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Abstracts

Disinfection Byproduct Speciation and Pathways Resulting from Ozone or Chlorine Application in Seawater Systems

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Treatment of seawater (and artificial seawater formulations) in marine aquaria with ozone result in a mixture of disinfection byproducts (e.g., trichloramine and tribromamine). Due to the high concentration of chloride in seawater, ozone can degrade to free chlorine species (i.e., hypochlorous acid/hypochlorite; or $HOCl/OCl^-$). Depending on the bromide concentration in solution, both ozone and chlorine addition can lead to the formation of free bromine species (i.e., hypobromous acid/hypobromite; or $HOBr/OBr^-$). Free chlorine and bromine both react with other constituents in seawater (including ammonia) to form many disinfection byproducts including haloamines (e.g., trichloramine (NCl_3) and tribromamine (NBr_3).), trihalomethanes, haloacetic acids and other species. In this project, a suite of analytical methods were developed, validated and used to study the formation of disinfection byproducts in varied seawater treatment scenarios. Analytical methods included liquid chromatography, gas chromatography, and ion chromatography coupled with mass spectrometry and other detectors (in addition to titrimetric and other methods). Analytical methods were used to examine the concentration of both inorganic and organic disinfection byproducts under a wide range of treatment conditions both in laboratory and full-scale systems. In addition, kinetic chemical models were developed to predict the formation of varied chlorinated and brominated species during ozone and chlorine treatment. Specific results

of the chemical modeling were validated using chemical analyses, and more recent methods are currently being used to validate the formation of other disinfection byproduct species.

Reducing Biological Filter Cycling Times During Construction of Aquatic Systems: Pre-nitrification via a Temporary Process Loop

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Abstract: Establishing stable ammonia-oxidizing (AOB) and nitrite-oxidizing bacteria (NOB) populations to adequately process nitrogenous wastes in a new aquatic animal life support system typically requires three to six weeks and much longer at temperate to polar temperatures. AOB/NOB colonization of biological media typically begins after system commissioning and adds three to six weeks to construction time before animal introduction can commence. AOB/NOB populations can be established by building a pre-nitrification process loop concurrent with aquatic system fabrication, effectively reducing the construction schedule by three to six weeks. The pre-nitrification loop consists of a sump with a pump that feeds water to filtration components containing appropriate substrate for AOB/NOB growth. These biological reactors in

turn supply water back to the sump to complete the closed loop. The sump has significantly less volume than the final aquatic system (10% or less), so daily dosing with a nitrogen source, such as urea, is readily and economically achieved. In 2013, the National Aquarium, Baltimore, applied this technique during the construction of a 275,000-gallon mixed species exhibit. Using regular water quality measurements (ammonia, nitrite, alkalinity, pH and salinity) incremental increases in daily urea additions were calculated for the 30,000-gallon pre-nitrification system. After characteristic ammonia and nitrite peaks, a stable concentration of daily nitrogen input, equivalent to a fully stocked system, was achieved, in less than one month (26 days). Thereafter the filters were fed a stable maintenance dose of urea until the final life support system was connected, at which point daily urea doses were reduced to offset nitrogen input from food fed to stocked fishes. Urea was introduced immediately prior to the sand filters and no ammonia or nitrite was detected in the exhibit, allowing maintenance of AOB/NOB populations without risk to the fishes.

Use of Foam Fractionation to Achieve Disinfection and Removal of Dissolved Organics from Marine Aquaria

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Abstract: The benefits of Foam Fractionation for marine aquarium water quality have been well documented. No other Life Support System technology is designed specifically for the continual removal of dissolved and suspended organic materials. Organic materials are removed via adsorption and micro- flocculation processes at air/water interfaces within Fractionators. Effectiveness of these processes is increased when a very small dose of ozone is employed. With continual removal of organic materials comes significant improvement in environmental stability and water quality, such as increased Redox Potential, Dissolved Oxygen concentration, pH, and water clarity. In addition, disinfection is achieved via two independent methods: physical removal from the water column and destruction by ozone (when employed). Appropriate sizing of fractionators, pumps and injectors, appropriate air/water ratios, appropriate dosing of ozone, identification of hydraulic concerns, and effective placement of FF within the LSS sequence are critical to successful implementation of fractionation.

User-Friendly, High Efficiency Denitrification

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Abstract: Advances in denitrification systems continue to be made, however risks associated with systems that must work within narrow tolerances, and which are susceptible to mismanagement of operational complexity, have prevented their widespread use. Heterotrophic, e.g. methanol-based, systems can be problematic due to high levels of bio-growth and bio-fouling, as well as erratic nitrate removal rates resulting in production of hydrogen sulfide. Autotrophic, e.g. sulfur-based systems for large aquaria can be too large to suitably fit in mechanical rooms due to inefficient removal rates. The National Aquarium in Baltimore employs an efficient sulfur-based autotrophic denitrification system that attains a peak removal rate of 7 kg NO3-/m3 S-day, which is more than three times greater than the removal rate of common autotrophic sulfur denitrification systems. The total footprint of the system is <8 m2. Nitrate removal rates are high while bio-growth and bio-fouling remain low. Annual seawater savings is 855 m3 for each system. Operation of the system does not require elaborate control equipment such as ORP sensors or modulating valves. Operation is user-friendly, and consists of only three operator functions: manual adjustment of system flow rates, filter backwashing and purging of nitrogen gas.

