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NUTRIENT AND ATMOSPHERIC EMISSIONS PERFORMANCE OF A MICROAEROBIC BIOLOGICAL NUTRIENT REMOVAL PROCESS (BNR) TREATING DAIRY RESIDUALS

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ABSTRACT:

Concentrated Animal Feeding Operations (CAFOs) often have insufficient land available to receive nutrient residuals. This can lead to elevated soil phosphorous (P) concentrations and increased potential for P and nitrogen (N) runoff negatively impacting surface waters and groundwater. Air emissions from CAFOs can be substantial and potentially troublesome as well. A Bion™ biological process has been retrofitted to an existing anaerobic lagoon to manage both nutrient and atmospheric discharges from a 1,250 cow dairy in Central Texas. The system has been operational for over two years and several periods of intense system performance evaluation have been completed. Relative to nutrient removal the system achieved an overall removal rate of 79% of the wastestream load P and 74% of the wastestream load N when a combination of screens and centrifuge technology was used to capture solids after the biological process. The remaining P & N was discharged in the effluent stream to a storage lagoon to be utilized for irrigation of cropland. The quiescent conditions and detention time in the storage lagoon further polished the system effluent resulting in total systems removals well in excess of 80% for both phosphorus and nitrogen. In addition, the system achieved substantial reductions for measured air emissions. Relative to baseline air emissions for anaerobic lagoons serving dairy operations, direct emissions from the Bion™ system were 99.5 to 99.9% lower for ammonia, from 95 to 99.6% lower for oxides of nitrogen and volatile organics, from 94% to 98% lower for hydrogen sulfide, and lower by 80% or more for methane. The nutrient rich solids generated at approximately 20% solids may be readily transported for agricultural application or further processing. Process configurations of a Bion™ system may be installed to manage manure/residual streams from swine and poultry operations as well.

Keywords: animal residuals, manure/bedding, nutrient management, atmospheric emissions control, biological nutrient removal, odor, dairy

INTRODUCTION:

Background. Concentrated Animal Feeding Operations (CAFOs) present a unique set of challenges relative to the management and monitoring of their total environmental impact. Solids residuals and liquid effluents must be analyzed for nutrients, and gaseous emissions to atmosphere must be monitored for a wide variety of compounds that may cause odor or other negative environmental effects. This holds not only for the CAFO itself and any contiguous waste management system that may be present, but also usually holds for extensive areas of nearby cropland that may receive both solid residuals and liquid effluents from the CAFO as a source of nutrients for the crops. The complexity of this situation means that a waste management technology must control the form of the nutrients it discharges in its solid residuals, liquid effluents and gaseous emissions. The technology must also minimize other odorous or environmentally harmful gaseous emissions not only from the primary process units but all associated collection surfaces (such as flush lanes), additional treatment units, storage units, and the land application processes as well.

For example, it is crucial not only to capture nutrients for reuse but to do so in a manner whereby they will not cause a negative environmental impact during their reuse. Land application of phosphorus in a liquid effluent has less potential to cause environmental problems if the phosphorus is organically bound than if it is in ionic form as orthophosphate because organic phosphorus will be less likely to enter surface waters via runoff than will soluble phosphate. This means that a treatment technology which can control the phosphorus concentration in a liquid effluent should also control the form of the phosphorus in that effluent, to maximize the non-soluble fraction, thus minimizing the potential for environmental problems after land application. Similarly, a technology which maximizes the capture of nitrogen in a non-soluble form should also control the form of the fraction of nitrogen which is lost to atmosphere so that it is discharged as nitrogen gas and not as ammonia. From a monitoring and control perspective this means that both the soluble and particulate forms of nutrients require tracking and management.

From the perspective of atmospheric emissions it is necessary to control the liquids of the treatment technology so that they do not emit sufficient quantities of gases that can cause odors or negative environmental effects. This will then require a monitoring system which can verify that these process liquids will not emit such gases.

DeVries Installation. To demonstrate that the Bion™ system does in fact address all of these constraints Bion™ installed a retrofit system at the 1,250 cow DeVries Dairy in Dublin Texas in 2003. The Bion™ process is protected by eight U.S. patents, one U.S. patent pending* and patents in several other countries. This system has been operational for over two years and has been the subject of several intense analytical evaluations and studies over that time span. Descriptions of some of these, and their results, are presented in this report. Because of the complexity of the gaseous emission situation Bion™ developed an enclosed tank, process simulation system to accurately monitor emissions from both a mixed anaerobic treatment zone and an aerated and mixed microaerobic/anoxic treatment zone.

A schematic Process Flow Diagram with Sampling Points for the Bion™ System at DeVries Dairy is presented in Figure 1. The dairy has two main barns. Each barn is flushed four times a day with the feed lanes for each barn flushed once daily. The flush water carries manure, urine, milking parlor wastewater, residual bedding and spilled feed into a Contact-Mix Sump where it is collected, mixed, and then pumped through a coarse inclined static screen. Effluent from the coarse screen flows directly into a 100,000 gallon anaerobic zone of the Bion™ bioreactor and from there flows into a one million gallon microaerobic/anoxic main bioreactor zone. Liquid from the end of the microaerobic zone is recycled for flush water and is sent to two rotary vibrating (Sweco) fine screens connected in series. Solids from the coarse screen and the first fine vibratory screen are removed from the system for further processing and land application. Solids from the second fine vibratory screen may also be removed from the system or they may be returned to manage bioreactor solids concentrations. Effluent from the second fine screen is discharged to preexisting Lagoon 1 and is defined as the Bion™ process effluent at that point. This effluent passes through Lagoon 1 to Lagoon 2 and from there it is pumped to irrigate fields.

