclusions:

- While biological treatment alone will somewhat lower wastewater TDS, addition of chemicals will almost always increase TDS.
- Theoretically predicted TDS impacts from chemicals use and from biodegradation are consistent with experimental data.
- Contribution of softener regeneration brines could have significant impact on raw wastewater TDS.
- Chemical sludge generation impacts could be compounded by deterioration of waste sludge thickening properties and potential impacts of inert sludge on nitrification.