Management of Marine Mammal Pool Waters Without Chlorine Injection

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Abstract: Marine Mammal pool waters require disinfection to minimize viability of disease-causing fecal bacteria emanating from the mammalian gut. To mitigate ill health effects of oxidant exposure to megafauna, off-pool disinfection processes are used, which reduce oxidant demand within the pool. However, a low concentration of oxidant is usually maintained in the pool itself. For over ten years, control of infectious organisms has been managed in the National Aquarium's Dolphin Discovery pool without chlorine addition. A portion of infectious organisms is removed via fractionation, and a portion is destroyed via ozone disinfection. Approximately 10% of water treatment flow is exposed to an applied ozone dose of 0.3 mg/L in contact chambers. Foam fractionators process approximately 33% of the recirculation flow. Fractionator flow can be, but is not always, treated with an applied ozone dose of 0.03 mg/L. Although ozone quickly converts to chlorine in solution, ozone is preferred over direct chlorine injection because of its ability to improve watercolor, its ability as a micro flocculent and it's greater effectiveness in destroying infectious organisms. These are features that chlorine cannot provide or cannot provide as well as ozone. Total chlorine as measured by DPD is maintained in the pool at 0.10 – 0.15 mg/L. Coliform counts are consistently maintained at an MPN <3.

Coliform Bacteria Monitoring in Large, Mixed Species Marine Fish Exhibits

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Abstract: In the absence of aquarium-specific guidelines for water bacteria limits, most zoo/aquarium staff rely on state and local limits for recreational water use. The specific indicator organisms vary; some states monitor *E. coli* and/or *Enterococcus* species. Total/Fecal coliforms (Gram negative bacteria) and *Streptococcus*/*Enterococcus* (Gram positive) are measured by the standard multi-tube fermentation technique, reporting results as most probable number (MPN/100 mL) or the membrane filtration method, reported as colony forming units (CFU/100 mL). EPA guidelines are based upon frequency of reported illness associated to recreational water exposure. Further studies are needed to determine if these guidelines are applicable to divers in public aquarium systems.

Ion Exchange in Aquatic LSS

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Abstract: A thorough knowledge of ion exchange is essential to the successful management of aquarium systems. Ion exchange occurs both before the water is added to the aquarium and within the aquarium system itself. Understanding what ions are present and how they affect your aquariums' water quality is essential to maintaining the quality of life of the inhabitants within the aquarium. This correct balance of common ions is obtained in the water column through the use of the aquarium life support system and properly calculated chemical additions.

Ultraviolet Disinfection of Aquatic Waters

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Abstract: The use of ultraviolet (UV) light as a method of disinfection in aquatic life support systems has played a key role in protecting aquatic animals against pathogenic microorganisms, controlling algal growth, and in some cases improving water clarity. The use of UV disinfection in aquatic systems, such as in public aquariums, zoos, and in aquaculture, has increased over the past two decades and has proven to be widely accepted as an alternative to other methods of disinfection. The principles of UV disinfection will be introduced, the components and technical aspects of the equipment will be described, methods for determination of appropriate UV application will be discussed, and the impact on water quality will be evaluated. The information will enable the reader to select the appropriate equipment and determine fluence (UV dose) based on the target microorganism(s) to achieve the desired level of water disinfection and/or algal control.

Management of Inorganic Chloramines in Marine Mammal Pools

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Abstract: Hypochlorite is widely used for disinfection in marine mammal exhibits. Free chlorine residuals reduce bacterial cross-contamination between animals and algal growth on surfaces exposed to sunlight. Chlorine shock treatments or massive water changes are however often necessary to manage elevated chloramine levels, in particular toxic trichloramines that result from system's malfunction, mismanagement or design deficiencies. UV irradiation provides a simple means of breaking down chloramines (dechloramination) by catalysing reactions between chlorine, organics and other molecules but can create toxic volatile molecules such as trihalomethanes, cyanogen chloride, etc. These risk rendering the atmosphere more dangerous for air breathing mammals than any risk associated with combined chlorines in the water. Ozone treatment prior to chlorination offers a legitimate means of reducing the organic load enhancing sterilisation and controlling chloramine levels although it can form hypobromous acid in seawater systems. Such systems are nevertheless complex and the equilibrium between chlorine dosage and ozone treatment is difficult to manage as RedOx probes are incapable of distinguishing between the two oxidants. The biofilm within any chlorinated system has now been identified as the primary site of trichloramine production. Elimination of this site by use of bio-resistant filtration media and catalytic polysilicates for treatment of other surfaces now allows the problem to be treated at source. As a result simpler and more affordable chlorinated systems can be used to achieve stable water quality without either eye irritation or air quality problems.

Microscreen Drum Filtration

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Abstract: Microscreen drum filters have been used in water/wastewater and aquaculture systems for decades and now have considerable presence in zoos. But only recently have a small number of aquariums and oceanariums used them to either replace or supplement granular media filters. While corrosion and biofouling may impact both operation and service life, drum filters have the benefits of low head requirements and a low water demand for backwashing. They also function continuously at relatively fixed flow rates. These features may provide substantial system performance and life cycle cost benefits. But with only gravity flow operation, inability to remove particulates smaller than their mesh size and lack of surface area for biological filtration, a fundamental shift in life support system design may be essential to meet water quality requirements, especially for large exhibits. This shift may include the rearrangement of building elements to move life support equipment to where the system can maximize the use of gravity instead of pump head, with increased capital costs. But the potential for substantial energy and water savings with such a system is high.

