Bord na Móna Environmental Products U.S. provides a range of wastewater nitrogen reduction solutions for:

- High strength nitrogen influents >100 mg/l
- Treatment standards <5 mg/l total nitrogen (TN)
- Treatment standards <1 mg/l ammonia
- Tertiary applications.

**Forms of nitrogen and common terms in wastewater treatment**

The different forms of nitrogen and some commonly referred to terms in wastewater treatment include:

- Total Nitrogen (TN) is the sum of the nitrogen forms, Total Nitrogen = TKN + NO2 + NO3
- TKN stands for Total Kjeldahl Nitrogen which is the sum of NH3 + Organic Nitrogen
- NH3 stands for Ammonia Nitrogen
- Organic Nitrogen is delivered from amino acids and proteins
- NO2 stands for Nitrite
- NO3 stands for Nitrate
- N2 stands for Nitrogen Gas
- Refractory Nitrogen is the nitrogen that can not be biologically decomposed
- Alkalinity, as CaCO3, is easiest defined as the ability to resist a drop in pH
- All results are expressed as nitrogen rather than the specific chemical compound so you can total them to determine the total nitrogen values, for example, 10 mg/l of NO3 –N is equivalent to 45 mg/l of NO3.

**What is nitrification?**

Nitrification is the conversion of ammonia (NH3) to nitrate (NO3). This is a two-step process in the presence of oxygen and two types of nitrifying bacteria, nitrosomonas and nitrobacter.

- Ammonia (NH3) + Oxygen (O2) + Alkalinity + Nitrosomonas = Nitrite (NO2)
- Nitrate (NO2) + Oxygen (O2) + Alkalinity + Nitrobacter = Nitrate (NO3)

Nitrification is reliant on removal of biochemical oxygen demand (BOD) from the influent by the dominant heterotrophic bacteria, allowing the nitrifying bacteria to proliferate. The two-step reactions usually occur very rapidly and it is rare to find nitrite levels higher than 1 mg/l.

Nitrification is required because ammonia is toxic to fish and other aquatic life, places a high oxygen demand on the receiving waters and provides nutrient that can lead to algal blooms.

The ammonia values are approximately 60% of the total kjeldahl nitrogen (TKN) values in raw wastewater and the remaining organic nitrogen is generally converted to ammonia or removed in the settled sludge in a septic or primary stage of treatment which can remove 10% to 30% of Total Nitrogen. Also, TKN generally equals 15 to 20% of the BOD of the raw sewage.

The total conversion of ammonia to nitrate takes 4.6 parts oxygen and 7.1 parts alkalinity to convert 1 part ammonia. You should maintain the pH of the aeration tank above 6.5. Below this level biological activity will become inhibited and toxic ammonia (NH3) can bleed through the system.

When alkalinity drops below 50 mg/l pH can drop dramatically. If the ammonia multiplied by 7.1 mg/l is less than 100 mg/l of the influent alkalinity concentration, you need to add alkaline such as sodium hydroxide or lime prior to the aeration tank.

High levels of nitrite in the system indicate there is, or there is about to be, a problem with the nitrification cycle. Nitrosomonas bacteria are harder to kill than nitrobacter bacteria. If nitrobacter bacteria are killed off, nitrosomonas bacteria will continue working in the ammonia resulting in a jammed cycle with high levels of nitrite.

The important parameters for nitrification include the hydraulic retention time of the aeration stage and the provision of sufficient oxygen. The nitrification process is temperature dependent with the nitrification rate decreasing as temperatures reduce below 10 degrees C.

**What is denitrification?**

Denitrification is often required due to health concerns, for example the United States Environmental Protection Agency (US EPA) has set a maximum contaminant level of 10 mg/l nitrate in drinking water to prevent methemoglobinemia (blue-baby syndrome) and nitrates have been linked to carcinogenesis and birth defects.

Denitrification is the conversion of nitrate (N03) to nitrogen gas (N2). Heterotrophic bacteria use the nitrate as an oxygen source under anoxic conditions to break down organic substances.