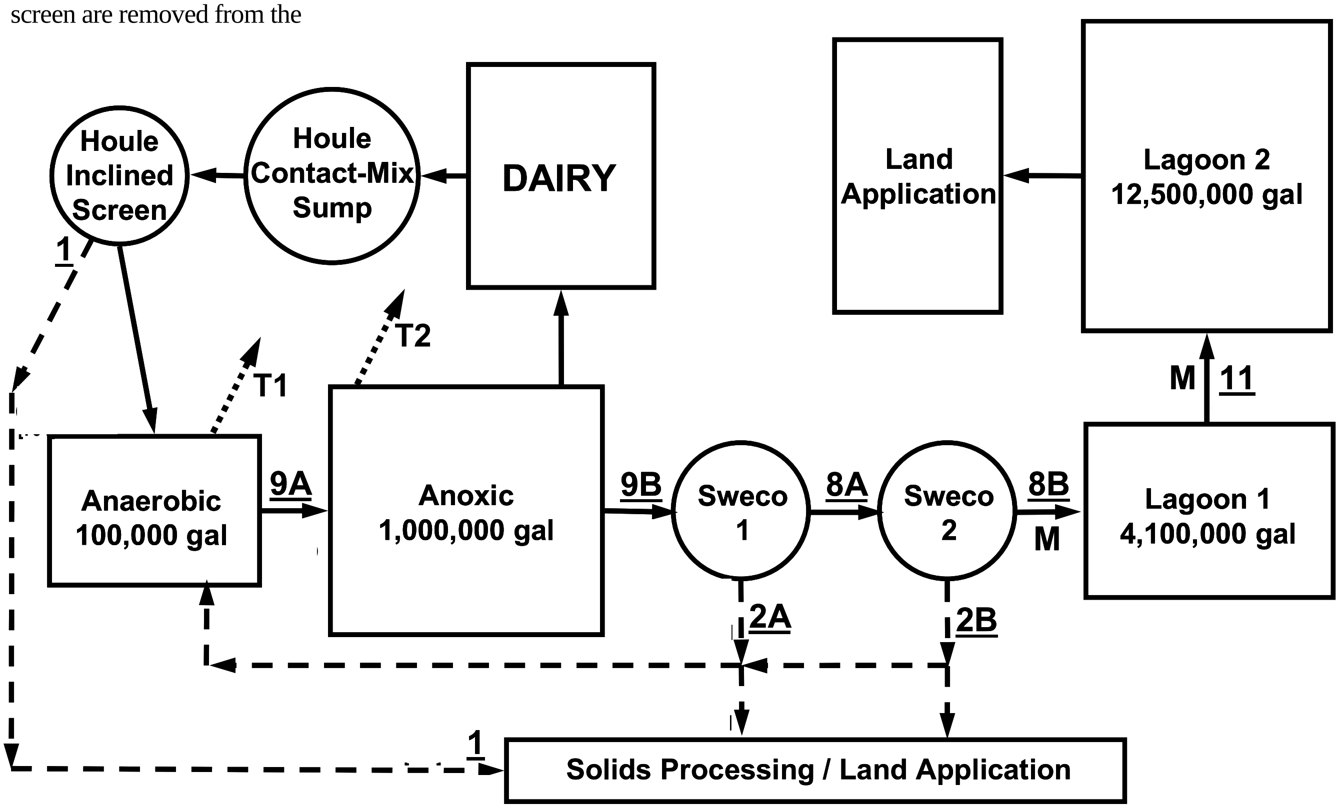


Figure 1. Process flow diagram for DeVries Dairy Bion™ Nutrient Management System. Also shown are selected system sampling points (i.e. **8B**) and flow meter locations - **M** (from the Nutrient Sampling Protocol).

United States Patent numbers 4721569, 5472472, 5538529, 5078882, 5626644, 5755852, 6689274, 6908495; and patent pending 11/106751.

Samples were taken from sample locations throughout the waste management system during the overall DeVries Project. The locations for those discussed in this report are shown in Figure 1. Samples 1, 2A, and 2B are solids samples. Samples 9B, 8A, 8B, and 11 are liquid samples. Samples T1 and T2 are gas emissions samples.

There are two principle intensive and detailed sampling and analyses intervals covered by this report. The first of these concerns a mass balance analysis for the nutrients nitrogen (N) and phosphorus (P). This analysis took place over a 159 day period from 12/10/03 to 5/17/04. This period was chosen primarily because it would monitor biological activity during the coldest operation period of the year when process kinetics would be the slowest. While the average system mixed liquor or bioreactor liquid temperature for a typical year is 22.2ºC, this period's average was 16.7ºC. For 81 of the 159 day period the temperature averaged only 13.3ºC with several days below 11ºC. Thus, the nutrient conversions and results observed during this period will likely reflect a conservative low system response to loadings. A period of system acclimation and operating shakedown ending with consistent operation had been completed prior to the beginning of this assessment period.

After the intensive mass balance analysis interval, monitoring of the system has continued at regular intervals. Bioreactor concentrations of both the soluble and particulate forms of N and P from 5/17/04 through 7/12/05 are compared with those obtained during the mass balance study interval of 12/10/03 through 5/17/04. These comparisons show that system performance has continued at comparable levels to those documented during the mass balance study.

A second interval was used for atmospheric emissions evaluation. This interval covered 86 days from 4/20/04 to 7/15/04 and considered six parameters; carbon dioxide, methane, hydrogen sulfide, ammonia, nitrogen oxides, and Non Methane Organic Compounds (NMOCs). Two major factors determined the choice for this period of testing. First the installation, commissioning and steady operation of all air emission program components was required before testing was initiated. Secondly, this period represented relatively high system bioreactor operating temperatures. The average system liquid temperature for the period was 26.6 ºC with several days approaching 31 ºC. At warmer temperatures gas solubility is decreased, aeration oxygen transfer reduced, and stripping of gases and potential for anaerobic activity increased; all of which lead to expected higher rates of emissions. Thus, the results obtained should represent a conservative high emissions response by the system.