Water Quality Considerations and Life Support System Design for Cephalopods

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Abstract: The captive management of cephalopods necessitates the maintenance of water quality within precise ranges. Cephalopods have a microvillus epidermis that is one cell layer thick and contains many pores, increasing the overall surface area. The increased surface area and permeability make cephalopods highly sensitive to the chemistry and bacterial load of surrounding water. In addition to an inherent chemical sensitivity, cephalopods also possess increased metabolic rates; as much as two to three times higher than teleost fishes. As such, cephalopods produce increased amounts of nitrogenous wastes (NH_3/NO_2) which must be oxidized by nitrification in closed systems below 0.10 mg/L. Cephalopods are also highly sensitive to nitrate concentrations well below acceptable thresholds for fishes (50-80 mg/L). Thus, life support strategies must address these particular aspects of water quality to ensure animal welfare. Decades of laboratory culture have provided insights into the most effective filtration components to meet the unique demands of these animals. Life support systems in laboratories and public aquaria typically employ mechanical filtration followed by foam fractionation, biofiltration, activated carbon, and sterilization before returning water to the exhibit. Filtration strategies designed with the unique physiology of cephalopods in mind are best suited to meet their stringent needs for water quality and facilitate good husbandry.

Open and Semi-Open Aquatic Life Support Systems – The Atlantis Case Study

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Abstract: The Atlantis Resort contains one of the largest displays of marine life in the world. Built in three major phases, the life support systems adopt different methods of water supply and water treatment. Each phase used either fully open or semi-open systems and there are different advantages and challenges that each system type presented. The type of animals displayed, as well as site-specific opportunities for sourcing and disposal of seawater, were a major factor in the selection of water treatment processes. Water temperature control was a key consideration for system design. There have been successes throughout the operational history of the system, as well as some challenges that have been addressed with post-construction modifications.

Ultrafiltration Membrane Treatment in Aquarium Systems of the 21st Century

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Abstract: The attempt to move aquarium design to better control turbidity, suspended solids, bacteria, algae, and nutrients can be contradictory to the goal of sustainability when coupled with traditional design practices. Current state-of-the-art advancements in life support system design could lead to a facility that is considered greener and more sustainable. Membrane treatment alternatives are currently available and include reverse osmosis, ultrafiltration, microfiltration, and nanofiltration depending on the filtration requirements. Pilot testing results of different systems demonstrates that there are advantages and disadvantages to membrane filters, but they can be used as supplemental filtration to more conventional systems. These membranes can augment treatment efficiency and reduce turnover rates, resulting in reduced energy consumption.

Keywords: "Life Support Design" "Membrane Technology" "Sustainability"

Water Quality Parameters for Successful Live Coral Exhibits

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Abstract: In the last 20 years, live tropical coral exhibits have become increasingly common in public aquariums. It is not unusual today to find at least one live coral system, and often several exhibits housing live corals and other calcifying marine organisms. Recent trends have also included increasingly larger sized exhibits that present their own unique challenges for life support systems (LSS). Several water quality parameters are critical to monitor and maintain for live coral systems, these include temperature, pH, calcium, alkalinity, phosphate, nitrate, magnesium, and trace and minor elements such as manganese, strontium, iodide, iron and barium all thought to play roles in coral health. Paradigms for acceptable nitrate and phosphate levels for coral exhibits also could be challenged as recent studies have shown that nitrate and phosphate levels ten to twenty times that of natural seawater actually increase coral growth rates in some species.

Use of Biodegradable Carbon Pellets for Denitrification, Aerobic Nitrogen Assimilation and Phosphate Control in Aquatic Systems - Potentials and Pitfalls

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Abstract: Biodegradable carbon pellets such as Polyhydroxyalkanotes (PHAs), have many uses in the filtration of public aquarium display waters because of their ability to serve as both a consumable carbon source and bacterial substrate. They can be used anaerobically as an external carbon source to transform dissolved nitrate-nitrogen into gaseous nitrogen (N_2), or aerobically as a carbon source to promote bacteria assimilation resulting in reduced concentrations of nitrogen (both ammonia-nitrogen and/or nitrate-nitrogen) and phosphate, creating a nutrient limited environment without the risk of producing hydrogen sulfide. Recent research shows the assimilation of ammonia-nitrogen in soft, acidic waters where biofiltration is typically inhibited due to low pH, occurs at similar volumetric conversion rates as seen in biofilters operating at optimal pH (6.8 to 8.0). Further, recent research has shown that the introduction of a biodegradable carbon source also can help to eliminate ammonia spikes in newly started biofilters and/or help reduce the impact of shock loading resulting from the fast acclimation of the assimilation process (days) versus traditional nitrification (weeks). Operated anaerobically, nitrate removal rates are between 1.0 - 3.5 g NO_3^--N/L pellets/day compared to aerobic removal of nitrate/ammonia between 0.250-0.750 g NO_3^--N/L pellets/day. Aerobic PHA consumption rates (15-20 g-PHA consumed/g-N removed) are 5-8 times higher than anaerobic consumption rates (2-3 g-PHA/g-N). As a result, anaerobic designs are favored for larger operations with control/monitoring capabilities. Aerobic operations can be operated passively and are more appropriate for smaller individual tank systems.

The Mechanical Filtration of Water by Pressure Sand Filters Using Activated Filter Media (AFM)

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Abstract: Sand filters provide the primary mechanism for the mechanical filtration of recycled water. Sand is a good filtration media but suffers from biofouling and bio-coagulation of the filter bed, leading to compaction and wormhole channelling of un-treated water through the filter. Activated filter media (AFM) is manufactured from glass as a raw material. The product has been engineered to prevent biofouling, compaction and channelling. The leading accredited filter media laboratory in Europe has tested the mechanical filtration performance and back-wash efficiency of both AFM and high quality silica sand. The results are discussed and optimised filter bed operational criteria are established.

