Holland America Line End-of-Season Ammonia Reduction Pilot Study Report

This report provides a summary of the current status of the Ammonia Reduction Pilot Project jointly conducted by Princess Cruise Lines and Holland America Line in the summer of 2009. This report is submitted pursuant to the approved Source Reduction Evaluation plan submitted in August of 2008 and subsequently approved by the Alaska Department of Environmental Conservation. This report is based primarily on input from a review of ship-board operations conducted by HAL personnel on board the Golden Princess in Seattle in September of 2009, as well as an interim report provided by Hamworthy, the vendor, in September 2009 (see Appendix attached, Princess Cruise Line has already provided this report to ADEC as well).

The pilot project equipment is installed on the Golden Princess. The project has been funded by Carnival Corporation, the parent company of both Holland America Line and Princess cruises. Golden Princess is equipped with three separate Hamworthy membrane bio-reactor advanced waste water treatment facilities, each with a designed capacity of approximately 280-300 m^3 per day. Preliminary influent and effluent characterizations were completed during Phase I of this project earlier this year.

The Golden Princess was modified during the May dry dock to allow commissioning of the system in June and July of this year. One of the Hamworthy units was converted for this pilot project. Installation included a homogenization tank, monitoring and control equipment, a two stage nitrifying tank, associated pumps, flow meters, dosing stations, pipes and alarms, visual control displays etc. The capacity of this system has been reduced from the above stated volume to approximately 80-100 m^3 per day. Operations were initially in the vicinity of 100 m^3 per day, with more recent experiments conducted at approximately 80 m^3 per day to evaluate the effect of longer residence time in the treatment unit. This highlights one of the fundamental trade-offs associated with this system: more complete nitrification-denitrification requires a longer residence time in the tank, thereby reducing treatment capacity for a given tank volume.

During the September ship visit, Mr. Wei Chen of Hamworthy described the current status of the system. The first stage of the process is to collect influent in the homogenization tank (referred to as "Tank 5" in the Hamworthy report). This was determined to be necessary during an earlier phase of this pilot project due to the unusual variation in influent throughout the day. In normal, land based applications, this is less critical as municipal systems typically serve a more diverse customer base, plumbing and sewer systems are larger, extending many miles throughout the community. This allows greater mixing and homogenization as the waste travels through the sewer system. Municipal sewage systems are immediately more dilute because they rely on gravity rather than vacuum based conveyance and therefore use more water for transporting the waste. As a result, the Golden Princess (GP) system is designed to manage the influent, targeting approximately a 2:1 gray water : black water ratio. Hamworthy representatives commented that the blending system is not that precise, and that there is some variation in their ability to achieve this idealized blend.

HAL representatives then took an equipment tour which first went to the homogenization tank (Tank 5). This tank is approximately 2.3 meters tall x 3.5 meters wide by 7.3 meters long comprising a volume of 59 m^3.

Figure 1: homogenization Tank

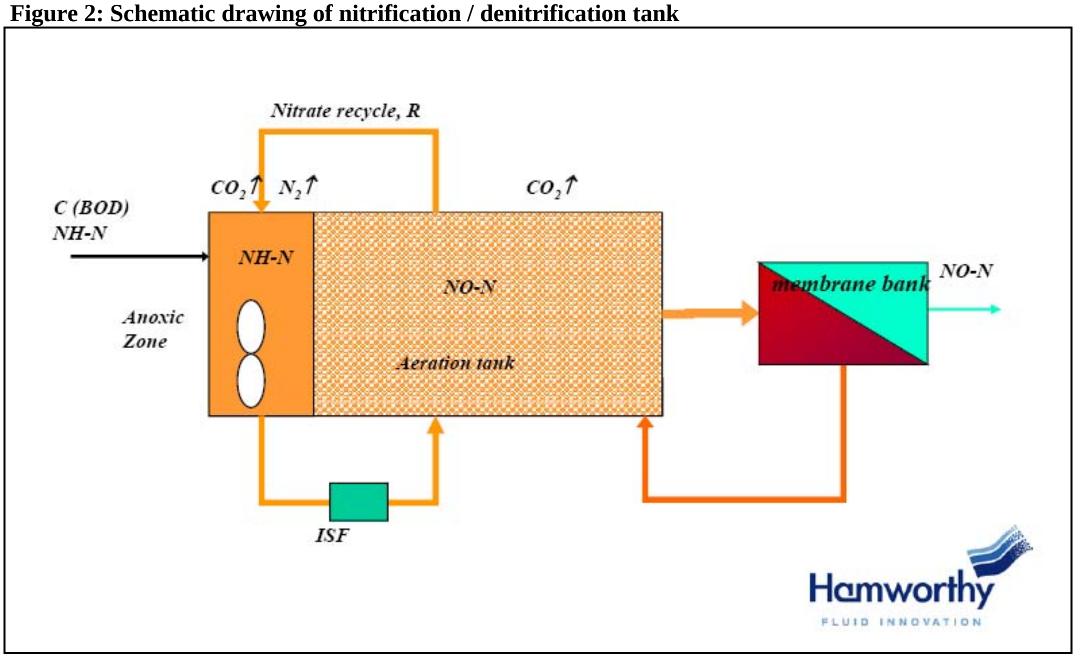
The mixing tank is operated to contain approximately 30 m^3 of mixed gray and black water.

