Appendix A-5

COST MODULE FOR OPTION 4

(Nitrification + Denitrification + Phosphorus Removal)

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1.0 COST OVERVIEW AND ASSUMPTIONS

Effluent concentrations associated with Option 4 require nitrification, denitrification, and removal of phosphorus from meat and poultry product (MPP) wastewater (i.e., nitrogen in the form of ammonia is converted to nitrate/nitrite then to nitrogen gas plus phosphorus is removed). Option 4 long-term average (LTA) concentrations are shown in Table 2 of the main section of this document, titled "Revised Methodology For Estimating Incremental Capital and Operating and Maintenance Costs for the Meat and Poultry Products Effluent Limitations Guidelines and Standards." A facility with a wastewater treatment plant designed for nitrification can be upgraded to a nitrification and denitrification and phosphorus removal system (N+DN+DP = Option 4) by installing anoxic and aeration tanks with accessory equipment, pumps, mixers, a methanol feed system and an alum feed system with mix tanks. A schematic of an N+DN+DP system for treating MPP wastewater is shown in Figure A-5.1.

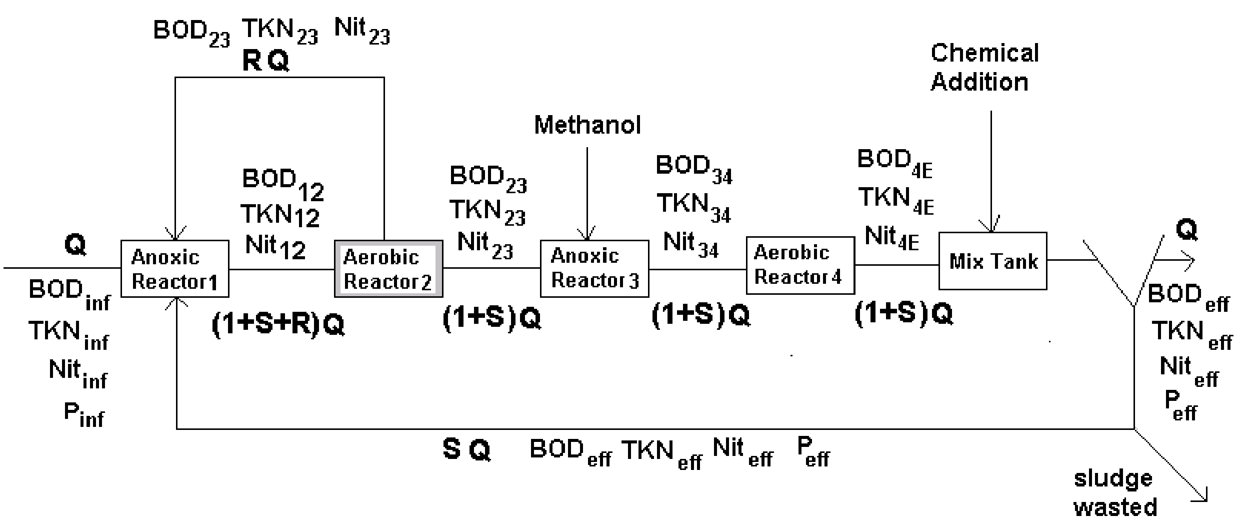

Figure A-5.1: Schematic of Nitrification, Denitrification and Phosphorus Removal System (N+DN+DP)

In this model, a facility with a wastewater treatment plant designed for nitrification has an aerobic reactor in place (aerobic reactor 2) and is costed for (i) anoxic tanks (hereinafter referred to as anoxic reactor 1) with mixers before the existing aeration tank; (ii) recycle pumps for recycling nitrate/nitrite from the existing aeration tanks to the anoxic reactor; (iii) intermediate process pumps for pumping wastewater through the treatment plant; (iv) additional anoxic tanks (hereinafter referred to as anoxic reactor 3) with mixers after the existing aeration tanks; (v) additional aeration tanks (hereinafter referred to as aerobic reactor 4); (vi) aeration system for aerobic reactor 4; (vii) methanol feed system; (viii) alum feed system; and (ix) mix tanks to achieve Option 4 LTA concentrations.

In aerobic reactor 2, biochemical oxygen demand (BOD) removal and nitrification takes place. The nitrate/nitrite produced in aerobic reactor 2 is recycled to anoxic reactor 1 for denitrification. During denitrification, a significant amount of BOD is consumed, reducing the BOD load on aerobic reactor 2. The wastewater from the aerobic reactor 2 flows into anoxic reactor 3 where methanol is added to denitrify the remaining nitrate/nitrite in the wastewater. In aerobic reactor 4, nitrogen gas (formed due to denitrification) attached to the solids in the wastewater is stripped off. Any residual BOD left in the wastewater is also removed in aerobic reactor 4. The wastewater then flows through the mix tanks into the clarifier(s) where the biomass is separated from the wastewater. A portion of the biomass separated is recycled to anoxic reactor 1 while the other portion is wasted (i.e., removed for further processing and ultimate disposal). Alum is fed at or before the mix tanks for phosphorus removal.

To simplify the cost model, factors that do not contribute significantly to the cost estimation are neglected. The following assumptions are applicable to the cost model:

a. Influent nitrate/nitrite concentration entering the N+DN+DP system is practically zero;
b. Endogeneous decay is neglected;
c. Nitrogen removal due to biomass growth is negligible; and
d Total mass of total Kjeldahl nitrogen (TKN) entering and leaving the anoxic reactor 1 does not change.

2.0 NOTATIONS

The equations for the model are based on mass balance of the N+DN+DP system shown in Figure A-5.1. The notations used in the figure are listed below:

Q	= influent wastewater flow (gal/day)
R	= ratio of nitrate/nitrite recycle flow to influent flow
S	= ratio of sludge recycle flow to influent flow

Current Nitrification System

Influent Concentrations

$BOD_{inf\_current}$	= current influent BOD concentration (mg/L)
TKN_{inf}	= influent TKN concentration (mg/L)
Alk_{inf}	= influent alkalinity used in the analysis (mg/L)
Nit_{inf}	= influent nitrate/nitrite-N concentration (mg/L)
	= 0 (assumed)
P_{inf}	= influent P concentration (mg/L)

Effluent Concentrations

$BOD_{eff\_current}$	= current effluent BOD concentration (mg/L)
$TKN_{eff\_current}$	= current effluent TKN concentration (mg/L)
$TSS_{eff\_current}$	= current effluent total suspended solids (TSS) concentration (mg/L)
$P_{eff\_current}$	= current effluent phosphorus concentration (mg/L)

N+DN+DP System (Option 4)

LTA Concentrations

BOD_{eff_LTA}	= option effluent BOD LTA concentration (mg/L)
TKN_{eff_LTA}	= option effluent TKN LTA concentration (mg/L)
TSS_{eff_LTA}	= option effluent TSS LTA concentration (mg/L)
Nit_{eff_LTA}	= option effluent nitrate/nitrite-N LTA concentration (mg/L)
P_{eff_LTA}	= option effluent phosphorus LTA concentration (mg/L)

Influent Concentrations

BOD_{inf_req} = influent BOD concentration requirement based on influent BOD:TKN ratio of 3 (mg/L)

BOD_{inf} = influent BOD concentration used in the analysis (mg/L)

Target Effluent Concentrations

BOD_{eff} = target effluent BOD concentration (mg/L)

TKN_{eff} = target effluent TKN concentration (mg/L)

TSS_{eff} = target effluent TSS concentration (mg/L)

Nit_{eff} = target effluent nitrate/nitrite-N concentration (mg/L)

P_{eff} = target effluent phosphorus concentration (mg/L)

Effluent from Anoxic Reactor 1

BOD_{12} = effluent BOD concentration (mg/L)

TKN_{12} = effluent TKN concentration (mg/L)

Nit_{12} = effluent nitrate/nitrite-N concentration (mg/L)

Effluent from Aerobic Reactor 2

BOD_{23} = effluent BOD concentration (mg/L)

TKN_{23} = effluent TKN concentration (mg/L)