Developing an Environmental Testing Program

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Abstract: Air and water quality are important factors to monitor, especially when you have aerosolized seawater and potentially immune compromised cetaceans in your care. In 2010, the Georgia Aquarium started a small environmental testing plan that involved sampling both the dry surface and settled water in the dolphin show water features, analyzing for fungal and microbial agents that could be potentially harmful. The plan has since grown to a more structured program providing baseline and actionable data for all our marine mammal and bird systems with over ninety different sampling sites. The program encompasses testing air sampling sites throughout the Aquarium, both back of house and public side. Sterile swabs are taken from air handlers and animal housing spaces and then plated on culture media. Concurrent with a diagnostic lab, paired samples are analyzed on-site. This complete practice was shown to be a useful husbandry tool when a zygomycete, *Cunninghamella* sp., was found in the environment that housed *Tursiops truncatus* during environmental testing. The testing protocols were used to eradicate and monitor the zygomycete in the environment.

Effectively Monitoring Praziquantel in Immersion Baths

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Abstract: Praziquantel (PZQ), as used in an immersion bath to treat monogeneans, is normally dosed once to a system and thought to maintain a stable concentration over several weeks to a month at a time as referenced in the Merck Veterinary Manual and validated by the work of Crowder and Charanda. In an effort to understand and build an effective dosing strategy for PZQ, varying concentrations of treatments from 3 mg/L to 6 mg/L were submitted from five different aquariums. Using the testing method from Crowder and Charanda (2010), a blank, plus samples at 1, 2.5, 5, 24, and 48 hours post-addition were collected, submitted, analyzed, and the data compiled. The systems sampled varied in volume, life support design, location, and fauna. The data showed that the systems with disabled protein skimming and no disinfection would show decreased PZQ within 36 hours to a not detected level, less than 0.1 ppm. Several factors such as sunlight, system volume, and chemical manufactures have been examined to reveal the same effect of a downward trend in dose over a short period of time.

Benefits of Spectral Wavelength Analysis for Aquarium Health

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Abstract: A method of quantification for immersion bath medications is beneficial for veterinarians in the aquatic field and is becoming more important for environmental wastewater standards. Spectral wavelength analysis is an easy alternative method that allows the user to quickly obtain results for the concentration of an immersion bath without using any other additional chemicals. The Georgia Aquarium has developed two of these assays, Metronidazole and Trimethoprim & Sulfathiazole Sodium (TMS). A third that is used quite frequently is Chloroquine phosphate. These three assays utilize saltwater from a system run at a specified ultraviolet wavelength, 292nm/TMS, 328nm/Chloroquine and 333nm/Metronidazole.

Nitrate Control at Oceanário de Lisboa Large Aquariums: Denitrification System

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Abstract: Oceanário de Lisboa is a large public aquarium opened in 1998 as part of the Lisbon World Exposition. It is a closed system and has a total water volume of approximately 7000 m^3 divided in 5 large exhibition aquariums, 25 smaller ones, and several quarantine tanks. Nitrate accumulation is one of the challenges in closed system aquariums. In 2003, a heterotrophic denitrification system using methanol as its carbon source was installed at Oceanário de Lisboa as part of its water recovery treatment. As an independent system, it allowed the use of denitrified water in different aquariums. Although it had a nitrate removal of 0.71 kg/day $N\text{-}NO_3^-$ with a water flow of 1.5 m^3/h, this system had to be turned off in 2007 due to operational problems. After some changes, including a reactor filled with Styrofoam™ and the development of a backwash procedure, the system was restarted in 2009. The system control is based on nitrite, nitrate, turbidity, sulfide, and methanol analysis. The last three years of experience and data allowed stopping the methanol analysis. The maximum nitrate removal achieved with this system was 1.34 kg/day $N\text{-}NO_3^-$ with a water flow of 0.94 m^3/h, but because of pressure problems inside the reactor the flow had to be kept at lower levels (0.53 m^3/h) and the actual nitrate removal is 0.67 kg/day $N\text{-}NO_3^-$. The use of this system will maintain nitrate levels stable at acceptable values at Oceanário de Lisboa and other large aquariums.

Biological and Mechanical LSS Design Considerations for Coral Reef Aquariums

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Abstract: Given food, substrate, and optimal physical and chemical conditions, coral reefs will thrive creating one of the most biologically diverse ecosystems on the planet. In pursuit of these conditions, aquarists are forced to navigate a myriad of different mechanical and biological life support options. The choices made in the initial design, set-up, and maintenance of filtration components can drastically affect the performance of the system with regards to labor costs, coral health, and limitation of nuisance organisms. Systems using algae, live rock, and/or sand as the sole source of biological filtration typically had less accumulation of nitrate over time. Minimal live rock was necessary to maintain undetectable levels of ammonia and nitrite with moderate food input. All public aquarium systems surveyed had a form of mechanical filtration installed, although some had their mechanical life support system (LSS) components offline, with seemingly good water clarity and coral growth. In other cases the use of mechanical filtration, such as rapid sand filters, was necessary to maintain water clarity. A variety of mechanical and biological filter varieties are available and their use helps replicate and sometimes deviate from conditions seen on a natural coral reef.

Current Knowledge of Nitrification in Marine Aquarium Systems

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Abstract: Nitrification, the oxidation of ammonia to nitrite and nitrite to nitrate, while a fundamental process in marine aquaria, is nevertheless poorly understood in terms of the organisms responsible. Recent research shows a much greater diversity of organisms responsible for nitrification than previously believed, especially for the ammonia-oxidizing bacteria (AOB). In marine systems water temperature and organic load play a major role in determining AOB species composition of the nitrifying bacteria consortium. The significance of ammonia-oxidizing Archaea (AOA) has been the subject of much recent research; however, the importance of AOA in marine systems has not yet been definitively answered.