Mixing is achieved with aeration, typically one minute of aeration followed by five minutes of no aeration (constant aeration could lead to foaming and a reduction of carbon source for the denitrification process). Influent has been found to settle at approximately 40° C, somewhat higher than the optimum of 25°C.

This tank is equipped with Membrane BioReactor (MBR) feed pumps, an aeration blower, in line monitoring (to determine influent ammonia content) and other associated equipment.

Once homogenized, mixed liquor is sent to the first stage of the Membrane Bioreactor (MBR) Plant, demonstrated in the graphic below.

Figure 2: Schematic drawing of nitrification / denitrification tank



This tank is partitioned into two stages: an anoxic zone and an aeration zone which manage a two step reaction:

$NH\text{-}N + O_2 \rightarrow NO_2^-$ (nitrite) + $H_2O + H^+$ (by nitrosomonas)
$NO_2^- + O_2 \rightarrow NO_3^-$ (nitrate) (by nitrobacter)

The anoxic tank (including the "swing zone" which allows mixing between the anoxic and aeration tanks) measures 1.4 m x 3.5 m x 2.6 m ≈ 13m^3 while the aeration zone measures 1.8 m x 3.5 m x 4.7 m ≈ 30m^3. The combined dimensions of this tank are therefore approximately 1.8 m x 3.5 m x 7.2 m ≈ 45 m^3. Thus the combined foot print for the mixing tank and the MBR tank is approximately 50 m^3, not including auxiliary equipment such as pumps, monitoring equipment, etc.

Stage 1 is an anoxic stage (<0.3 mg/L dissolved oxygen) in which de-nitrifying bacteria convert nitrate and nitrite into nitrogen gas. This tank is equipped with a mixing pump to keep solids in circulation without aeration pumps, which supports bacterial digestion while maintaining the anoxic environment.

The second stage of this tank contains nitrosomonas bacteria and nitrobacter bacteria, which oxidize ammonia into nitrite ($N0_2^-$), and then nitrite into nitrate (NO_3^-). Mixed liquor is re-circulated from this section back to the first stage, to enhance nitrate removal. It is believed that if nitrobacter bacteria suffer, the system will 'accumulate' nitrites in the waste water – as has been experienced with Golden Princess. This may require a larger reactor, with longer sludge retention times. Conversely, a reduced flow through capacity would yield a longer sludge retention time with a lower treatment capacity.

Figure 3: pH adjustment chemicals

Both Nitrosomonas and Nitrobacters are slow growing and vulnerable bacteria, particularly when compared to the bacteria typically used to reduce Biological Oxygen Demand (BOD). As a consequence, these bacteria require more active control of their environment and a more stable influent (for example for pH). This requires the ability to monitor and adjust the mixed liquor – particularly for pH, to assure an optimum environment. The slow growing nature of these bacteria requires longer solids retention time to assure an adequate repopulation rate. If flow-thru is too rapid, populations will die-off and be wasted before their replacements can re-grow.