Nit_{23} = effluent nitrate/nitrite-N concentration (mg/L)

Effluent from Anoxic Reactor 3

BOD_{34} = effluent BOD concentration (mg/L)

TKN_{34} = effluent TKN concentration (mg/L)

Nit_{34} = effluent nitrate/nitrite-N concentration (mg/L)

Effluent from Aerobic Reactor 4

BOD_{4E} = effluent BOD concentration (mg/L)

TKN_{4E} = effluent TKN concentration (mg/L)

Nit_{4E} = effluent nitrate/nitrite-N concentration (mg/L)

All Reactors

MLVSS = concentration of mixed liquor volatile suspended solids in the reactors (mg/L)

3.0 COST MODEL INPUT PARAMETERS

The following parameters are inputs to the model (i.e., entered in the "input" spreadsheet in the cost model):

Flow and flow ratios:

Q, R, and S

Influent concentrations:

$BOD_{inf\_current}$

TKN_{inf}

Alk_{inf} (if available)

P_{inf} (not required if $P_{eff\_current}$ is available)

Effluent concentrations:

$BOD_{eff\_current}$

$TKN_{eff\_current}$

$TSS_{eff\_current}$

$P_{eff\_current}$ (if available)

Mixed liquor volatile suspended solids:

MLVSS

Option effluent LTA concentrations (entered in the "LTA" spreadsheet in the cost model):

BOD_{eff_LTA}

TKN_{eff_LTA}

TSS_{eff_LTA}

P_{eff_LTA}

Nit_{eff_LTA}

4.0 CONSTANTS

The various constants used by the model (i.e., "constants" spreadsheet in the model) are available in Table A-12.1 through Table A-12.5 in Appendix A-12. The constants used in the model to calculate the design parameters are shown in Table A-12.1 while the cost constants used to calculate costs are shown in Table A-12.2. Cost equations for capital and annual operating and maintenance (O&M) Costs are shown in Table A-12.3 and A-12.4. One-time costs are shown in Table A-12.5.

5.0 DESIGN CALCULATIONS

The following section discusses the method used to determine the design parameters for the N+DN+DP system.

5.1 Concentrations and Removals

5.1.1 Influent BOD Concentration used for Analysis (BOD_{inf})

For optimal denitrification the influent BOD to TKN ratio should be at least 3 (Table A-12.1).

Therefore:

- BOD_{inf_req} mg/L = {[3] [TKN_{inf} mg/L]} (A-5.1)

where:
the factor of 3 is obtained from Table A-12.1
TKN_{inf} is input to the model

If adequate BOD is not present for denitrification in the influent, then an additional carbon source is required. Data from the MPP detailed surveys indicate that MPP wastewater normally has an adequate BOD:TKN ratio. However, facilities that use anaerobic lagoon(s) for treatment may have a BOD:TKN ratio of less than 3. For those facilities, a portion of the influent wastewater to the lagoon may be bypassed directly to the anoxic reactor 1 to supply additional BOD to the system (See Section 7.1). This type of bypass has been demonstrated within the MPP industry.

The model first compares the current influent BOD concentration ($BOD_{inf\_current}$) with the calculated BOD_{inf_req} (see equation A-5.1). Values of $BOD_{inf\_current}$ and TKN_{inf} are inputs to the model. If $BOD_{inf\_current}$> BOD_{inf_req} then $BOD_{inf\_current}$ is used in the calculation. However, if $BOD_{inf\_current}$ < BOD_{inf_req} then BOD_{inf_req} is used for analysis and the facility incurs a one-time cost for lagoon bypass. This algorithm in the model ensures that adequate BOD for denitrification is present in the influent.

Therefore:

- BOD_{inf} mg/L = Max [BOD_{inf_req} mg/L, $BOD_{inf\_current}$ mg/L] (A-5.2)

where:

the maximum value is selected
BOD_{inf_req} is obtained from equation A-5.1
$BOD_{inf\_current}$ is input to the model

5.1.2 Target Effluent Concentrations (BOD_{eff}, TKN_{eff}, TSS_{eff}, Nit_{eff})

The target effluent concentrations are determined by comparing the Option 4 LTA concentration and the current effluent concentration for a parameter and choosing the lower value.

Therefore:

- BOD_{eff} mg/L = Min [$BOD_{eff\_current}$ mg/L, BOD_{eff_LTA} mg/L] (A-5.3)
- TKN_{eff} mg/L = Min [$TKN_{eff\_current}$ mg/L, TKN_{eff_LTA} mg/L] (A-5.4)
- TSS_{eff} mg/L = Min [$TSS_{eff\_current}$ mg/L, TSS_{eff_LTA} mg/L] . (A-5.5)

where:

the minimum values are selected

All parameters on the right-hand side of equation A-5.3 through A-5.5 are inputs to the model.

The effluent nitrate/nitrite-N concentration is equal to the Option nitrate/nitrite-N concentration ($Nit_{eff} = Nit_{eff\_LTA}$).

If $P_{eff\_current}$ is available in the input,

Then:

- P_{eff} mg/L = Min [$P_{eff\_current}$ mg/L, P_{eff_LTA} mg/L] (A-5.6)

where:

the minimum value is selected

All parameters on the right-hand side of equation A-4.6 are inputs to the model.

5.1.3 Effluent Concentrations from Aerobic Reactor 4 (BOD_{5E}, TKN_{4E}, Nit_{4E})

Alum is added in the mix tank to primarily remove phosphorus from the wastewater. Therefore, the effluent BOD, TKN, and nitrate/nitrite-N concentrations from aerobic reactor 4 are equal to those of the final target effluent concentrations.

- BOD_{4E} mg/L = BOD_{eff} mg/L (A-5.7)
- TKN_{4E} mg/L = TKN_{eff} mg/L (A-5.8)
- Nit_{4E} mg/L = Nit_{eff} mg/L (A-5.9)

All parameters on the right-hand side of equation A-5.7 through A-5.9 are either inputs to the model or have already been calculated.

5.1.4 Effluent Concentration from Anoxic Reactor 3 (BOD_{34}, TKN_{34}, Nit_{34})

The primary purpose of aerobic reactor 4 is to strip nitrogen gas from biomass with a negligible BOD reduction.

Therefore, using equation A-5.7 through A-5.9:

- BOD_{34} mg/L = BOD_{4E} mg/L = BOD_{eff} mg/L (A-5.10)
- TKN_{34} mg/L = TKN_{4E} mg/L = TKN_{eff} mg/L (A-5.11)
- Nit_{34} mg/L = Nit_{4E} mg/L = Nit_{eff} mg/L (A-5.12)

BOD_{eff}, TKN_{eff}, and Nit_{eff} either inputs to the model or have already been calculated.

5.1.5 Effluent TKN Concentration from Aerobic Reactor 2 (TKN_{23})

Assuming no change in TKN removal in anoxic reactor 3 (See Section 1.0) and using eq (A-5.11):

- TKN_{23} mg/L = TKN_{34} mg/L = TKN_{eff} mg/L (A-5.13)

where:

TKN_{eff} is obtained from equation A-5.4

5.1.6 Effluent TKN Concentration from Anoxic Reactor 1 (TKN_{12})

Assuming no change in TKN removal in anoxic reactor 1 (See Section 1.0) yields:

- $\{[(Q)\ (TKN_{inf})] + [(R)\ (Q)\ (TKN_{23})] + [(S)\ (Q)\ (TKN_{eff})]\} = \{[1+S+R]\ [Q]\ [TKN_{12}]\}$

Using equation A-5.13 yields:

- TKN_{12} mg/L = $\{[TKN_{inf}$ mg/L$] + [(S+R)\ (TKN_{eff}$ mg/L$)]\}\ /\ \{1+S+R\}$ (A-5.14)

All parameters on the right-hand side of equation A-5.7 through A-5.9 are either inputs to the model or have already been calculated.