Nitrates + Organics + Heterotrophic Bacteria = Nitrogen Gas & Oxygen & Alkalinity

An anoxic zone is established which is an unaerated basin where the dissolved oxygen levels are kept below 1 mg/l and must be as close, without reaching 0 mg/l, as possible. A target would be 0.2 to 0.5 mg/l.

The heterotrophic bacteria obtain their oxygen using the following sequence: free and dissolved oxygen, nitrate, and then sulfate. If your zone has no free or dissolved oxygen, the “bugs” will have to obtain their oxygen source by breaking down the nitrates that are returned to the anoxic zone in the activated sludge.

As the bugs use the nitrate as an oxygen source to break down the carbon, their source of food, nitrogen gas will be released to the atmosphere. The mixed liquor suspended solids concentration must be kept in balance. The pH of the anoxic zone should be close to neutral (7.0) and never drop below 6.5

There must be a carbon source. Typically 2.72 mg BOD5 are required per mg of NO3-N removed. This is a particularly important consideration where the biochemical oxygen demand (BOD) is low compared to the ammonia levels, for example in commercial applications such as offices and schools or where a residential subdivision has a slow build-up of BOD load as houses are occupied.

Using the raw influent as the carbon source through recirculating the nitrified effluent to an anoxic zone prior to the aeration stage or to an adequately designed septic tank (sufficient hydraulic retention time for denitrification and settlement must be provided) is common. Recirculation is typically suitable where influent levels of total kjeldahl nitrogen (TKN) are <50 mg/l and the nitrate standard is not more stringent than 10 mg/l requiring a recirculation rate in the order of four times the influent flow rate.

Where insufficient BOD is available a carbon dosing system may be required. Sufficient flow equalization is required to reduce the peak flows prevalent in residential and decentralized systems. A benefit of recirculation is the recovery of alkalinity where approximately half the alkalinity lost during nitrification is recovered which may remove the need for chemical dosing systems in low alkalinity wastewaters.

Other denitrification methods include cycling the aeration system on and off allowing the whole aeration basin to be used intermittently as an anoxic zone, such as in a sequencing batch reactor (SBR), and using a post anoxic tank after aeration where a supplemental carbon source such as Micro C, methanol or ethanol is added. It takes on the order of 2.0 – 2.5 parts methanol for every part nitrate that is denitrified.

Bugs + Carbon + Nitrate (CO3) = Nitrogen Gas (N2) + Oxygen (O2) + 3.6 parts Alkalinity

**Nitrogen reduction for decentralized wastewater systems**

While larger treatment plants can be designed and operated to achieve low levels of total nitrogen, smaller on-site and decentralized plants suffer from wide variations in the influent Total Kjeldahl Nitrogen (TKN) concentrations, large flow variations and a lack of operational attendance to adjust the plant to the conditions experienced, all of which require additional design considerations to be taken into account.

The United States Environmental Protection Agency (US EPA) onsite wastewater treatment systems manual 2002 indicates a range of influent TKN concentrations from 26 to 75 mg/l while sampling of single house and commercial systems has found that TKN levels can have concentrations of up to 120 mg/l leading some states to indicate a design requirement of 100 mg/l for design of on-site systems.

The selection of an appropriate technology will largely be dependent on the influent TKN concentration and the effluent standard to be achieved. Where a percentage reduction of the influent concentration is required or where the influent TKN concentration is known to be at average or low levels a suspended growth, attached growth or media filter recirculation system can be designed.

Where the influent concentration cannot be determined, a high influent concentration is specified, (above 50 mg/l) or a low effluent concentration below 10 mg/l is specified a combination of recirculation and post anoxic denitrification or membrane treatment systems are the most effective solutions.

Where a biochemical oxygen demand (BOD) standard below 10 mg/l in addition to a total nitrogen standard is required a membrane treatment system would be an appropriate solution as control of the carbon dose will be difficult unless a time dosed system is used to balance the flow.

The design of nitrogen reduction technologies must take into account the design temperature. As the temperature of the wastewater decreases below 10 degrees centigrade the nitrification and denitrification processes will slow requiring greater hydraulic retention time.