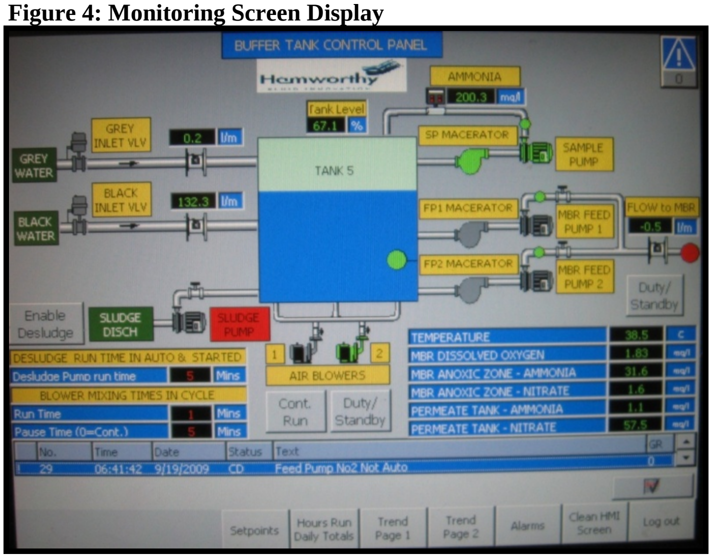
This would indicate that recovery from system upsets will take much longer than has been experienced with currently installed AWWPS systems that have thus far targeted BOD and TSS removal. A target of 15 days solids retention would thereby specify a wasting of approximately 6% solids per day.

Shipboard Monitoring:
Key measurements are:

Temperature (homogenizer and nitrifying tanks)	MBR Anoxic zone – Total Organic Nitrogen
MBR Dissolved Oxygen	Permeate Tank – ammonia, Total Organic Nitrogen
MBR Anoxic zone – ammonia	Permeate Tank – Total Organic Nitrogen

The below photo shows the on-line monitoring capability of the installed system.

Figure 4: Monitoring Screen Display

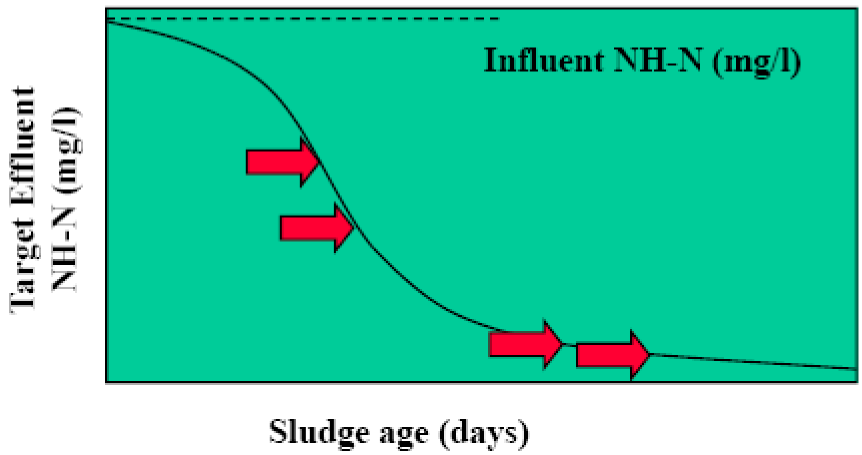


Additionally, shipboard sampling and analysis is conducted in a small field laboratory which uses a Hach-Lange DR2800 equipment to measure for ammonia, nitrate, nitrite, phosphorous, and COD. Ship-board training is required to educate the technicians on the use of this equipment.

Hamworthy Reports of Preliminary results
The consultant's report shares some results indicating significant reduction of ammonia concentrations, tempered by an apparent buildup of nitrites. It is noted that the system was not yet delivering ammonia reductions capable of meeting long-term limits required under the Alaska permit and in fact was yielding results *already* obtained by the Zenon systems installed on several Holland America Line ships. This is largely due to the much higher gray water to black water ratio treated in the Zenon systems.

With respect to influent concentrations, the consultant emphasized that the ammonia reduction process is asymptotic – i.e. reductions from typical influent concentrations experienced in this pilot of 1,000 mg/L to effluent values of less than 100 mg/l, (more than 90%), would not likely be repeated when attempting to reduce ammonia concentrations from, say, 30 mg/L to 2.9 mg/L (long term limit of the Alaska permit).