5.1.7 Effluent Nitrate/Nitrite Concentration from Anoxic Reactor 1 (Nit_{12})

The nitrate/nitrite recycled to anoxic reactor 1 are denitrified in anoxic reactor 1. If adequate influent BOD is present, then practically all the nitrate/nitrite is denitrified, resulting in a low effluent nitrate/nitrite-N concentration from anoxic reactor 1. Because the model is designed to ensure that adequate BOD is present for denitrification (see discussion in Section 5.1.1), Nit_{12} is assumed to be very low. The value used in the cost model is taken from the data provided by the Industry Coalition in response to the proposed rule (Industry Comments, 2002):

- Nit_{12} = 1 mg/L (A-5.15)

5.1.8 Effluent Nitrate/Nitrite Concentration from Aerobic Reactor 2 (Nit_{23})

Performing a mass balance for nitrogen in aerobic reactor 2 yields:

- $[Nit_{12}] + [TKN_{12}] = [Nit_{23}] + [TKN_{23}]$
- Nit_{23} mg/L ={[TKN_{12} mg/L] + [Nit_{12} mg/L] - [TKN_{23} mg/L]} (A-5.16)

TKN_{23}, TKN_{12}, and Nit_{12} are obtained from equations A-5.13, A-5.14 and A-5.15, respectively.

5.1.9 Nitrate/Nitrite Removed Daily in Anoxic Reactor 1

All nitrate/nitrite removal is expressed in terms of nitrogen. Performing a mass balance for nitrate/nitrite on anoxic reactor 1 yields:

- {[(Q) (Nit_{inf})] + [(S) (Q) (Nit_{eff})] + [(R) (Q) (Nit_{23})] - [nitrate/nitrite removed]}
  = {[1+S+R] [Q gal/day] [Nit_{12} mg/L]} (A-5.17)

Simplifying equation A-5.17 and setting $Nit_{inf} = 0$ (See Section 1.0) yields:

- Nitrate/nitrite removed = {[(R) (Nit_{23})] + [(S) (Nit_{eff})] - [(1+S+R) (Nit_{12})]} {Q}

where:

Nit_{12} is obtained from equation A-5.15

All other parameters on the right-hand side of the equation are either inputs to the model or have already been calculated.

Therefore:

- Nitrate/nitrite removed (mg/day)
  = {[(R) (Nit_{23} mg/L)] + [(S) (Nit_{eff} mg/L)] - [(1+S+R) (Nit_{12} mg/L)]}
  {[Q gal/day] [3.78 L/gal]} (A-5.18)

- Nitrate/nitrite removed (lbs/day)
  = {[nitrate/nitrite removed (mg/day)] / [453,600 mg/lb]} (A-5.19)

where:

3.78 and 453,600 are conversion factors

5.1.10 Nitrate/Nitrite Removed Daily in Anoxic Reactor 3

All nitrate/nitrite removals are expressed in terms of nitrogen.

Performing a mass balance for nitrate/nitrite on anoxic reactor 3 yields:

- {[(1+S) (Q) (Nit_{23})] - [nitrate/nitrite removed]} = {[1+S] [Q] [Nit_{34}]}

Using equation A-5.12:

- Nitrate/nitrite removed = {[1+S] [Q] [Nit_{23} - Nit_{eff}]}

Nit_{23} is obtained from equation (A-5.16) while the other parameters on the right-hand side of the equation are either inputs to the model or have already been calculated.

- Nitrate/nitrite removed (mg/day)
  = {[1+S] [Q gal/day] [Nit_{23} - Nit_{eff} mg/L] [3.78 L/gal]} (A-5.20)

- Nitrate/nitrite removed (lbs/day)
  = {[nitrate/nitrite removed (mg/day)] / [453,600 mg/lb]} (A-5.21)

where:

3.78 and 453,600 are conversion factors

5.1.11 BOD Removed in Anoxic Reactor 1 and Anoxic Reactor 3

The ratio of BOD removed to nitrate/nitrite removed in an anoxic reactor treating MPP wastewater is obtained from Table A-12.1.

- BOD removed in anoxic reactor 1 (mg/day)
  = {[2.75] [nitrate/nitrite removed in anoxic reactor 1 (mg/day)]} (A-5.22)

and

- BOD removed in anoxic reactor 3 (mg/day)
  = {[2.75] [nitrate/nitrite removed in anoxic reactor 3 (mg/day)]} (A-5.23)

where:

2.75 is obtained from Table A-12.1
nitrate/nitrite removed (mg/day) in anoxic reactor 1 is obtained from equation A-5.18
nitrate/nitrite removed (mg/day) in anoxic reactor 3 is obtained from equation A-5.20

5.1.12 Effluent BOD Concentration from Aerobic Reactor 2 (BOD_{23})

Negligible BOD is removed in aerobic reactor 4. Methanol is added in stoichiometric amounts in anoxic reactor 3 to remove remaining nitrate/nitrite in the wastewater. Practically all of the BOD entering the biological system is removed in anoxic reactor 1 and aerobic reactor 2.

Therefore:

- BOD_{23} mg/L = BOD_{34} mg/L = BOD_{4E} mg/L = BOD_{eff} mg/L (A-5.24)

where:

BOD_{eff} is obtained from equation A-5.3

5.1.13 Effluent BOD Concentration from Anoxic Reactor 1 (BOD_{12})

Performing a mass balance on combined anoxic reactor 1 yields:

- {[(Q) (BOD_{inf})] + [(S) (Q) (BOD_{eff})] + [(R) (Q) (BOD_{23})] - [BOD removed in anoxic reactor 1]} = {[1+S+R] [Q] [BOD_{12} mg/L]

Using equation A-5.24:

- BOD_{12}
  = {[(Q) (BOD_{inf})] + [(S+R) (Q) (BOD_{eff})] - [BOD removed in anoxic reactor 1]} / {[1+S+R] [Q]}

- BOD_{12} mg/L
  = {[(Q gal/day) (BOD_{inf} mg/L) (3.78 L/gal)] + [(S+R) (Q gal/day) (BOD_{eff} mg/L) (3.78 L/gal)] - [BOD removed in anoxic reactor 1 (mg/day)]} / {[1+S+R] [Q gal/day] [3.78 L/gal]} (A-5.25)

where:
3.78 is a conversion factor

BOD removed in anoxic reactor 1 (mg/day) is obtained from equation A-5.22 while the other parameters on the right-hand side of the equation are either inputs to the model or have already been calculated.

5.1.14 BOD Removed in Aerobic Reactor 2

BOD removed in aerobic reactor 2 is expressed as:

- BOD removed (mg/day) = {[Q gal/day] [1+R+S] [BOD_{12} - BOD_{23} mg/L] [3.78 L/gal]}

Using equation A-5.24:

- BOD removed (mg/day)
  = {[Q gal/day] [1+R+S] [BOD_{12} - BOD_{eff} mg/L] [3.78 L/gal]} (A-5.26)

- BOD removed (lbs/day) = {[BOD removed (mg/day)] / [453,600 mg/lb]} (A-5.27)

where:
3.78 and 453,600 are conversion factors

All parameters on the right-hand side of equation A-5.26 are either inputs to the model or have already been calculated.

5.1.15 TKN Removed in Aerobic Reactor 2

TKN removal occurs only in aerobic reactor 2 and is given by:

- TKN removed (mg/day) = {[Q gal/day] [TKN_{inf} - TKN_{eff} mg/L] [3.78 L/gal]} (A-5.28)

- TKN removed (lbs/day) = {[TKN removed (mg/day)] / [453,600 mg/lb]} (A-5.29)

where:

3.78 and 453,600 are conversion factors

All parameters on the right-hand side of equation A-5.28 are either inputs to the model or have already been calculated.