Ozone in Aquaria: Safe Installations and Application – The SEA LIFE Way

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Abstract: Ozone has been successfully used in aquaria for decades, with undoubted benefits to water quality. However, there are many misconceptions about ozone system design and installation, appropriate applied ozone dosage rates, and ozone control mechanisms, resulting in risk to both animals and operators. A thorough analysis of different available systems has led to a worldwide Merlin Entertainments policy regarding ozone and its implementation. Only safe vacuum ozone systems are installed, in compliance with strict German ozone regulation. Health and safety controls, and associated alarms, as well as safe dosage of ozone using a combination of established concepts such as AOD (applied ozone dose), regular checks for TRO (total residual oxidants) and controlling systems via ORP (oxidation reduction potential) probes, are employed.

Maintaining Water Quality at Urban Aquaria

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Abstract: Osaka Aquarium Kaiyukan is situated in the bay of Osaka, the second largest city in Japan. The water quality of nearby sea is not suitable for maintaining aquatic species. The "Pacific Ocean" exhibit, the main exhibit holding 5,400 m^3 of water, houses elasmobranchs (e.g. whale sharks, *Rhincodon typus*) and pelagic fishes. For long term health of the animals, water quality parameters including NH_4-N, NO_2-N, PO_4-P, NO_3-N, and pH have specific targeted ranges. The technological approach for water purification includes vacuum cleaning to remove leftover food and feces accumulated on the tank bottom, operation of a circulating filtration system, effective water changes, introduction of fresh seawater at low cost, pH control via chemical application, and other special devices.

Ecological Purification in a Coral Reef Mesocosm: Controlling Nutrient Mass Balance and Dynamics

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Abstract: When keeping aquatic animals in captivity, a method of water management is necessary to maintain water quality parameters within acceptable limits. Technical means are typically used to control different waste problems within closed systems, where for every waste type encountered another technique is applied. An alternative approach to technical purification is to apply "ecological purification", which simulates natural systems, to an artificial surrounding like an aquarium system. This system uses an holistic approach, in which components of the food chain and food web are simultaneously managed to mitigate waste accumulation within the system. Examples of approaches applied in the field of "ecological purification" are algal scrubbers, periphyton, "live" rock, "live" sand bottom, and organic carbon dosing to maintain water quality. Or even a total system approach, which combines the different ecological purification techniques. In combination, balancing these different approaches concurrently results in "ecological purification". Understanding and quantifying the mass balance of nutrients within a micro- or mesocosm helps to manage the natural processes within the system.

Diagnostic Approach to the Biofilter's Biofilms

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Abstract: Biofilms are complex microbial communities that adhere to wet surfaces and process aquatic borne nutrients cooperatively. Biofilms in the recirculating water systems for fishes provide an example in which the bacteria have been identified and studied by normal bacteriological methods. Designed for ammonia and nitrite reduction, the nitrification process in biofilters adds a living community to the aquarium that requires similar provision of oxygen, nutrition, and waste transport to that of the animals in that water. The biofilms in biofilters require appropriate diagnostic evaluation when they become incapacitated.

Reverse Osmosis in Aquatic Animal Life Support Systems

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Abstract: Reverse Osmosis (RO) is a membrane filtration process used to separate small and dissolved impurities from water. RO processes are suitable for many aquatic animal life support system purposes. Performance of an RO membrane is affected by numerous operational conditions. Examples of applications for reverse osmosis include desalination of water, removal of impurities in incoming fresh water, pre-treatment for water for seawater manufacture, softening of water for freshwater aquarium use, and removal of rainwater from outdoor seawater exhibits with strict environmental discharge requirements. Domestic RO systems are significantly less expensive and require much less energy than their commercial counterparts. Domestic RO systems are suitable for aquatic animal life support applications, which have lower production requirements than many municipal authorities require for commercial application.

Reduction of Nitrogen Supersaturation in an Open-Living System at Sea World, Durban

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Abstract: Gas supersaturation of water occurs when there is a higher concentration of gas dissolved in that water when compared with the surrounding ambient atmosphere. This condition may occur for a wide variety of reasons – such as heating water rapidly, introducing air into the low pressure side of a pump, and cavitation. It can have a negative and potentially fatal effect on the fishes when gases leave solution and form bubbles in tissues. At Sea World, uShaka Marine World, Durban, the Open Ocean display frequently exhibited signs that fishes were suffering from nitrogen supersaturation, such as bubble formation under the skin. The possibility of these signs indicating nitrogen supersaturation was confirmed using total gas pressure and percentage nitrogen concentration measurements. A possible cause of nitrogen supersaturation within our system was the introduction of air into the low pressure suction side of a pump. Supersaturation was reduced through the installation of gas stripping headers as well as bubbling oxygen into the stripping tower in order to facilitate dissolved nitrogen gas release were investigated and applied. These procedures resulted in nitrogen saturation levels decreasing from 116% to 103%. The relative impact of these two measures in decreasing total gas pressure as well as nitrogen supersaturation was noteworthy.

Development and Use of Nitrate and Total Ammonia Testing Procedures at the Monterey Bay Aquarium

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Abstract: Monitoring of nitrogen species is critical to proper maintenance of aquatic life support systems. Adopting or changing analytical procedures requires numerous considerations including, costs, difficulty, chemical hazards and disposal, detection limits, and how results from both methods compare side-by-side. Nitrogen testing procedures in use at Monterey Bay Aquarium facilities include a multi-wavelength UV nitrate method and a modified ammonia salicylate method. They were developed for use at both our main facility where an Agilent HP8453 UV/Vis spectrophotometer is used and at our offsite Animal Research and Care Center where a Hach DR 5000 UV/Vis spectrophotometer is used. The nitrate procedure is a multi-wavelength UV procedure that does not require any sample modification. To aid in calculations the multi-wavelength data generated during the nitrate analysis should be sent directly to a computer or captured by a USB memory stick. The total ammonia procedure was modified from the Hach Company's total ammonia salicylate procedure by the addition of another reagent to allow it to work in natural seawater with a low detection limit.

