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Ammonia Recovery Process

**Cost Benefits to the
Operation of a Typical
Wastewater Treatment
Plant**

BioWin® Model Analysis

Presented By:

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Cost Benefits to the Operation of a Typical Wastewater Treatment Plant:

BioWin Model Results

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Executive Summary

Potential capital cost reductions have been estimated as at least a factor of five with the Ammonia Recovery Process for equivalent ammonia reduction relative to biological methods. Substantial operating cost and energy savings have also been estimated, and this study was undertaken to improve those estimates. The complexity of the municipal wastewater process dictates that a simulation model of the process be used for accurate estimation of their operation. BioWin is the industry standard simulation software and has been used previously to model operations of New York City and other major municipal plants.

Generic models of the two major classes of nutrient reduction technology, single sludge and two sludge, were adapted to provide similar operation to those of New York City for the single sludge category and the Blue Plains plant of WASA for the two sludge category. Sensitivity analyses indicate that the following table reasonably estimates the expected benefits of the Ammonia Recovery Process for each category.

Bio Win Model Results	Single Sludge Plant	Two-Sludge Plant
Methanol Reduction	38%	19%
Alkalinity Reduction	10%	13%
Sludge Reduction	6%	3%
Oxygen ("Energy") Reduction	Up to 10%	Up to 13%

Reduction figures are calculated on plant-wide basis

1. Introduction

The Ammonia Recovery Process (ARP) is a patented technology of the ThermoEnergy Corporation, and has been extensively studied at both the computational and pilot test level as a stand alone technology for the removal of ammonia from concentrated waste streams. Cost estimates for removal of about 90% of the centrate ammonia for the 85 mgd plant of NYC DEP (26th Ward) indicate that a capital cost of \$15 million for centrate treatment would accomplish the same reduction as would a capital cost of \$115 million for BNR applied to the main stream. Estimates of operating costs similarly indicated major reductions in costs for energy, chemicals, and sludge disposal.

Operating benefits for side-stream treatment of centrate can not be fully described in standard estimation worksheets due to the multiple interactions between processes involved in nutrient reduction in a WPCP. A leading water modeling firm, HydroQual, Inc, was hired by ThermoEnergy to conduct studies on the impact of centrate side-stream treatment with ARP on inputs needed for BNR. Outputs of the HydroQual study are the projected required process inputs to achieve a desired level of ammonia removal by the WPCP.

2. Background & Conditions Modeled

Contemporary WPCP are multi-stage bio-chemical facilities, with complex interaction of the stages. Simple linear reasoning is inadequate to describe the ecology of the active organisms, which controls operation at aerobic secondary treatment, anoxic and aerated zones of nutrient reduction, and the anaerobic digesters. Consideration of the feedback of intermediate streams and the behavior of clarifiers and dewatering devices reinforces the conclusion that a simulation that accounts for these phenomena is needed for a realistic computational model. The most widely used simulation software, and the one used for most NYC DEP models, is BioWin, developed by EnviroSim Associates.. HydroQual was contracted by ThermoEnergy to conduct BioWin simulations to estimate the impact of ARP use on the inputs required for reduction of the ammonia effluent from a typical WPCP. All simulations were for steady-state operation at 20 C.

Two broad categories of WPCP were studied: *single-sludge* plants, such as those of NYC DEP, in which modification of the secondary treatment is employed for nutrient reduction, and *two-sludge plants*, such as the Blue Plains plant of WASA, in which separate treatment trains are used for carbonaceous BOD removal and nutrient reduction. Generic 100 mgd models were used for each of these categories, and performance of an example of each category was used to adjust the model operation parameters to match typical centrate ammonia concentration. Parameters were specified in the generic BioWin model for each category using default values for rate constants, tank volumes, etc, and identical influent characteristics were used for the two categories of plant. Total nitrogen in plant effluent of 5 ppm was achieved for the single-sludge model and the 2 ppm for the two-sludge case. This is displayed for the single-sludge case in **Exhibit 1**, and for the two-sludge case in **Exhibit 2**.