Figure 5: Asymptotic Ammonia Removal Curve



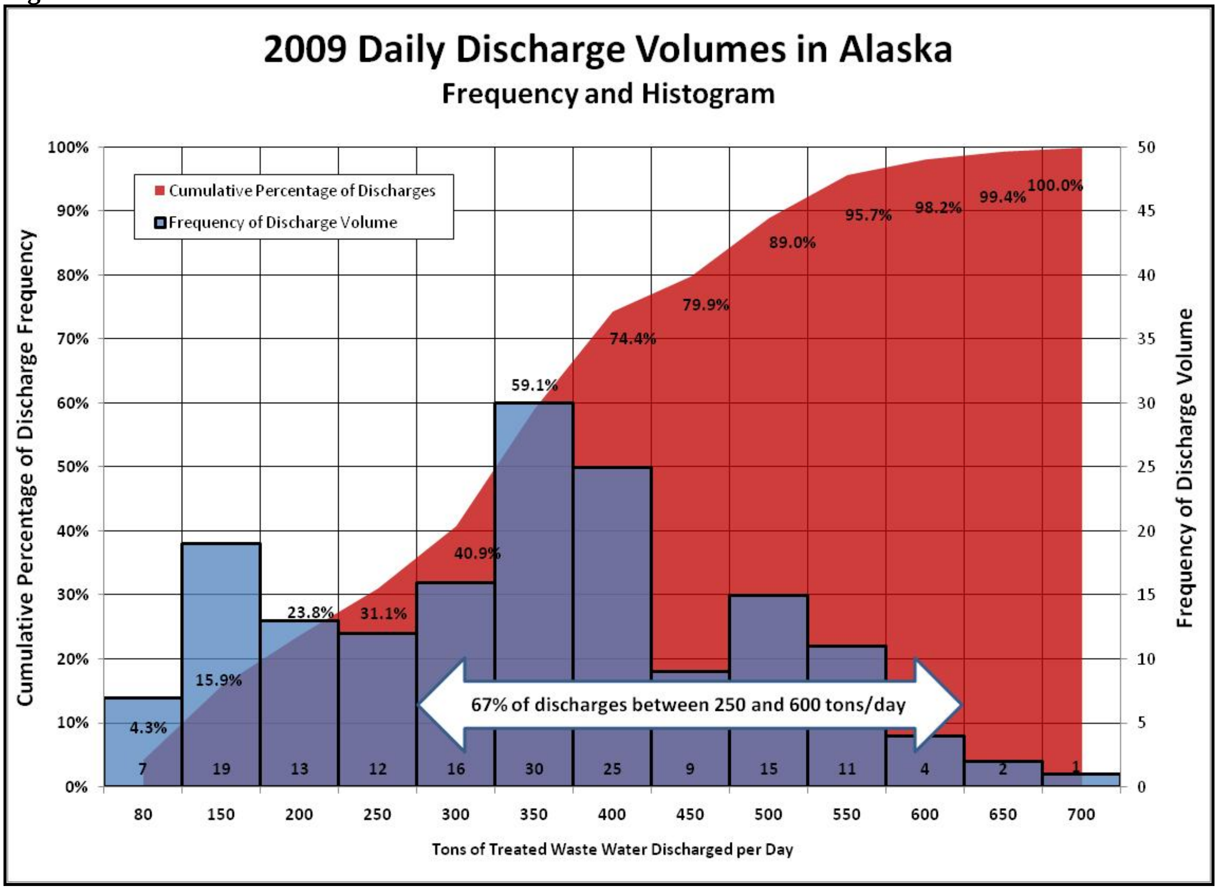
Next Steps
There will be continued refinement of the treatment process, along with experimentation on the sludge retention time, to determine whether further removal is achievable. Greater operational experience will also determine stability of the system, as well as other considerations. Increasing the ratio of gray water to black water to reduce influent concentrations will be of particular interest relative to HAL operations, as the blended effluent typically treated in HAL's Zenon systems is of much lower ammonia values than that of the Golden Princess.

HAL Specific Issues

Required Treatment Capacity
The pilot project on the Golden Princess has treated only a portion of the daily waste stream generated each day. The mixing tank (Tank 5), associated equipment and nitrifying tank are sized to treat approximately 80 tons of waste water per day.

Although HAL ships are smaller, this capacity represents just a fraction of the waste water generated each day on R and S Class vessels. Based on data compiled for the 2009 season, the chart below shows the percentile for discharge volumes averaged between these two classes of vessels.

Figure 6



As indicated, a daily discharge of 80 tons or less of waste water occurred on less than 4.5% of the days in which HAL discharging vessels operated in Alaskan waters in 2009. These data include days in which discharges are restricted, such as in Skagway Harbor and Glacier Bay.

This is significant as most Alaska itineraries involve several consecutive days in Alaska state waters. This would necessitate accumulation of wastewater in tanks for discharge outside of waters subject to the long-term limits, with consequent requirements for increased sailing distance and speed. The result would be a considerable increase in fuel consumption / with associated emissions and expense.