Control and Removal of Perchlorate Ion Generated by Chlorine Use in Closed and Semi-Closed System Marine Mammal Life Support Systems

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Abstract: The application of chlorine as a disinfectant and oxidizer in marine mammal pools and habitats in aquariums, zoos, and marine parks has been an accepted practice for more than 40 years. Even with advances in ozone technology, chlorine remains the primary oxidant favored, often reluctantly, by facilities that exhibit marine and freshwater mammals. Aquarium and zoo professionals continue to encounter and address irritating chlorine byproducts that are known to impact animal health. The most common byproducts are chloramines, trihalomethanes, and a wide variety of chlorinated organic substances and other volatile organic complexes. It has recently been discovered in closed and semi-closed marine mammal habitats compelled to use chlorine, that a harmful chemical substance, perchlorate ion, can form and accumulate in systems; especially where water changes are restricted (as in closed or semi-closed life support systems). Perchlorate is not a volatile substance, so it is not controlled or removed using routine methods such as aeration or activated carbon. As a result, perchlorates are persistent and will accumulate in system water. Harmful and health threatening levels of this substance are well documented, particularly its impact on the thyroid and the immune system of aquatic mammals. In the fall of 2013, the Animal Care and Life Support Staff at the Mirage/MGM Resorts completed a four-year study that successfully managed the generation and accumulation of perchlorate in their cetacean water system. The serious health concerns associated with Perchlorate ion were evaluated and modifications to the Mirage Dolphin pool life support systems that were installed in the past two years.

Activated Carbon

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Abstract: Activated Carbon describes a large class of materials, mainly carbon with great porosity and large surface area to volume ratio. Carbon forms very stable structures of repeating hexagonal rings called graphene. Addition of pentagons and heptagons produces curved sheets called fullerenes. Jumbled assemblages of graphenes and fullerenes probably produce the porous structure. These sheets can be one atom thick, resulting in a large surface area. Activated carbon is mostly produced from bulk natural carbon sources so it may contain other naturally occurring compounds. Adsorption on this large surface area makes it useful for removing undesired compounds from water. This wide variety of carbon sources and means of activation result in variation of adsorptive properties, thus the selection of activated carbon should be compared to target contaminant characteristics. The specific goal for use of activated carbon should be determined, leading to the selection of a suitable commercial product to achieve the best results. Catalytic dechlorination of source water is a common use. Dechlorination of chloramine is much slower so larger vessels and longer contact time is needed. Treatment to increase catalysis produce active groups to enhance the reaction. Possible adsorption of trace minerals, ability to catalyze some reactions, and production of very fine particles influence use of activated carbon.

Energy Savings, Improvement Mechanical Reliability and Optimized Dissolved Gas Balance via an Air-Fed Ozone System Retrofit at Atlantis Bahamas Dolphin Cay

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Abstract: Oxygen-fed ozone generator systems are more mechanically complicated and require more energy per gram of ozone produced than do air-fed ozone generator systems. When used in conjunction with pressurized ozone contact chambers, oxygen-fed generators create a disequilibrium of dissolved gas concentrations in process water and, when a gas-exchange column is not present as part of the treatment stream, within exhibit waters. At Atlantis Bahamas' Dolphin Cay an oxygen-fed ozone generator system was designed and installed to work in conjunction with pressure contact vessels, but without a gas-exchange column. Over time, dissolved oxygen concentration in Dolphin Cay increased until it exceeded the upper measurable limit of a hand-held sensor. Nominal energy consumption of the oxygen-fed ozone system was 97.9 kilowatts. Mechanical system complexity and the sophistication of electronic controls for the oxygen-fed system proved unreliable in the high humidity and inconsistent power supply prevalent in the Bahamas. Frequent mechanical failures eventually led to replacement of the oxygen-fed system with an air-fed ozone generation system, which was favored by its simpler mechanical system and more stable electronics. The air-fed ozone generation system proved to be more mechanically reliable and nominal energy costs dropped to 50.8 kilowatts; nearly half the cost to operate the oxygen-fed system. Dissolved oxygen concentrations correspondingly dropped to 110%.

Introduction to Bead Filter Technologies: Sustainable Alternative to Traditional Sand Filters Used in Life Support Systems

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Abstract: Bead filters are expandable granular media filters and use plastic floating beads to capture the solids while simultaneously providing a large surface area (1300 m^2/m^3) for the attachment of nitrifying bacteria. The beads are capable of capturing 100% of particles greater than 50 microns per pass and a large portion of smaller particles. Bead filters were designed to reduce the water use associated with sand filters in recirculating aquaculture systems. Compared to sand filters the reduced head loss through a bead filter represents a savings of approximately 28% for similar system designs using sand filters. The savings in backwash water loss is approximately 75% of the amount used for sand filters, and bead media have been shown to have a life span of over 10 years. Bead filters have been used for a variety of aquatic animals, clams, and oyster seed production. In recent years, acceptance of bead filter technology by the aquarium and zoological communities has grown. Bead filters have been used on sea lion, otter, elephant, alligator, and polar bear exhibits. Bead filter have also been applied to many backyard Koi water gardens throughout the world.