Recent research on dairy emissions and the availability of more precise analytical methodologies has led to a definition of Reactive Organic Gases (ROG) as being more appropriate than NMOC analysis in determining volatile organic gas emissions from dairies. Consequently a new series of gas collection and analysis was conducted on July 12 through 14, 2005. With bioreactor water temperatures of 31.2 ºC, a greatly expanded and more comprehensive list of analyzed substances, and much lower detection limits, this data provides a more detailed and accurate picture of emissions from the Bion™ treatment system.

MATERIALS AND METHODS:

Nutrient Mass Balance Study. The determination of the nutrient mass balances from 12/10/03 to 5/17/04 involved four different areas of investigation. These included the nutrient load to the system, the harvested solids removed from the system, the flow into, through and out of the system, and the nutrient analyses themselves. These four areas are described as follows:

Determination of Nutrient Load to the System. The influent waste load to the system is a combination of gin trash bedding, manure and milkhouse wastewater. The manure and bedding is transported very well by the dairy's flush alley system. However, this mixture is extremely heterogeneous and varies spatially and temporally at different locations within the dairy waste collection system. This makes measuring system inputs a challenge. In addition, the flush lane configuration, use of mats in the lanes, and the tight geometry of the small premilking holding area combined to make the complete quantitative removal, volume measurement and sampling by scrapping and vacuuming the influent waste load impractical.

As an alternative, a rations fed approach was used to quantify influent loadings. Since the total weight variation of a production herd is insignificant, all P and N fed to the cows, less the amount of P and N removed in the milk, becomes manure nutrient waste loading to the treatment system. The DeVries Dairy has very accurate numbers for daily cow numbers, dry matter intake (rations consumed by the cows), the nutrient composition of the ration, and milk production and nutrient composition. An allowance was made for the minor amount of feed spillage that also contributes to system load, on the order of 2% to 5% (Steve Martin animal nutritionist for DeVries Dairy – conversation 11/26/03). It was felt that this approach provided the best measurement of system load. This approach is recommended by Lorimor, Jeff, et al.

(2000), “Manure Characteristics – Manure Management System Series,” MidWest Plan Service, Ames Iowa, MWPS-18 Section 1, pp 19, 23.

Contributions from non-milkers were determined using the equations and tables presented in the recently proposed ASAE standards. The last significant load contribution was derived from bedding. The weight of bedding mixture used was determined and the mix was periodically analyzed for nutrient composition.

Minor contributions from cleaning agents and other potential sources were estimated by the quantities purchsed on an average basis and were found to be insignificant.

Determination of Nutrients Removed in Harvested Solids. Solids separated from the process waste stream are referred to as Harvested Solids Material (HSM). HSM sources include coarse solids from a preliminary coarse screening unit operation and fine solids from effluent polishing unit operations. Coarse solids were separated from the process waste stream by an inclined static screen manufactured by Houle. This screen removed coarse solids from the combined recycled bioreactor process water and influent waste stream prior to discharge to the two-stage bioreactor. Effluent from the two-stage bioreactor was discharged through two fine vibratory screens installed in series for fine solids separation prior to discharge to the Lagoon 1 storage volume outside of the two-stage bioreactor.

The masses of coarse and fine HSM separated from the process waste stream were measured in the field over the course of the study as follows:

- Coarse and fine HSM separated from the process waste stream at the DeVries Dairy were trucked from the site to licensed composting operations in the area. Trucks hauling HSM from the site were weighed at the farm to determine the mass of HSM removed. Throughout the study period there was some variability in the schedule and regularity with which HSM was removed from the site to the composting operations. This variability was averaged to determine a daily production rate over the course of the study.

- The mass discharge of fine HSM from fine screen 1 was tracked daily and reported as a lb/minute discharge rate. The mass discharge rate was then used with equipment run time to determine the mass of fine solids produced over a given time period.

- Periodically, short term HSM production tests were conducted wherein all the coarse and fine HSM would be collected over a given time period (ranging from 1 to 3 days) and weighed as produced. These tests were used to validate the long term averages developed over the course of the entire study.

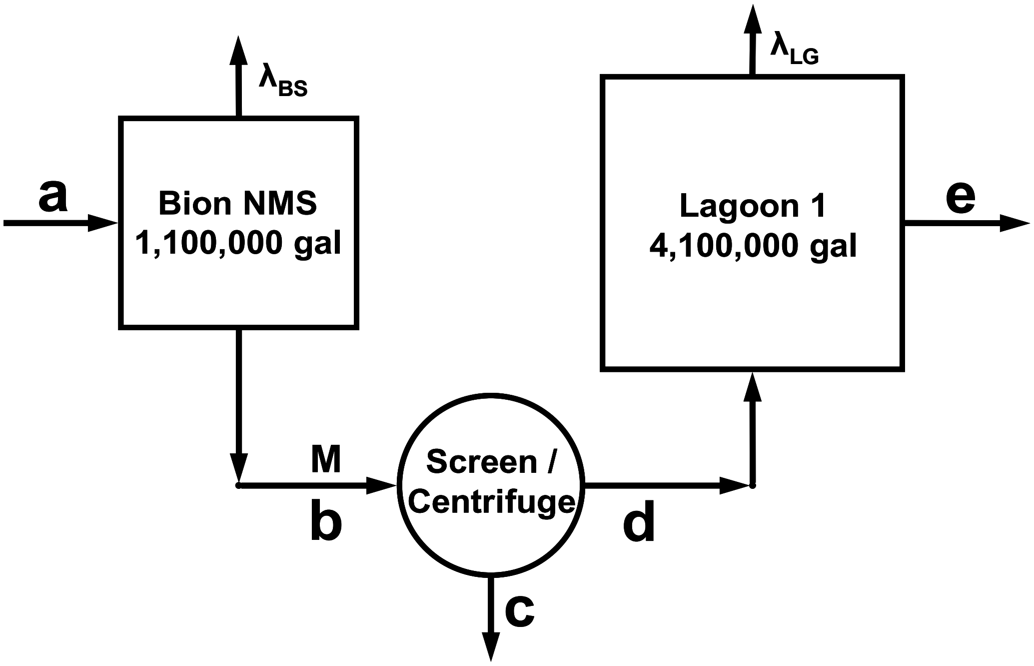
Centrifuge trials on both bioreactor and fine screen effluents were conducted from 6/22/04 through 6/24/04 using a Sharples solid bowl decanter centrifuge. Centrifuge removal efficiencies are a function of machine set-up parameters such as solids dam height, bowl rotation speed and scroll differential speed. Dam height and rotation speed combinations were determined for bioreactor liquid and fine screen effluent. These set-up parameters were then tested for solids capture. Flow into the centrifuge was set by a variable speed positive displacement feed pump. Of the analyses performed on conservative parameters (not generated or consumed), solids data is the most accurate. Knowing the TSS concentration for influent, effluent and solids removed, together with the influent flow rate, allowed the effluent and solids generation flow rates to be accurately determined. These flow rates were then used to determine parameter mass influent loading, mass effluent discharge and mass solids harvested or removed for the parameters: TSS, Tot-P and TKN. Results were applied to the long term operating data to determine removal efficiencies for the Bion™ system incorporating centrifuge technology.