As the temperature of the wastewater increases, the solubility of oxygen into the wastewater decreases, requiring provision of more air in order to maintain the nitrification process. The temperature affect is particularly evident during the period when the nitrification bacteria are becoming established following commissioning. Any ammonia or total nitrogen standard may not therefore be achieved following commissioning in cold weather conditions. Where required the plant could be seeded with sludge from a local nitrifying wastewater treatment works to reduce the commissioning period.

Weaker strength influent wastewater can cause problems in terms of providing sufficient carbon for the denitrification process to operate and having sufficient oxygen demand to reduce the dissolved oxygen levels in the recycle to levels that will not inhibit the process. Typically a weaker strength wastewater with relatively high mixed liquor recycle dissolved oxygen (DO) concentrations are likely to limit the maximum beneficial mixed liquor recycle rate to less than 200% with expected denitrification rates limited to a maximum of 65%. Higher strength wastewater and low mixed liquor recycle dissolved oxygen concentrations may allow beneficial use of mixed liquor recycle rates as high as 400% in suspended growth activated sludge systems.

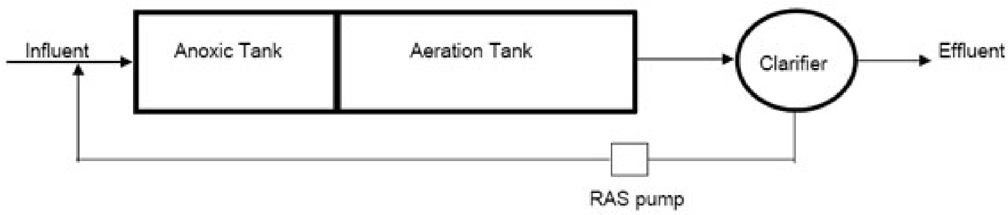
Where possible the alkalinity level in the wastewater or from the local water supply should be provided in order to determine the need for alkalinity dosing. The specialization of the nitrifying population can be improved and the effect of inhibitory substances can be reduced by the provision of a two compartment aeration system. Separate stage nitrification is therefore strongly recommended for small flow systems.

The type of sampling, whether composite or grab, and effluent standard in terms of absolute figures or monthly, seasonal or yearly averages can be important in determining the technology. On-site regulations generally require grab samples based on absolute figures which require balancing of flows and a design level as much as 5 mg/l below the effluent standard required to ensure compliance.

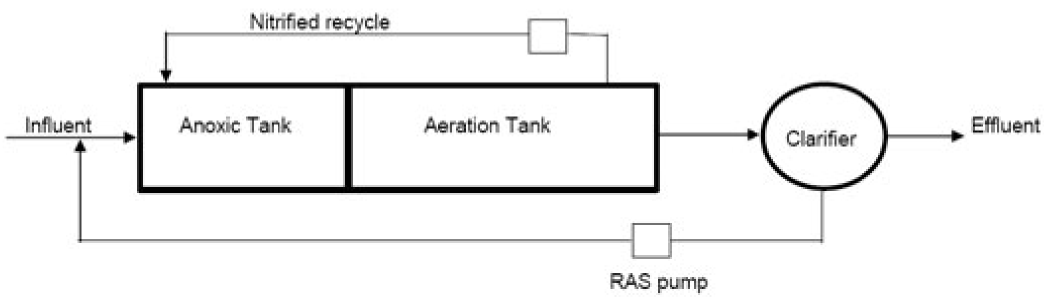
**Wastewater  Treatment Options for Processing Nitrogen**