Overview of Biological Nitrate Removal Methods in Recirculating Aquaria: Introduction and Design Considerations

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Abstract: In recirculating aquatic systems, nitrate accumulates as a byproduct of the mineralization and oxidation of nitrogenous compounds produced by the metabolic processes of fishes and other system inhabitants. Nitrate is less toxic than ammonia or nitrite but, in high concentrations, nitrate can pose a health threat to numerous aquatic organisms. In the past, aquarium and aquaculture facilities have relied on partial water changes to control nitrate levels; however, the cost incurred by replacing significant volumes of water in large-scale aquariums can be problematic. In recent years, many facilities have employed methods of biological denitrification to reduce and manage nitrate levels in aquaria. Biological denitrification can be accomplished through autotrophic or heterotrophic processes. Heterotrophic methods contribute to alkalinity and have higher nitrate removal rates than autotrophic methods. Autotrophic denitrification has lower energy yields, but does not require the addition of an external carbon source, produces less sludge and sulfide, and has a higher tolerance for oxygen. There are several common denitrification reactor designs including batch reactors, continuous flow reactors, and mixed design reactors. Additionally, packed bed/column and moving bed reactor configurations are frequently utilized as microbial growth/electron donor substrates. Critical design factors include hydraulic loading rate, nitrogen production rate, hydraulic residence time, and nitrate removal rate.

Life Support Systems and Exhibit Design for Pelagic Gelatinous Species

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Abstract: Pelagic gelatinous animals like cnidarians, ctenophores, and pteropods present a number of challenges for captive display: they are often difficult to culture or capture in the wild, their bodies are physically delicate, they have unique Life Support System (LSS) needs, and they require specialized enclosures and food. In order to successfully design exhibits for these animals, it is essential to understand the biomechanics of the different phyla of gelatinous organisms. Through the use of fluorescein dye injected into the pathway of swimming jellies, we can elucidate the ideal flow regime and enclosure design for displays through the visualization of these flow patterns. Kreisels (pseudo, true, or stretch) are better suited for ctenophores, pteropods, and "weak swimming" cnidarians, while "active" swimming cnidarians can be maintained in a variety of tanks shapes and flow regimes. The fluorescein dye technique is also helpful for visualization of the flow fields around system injection boxes and allows one to find areas where flow may damage jellies. LSS components are critical to a well-designed system. Foam fractionators have a large impact on the concentration of DOC (dissolved organic carbon), which negatively affects the uptake of dissolved nutrients for some gelatinous species. Other key LSS components, such as de-gas towers, light (both for exhibit lighting and as a component of LSS), heat exchangers, pumps, kreisels and other tank designs, and the use of LSS bypasses are essential to good design.

Biogeochemical Cycles: Imports and Exports of Heavy Metals and Nutrients in the Seas Main Tank System

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Abstract: In 1985, the 24-million liter Seas Tank at Epcot, was filled with synthetic seawater. Since that time, there have been no significant water changes. A one year (38 LPM) water change is planned, resulting in the addition of nearly 20-million liters of new saltwater by dilution, effecting a calculated maximum reduction of contaminants as high as 65%. It is important to understand potential changes in water chemistry during this planned process. Throughout the history of the Seas Main Tank, we have identified important fluxes of nutrients and trace metals, and have used chemical and biological means to manage water quality. Inputs include sea salt, animal feed, and metal ions from corrosion. Remediation methods include chemical precipitation, and biological removal of metals and nutrients with algae and microbes. In addition, there are conceptual designs for a constructed wetland system engineered specifically for continuous biological treatment of the Seas system water. A pilot-scale biological phosphorus (P) removal system was recently tested at a smaller (1.7 million L) closed marine system. Shallow raceways (1.49 m^2) at a hydraulic loading rate of 0.77 cm d^{-1} were used to grow and harvest naturally colonizing algae. Algae harvest rates were 11,000 mg m^{-2} d^{-1}, or 55 mg P m^{-2} d^{-1}. Minimal differences were found in phosphorous removal rates at different flow rates, and no differences were seen between seasons. A larger scale system is being designed to reduce P to < 20 ppb in about one year.

Techniques for Manufacturing Artificial Seawater

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Abstract: For nearly ninety years, Steinhart Aquarium's marine exhibits relied upon natural seawater obtained through a Ranney collector system at San Francisco's Ocean Beach. Despite a recent renovation of the beach pumping station, incoming water quality was highly variable. Because of the inconsistent quality of incoming seawater, specifically low salinity and high phosphate, a decision was made in 2010 to switch to synthetic salt water. In order to optimize this change, a team of biologists, life support operators, and animal health personnel conducted a thorough review of available commercial and institutional salt mixes used in public aquaria throughout the United States. The development of this formulation consisted of careful identification of suppliers, thorough water chemistry analysis and biological testing on live organisms including delicate reef-building corals. Formulations vary and can be tailored to fit local source-freshwater chemistry, the location of the facility in relation to commercial suppliers of major ingredients, and other specific institutional factors.

Management and Application of Ozone in Aquatic Life Support Systems

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Abstract: Ozone is an effective treatment resource capable of significantly improving water quality and water clarity in aquatic systems. When applied and managed appropriately ozone can ameliorate contaminants that degrade water quality. However, poorly controlled ozone dosing may result in persistent, highly reactive and toxic by-products that can harm aquatic life. Reactive ozone by-products are collectively called residual oxidants. By understanding and using the concept of applied ozone dose (AOD), ozone can safely be applied and controlled to achieve desired benefits, while minimizing the risk of overdosing. Monitoring and recording oxidation-reduction potential (ORP), residual oxidants, water turbidity, animal behavior, and husbandry activities are an essential part of a comprehensive ozone-management strategy.