ARP is itself a sequence of steps that are dependent on both the waste stream to be treated and the effluent specifications. A version of ARP to be modeled for centrate treatment in this study takes the effluent from the vacuum separation step as the return stream to the plant. This preserves the alkalinity of that stream to be used in the plant's BNR, while returning a stream with 100 ppm of ammonia-nitrogen. The effect of this application of ARP treatment of the centrate on chemical and energy inputs was projected for each category of plant. The BioWin model for each category was modified to include ARP as shown in **Exhibits 1 and 2**. Centrate flow to the head of the plant was eliminated in the ARP models and the ARP treated centrate introduced as a flow to the head end of the BNR process. The chemical (methanol and

alkalinity) and oxygen inputs to the BNR process were adjusted in order to keep effluent nitrogen the same for ARP and non-ARP results. Oxygen demand was taken as a surrogate for energy use since the major energy benefit of ARP is the decrease in aeration required. A conservative estimate of caustic demand for ARP based on full conversion of centrate bicarbonate to carbonate was employed. Input and output for ARP in these models is displayed in **Exhibit 3**.

In order to properly interpret the model results it is important to know the sensitivity to the model parameters. In this study the model parameters varied were influent TKN (sum of ammonia-nitrogen and organic nitrogen), SRT (solids retention time in secondary process for single-sludge, and the values for both secondary and BNR processes for two-sludge), and TS (total solids input to the anaerobic digester). Each of these parameters influences the solids sent to the anaerobic digester and thereby the ammonia influent to the ARP. These results are discussed in the following sections.

3. Findings

Identical influent streams are assumed for the two plant categories studied. The impact of ARP on plant operations is measured by changes in the following set of variables for each category.

Input to Model of Wastewater Plant	Definition
Total 'N' Load	Total nitrogen input to BNR = influent-N + Centrate-N
Sludge Produced	Total sludge output from plant
Alkalinity	Total alkalinity required for nutrient reduction and maintaining an effluent pH of 7.3
Methanol	Methanol required for BNR
Oxygen	Oxygen input for carbonaceous BOD removal and nitrification

The N-load on the BNR process for either category of plant includes recycled centrate (and small amounts from other recycle streams) as well as influent nitrogen. Typically nitrogen in recycled centrate is about 20-40% of the total N load. Sludge produced by the plant is reduced by ARP treatment of the centrate, since nitrifier bacterial growth in the BNR is reduced due to the ammonia removed by ARP. Alkalinity demand is similarly reduced in the BNR process by the removal of ammonia by ARP, while half of the alkalinity added for ARP is available for use in the treated centrate that is recycled to the BNR process. Methanol demand is obviously reduced as well by the removal of ammonia by ARP, but in addition the soluble carbon made available by anaerobic digestion is not affected by ARP and is returned to the BNR as bio-available carbon replacing an equivalent amount of methanol. Last, the oxygen demand is lowered by the reduced ammonia nitrogen load caused by removal of ammonia by ARP.

The sensitivity of the effect of ARP on each of these input requirements is also presented for each category of WPCP.

3.1. Single-Sludge Plant

The single-sludge plant, as shown in **Exhibit 1**, adapts secondary treatment to achieve nitrification and denitrification. This allows considerable capital cost savings in retrofit of existing equipment. The left-two columns, Base Case, of **Exhibit 4** demonstrate the ability of ARP to substantially reduce the input requirements for this category of plant. The % reduction of sludge

produced is less than the reduction in N load, since BNR is not the only source of bio-solids. Methanol reduction exceeds the reduction of nitrogen load since treated centrate and influent provide a source of bio-available carbon. Reduction of the nitrogen load to the equivalent of this available carbon would eliminate the methanol demand.