System Flow Determination and Analysis. The Bion™ NMS reactor is located within a preexisting lagoon having a total volume of 5,200,000 gallons. Floating baffles, securely sealed and anchored to the bottom and sides of the lagoon, enclose the reactor’s 1,100,000 gallons liquid volume or mixed liquor, which is physically located inside the preexisting lagoon. It is estimated that the slack present in these baffles allows the contained volume to vary by 30,000 to 40,000 gallons as a buffer between short-term differences in inflow and outflow. Recycle flush water is pumped from the mixed liquor and returns by gravity with the added volume of manure, bedding and wasted feed from dairy housing to the contact chamber/mix sump. Milk-house wash water, spilled drinking water and runoff from minor rain events (less than 0.25 inches over three hours or more) generated by the dairy also flow by gravity to this sump (please refer to Figure 1). All of these inflows are generated from multiple sources within the four barns and milk-house of the dairy. Large rain events overflow the sump to the outside of the baffle enclosed volume and thus bypass the Bion™ NMS reactors.

However, these major rain events do flow into Lagoon 1 and exit via the lagoon 1 discharge pump and meter except for extreme events which overflow directly to Lagoon 2.

Recycled process flush water and influent wastes are discharged to the contact chamber/mix sump where the mixture is vigorously mixed, pumped over the inclined static screen and enters the 100,000 gallon bioreactor anaerobic zone by gravity. Mixed liquor is withdrawn from the complete mix anoxic zone and pumped through either of the fine screens or a fine screen – centrifuge combination. Figure 2 is a simplified representation of the flows through the system. The flow at **a** is the net forward flow (less recycle), an average of 52.5 kgpd. This flow is balanced by the flow pumped through the screen / centrifuge. Effluent from the screen / centrifuge is discharged outside the reactor volume into Lagoon 1. If the screen / centrifuge discharge **d** is not balanced relative to the net inflow **a**, the difference will be forced past the baffles into or out of the mixed liquor volume once the buffer volume is exceeded. It is not possible to measure **a** directly at this installation.

Lagoon 1 has an overflow spillway so that volume added to the lagoon less evaporation, and including precipitation onto the lagoon and surrounding embankments and direct catchment area, are displaced by gravity. The low average flows, in the range of 36 gpm, coupled with high variability posed a challenge for measuring the discharge from Lagoon 1. However, the level of Lagoon 1 can be held steady within a reasonable range by discharging through a pump and flow meter arrangement. This allowed accurate average flow measurements to be obtained. A pump and meter installation provided flow information at **e**. Since the pump acted on a small float difference to maintain near constant system volume, the short term volume measurements were quite variable (driven mostly by wind action) but long term averages were accurate. All flow meters were periodically calibrated.



] **Figure 2 Bion™ NMS Flow Relationships.**

Even in cool periods evaporation can represent a significant daily volume loss from open lagoon surfaces in Central Texas. A weather observing station is operated by Texas A&M University in Stephenville, Texas less than 5 miles from the system. They report the Class A Pan Evaporation measured daily on their internet web site. This value in inches is multiplied by the local small lake and pond factor of 0.7 to arrive at the calculated evaporative losses from the system and Lagoon 1. An on-site recording rain gauge continuously monitored by the dairy was used to determine precipitation additions to Lagoon 1.

These daily values were used by the operators to determine the pump rate to the screens / centrifuge and was checked against the totalized flow measured and is the Bion™ NMS discharge rate **d** on Figure 2 and the long term average of 51.8 kgpd on Figure 1 at 8B.

If $\underline{\boldsymbol{\lambda}}$ = evaporation – precipitation for combined surfaces of the Bion™ system and Lagoon 1 = $\boldsymbol{\lambda}_{BS} + \boldsymbol{\lambda}_{LG}$, then the flow measured through the Lagoon 1 effluent pump at $\underline{\mathbf{e}}$ (Figure 2) plus $\underline{\boldsymbol{\lambda}}$ equals the amount discharged from the system to Lagoon 1 at $\underline{\mathbf{d}}$ or 8B on Figure 1. Since $\mathbf{d} = \mathbf{b} - \mathbf{c}$:

$$\mathbf{b} - \mathbf{c} = \mathbf{e} + \boldsymbol{\lambda}$$

This relationship was used by the system operators to daily adjust the metered pump rate to the screen / centrifuge. In any event the long term average of $\underline{\mathbf{e}}$ + $\underline{\boldsymbol{\lambda}}$ represents the system discharge at 8B on Figure 1 or $\underline{\mathbf{d}}$ on Figure 2. This is the basis for all system discharge values reported and that used for mass discharge calculations.