Additionally, since the system has not yet achieved the long term permit limits on a pilot scale, we are unable to predict whether it can be effectively scaled to treat the 250-600 tons typically discharged per day. Continued study under the pilot program will be necessary to determine mixing tank requirements, or what modifications to our membrane bioreactors would be necessary.

Equipment Footprint
The Golden Princess pilot project highlights the need for additional tankage and equipment were this approach to be scaled up to address the full treatment requirement – particularly given the challenges presented by the need to homogenize the treatment influent. The mixing tank occupies a footprint of approximately 25 m^2. If this were to be scaled up linearly to accommodate a typical discharge volume of 400 tons, this could require as much as 200m^2 of tank footprint. Figure 7 provides a general arrangements layout of Deck C on Volendam – an R-class vessel that sails in Alaska. Obviously the required floor space can vary with changes in tank volumes adjusted by height, however mixing and aeration issues would need to be considered as well. Regardless, this gives an idea of the scale of space that must be identified in an already crowded engine room before a full scale implementation could be initiated.

The Golden Princess is a "Post-Panamax" vessel, meaning it will not fit through the Panama Canal. This is because the beam of the vessel is 118 feet and thus wider than the canal.[1] In comparison, All HAL vessels can pass through the Panama Canal with a beam of 106 feet or less. The implications for this are that HAL ships have a smaller foot print than is potentially available on the Golden Princess. Of course larger ships have their own floor space demands in the engineering spaces, and it is not our purpose to conduct a definitive comparison here, but the fundamental differences between the vessel dimensions is an important consideration.

Next Steps

At this writing it is inconclusive as to whether this ammonia reduction process will be capable of meeting the long-term limits of the Alaska permit. Hamworthy is planning to adjust the gray water/black water ratio to manipulate the influent ammonia levels to a lower concentration. As documented in our SRE submittal of January 2009, HAL's measured ammonia concentrations before treatment ranged between 69 and 150 mg/L – a variation believed to be caused by the percentage of graywater in the combined influent. Future work and success in meeting long-term permit limits given a lower influent concentration will dictate whether this technology proves feasible.

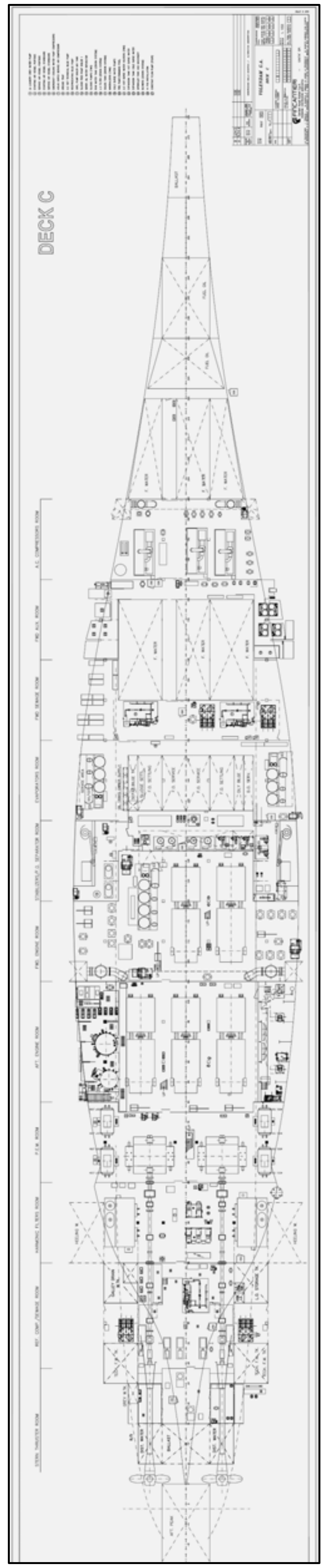


Figure 7: Volendam Deck C Plan

[1] The maximum dimensions allowed for a ship in transiting the canal are: Length-965 ft. (294.13m); Beam – 106 ft. (32.31m); Draft - 39.5 ft (12.04).

On Going Source Reduction Activities

In addition to the pilot program on the Golden Princess, HAL has committed to several initiatives under its SRE program including:

1. Strategic source water bunkering
2. Laundry water investigation (including Ozonator installation)
3. Water conservation
4. Enhanced Nitrification using additives to existing waste water treatment systems

These efforts are on-going and will be discussed in detail in the annual SRE report due January 14, 2010.