The generic model produced a centrate-N load of about 10% of influent TKN, whereas NYC DEP plants typically have centrate-N loads of about 20%. A calibrated site-specific model would be required for accurate estimation of savings to be achieved at a specific plant. However, the substantial % reductions in, methanol and alkalinity inputs and aeration are expected to be similar at an actual plant. The sensitivity results indicate that this is a robust conclusion.

3.2. Two-Sludge Plant

The two-sludge plant dedicates a separate process to nutrient reduction, as shown in **Exhibit 2**. The generic model demonstrates that the two categories of plant have materially different benefits from the application of ARP. Influent carbon and BNR recycle in the single-sludge category lowers demand for addition of both alkali and methanol relative to the two-sludge category. While the reduction of methanol demand related to ARP is over 6000 kg/d for the two-sludge and about 5300 kg/d for the single-sludge model, the percent reduction calculated for the single-sludge model is much higher due to the lower overall demand for the single-sludge category. A similar result was obtained for the alkali demand.

4. Conclusion

The generic BioWin model results are indicative of substantial savings in both operating and energy costs when ARP is integrated into the nutrient reduction design for either a single sludge or a two-sludge wastewater treatment plant. A more accurate estimate of cost savings for a specific plant requires use of actual plant parameters in the BioWin model and calibration of the model to match plant operational data, as well as unit prices for the process inputs and outputs for the plant location. The beneficial outputs include:

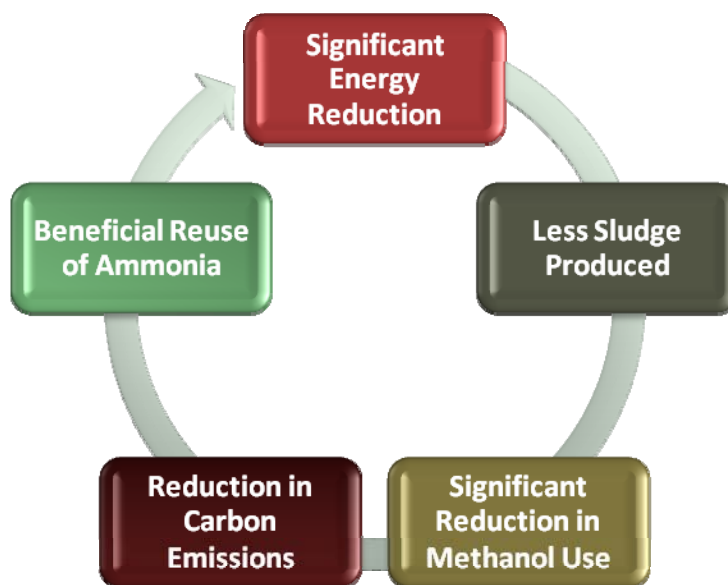


Exhibit 1. BioWin Model for Single Sludge Model

Flow: 100 MGD

Centrate TN: 795 mg/L at 0.41 MGD

Influent Quality

Flow	MGD	100
TKN	mg/L	25
COD	mg/L	290
CBOD	mg/L	142
TSS	mg/L	138
pH		7.0

Effluent Quality

			With ARP
NH ₃ -N	mg/L	0.56	0.58
NO ₃ -N	mg/L	2.54	2.28
TN	mg/L	5.3	5.1
COD	mg/L	33.5	32.5
CBOD	mg/L	8.66	8.28
pH		7.3	7.3