Green Chemistry in the Water Quality Laboratory

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Abstract: "Going Green", or sustainable practices, are becoming increasingly understood and adopted by both general society and industry. Water quality laboratories supporting zoos and aquariums should strive for sustainability best practice; leading by example and directly aiding the preservation of the animals within their care and the habitats represented by their displays. Environmental responsibility in the laboratory can be achieved through the application of 12 principles of green chemistry, including: purchasing environmentally friendly chemicals and products, reducing and eliminating hazardous waste, using energy efficient practices and equipment, conserving reverse osmosis and deionized water, selecting greener alternative testing methods, and recycling and reusing laboratory supplies. The benefits of these sustainable measures include cost savings, reduced health risks to personnel, and a clean ecological conscience, all the while achieving the highest possible level of animal care.

Noise Reduction and Energy Savings in Life Support Systems

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Abstract: Like in the human body, the pump is the heartbeat of a Life Support System (hereafter called LSS). These systems rely on pumps creating flow and for driving the various filtration processes. Many LSS pumps, however, generate high noise levels, degrading the pump to an important sound source in the LSS environment. A combination of suction piping lay-out and the use of variable speed control for energy saving may have unexpected negative effects, if in the design stage duty points have not been determined correctly. When pumps operate at a lower speed or discharge pressure than originally calculated, but at the designed flow rate, there is a higher vibration risk and even cavitation is possible. In such situation, the pumps will be noisier. Higher cavitation risk and subsequent additional noise can be expected also when pumps are running at design speed, but when delivery head is failing. In both situations the dutypoint of the pump is drifting away from its best efficiency point (hereafter called BEP). With respect to noise and vibration, material hardness (reflectivity), damping characteristics and absorption are keywords. From literature and general knowledge of mechanical material properties it can be explained that pumps made of thermoplastic material do absorb more and reflect less sound than pumps made of material with a higher hardness. Consequently, material choices of LSS pumps will be of influence to sound and vibrations levels in LSS.

Medium Pressure Ultra Violet Radiation (MPUV) Application in Aquariums and Aquatic Zoological Facilities

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Abstract: The use of UV technology in water treatment was first used in Europe in 1915 soon after the invention of the UV lamp in 1910, since then it has been used in many industrial and municipal water treatment applications. It was not until the mid-1970 that design engineers started using Medium Pressure Ultra Violet (MPUV) technology (polychromatic lamps). This technology is comparatively new to aquarium, marine mammal and aquatic zoological facilities and there is little information available regarding this application in aquariums however there has been much research into the use of MPUV for industrial, potable water, waste water, vessel bilge water disinfection, swimming pool disinfection, photo oxidization and photo disassociation. The first aquarium project that we are aware of where MPUV was used as an essential component of the life support system (LSS) was the "Shark Bay" aquarium on the Gold Coast, Australia. Since then there have been many applications of this technology in aquariums and marine mammal facilities with mixed success. MPUV does much more than provide point of contact sterilization, its capacity to photo oxidize at selective radiation frequencies can result in reduction of color, DOC, nitrate, chloramines and bromomines.

The Role of the Aquarium Microbiome: Implications for Simulated Environments and Animal Health

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Abstract: The microbial constituents of aquaria demonstrate tremendous variability, are strongly influenced by simple alterations to the tank environment, and have profound impacts on tank chemistry and the well-being of larger fauna. To date there remains little data on the role and distribution of many species of microbes within aquaria, and no systematic assessment of archaea has been attempted. In this study, samples from water, filter material, or substrates were collected from over 750 tank systems at aquariums around the United States of America. Parallel sampling of rRNA sequences via Illumina MiSeq next-generation sequencing, and laboratory extraction and analysis of glycerol dialkyl glycerol tetraethers (archaeal membrane lipids), were compared with concomitant aquarist records of tank environmental and water quality variables (including tank features such as lighting, ammonia concentration, organic density, etc.). Statistical correlations between taxonomic groups, lipids, and environmental conditions were assessed. Additional experiments addressing the role of additives (large animal food sources, etc.) were also conducted. This dataset has been used to evaluate the role of non-temperature influences on archaeal lipids, and has the potential to address important questions about what governs the distribution and constituents of the microbiome, and how they can be adjusted to optimize water quality.

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How to Provide Enough Flow so Your Corals and Aquarists Don't Complain

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Abstract: For over 25 years, proper water flow and circulation remains one of the most crucial aspects of long term reef keeping success. Back in 1989 a 180 gallon reef tank was considered large, in 1993 a 1400 gallon reef tank was obscenely large, and in 2000 a 20,000 gallon reef tank was unheard of. Today's reef tanks now check in at over 200,000 gallons. The design is most important to accommodate the ever growing massive coral colonies. Achieving proper water flow for a wide range of coral reef tanks involve technologies that range from the Romans to today's most advanced methods.

Methods to Control Phosphate for Algae Management

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Abstract: The uncontrolled growth of unwanted algae is one of the scourges aquarium staff deal with on a daily basis. It detracts from the pristine look of an exhibit and can be quite labor intensive to maintain. Even the use of chlorine and ozone for algae management can produce unwanted disinfection by-products, a health risk to the animals. Life support system design can be quite different for aquatic invertebrates, fishes, and mammals, yet they share similar problems concerning phosphate loading and management. Since orthophosphate is an essential nutrient for algal growth, removing it can control the growth of unwanted algae. Lanthanum-based products, granular ferric oxide (GFO), cerium chloride and others have been quite successful in decreasing the concentration of orthophosphate. A comparative evaluation between these products has provided the optimal conditions for various animal exhibits for minimizing orthophosphate concentrations and their impact of algae growth. The use of La35, a lanthanide element product from Lo-Chlor Industries, to physically remove phosphate build up in coral, fish, and marine mammal life support systems is the most cost effective method.