5.1.16 Mass of Biomass Required in Anoxic Reactor 1

- Mass of biomass required in anoxic reactor 1 (mg)
  = {[nitrate/nitrite removed in anoxic reactor1 (mg/day)]
  / [denitrification rate (mg/mg MLVSS-day)]} (A-5.30)

where:

nitrate/nitrite removed (mg/day) in anoxic reactor 1 is obtained from equation A-5.18
denitrification rate = 0.171 mg nitrate/nitrite-N denitrified/mg MLVSS-day (Table A-12.1)

5.1.17 Mass of Biomass Required in Anoxic Reactor 3

- Mass of biomass required in anoxic reactor 3 (mg)
  = {[nitrate/nitrite removed in anoxic reactor 3 (mg/day)]
  / [denitrification rate (mg/mg MLVSS-day)]} (A-5.31)

where:

nitrate/nitrite removed (mg/day) in anoxic reactor 3 is obtained from equation A-5.20
denitrification rate = 0.171 mg nitrate/nitrite-N denitrified/mg MLVSS-day (Table A-12.1)

5.2 Reactor Volume and Detention Time

5.2.1 Minimum Anoxic Detention Time

The minimum detention time of anoxic reactors selected for denitrification is 2 hours (Table A-12.1)

5.2.2 Minimum Volume of Anoxic Reactor 1 and Anoxic Reactor 3

Based on a minimum detention time of 2 hours, the minimum volume of anoxic reactors (gal),

$$V_{anoxic\_min} = \{[Q \text{ gal/day}] [2 \text{ hrs}] / [24 \text{ hrs/day}]\} \quad \text{(A-5.32)}$$

where:

Q gal/day is input to the model

5.2.3 Volume of Anoxic Reactor 1

- Required anoxic volume (gal), $V_{anoxic1\_req}$
  = {[biomass required in anoxic reactor 1 (mg)] / [MLVSS mg/L]} / {3.78 L/gal}
  (A-5.33)

where:

3.78 is a conversion factor
biomass required in anoxic reactor 1 (mg) is obtained from equation A-5.30
MLVSS is input to the model

The maximum of the V_{anoxic_min} and the calculated required volume of anoxic reactor is taken as the volume of the reactor.

Therefore:

- $V_{anoxic1}$ (gal) = Max [V_{anoxic_min} (gal), $V_{anoxic1\_req}$ (gal)] (A-5.34)

where:

the maximum value is selected

V_{anoxic_min} and $V_{anoxic1\_req}$ are obtained from equations A-5.32 and A-5.33, respectively

5.2.4 Volume of Anoxic Reactor 3

- Required anoxic volume, $V_{anoxic3\_req}$ (gallons)
  = {[biomass required in anoxic reactor 3 mg] / [MLVSS mg/L]} / {3.78 L/gal} (A-5.35)

where:

biomass required in anoxic reactor 3 (mg) is obtained from equation A-5.31

MLVSS is input to the model

The maximum of the V_{anoxic_min} and the calculated required volume of anoxic reactor is taken as the volume of the reactor.

Therefore:

- $V_{anoxic3}$ (gal) = Max [V_{anoxic_min} (gal), $V_{anoxic3\_req}$ (gal)] (A-5.36)

where:

the maximum value is selected

V_{anoxic_min} and $V_{anoxic3\_req}$ are obtained from equations A-5.32 and A-5.35, respectively.

5.2.5 Volume of Aerobic Reactor 4

The aerobic reactor 4 is primarily used to strip off nitrogen gas from the solids and to remove residual BOD. The recommended hydraulic retention time (HRT) is between 0.5 and 1 hr (USEPA,1993). The data provided by the Industry Coalition in response to the proposed rule (Industry Comments, 2002) assumes 1-hr HRT. For this analysis 1-hr detention time is assumed.

- Volume of aerobic reactor, $V_{aerobic4}$ (gal) = {[Q gal/day] [1 hr]} / {24 hrs/day} (A-5.37)

where:

Q gal/day is input to the model

5.2.5 Purchase Volume of Anoxic Reactor 1, Anoxic Reactor 3, and Aerobic Reactor 4

The purchase volume of the reactor is 160% of the actual volume of reactor required (Table A-12.1). The extra 60% volume is added for peak flows, freeboard, low temperature conditions, multiple tanks, and to account for other factors that may contribute to increase in costs. Therefore, the volume of reactors that need to be purchased is expressed as:

- $V_{anoxic1\_purchase}$ (gal) = {[1.60] [$V_{anoxic1}$ (gal)]} (A-5.38)
- $V_{anoxic3\_purchase}$ (gal) = {[1.60] [$V_{anoxic3}$ (gal)]} (A-5.39)
- $V_{aerobic4\_purchase}$ (gal) = {[1.60] [$V_{aerobic4}$ (gal)]} (A-5.40)

where:

$V_{anoxic1\_purchase}$ = volume of anoxic reactor 1 to be purchased (gal)
$V_{anoxic3\_purchase}$ = volume of anoxic reactor 3 to be purchased (gal)
$V_{aerobic4\_purchase}$ = volume of aerobic reactor 4 to be purchased (gal)
$V_{anoxic1}$ = required volume of anoxic reactor 1 (gal)
$V_{anoxic3}$ = required volume of anoxic reactor 3 (gal)
$V_{aerobic4}$ = required volume of aerobic reactor 4 (gal)
The factor 1.60 is obtained from Table A-12.1
$V_{anoxic1}$,$V_{anoxic3}$, and $V_{aerobic4}$ are calculated from equations A-5.34, A-5.36, and A-5.37, respectively

5.3 Mixers

Mixers are required for anoxic reactor 1 and 3.

5.3.1 Mixing Power

Mixing requirement = 60 HP/Mgal (Table A-12.1)

The mixer power for anoxic reactor 1 and anoxic reactor 3 is obtained from the following equation:

- Mixer power required (HP) = {[60 HP/Mgal] [purchase volume of reactor (gal)]} (A-5.41)

where:

purchase volume of reactor is obtained from equations A-5.38 and A-5.39

5.3.2 Purchase Mixer Power

The purchase mixer power is 150% of the required mixer power (Table A-12.1). The extra 50% is added for peak flows, multiple mixers, and to account for other factors that may contribute to increase in costs. Therefore, the purchase mixer power is expressed as:

- Purchase mixer power (HP) = {[1.50] [mixer power required (HP)]} (A-5.42)

where:

mixer power required (HP) is obtained from equation A-5.41
the factor 1.50 is derived from Table A-12.1

5.4 Pumps

5.4.1 Pump Energy

Pump energy is required (i) to recycle nitrate/nitrite from aerobic reactor 2 to anoxic reactor 1 (recycle pump), and (ii) to pump the wastewater through the treatment plant (intermediate process pump) and is expressed as:

- Pump power (HP)
= {[flow (gpm)] [total dynamic head (ft)] [specific gravity of liquid]} / {[3,960] [pump efficiency]}(Perry, 1984) (A-5.43)

where:

specific gravity	= 1 for water	(Table A-12.1)
pump efficiency	= 0.77	(Table A-12.1)
Total dynamic head	= 15 ft	(Table A-12.1)

flow (gpm) = {[(R) (Q gal/day)] / [(24 hrs/day) (60 mins/hr)]} (for recycle pump)
= {[Q gal/day] / [(24 hrs/day) (60 mins/hr)]} (for intermediate pump)
3,960 is a conversion factor
Q (gal/day) and R are inputs the model

5.4.2 Maximum Flow of Pump

The maximum flow of the recycle pump is 150% of the average recycle flow (Table A-12.1). The extra 50% is added for peak flows, multiple pumps, and to account for other factors that may contribute to increase in costs.

Therefore, the maximum flow is expressed as:

- Maximum flow (mgd) = {[1.50] [average recycle flow (mgd)]} (A-5.44)

where:
average flow (mgd) = [(R) (Q gal/day) (10^{-6} gal/Mgal)] (for recycle pump)
= [(Q gal/day) (10^{-6} gal/Mgal)] (for intermediate pump)
Q gal/day and R are inputs to the model
10^{-6} is a conversion factor
The factor 1.5 is derived from Table A-12.1

5.5 Aeration System

An aeration system is required to strip off nitrogen gas from the solids and to remove residual BOD.

5.5.1 Aeration Power

- Aeration power requirement = 50 HP/Mgal (Table A-12.1)

The aeration power for aerobic reactor 4 is obtained from the following equation:

- Aeration power required (HP) = {[50 HP/Mgal] [volume of reactor (gal)]} (A-5.45)

where:
volume of reactor (gal) is obtained from equation A-5.37

5.5.2 Purchase Aeration Power

The purchase aeration power is 150% of the required aeration power (Table A-12.1). The extra 50% is added for peak flows, multiple aeration systems, and to account for other factors that may contribute to increase in costs.