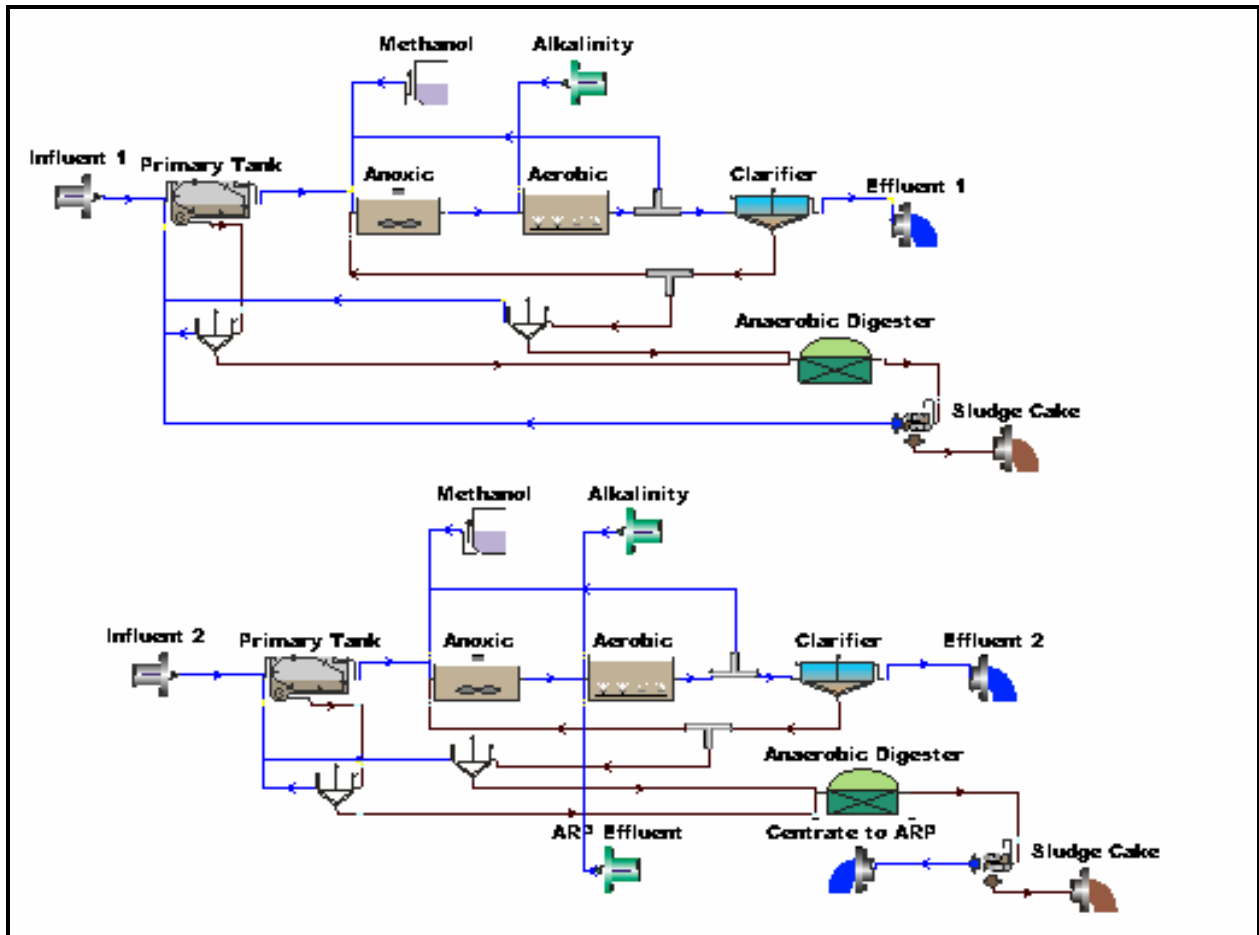


Exhibit 2. BioWin Model for Two Sludge System

Flow: 100 MGD
 Centrate TN: 795 mg/L at 0.41 MGD

Influent Quality

Flow	MGD	100
TKN	mg/L	25
COD	mg/L	290
CBOD	mg/L	142
TSS	mg/L	138

Effluent Quality

			With ARP
NH ₃ -N	mg/L	0.06	0.08
NO ₃ -N	mg/L	0.47	0.46
TN	mg/L	1.96	1.91
COD	mg/L	22.7	22
CBOD	mg/L	3.1	2.9
pH		7.3	7.3