Operations at a dairy are very stable. Though flows generated by such a facility do vary from day to day, they are not reflected by the very large variations seen at the Lagoon 1 discharge. However, long term averages provided reasonable measures of flow discharged. The hydraulic detention time of the system for the nutrient study period of 12/10/03 to 5/17/04 was approximately 21 days. Therefore, flow values were averaged over a 21-day period. Before applying the running 21-day averaging, 18 of the 148 flow figures for the nutrient study period were deleted from the raw data according to the following criteria: 1) days when substantial system bypass occurred due to major rainfall events or equipment maintenance, 2) negative values and 3) values greater than the average by more than two standard deviations, (a statistical criteria for outliers). The edited data reflected measured normal daily discharge flows.

Nutrient Analysis. Samples were collected at weekly intervals at the locations identified in Figure 1, and were shipped to an independent laboratory for analysis of solids and nutrients. This practice has been continued from the end of the mass balance study interval, which ended on 5/17/04, through July of 2005.

As was the case with system discharge flows, daily discharge values based on 21-day running averages adjusted to the normal discharge raw parameter analyses were determined. These normalized 21-day average numbers were considered as the parameter concentration and mass discharge variation as seen by the system over the period. Their use portrayed the variation experienced by the system over the nutrient study period. The calculations were done as follows:

- The normal operating day raw data averages for the three concentration parameters differs slightly from the average for the 21-day averages. To allow daily 21-day averages to be considered as components of the total mass discharge for the period, these values were adjusted (normalized) in the same manner as the 21-day average discharge flow values in the previous section. This is a minor adjustment since the two averages were only ±0.8%, ±1.1%, and ±1.1% apart for Tot-P, Part-P and Sol-P respectively, and only ±0.7%, ±0.4%, and ±2.1% apart for Tot-N, Part-N and Sol-N respectively, as well. This is well within the expected accuracy of the analyses. This treatment is parallel to the daily value calculation for the discharge flows. Note that these daily values were only used to determine system operation variation. The average concentration times the average discharge flow for the period determines the average daily mass discharge rate for the period.

Analytical Methods. Samples were collected in a manner such that they were representative of the medium being sampled. For liquid and solids streams, samples were generally "grab" type samples. Generally, a series of at least four grab samples were taken over no less than a three hour period for each sampling event. The four grab samples for each location were combined to create a composite sample for laboratory testing. All samples were collected and handled in accordance with the latest addition of "Standard Methods for the Examination of Wastewater".

After samples were collected they were sent overnight to Midwest Laboratories, Inc. for analysis. Analysis of samples followed Standard Methods or current U.S. Environmental Protection Agency Methods. Liquid samples were tested for Total Suspended Solids (TSS), Volatile Suspended Solids (VSS), Total Kjeldahl Nitrogen (TKN), Ammonia, and Total Phosphorus. Portions of the samples were filtered and analyzed for TKN and Total Phosphorus to determine soluble levels of these nutrients. The bioreactor (sample location 9B) was also analyzed for Nitrate and Nitrite. Solid samples were analyzed for Total Solids (TS), Percent Volatile, Density, TKN and Total Phosphorus.

The bioreactor was continuously monitored for Temperature, Dissolved Oxygen, pH, and Oxygen Reduction Potential (ORP).

ATMOSPHERIC EMISSIONS STUDY.

From 4/20/04 to 7/15/04 an intensive study of atmospheric emissions from the system was conducted. Prior to the start of this study a sealed two tank, side stream monitoring test system was constructed and brought on line to accurately simulate the open cell full-scale system in a smaller enclosed tank space. Samples collected from the vent pipes discharging from the vapor head spaces in the sealed tanks were analyzed for six parameters; methane, carbon dioxide, ammonia, hydrogen sulfide, nitrogen oxides (NOx) and non methane organic compounds (NMOC).

Monitoring System Design. Because the Bion™ system is composed of an anaerobic zone and an aerobic zone, both of which are complete mix systems, it was possible to construct an enclosed two tank monitoring system that accurately replicated the emission behavior of the total system. The two tanks were selected so that the depth of reaction liquid within the tank, and the surface area to volume ratios were identical to those in the respective full-scale system anaerobic and microaerobic/anoxic zones. Flow was pumped from the full-scale zones through the respective monitoring tanks so that the enclosed tanks became process continuums of the anaerobic and anoxic bioreactor process environments. Aeration and mixing levels were adjusted to match that used in the full-scale anaerobic and anoxic bioreactor treatment zones.

The enclosed tanks provided total containment, thereby allowing capture of all air emissions from the bioreactor anaerobic and anoxic liquor. From a process standpoint the bioreactor liquor in the two sealed process tanks behaves the same as in the full-scale unit processes, with biological and physical processes continuing uninterrupted, releasing process off-gasses at the same rate as in the full-scale bioreactor anaerobic and anoxic treatment zones. Tank vent lines were monitored for the volume and composition of off-gasses from the bioreactor anaerobic and anoxic treatment zones. The emissions quantified from the enclosed tanks were multiplied by the ratio of enclosed vessels surface area to the open bioreactor surface area to obtain an accurate estimate for emissions from the total open system.

Anaerobic Zone, Monitoring Tank T1. The anaerobic zone sealed process tank, T1, is a 12,250-gallon polyethylene tank having a nominal diameter and overall height of 12-ft. and 17-ft, respectively. The tank overflow is configured to operate at a variety of volumes, depths and volumetric to surface area ratios. Bioreactor process water is transferred to the enclosed anaerobic zone process tank by a submersible pump. Flow to the tank is discharged into the bottom of the tank through two discharge nozzles thereby mixing the tank. The pump flow rate may be varied to provide appropriate hydraulic retention times and mixing rates.