Therefore, the purchase aeration power is expressed as:

- Purchase aeration power (HP) = {[1.50] [aeration power required (HP)]} (A-5.46)

where:
the factor 1.50 is derived from Table A-12.1
aeration power required (HP) is obtained from equation A-5.45

5.6 Feed Systems and Mix Tank

5.6.1 Methanol Feed System

Methanol addition may be required at two locations in the wastewater treatment system.

a. Anoxic reactor 1: For optimal denitrification the influent BOD to TKN ratio entering anoxic reactor 1 should be at least 3 (Table A-12.1). If adequate BOD is not present, an additional carbon source is supplied during the weekdays by lagoon bypass. During the weekends, methanol is added to supplement BOD in the influent wastewater.

b. Anoxic reactor 3: Methanol is added to denitrify the remaining nitrate/nitrite which are exiting aerobic reactor 2. This process ensures low effluent nitrate/nitrite-N concentrations.

The total methanol dose required is estimated using the method described in the methanol feed system module in Appendix A-6.

5.6.2 Polymer Feed System

Polymer may be added to wastewater at or before the secondary clarifier to improve the settleability of sludge and to lower the effluent TSS concentration. The required polymer dose and estimate of sludge generated as a result of polymer addition are developed using the methods described in the polymer feed system module in Appendix A-7.

5.6.3 Alum Feed System

Alum is used to remove phosphorous from wastewater. Alum is added at or before the mix tank that is located between the final aeration basin and the secondary clarifier. Flocculation and settling of solids take place at the secondary clarifier. Alum doses required, alum sludge formed, and alkalinity loss due to alum addition are obtained from the alum feed system module in Appendix A-8.

5.6.4 Mix Tanks

Alum used for phosphorus precipitation is thoroughly mixed with the wastewater in the mix tanks to ensure uniform dispersion and efficient application of alum. Design parameters for mix tank are obtained from mix tank module in Appendix A-9.

5.7 Alkalinity Savings

5.7.1 Influent Alkalinity (Alk_{inf})

Influent alkalinity is a user input if the value for a facility is available. If an influent alkalinity value is not available, then the model assumes an influent alkalinity of 900 mg/L for facilities with anaerobic lagoons and 100 mg/L for facilities without anaerobic lagoons (Table A-12.1). The default value of influent alkalinity for facilities with anaerobic lagoon are estimated based on the data provided in the MPP detailed surveys. The default value of influent alkalinity for facilities without anaerobic lagoons were based on typical alkalinity concentration in surface waters and domestic wastewaters.

5.7.2 Effluent Alkalinity (Alk_{eff})

Effluent alkalinity from nitrification is assumed to be 100 mg/L (Table A-12.1). The default value of effluent alkalinity were based on typical alkalinity concentration in surface waters.

5.7.3 Current Alkalinity Requirement for the Nitrification System

Approximately 7.1 lbs. of alkalinity are destroyed per lb. of ammonia-N nitrified (Table A-12.1). Therefore:

- Total alkalinity destroyed (lbs/day)
  = {[Q gal/day] [TKN_{inf} - $TKN_{eff\_current}$ mg/L] [8.34 x 10^{-6} lb/gal-mg/L]}

where:
  8.34 x 10^{-6} is a conversion factor

Therefore:

- Calculated alkalinity requirement for nitrification, Alk_N (lbs/day)
  = {[alkalinity destroyed (lbs/day)] + [effluent alkalinity (lbs/day)] - [influent alkalinity (lbs/day)]}
  = {[Q gal/day] [8.34 x 10^{-6} lbs/gal-mg/L] [(TKN_{inf} - $TKN_{eff\_current}$ mg/L) (7.1 lbs/lb)
  + (effluent alkalinity mg/L) - (influent alkalinity mg/L)]} (A-5.47)

As mentioned in Section 5.7.1 and Section 5.7.2, influent alkalinity and effluent alkalinity are available in Table A-12.1. All other parameters on the right-hand side of equation A-5.47 are inputs to the model. Use of equation A-5.47 for facilities with high influent alkalinity may result in a negative number. A negative alkalinity requirement number indicates that no alkalinity is currently added to the nitrification facility.

Therefore:

- The current alkalinity requirement (lbs/day) = Max [0, Alk_N (lbs/day)] (A-5.48)

where:

the maximum value is selected

Alk_N (lbs/day) is obtained from equation A-5.47

5.7.4 Alkalinity Requirement for the N+DN+DP System

Approximately 7.1 lbs. of alkalinity are destroyed per lb. of ammonia-N nitrified (Table A-12.1).

Therefore:

- Total alkalinity destroyed (lbs/day) due to nitrification for the N+DN+DP system
  = {[Q gal/day] [TKN_{inf} - TKN_{eff} mg/L] [8.34 x 10^{-6} lbs/gal-mg/L] [7.1 lbs/lb]}

where:

8.34 x 10^{-6} is a conversion factor

Approximately 50% of the alkalinity destroyed during nitrification is recovered during denitrification. Typically, 3.57 lbs. $CaCO_3$ alkalinity are recovered / lb of NO_3-N denitrified (Table A-12.1).

Therefore:

- Alkalinity recovered in anoxic reactor 1 (lbs/day)
  = {[3.57 lbs/lb] [nitrate/nitrite denitrified in anoxic reactor 1 (lbs/day)]} (A-5.49)

Alkalinity is also recovered in anoxic reactor 3.

- Alkalinity generated in anoxic reactor 3 (lbs/day)
  = {[3.57 lbs/lb] [nitrate/nitrite denitrified in anoxic reactor 3 (lbs/day)]}

However, only the fraction of alkalinity recycled by sludge can actually be realized as savings.

Therefore:

- Alkalinity recovered in anoxic reactor 3 (lbs/day)
  = {[3.57 lbs/lb] [nitrate/nitrite denitrified in anoxic reactor 3 (lbs/day)] [S]} / {1+S}
  (A-5.50)

Alum addition results in destruction of alkalinity due to precipitation of aluminum hydroxide. The amount of alkalinity destroyed is obtained from alum feed module in Appendix A-8.

Therefore:

- Calculated alkalinity requirement for the N+DN+DP system, Alk_N+DN+DP (lbs/day)
  = {[alkalinity destroyed by nitrification (lbs/day)] + [effluent alkalinity (lbs/day)] - [influent alkalinity (lbs/day)] - [alkalinity recovered in anoxic reactor 1 (lbs/day)] - [alkalinity recovered in anoxic reactor 3 (lbs/day)] + [alkalinity destroyed by alum addition (lbs/day)]}
  = {[Q gal/day] [8.34 x 10^{-6} lbs/gal-mg/L] [(TKN_{inf} -TKN_{eff} mg/L) (7.1 lbs/lb)] + [(effluent alkalinity mg/L) - (influent alkalinity mg/L)]} - {alkalinity recovered in anoxic reactor 1 (lbs/day)} - {alkalinity recovered in anoxic reactor 3 (lbs/day)} + {alkalinity destroyed by alum addition (lbs/day)} (A-5.51)

where:

8.34 x 10^{-6} is a conversion factor

As mentioned in Section 5.7.1 and Section 5.7.2, influent alkalinity and effluent alkalinity are obtained from Table A-12.1. Alkalinity recovered in anoxic reactor 1 is from equation 5.49, alkalinity recovered in anoxic reactor 3 is from equation A-5.50, and alkalinity destroyed by alum addition is from Appendix A-8. All other parameters on the right-hand side of equation A-5.51 are either inputs to the model or have already been calculated.

Use of equation A-5.51 for facilities with high influent alkalinity and/or high alkalinity generation may result in a negative number. A negative alkalinity requirement number indicates that no alkalinity is required.