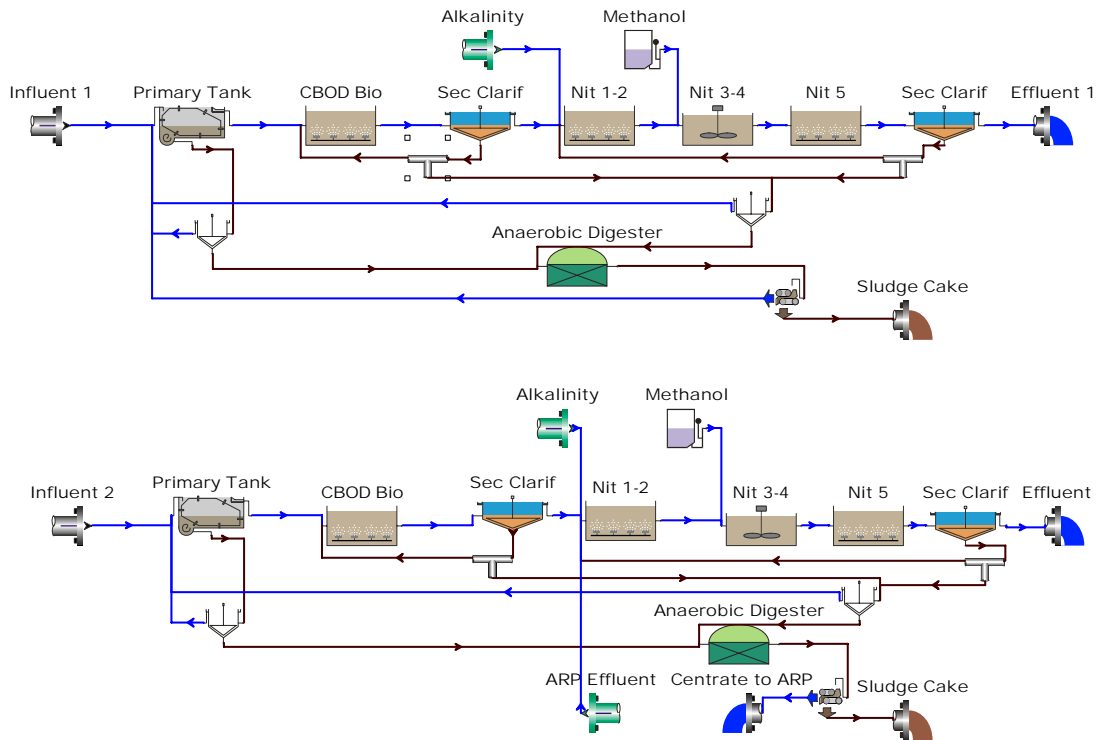


Exhibit 3: Parameters for ARP in BioWin Simulation

I/O for ARP for HydroQual model of ARP return to BNR

Assume quantities in mass units
 output of 100 ppm NH₃-N independent of centrate NH₃-N
 mass ratios of caustic and acid to NH₃ reduction are constant
 for each NH₃ removed, one HCO₃ is lost and one CO₃ is gained
units of ammonia removed = (centrate [NH₃-N] - 100 ppm)*centrate volume

<u>Inputs</u>		
	conc. %	g/gNH ₃ -Nremoved
H ₂ SO ₄	conc.	3.50
NaOH	50%	5.71
<u>output</u>		
	conc. %	g/gNH ₃ -Nremoved
(NH ₄) ₂ SO ₄	40%	11.79
CaCO ₃ equiv.		3.57
COD	[input]	0