The contents of the full-scale anaerobic zone are replaced approximately every 6 to 8 hours by influent flow to the system. The pump recycling flow between T1 and the anaerobic zone turns the T1 volume over 15 to 29 times during one resident time (including all recycles) in the anaerobic zone. The full-scale anaerobic zone is also mixed at a rate of 0.1hp/1,000-ft^3 of volume. This mixing rate is very low and only serves to inhibit short-circuiting of the anaerobic zone by influent flow. Since the mixed liquor is at concentrations between 2% to 3% and does not settle significantly even over a quiescent 24 hour period, mixing energies normally associated with biological systems are not required. Settleometer tests reveal settling of less than 5% over the standard 30 minute time period and only a maximum of about 10% when left for 24 hours. Given the small amount of mixing energy used in the full-scale system, the transfer pump flow rate was adjusted to provide appropriate detention times and mixing rates for the anaerobic tank.

Emission rates from process occurring in the anaerobic emission testing tank T1 could be well below 1 ft^3/hr. At such low anaerobic tank emission rates there was potential for the elevated partial pressures (gas concentrations in the headspace) to suppress the rate of evolution compared to the full-scale system which is open to the atmosphere. Henry's law would indicate that both the liquid dissolved equilibrium concentrations and rate of emissions may impact the quantity emitted. This issue was resolved by providing a ventilation fan with the capacity to provide 12 turnovers per hour, (or more), of the headspace volume. However, the flow rate was adjusted to lower turnover rates, allowing maximum parameter concentrations to enhance the accuracy of emissions measurements while not significantly suppressing emission rates.

Microaerobic/Anoxic Zone, Monitoring Tank T2. The anoxic zone sealed process tank is a 12,250-gallon polyethylene tank having a nominal diameter and overall height of 12-ft. and 17-ft, respectively. The tank overflow is configured to operate at a variety of volumes, depths and volume to surface area ratios. Bioreactor process water is transferred to the enclosed anoxic zone process tank by a submersible pump. Flow to the tank is discharged into the bottom of the tank through two discharge nozzles thereby mixing the tank. Air is provided to the tank via a compressor and submerged fine bubble diffusers.

Air is supplied to the full-scale anoxic zone at a design rate of 320 to 500-scfm or 2.4 to 3.8-scfm/1,000-ft^3 of reactor volume. The aeration rate in T2 tank was adjusted by a needle valve and flow meter on the discharge from a compressor such that the aeration rate per unit volume equaled that delivered to the bioreactor and steady operating dissolved oxygen levels in the enclosed tank are within ~ 0.3 mg DO/L to mimic conditions in the full-scale bioreactor anoxic zone.

The recycle pump between the bioreactor anoxic zone and T2 was sized to deliver sufficient flow to "turn over" the T2 volume 14 to 30 times for every hydraulic turnover in the bioreactor anoxic zone. This flow and aeration provided ample mixing rates for T2 so that the liquid in the enclosed anoxic tank for air emissions testing and the anoxic bioreactor mixed liquor are essentially an enclosed subset or sub-volume of each other.

Sampling. Samples were collected following USEPA standard operating procedure 1704 (USEPA/SOP # 1704) for samples collected as whole ambient air samples collected in Summa passivated stainless steel canisters. Two one-liter Summa canister 24-hour composites were collected normally from Monday ±1600 to Tuesday ±1600 to Wednesday ±1600. The quantity of emissions being produced from each emissions testing tank was determined at least twice at four-hour intervals on canister sampling days using a hot wire anemometer inserted directly into the vent to determine flow rate.

On two different days four additional field samples were collected to determine air quality influenced by the circulating process water or recycled flush water. The location and nature of these samples is as follows; **1 & 2)** On an active flushing alley, which occurs on approximately 30-minute cycles, twenty-minute canister grab samples were taken at two locations. **3)** A one-hour canister grab sample was taken below the rim of the coarse screen sump or contact / mixing tank at an elevation one foot above the maximum flush water elevation. Flow from this sump travels over an elevated inclined coarse screen. The vertical down-flow effluent pipe from this screen produces a continuous vacuum draw through the screen. These gasses are released in the flow splitter box adjacent to the fine screens. **4)** A one-hour grab canister was sampled from the splitter box headspace during active coarse screen flow.

Vent grabs were taken at least twice during canister sampling composites from T1 and T2. On-site air analyses were obtained using field instruments and protocols. These samples provided on-site checks and additional data to augment the more rigorous canister sample laboratory analyses.

For the 7/12/05 – 7/14/05 interval the sampling involved the collection of composite emissions over a 48 hour period in vacuum canisters as well as in a variety of sorbent tubes. Sorbent tubes allow the air being sampled to flow through media having a selective affinity for the target compounds sought, trapping them to then be released and analyzed in the laboratory. Sorbent tubes used in this study included Silica Gel Tubes, Tenax Traps, and Treated Alumina Tubes. Use of sorbent tubes also avoided any potential for sampling artifacts due to adherence of parameter compounds to the sampling apparatus.

Analytical Methods. All canisters from the 4/20/04 to 7/15/04 interval were sent to Ace Laboratories, Inc. for analysis. For methane, carbon dioxide, and hydrogen sulfide, air from the summa canister was analyzed using EPA method 18. This instrumentation involved use of Gas Chromatography, Mass Spectroscopy, and Total Carbon Detections. For NMOC air from the summa canister was analyzed using EPA method 18, with Gas Chromatography, Mass Spectroscopy, and Flame Induced Detection. For ammonia and nitrogen oxides air from the summa canister was analyzed using Drager Sample Tubes.

Field analyses were conducted as follows: For methane an LEL Solaris detector was used. For hydrogen sulfide, ammonia, carbon dioxide, and nitrogen oxides a Drager digital CMS Detector Chip Analyzer and a Drager Accuro manual pump analyzer were used.

For the 7/12/05 – 7/14/05 sampling all canisters and sorbent tubes were sent to Columbia Analytical Laboratories, Inc. and analyzed using GC/MS, GC/NPD, following EPA TO-3 Modified, EPA TO-15, EPA TO-17, and NCASI IM/CAN/WP-99.02 protocols.