Therefore:

- Alkalinity requirement for the N+DN+DP system (lbs/day)
  = Max [0, Alk_N+DN+DP (lbs/day)] (A-5.52)

where:
  the maximum value is selected
  Alk_N+DN+DP (lbs/day) is obtained from equation A-5.51

5.7.5 Net Alkalinity Savings due to the N+DN+DP System

- The net alkalinity savings due to the N+DN+DP system
  = {[current alkalinity requirement for nitrification system (lbs/day)]- [alkalinity requirement for N+DN+DP system (lbs/day)]} (A-5.53)

The values in the right-hand side of equation A-5.53 are obtained from equations A-5.48 and A-5.52.

5.8 Energy for Required Oxygen Transfer

- Oxygen requirement for BOD removal
  = 1.25 (lbs of oxygen/lb of BOD removed) (Table A-12.1)

- Oxygen requirement for TKN removal (nitrification)
  = 4.6 (lbs of oxygen/lb of TKN removed) (Table A-12.1)

5.8.1 Oxygen Required for the Existing Nitrification System

- Oxygen required for the existing nitrification system (lbs/day)
  = {[oxygen required for BOD removal (lbs/day)] + [oxygen required for TKN removal (lbs/day)]}
  = {[(Q gal/day) ($BOD_{inf\_current}$ - $BOD_{eff\_current}$ mg/L) (8.34×10^{-6} lbs/gal-mg/L) (1.25 lbs oxygen/lb BOD)] + [(Q gal/day) (TKN_{inf} - $TKN_{eff\_current}$ mg/L) (8.34×10^{-6} lbs/gal-mg/L) (4.6 lbs oxygen/lb TKN)]} (A-5.54)

where:

8.34×10^{-6} is a conversion factor

All parameters on the right-hand side of equation A-5.54 are either inputs to the model or have already been calculated.

5.8.2 Oxygen Required for the N+DN+DP System

- Oxygen required for the N+DN+DP system (lbs/day)
  = {[oxygen required for BOD removal in aerobic reactor 2 (lbs/day)]
  + [oxygen required for TKN removal (lbs/day)]}
  = {[BOD removed in aerobic reactor 2 (lbs/day)] [1.25 lbs oxygen/lb BOD]}
  + {[TKN removed in aerobic reactor 2 (lbs/day)] [4.6 lbs oxygen/lb TKN]}
  (A-5.55)

The BOD removed (lbs/day) and TKN removed (lbs/day) in aerobic reactor 2 are obtained from equations A-5.27 and A-5.29, respectively.

5.8.3 Net Oxygen Required due to the N+DN System

- Incremental oxygen required due to the treatment system (lbs/day)
  = {[oxygen required for the N+DN+DP system (lbs/day) from equation A-5.55]
  - [oxygen required for the existing nitrification system (lbs/day) from equation A-5.54]} (A-5.56)

5.8.4 Incremental Energy Required for Oxygen Transfer

Typically, air diffusion systems transfers 4 lbs. of oxygen per KWh of energy (Table A-12.1). Therefore:

- Energy requirement due to oxygen transfer (KWh/year)
  = {[incremental oxygen required (lbs/day) from equation A-5.56] [365 days/yr]}
  / {4 lbs/KWh} (A-5.57)

Note: A negative energy requirement indicates savings.

5.9 Excess Sludge Generated

The biokinetic values: $Y_{aerobic}$ (lbs biomass/lb BOD removed), Y_{anoxic} (lbs biomass/lb nitrate/nitrite-N), and $Y_{nitrification}$ (lbs biomass/lb TKN) are available in Table A-12.1.

5.9.1 Sludge Generation by the Existing Nitrification System

Biomass Generation

- Biomass produced by the existing nitrification system (lbs/day)
  = {[biomass generated due to BOD removal (lbs/day)] + [biomass generated due to nitrification by nitrifiers (lbs/day)]}
  = {[Q gal/day] [$BOD_{inf\_current}$ - $BOD_{eff\_current}$ mg/L] [8.34 x 10^{-6} lbs/gal-mg/L] [$Y_{aerobic}$ (lbs/lb)]} + {[Q gal/day] [TKN_{inf} - $TKN_{eff\_current}$ mg/L] [8.34 x 10^{-6} lbs/gal-mg/L] [$Y_{nitrification}$ (lbs/lb)]} (A-5.58)

Flow and concentrations on the right-hand side of equation A-5.58 are either inputs to the model or have already been calculated.

Other Solids

- MLVSS/MLSS = 0.80 (Table A-12.1)
  Other solids (other than biosolids) present in sludge (lbs/day)
  = {[biomass generated (lbs/day)] [1-0.80]} / {0.80} (A-5.59)

where:

biomass generated (lbs/day) is obtained from equation A-5.58

Total Sludge Produced by the Existing Nitrification System

- Total sludge produced (lbs/day)
  = {[biomass generated (lbs/day) from equation A-5.58]
  + [other solids (lbs/day) from equation A-5.59]} (A-5.60)

5.9.2 Sludge Generation by the N+DN+DP System

Biomass Generation

- Biomass produced by the N+DN+DP system (lbs/day)
  = {[biomass generated due to BOD (or nitrate/nitrite) removal in anoxic reactor 1 (lbs/day)] + [biomass generated due to BOD removal in aerobic reactor 2 (lbs/day)] + [biomass generated due to methanol (or nitrate/nitrite) removal in anoxic reactor 3 (lbs/day)] + [biomass generated due to BOD removal in aerobic reactor 4 (lbs/day)] + [biomass generated due to nitrification by nitrifiers (lbs/day)]}
  = {[nitrate/nitrite removed in anoxic reactor 1 (lbs/day)] [Y_{anoxic} (lbs/lb)] + [BOD removed in aerobic reactor 2 (lbs/day)] [$Y_{aerobic}$ (lbs/lb)] + [sludge produced due to nitrate/nitrite removal in anoxic reactor 3 (lbs/day)] + [sludge due to residual BOD removal in aerobic reactor 4 (lbs/day)] + [TKN removed (lbs/day)] [$Y_{nitrification}$ (lbs/lb)]} (A-5.61)

Nitrate/nitrite removed in anoxic reactor 1, nitrate/nitrite removed in anoxic reactor 3, BOD removed in aerobic reactor 2, and TKN removed are obtained from equations A-5.19, A-5.21, A-5.27, and A-5.29 respectively, and sludge due to residual BOD removal in aerobic reactor 4 (lbs/day) is obtained from methanol feed system module in Appendix A-6.

Other Solids

The amount of the other solids (other than the biosolids) in the sludge remains practically unchanged. The amount of other solids is obtained from equation A-5.59.

Sludge due to Incremental TSS Removal

If the Option effluent TSS LTA concentration is less than the current effluent TSS levels, then additional sludge is generated due to TSS removal.

Therefore:

- Sludge due to TSS removal (lbs/day)
  = {[Q gal/day] [$TSS_{eff\_current}$ - TSS_{eff} mg/L] [8.34 x 10^{-6} lbs/gal-mg/L]} (A-5.62)

where:
 8.34 x 10^{-6} is a conversion factor

All parameters on the right-hand side of equation A-5.62 are either inputs to the model or have already been calculated.

Sludge due to Polymer Addition

Sludge generation due to polymer addition is obtained from the polymer feed module in Appendix A-7.

Sludge due to Alum Addition

Sludge generation due to alum addition is obtained from the alum feed module in Appendix A-8.

Total Sludge Produced by N+DN+DP System

- Total sludge produced due to the N+DN+DP system (lbs/day)
  = {[biomass generation (lbs/day) from equation A-5.61] + [other solids present in the sludge (lbs/day) from equation A-5.59] + [sludge due to excess TSS removal (lbs/day) from equation A-5.62] + [sludge due to polymer addition (lbs/day) from Appendix A-7] + [sludge due to alum addition (lbs/day) from Appendix A-8]} (A-5.63)

5.9.3 Incremental Sludge Produced due to N+DN+DP System

- Incremental biomass generation due to the N+DN+DP system (lbs/day)
  = {[sludge produced by the N+DN+DP system (lbs/day) from equation A-5.63] - [sludge produced by the existing nitrification system (lbs/day) from equation A-5.60]} (A-5.64)

Note that a negative number indicates a reduction in sludge generation due to the N+DN+DP treatment.