Exhibit 4: Summary of Single Sludge Sensitivity Analysis

		Base Case		TKN = 40		High SRT		Higher SRT		High Sludge TS		Low Sludge TS	
	Units	w/o ARP	With ARP	w/o ARP	With ARP	w/o ARP	With ARP	w/o ARP	With ARP	w/o ARP	With ARP	w/o ARP	With ARP
Model Conditions													
Influent TKN	mg/L	25		40		25		25		25		25	
SRT	days	6.53	6.4	6.6	6.5	8.3	8.1	14.1	13.8	6.52	6.4	6.54	6.41
GT WAS	%TS	2.8	2.6	2.7	2.5	2.6	2.6	2.8	2.4	5.8	5.3	1.7	1.7
GT Primary Sludge	%TS	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	8	7.9	2.6	2.6
Centrate TKN	mg/L	1017	918	1087	1232	594	814	590	670	1388	1642	480	541
Effluent Quality													
NO3-N	mg/L	2.8	2.8	5	5	2.8	2.8	2.9	2.9	2.8	2.8	2.8	2.8
pH	mg/L	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3
Model Results													
Total N Load	kg/day	11046	9738	17028	15472	10568	9712	10430	9671	10808	9667	10741	9846
Reduction	%	12%		9%		8%		7%		11%		8%	
Sludge Produced	kg/day	28600	26800	30800	28900	29500	27100	28200	26400	26200	24600	28600	26500
Reduction	%	6%		6%		8%		6%		6%		7%	
Alkalinity	Meq/day	2.50	2.24	3.00	2.71	2.65	2.31	2.90	2.50	2.50	2.23	2.50	2.21
Reduction	%	10%		10%		13%		14%		11%		11%	
Methanol (COD)	kg/day	14280	8925	35700	25585	17850	9222.5	17850	9163	17850	8330	16065	9222.5
Reduction	%	38%		28%		48%		49%		53%		43%	
Oxygen	kg/day	61200	55080	85680	75480	63240	57120	67320	61200	61200	53040	61200	55080
Reduction	%	10%		12%		10%		9%		13%		10%	

Exhibit 5. Summary of Two-Sludge Sensitivity Analysis

		Base Case		TKN = 40		Lower SRT		Higher SRT		High Sludge TS		Low Sludge TS	
		w/o ARP	With ARP	w/o ARP	With ARP	w/o ARP	With ARP	w/o ARP	With ARP	w/o ARP	With ARP	w/o ARP	With ARP
<u>Model Conditions</u>													
Influent TKN	mg/L	25		40		25		25		25		25	
CBOD Stage SRT	days	1.4	1.4	1.4	1.4	1	1	1.9	1.9	1.4	1.4	1.4	1.4
BNR Stage SRT	days	12	11	11	11	5.9	5.9	16.2	16.2	11	11	10.9	10.8
GT WAS	%TS	2.4	2.3	2.6	2.5	3.1	3	3.1	3	4.8	4.6	1.4	1.4
GT Primary Sludge	%TS	5.5	5.5	5.5	5.5	5.5	5.4	5.5	5.4	7.9	7.8	2.5	2.5
Centrate TKN	mg/L	962	934	1273	1243	1124	1101	1124	1101	1701	1651	553	537
<u>Effluent Quality</u>													
NO3-N	mg/L	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
pH	mg/L	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3
<u>Model Results</u>													
Total N Load	kg/day	11550	9911	17871	15678	11780	10035	11321	9823	11550	9843	11570	10034
Reduction	%	14%		12%		15%		13%		15%		13%	
Sludge Produced	kg/day	33000	32000	33906	33100	33800	32600	32100	31100	32100	31100	33000	32000
Reduction	%	3%		2%		4%		3%		3%		3%	
Alkalinity	Meq/day	3.00	2.61	3.75	3.35	3.00	2.77	2.75	2.41	3.00	2.62	3.00	2.61
Reduction	%	13%		11%		8%		13%		13%		13%	
Methanol (COD)	kg/day	33915	27370	53550	47600	33915	25585	29155	23205	33915	27370	33915	27370
Reduction	%	19%		11%		25%		20%		19%		19%	
Oxygen	kg/day	63240	55080	86360	77520	57120	49640	68680	61200	63240	55420	63240	55420
Reduction	%	13%		10%		13%		11%		12%		12%	