RESULTS AND DISCUSSION:

Nutrient Mass Balance. A summary of the nutrient mass balance results for the period from 12/10/03 to 5/17/04 is presented in Table 1. For phosphorus a total daily load of 180 pounds compares very favorably with a total daily output of 191 pounds (the sum of the phosphorus in the coarse solids, fine solids, and effluent). This represents a closure of ±3 percent which is well within acceptable limits. The result further supports the rational for using the rations plus bedding minus milk approach for average load determination of nutrients.

In the case of nitrogen closure was not calculated because nitrogen gas was discharged to atmosphere and the amount was calculated as the difference between the load and the measurable output (again the sum of the nitrogen in the coarse solids, fine solids, and effluent). The difference method was necessary because air is about 79 percent nitrogen gas and it would be impossible to differentiate the nitrogen gas produced by the nitrification denitrification process within the system with that introduced into the system via aeration.

TABLE 1 - SUMMARY OF BION™ NMS PROJECT RESULTS FOR MASS BALANCE OF NUTRIENTS

Nutrients		
Average for the nutrient study period from 12/10/03 to 5/17/04		
	lb P/day	lb N/day
Load	180	1,529
Effluent discharge	162 (95% particulate solids)	720 (56% particulate solids)
Coarse solids removed	24	169
Fine solids removed	5	34
	180 in to 191 out Closure of ±3%	606 N_2 (by mass balance difference)
Given the final effluent, if an additional solids separation process (centrifuge, filtration, etc.) were to be fed this stream and a total phosphorous removal of 70% and a total nitrogen removal of 45% were obtained, a total of 79% Total-P removal and 74% Total-N removal would result for the entire system with this additional step.		

As the system was operated for the study period only a modest amount of nutrient was actually removed in the harvested solid material. This direct removal was 16.1 percent for phosphorus and 13.3 percent for nitrogen. The reason for these low numbers is that the coarse and fine screens used continuously in this study interval were not effective in capturing the microbial solids which contained the majority of the effluent nutrient. When this effluent was passed through a centrifuge 70 percent of the effluent phosphorus and 45 percent of the effluent nitrogen were further removed bringing the combined removal via harvested solids up to 79 percent for phosphorus and 34.5 percent for nitrogen. When the fraction of nitrogen lost to atmosphere as nitrogen gas is included the total removal for nitrogen rises to 74 percent. Gravity settling in the storage lagoons downstream of the Bion™ system brought final removals of both phosphorus and nitrogen to greater than 80 percent of influent system load.

The fact that significant fractions of effluent nutrient concentrations are in particulate form means that the Bion™ system has extensive environmental flexibility. Solids separation equipment can be selected to meet almost any level of effluent standard because most of the nutrients can be removed with the solids. Thus effluent quality is a function of solids separation efficiency and cost. This is especially true for phosphorus since 95 percent of the effluent phosphorus in this study was in particulate form. This number was further substantiated in the interval since the mass balance study was completed. In these 14 months system effluent phosphorus has averaged over 97 percent particulate. Figure 3 graphically depicts HSM phosphorus concentration by particle size separated in the static screen (> 500 micron), vibrating screen # 1 (350 micron), vibrating screen # 2 (100 micron) and the centrifuge which captured approximately 80% of the TSS in the discharge. As shown, the phosphorus is concentrated in the finer particle sizes which are more difficult to capture with effluent polishing operations. Also the mass proportion of P captured, at 80%, is removed in these fine solids.

Air Emissions.

Table 2 summarizes the air emissions results for the study interval from 4/20/04 to 7/15/04.

No Nitrogen Oxides or NMOCs were detected in any of the samples analyzed during this study period. The values reported in Table 2 are thus placeholder values obtained by using concentrations equal to one half of the detection limit for each of these two categories in the mass discharge calculations.

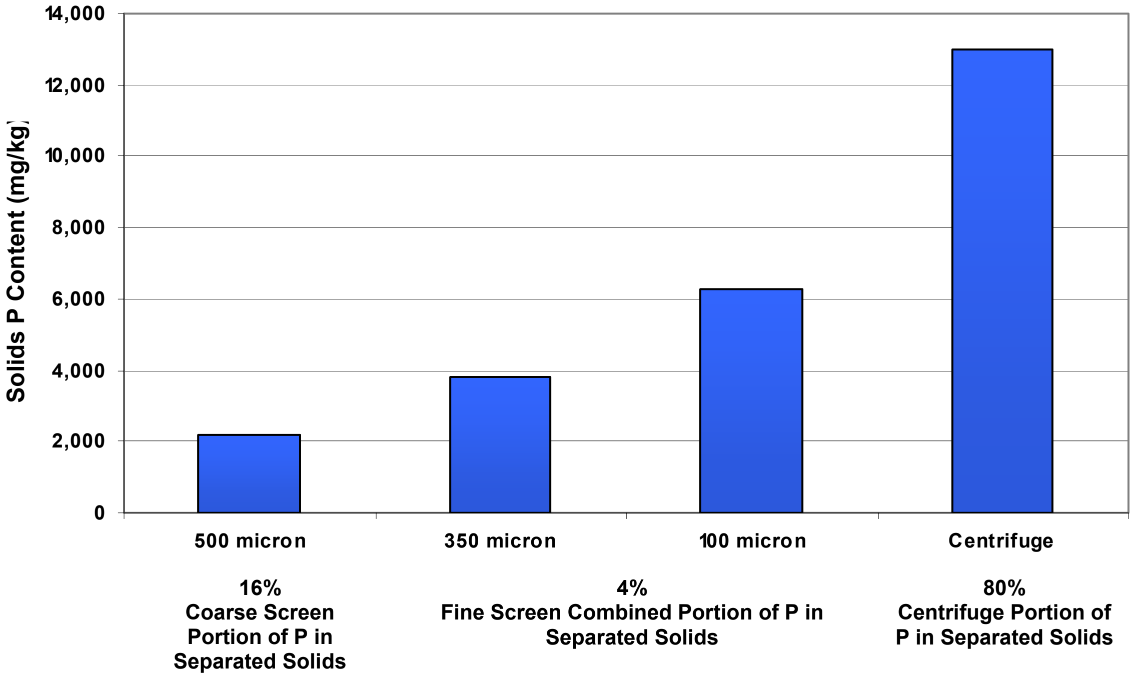


Figure 3 – Harvested Solids Material Phosphorus Concentration and Mass Proportion.