5.9.4 Percent Increase in Sludge due to N+DN+DP System

- Percent increase in sludge due to N+DN+DP system
  = {[incremental sludge produced due to N+DN+DP system (lbs/day) from equation A-5.64] [100]} / {biomass produced by existing nitrification system (lbs/day) from equation A-5.60} (A-5.65)

6.0 CAPITAL AND OPERATION AND MAINTENANCE (O&M) COSTS

This section shows the method used to calculate the incremental capital and O&M costs for a facility to convert a nitrification system to a N+DN+DP system. The facilities are costed for the following:

1. Biosystem consisting of
   a. anoxic reactor 1 for denitrification,
   b. mixers for anoxic reactor 1,
   c. recycle pumps for recycling the nitrate/nitrite from aerobic reactor 2 to anoxic reactor 1,
   d. intermediate process pumps to pump wastewater through the treatment plant,
   e. anoxic reactor 3 for denitrification,
   f. mixers for anoxic reactor 3,
   g. aerobic reactor 4 for final aeration,
   h. aeration system for aerobic reactor 4;

2. Polymer feed system;

3. Methanol feed system;

4. Alum feed system; and

5. Sludge dewatering system.

The cost constants and cost equations used in the model are shown in Table A-12.2 through Table A-12.5 in Appendix A-12.

6.1 Biosystem Costs

6.1.1 Capital Cost of BioSystem

Capital Cost of Anoxic Reactor 1, Anoxic Reactor 3, and Aerobic Reactor 4

The capital cost of the reactors is calculated using the following equations (Table A-12.3):

- For $V_{anoxic\_purchase}$ (gal) $\leq$ 100,000

  Capital Cost (\$) = {[\$2.81/gal] [$V_{anoxic\_purchase}$ (gal)]}

- For 100,000 < $V_{anoxic\_purchase}$ (gal) < 443,000

  Capital Cost (\$) = {[\$1.2126/gal] [$V_{anoxic\_purchase}$ (gal)]} + {\$159,483}

- For $V_{anoxic\_purchase}$ (gal) $\geq$ 443,000

  Capital Cost (\$) = {[\$0.3406/gal] [$V_{anoxic\_purchase}$ (gal)]} + {\$545,494} (A-5.66)

where:
$V_{anoxic\_purchase}$ (gal) is obtained from equation A-5.38, A-5.39, and A-5.40

Capital Cost of Mixers

The capital cost of the mixers is calculated using the following equation (Table A-12.3):

- Capital Cost (\$) = {[\$2,750.2/HP] [purchase mixer power (HP)]} + {\$6,657} (A-5.67)

where:
purchase mixer power (HP) is obtained from equation A-5.42

Capital Cost of Pumps

The capital cost of the recycle pumps is calculated using the following equation (Table A-12.3):

- Capital Cost ($) = {[$36,915/mgd] [max flow (mgd)]} + {$18,042} (A-5.68)

where:

max flow (mgd) is obtained from equation A-5.44

Capital Cost of Aeration System

The capital cost of the aeration system is calculated using the following equation (Table A-12.3):

- If purchase aeration power (HP) > 76

Then:

- Capital Cost ($) = {[$4,732.5/HP] [purchase aeration power (HP)]} + {$67,605}

- If purchase aeration power (HP) ≤ 76

Then:

- Capital Cost ($) = {[$5,467.4/HP] [purchase aeration power (HP)]} + {$11,737} (A-5.69)

where:

purchase aeration power (HP) is obtained from equation A-5.46

Total Capital Cost of Biosystem

- Total Capital Cost of biosystem ($)
  = {[Capital Cost ($) of anoxic reactor 1 from equation A-5.66] + [Capital Cost ($) of anoxic reactor 3 from equation A-5.66] + [Capital Cost ($) of aerobic reactor 4 from equation A-5.66] + [Capital Cost ($) of mixers for anoxic reactor 1 from equation A-5.67] + [Capital Cost ($) of mixers for anoxic reactor 3 from equation

A-5.67] + [Capital Cost ($) of recycle pumps from equation A-5.68] + [Capital Cost ($) of intermediate process pumps from equation A-5.68] + [Capital Cost ($) of aeration system for aerobic reactor 4 from equation A-5.69] (A-5.70)

6.1.2 O&M Cost of Biosystem

The cost constants and the cost equations used for the calculations are obtained from Table A-12.2 and Table A-12.4.

Maintenance Cost

- Maintenance Cost ($/yr) = 3% of Capital Cost (Table A-12.2 and Table A-12.4) (A-5.71)

where:

capital cost ($) is obtained from equation A-5.70

Labor Cost

Additional labor hours required for 1st and 2nd anoxic tanks with methanol feed system are estimated to be 6 hrs/day (Table A-12.1)

Labor rate = $25/hr (Table A-12.2)

Labor Cost ($/yr) = {[$25/hr] [6 hrs/day] [365 days/yr]}
= $57,750/yr (A-5.72)

Sampling and Analysis Cost for Process Control

For the N+DN+DP system, the sampling and analysis cost is estimated at $13,000 per year (Table A-12.4).

Mixer Energy Cost

The energy costs are based on $0.06/KWh with a 75% motor efficiency (Table A-12.1 and Table A-12.2).

- Mixer Energy Cost ($/yr)
  = {[mixer power (HP)] [0.746 KW/HP] [24 hrs/day] [365 days/yr] [$0.06/KWh]}
  / {0.75} (A-5.73)

where:
mixer power (HP) is obtained from equation A-5.41

Mixer Energy Cost is calculated for anoxic reactor 1 and anoxic reactor 3.

Pump Energy Cost

The energy costs are based on $0.06/KWh with a 75% motor efficiency (Table A-12.1 and Table A-12.2).

- Pump Energy Cost ($/yr)
  = {[pump power (HP)] [0.746 KW/HP] [24 hrs/day] [365 days/yr] [$0.06/KWh]}
  / {0.75} (A-5.74)

where:
pump power (HP) is obtained from equation A-5.43

Pump energy cost is calculated for recycle pumps and intermediate process pumps.

Incremental Energy Cost for Oxygen Transfer

The incremental energy required for oxygen transfer per year (KWh/yr) is obtained from equation A-5.57. A negative number in energy requirement (KWh/yr) from equation A-5.57 indicates savings. As a conservative estimate only 60% of the savings is used in the calculations. The energy costs are based on $0.06/KWh with a 75% motor efficiency (Tables A-12.1 and A-12.2).

Therefore:

- If incremental energy required (KWh/yr) < 0

Then:

- Incremental Energy Cost for oxygen transfer ($/yr)
  = {[0.60] [incremental energy required (KWh/yr)] [$0.06 /KWh]} / {0.75}

Note: a negative number indicates savings

- If incremental energy required (KWh/yr) > 0

Then:

- Incremental Energy Cost for oxygen transfer ($/yr)
  = {[incremental energy required (KWh/yr)] [$0.06 /KWh]} / {0.75} (A-5.75)

Total Energy Cost

- Total Energy Cost ($/yr)
  = {[Mixer Energy Cost of anoxic reactor 1 ($/yr) from equation A-5.73] + [Mixer Energy Cost of anoxic reactor 3 ($/yr) from equation A-5.73] + [Energy Cost of recycle pumps ($/yr) from equation A-5.74] + [Energy Cost of intermediate process pumps ($/yr) from equation A-5.74] + [Energy Cost for oxygen transfer ($/yr) from equation A-5.75]} (A-5.76)

Excess Sludge Disposal Cost

The cost for sludge disposal is $75/ton (Table A-12.2). The incremental sludge generated per day (lbs/day) is obtained from equation A-5.64. A negative number in sludge generation indicates savings. As a conservative estimate only 60% of the savings is used in the calculations.