The numbers reported in Table 2 are very low relative to published emissions rates. Research on emissions from anaerobic treatment lagoons show emissions of 250 pounds per KLAW per year or more for methane, 4 to 15 pounds per KLAW per year for hydrogen sulfide, 30 to 164 pounds per KLAW per year for ammonia, 0.22 to 4.4 pounds per KLAW per year for nitrogen oxides, and 1.1 to 4.5 pounds per KLAW per year for NMOC. The Bion™ results compared with these numbers show reductions of approximately 88 percent for methane, 90 to 99 percent for hydrogen sulfide, 99.5 to 99.9 percent for ammonia, 95 to 99.6 percent for oxides of nitrogen, and 98 to 99.6 percent for NMOC.

TABLE 2 - SUMMARY OF BION™ NMS PROJECT RESULTS FOR AIR EMISSIONS

System Air Emissions

Total System Average Emissions for the period from 4/20/04 to 7/15/04

Parameter	lb/day	lb/KLAW-year
Methane: CH_4	147.32	27.49
Hydrogen sulfide: H_2S	2.17	0.40
Ammonia: NH_3	0.75	0.14
Nitrogen oxides: NO_X (NO_2 standard)	0.062[a]	0.012[a]
NMOC: (C_5H_{12} pentane standard)	0.10[a]	0.020[a]
Carbon dioxide: CO_2	3,319	621

[a] - Note that all measurements for NO_X and NMOC were non-detect.

It should be noted that the results reported here, and the results cited for anaerobic lagoons, are for the direct emissions from the treatment units themselves. Thus they do not include enteric emissions from the cows, emissions from feed storage or raising facilities, from storage lagoons, or from other farm areas not involved with waste management. The results of the area wide emissions testing also indicated insignificant emissions from the flush lanes and mixed contact chamber and associated equipment.

While Bion™ was performing this initial phase of this study, the California Air Resources Board (CARB) and San Joaquin Valley Unified Air Pollution Control District (SJVUAPCD) were working with a variety of scientists and engineers to perform qualitative and quantitative determinations of the various species of organic compounds which comprise dairy emissions. This research found that the composition of the emissions previously measured as NMOC included significant amounts of acetone (which is not in the EPA Volatile Organic Compounds (VOC) definition) and did not include a number of reactive gases of concern which are components of VOCs but not measured by the established standard VOC sampling and analytical techniques. Compounds unmeasured included some alcohols, volatile fatty acids (VFAs), phenols and amines. This California research thus indicated new techniques for more precise sampling and analysis of dairy VOCs to expressly address those reactive in the atmosphere or reactive organic gases (ROG).

As a result of this recent work Bion™ did a second air emissions study on 7/12/05 – 7/14/05. This study looked at methane, ammonia and hydrogen sulfide and also incorporated new and more precise sampling and analytical techniques for VOCs as suggested by recent studies. Thus in addition to a total volatile organic compounds measurement based upon gas chromatograph mass spectroscopy data, the library of additional standards and tests consisted of 17 VFAs, 13 amines, 10 phenols and cresols, methanol, ethanol, and isopropyl alcohol. Acetone and methane were measured but excluded from the ROG category. The technical improvements incorporated into the new study resulted in detection limits far more accurate than those used earlier for NMOC, and this resulted in many compounds being detected.

The results of the recent study are reported in Table 3 and compared to the previous more extensive study's findings.

TABLE 3 - RECENT BION™ NMS PROJECT RESULTS FOR AIR EMISSIONS

System Air Emissions		
Total System Average Emissions in lb/KLAW-year		
Parameter	7/12/05 – 7/14/05	4/20/04 – 7/15/04
Methane: CH_4	28.81	27.49
Hydrogen sulfide: H_2S	0.48	0.40
Ammonia: NH_3	0.43	0.14
Dairy ROG:	0.057	NA
NMOC: (C_5H_{12} pentane standard)	NA	0.020[a]

[a] - Note that all measurements for NMOC were non-detect.

In general the new results were comparable to the old results with the new more comprehensive and precisely measured ROG being close to the old placeholder value for NMOC. At the low mass rates found it would be difficult to characterize the differences as being practically significant.

CONCLUSIONS:

The Results of these studies show that a Bion™ system is a comprehensive solution for the environmental problems of a large dairy facility. Its biological treatment of the dairy's waste stream results in minimal emissions of atmospheric pollutants and converts nutrients into particulate form so that they may be harvested by a variety of solids separation technologies. The resulting solids have a number of beneficial reuse options. Application of the Bion™ process in an operating dairy's waste management system has resulted in:

Nutrients

- Process effluent contained 95% or more of the remaining phosphorous in particulate form.
- A substantial portion, 80%, of effluent phosphorous is contained in particles smaller than 100 µm.
- Depending on the solids removal technology applied overall phosphorous and nitrogen removals of greater than 80% are readily achieved.
- The form of nitrogen and phosphorous remaining for land application is in a less mobile organic form significantly lowering the potential for run-off pollution.

Atmospheric Emissions

- Positive control of atmospheric emissions for primary substances responsible for poor air quality, odors and negative health effects was achieved.
- Compared to typical emissions from anaerobic lagoons, emissions directly from the Bion™ process were lowered:
  88%+ for methane 90-99% for hydrogen sulfide
  99.5-99.9% for ammonia 95-99.6% for oxides of nitrogen
  98 to 99.6 percent for NMOC (or ROG)
- Recently developed sampling and analytical protocols verify the very low emission rates reported.