Therefore:

- If incremental sludge generated (lbs/day) < 0

Then:

- Incremental Sludge Disposal Cost (\$/yr)
  = {[0.60] [incremental sludge generated (lbs/day)] [365 days/yr] [\$75/ton]} / {2,000 lbs/ton}

(Note: a negative number indicates savings)

- If incremental sludge generated (lbs/day) > 0

Then:

- Incremental Sludge Disposal Cost (\$/yr)
  = {[incremental sludge generated (lbs/day)] [365 days/yr] [\$75/ton]}
  / {2,000 lbs/ton} (A-5.77)

where:

2,000 is a conversion factor

Alkalinity Savings

From the MPP detailed surveys, it was observed that caustic is frequently used as a source of alkalinity. Typically, 1 lb. of caustic is equivalent to 1.25 lbs. of alkalinity with a cost of \$0.15/lb (Table A-12.2). Approximately 50% of the alkalinity destroyed during nitrification is recovered during denitrification which provides an opportunity of savings. Alkalinity savings are discussed in Section 5.7 and the amount of net alkalinity savings in lbs/day is obtained from equation A-5.53. A positive number in alkalinity savings from equation A-5.53 indicates savings. As a conservative estimate, only 60% of the savings is used in the calculations.

Therefore:

- If the net alkalinity savings (lbs/day) > 0

Then:

- Alkalinity Savings ($/yr)
  = {[0.60] [net alkalinity savings (lbs/day)] [365 days/yr] [$0.15/lb]} / {1.25 lbs/lb}

- If the net alkalinity savings (lbs/day) < 0

Then:

- Alkalinity Savings ($/yr)
  = {[net alkalinity savings (lbs/day)] [365 days/yr] [$0.15/lb]} / {1.25 lbs/lb} (A-5.78)

Total O&M Cost of Biosystem

- Total O&M Cost ($/yr)
  = {[Maintenance Cost ($/yr) from equation A-5.71] + [Labor Cost ($/yr) from equation A-5.72] + [Sampling and Analysis Cost of $13,000 per year] + [Energy Cost ($/yr) from equation A-5.76] + [Sludge Disposal Cost ($/yr) from equation A-5.77] - [Alkalinity Savings ($/yr) from equation A-5.78]} (A-5.79)

6.2 Methanol Feed System

As discussed in Section 5.6.1, methanol is added to the wastewater in anoxic reactor 1 and anoxic reactor 3. The capital and O&M costs of a methanol feed system are obtained from Appendix A-6.

6.3 Polymer Feed System

Polymer may be added to wastewater at or before the secondary clarifier to improve the settleability of sludge and to lower the effluent TSS concentration. The capital and O&M costs of a polymer feed system are obtained from Appendix A-7.

6.4 Alum Feed System

Alum is used to remove phosphorus from wastewater. The capital and O&M costs of an alum feed system are obtained from Appendix A-8.

6.5 Mix Tank

Alum used for phosphorus precipitation is thoroughly mixed with the wastewater in the mix tank. The capital and O&M costs of mix tanks are obtained from Appendix A-8.

6.6 Sludge Dewatering System

Excess sludge, if generated due to the N+DN+DP system, needs to be dewatered before disposal. The percent increase in sludge generation due to a N+DN+DP system is calculated in equation A-5.65. Based on engineering judgement it is assumed that the dewatering device present in the facility is capable of handling excess sludge of up to 15% of the current sludge generation rate. If the incremental sludge generated is greater than 15% of the current sludge generation then the facility is costed for new thickeners and filter presses. The capital and O&M costs of a sludge dewatering device (thickener + filter press) are obtained from the sludge dewatering module in Appendix A-10. However, facilities that waste sludge to the anaerobic lagoon or to a waste sludge pond do not require a sludge dewatering device. They incur costs only for sludge hauling, which is estimated in equation A-5.77.

6.7 Filtration System

A filtration system is required to achieve low effluent TSS concentrations. The capital and O&M costs of a filtration system are obtained from Appendix A-11.

6.8 Other Annual Costs

6.8.1 Performance Cost

Some facilities have the same treatment technology in place but are not achieving the Option 4 LTA concentrations. It is assumed that those facilities can improve the process performance and achieve the Option 4 LTA concentrations with an estimated cost of $25,000 per year.

6.8.2 Compliance Cost

Practically all of the direct discharge facilities who submitted detailed surveys are already required by their NPDES permits to monitor for many of the pollutants being considered for regulation under the MPP effluent guidelines, especially "conventional" pollutants (e.g., BOD, TSS, pH). Some are also currently required to monitor for one or more of the following pollutants: ammonia-N, total nitrogen, nitrates, and phosphorus. Based on these existing monitoring requirements, compliance cost of $20,000 per year (Table A-12.4) is estimated to accommodate the increase in frequency and number of pollutants that may need to be monitored for Option 4.

6.8.3 Methane Revenue Loss

Some facilities recover biogas from the anaerobic lagoon and do not have adequate BOD for denitrification. For those facilities a portion of the lagoon influent wastewater may be bypassed directly to the anoxic reactor to provide supplemental carbon (see section 7.1). Bypassing the lagoon results in BOD loss for methane generation in the anaerobic lagoon. The model is designed to bypass the lagoon on weekdays (5 days a week) and to feed methanol on the weekends (2 days a week). Methanol addition on weekends is necessary since a typical MPP facility operates 5 days a week, and practically no wastewater is available for bypass during the weekends. The loss in revenue due to reduced methane generation is estimated at $0.035/lb of BOD bypassed (Appendix A- 19).

- BOD bypassed (lbs/yr)
  = {[Q gal/day] [BOD_{inf} - $BOD_{inf\_current}$ mg/L] [8.34 x 10^{-6} lbs/gal-mg/L] [5 days/7 days]}

- Methane Revenue Loss
  = {[BOD bypassed (lbs/yr)] [$0.035/lb]}
  = {[Q gal/day] [BOD_{inf} - $BOD_{inf\_current}$ mg/L] [8.34 x 10^{-6} lbs/gal-mg/L] [5 days/7days] [$0.035/lb]} (A-5.80)

where:

8.34 x 10^{-6} is a conversion factor

All parameters on the right-hand side of equation A-5.80 are inputs to the model.

6.9 Total Incremental Costs

6.9.1 Total Incremental Capital Costs

- Total incremental Capital Cost ($)
  = {[Capital Cost ($) of biosystem from equation A-5.70] + [Capital Cost ($) of methanol feed system from Section 6.2] + [Capital Cost ($) of polymer feed system from Section 6.3] + [Capital Cost ($) of alum feed system from Section 6.4] + [Capital Cost ($) of mix tank from Section 6.5] + [Capital Cost ($) of sludge dewatering from Section 6.6] + [Capital Cost ($) of filtration system from Section 6.7]} (A-5.81)

6.9.2 Total Incremental O&M Costs

- Total incremental O&M Cost ($/yr)
  = {[O&M Cost of biosystem from equation A-5.79] + [O&M Cost of methanol feed system from Section 6.2] + [O&M Cost of polymer feed system from Section 6.3] + [O&M Cost of alum feed system from Section 6.4] + [O&M Cost of mix tanks from Section 6.5] + [O&M Cost of sludge dewatering from Section 6.6] + [Performance Cost from Section 6.8.1] + [Compliance Cost from Section 6.8.2] + [Methane Revenue Loss from equation A-5.80]} (A-5.82)

7.0 ONE TIME COST

7.1 Anaerobic Lagoon Bypass

For optimal denitrification the influent BOD to TKN ratio entering anoxic reactor 1 should be at least 3. If adequate BOD is not present additional carbon source is required. Meat and poultry product wastewater normally has an adequate BOD:TKN ratio. However, some facilities with an anaerobic lagoon may have a BOD:TKN ratio less than 3. For those facilities, a portion of the influent wastewater to the lagoon may be bypassed directly to the anoxic basin to provide supplemental carbon during the weekdays. The cost for the bypass is estimated to be $20,000 (Table A-12.5).

7.2 Miscellaneous Piping and Other Costs

The costs for piping are included in the cost equations of each equipment (see Appendix A-13). However, for a conservative estimate an additional one-time cost of $10,000 is assumed for miscellaneous piping and other expenses.