**Suspended growth activated sludge (ATU) systems**

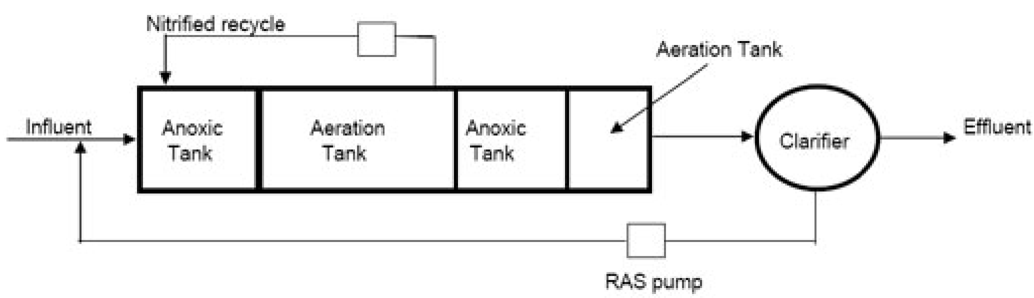
The traditional suspended growth activated sludge approach, like Platinum wastewater treatment systems, has been to obtain carbonaceous biochemical oxygen demand (BOD) reduction and nitrification in aerated reactors with nitrified effluent recirculated to an unaerated anoxic reactor upstream of the aerated zones typically at rates of up to 400% of the influent flow rate. There are a number of variations to the basic concept of recirculation including those detailed in Figure 1.



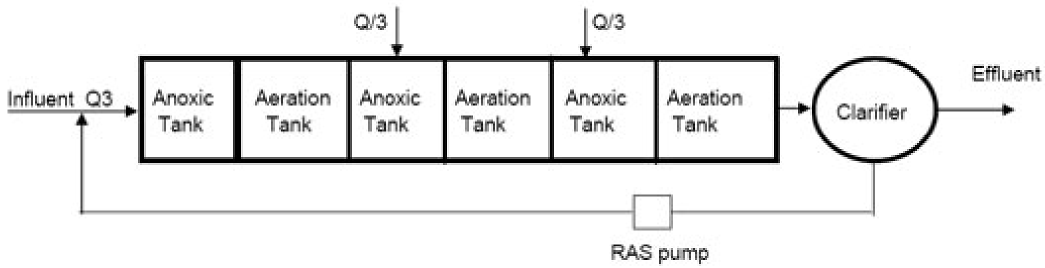

**Ludzack-Ettinger Process**




**Modified Ludzack-Ettinger Process**




**Four-Stage Bardenpho Process**




**Step-feed Process**

**Figure 1. Types of Suspended Growth Denitrification Processes**

The Ludzack-Ettinger process is the basic process used in small systems. This is, however, limited to the return activated sludge (RAS) flow which led to the development of the modified Ludzack-Ettinger process which adds the recirculation of the mixed liquor recycle from the end of the aeration tank.

A further development is the four-stage Bardenpho process incorporating two anoxic zones and an additional aeration zone that serves to strip any nitrogen gas formed and increases the dissolved oxygen. The step-feed process incorporates tankage where the influent is fed at multiple points along the reactor resulting in an overall size reduction of the reactor tankage.

Recirculating suspended growth (ATU) systems exhibit a number of advantages and limitations.

Advantages include:

- Relatively simple and cost effective on an average or low strength nitrogen sewage where a percentage reduction of the influent is required (percentage reductions will be dependent on the recirculation rate and often becoming limited at recirculation ratios greater than four to six Q)
- No requirement for supplemental carbon addition
- Recirculation allows recovery of alkalinity

Limitations:

- The design of an on-site system is typically standardized to achieve a predetermined level of recirculation, should the influent concentration or flow be greater than the designed concentration or flow the system can fail to meet the performance standard
- A recirculation ATU system is not generally adjustable as increasing the recirculation rate will decrease the hydraulic retention time in the aeration and anoxic stages and the carbon source is dependent on the influent load
- The benefits of increasing the recirculation above 4 x Q become limited in terms of the nitrate reduction achieved and the cost of increasing the tank size to maintain the hydraulic retention time
- ATUs often exhibit operational problems in maintaining the nitrifiers in the aeration stage which can lead to extended periods of poor nitrification performance
- Reliance on a clarifier
- Relatively large tank sizes required
- Poor performance for intermittent flows

Sequencing batch reactor (SBR) systems are a form of suspended growth activated sludge technology where the influent is batched and aeration and settlement is undertaken in the same tank as detailed in Figure 2. The SBR can be designed to achieve nitrogen reduction by increasing the duration of aeration for nitrification and adding an anoxic phase onto the batching cycle by turning the air off.

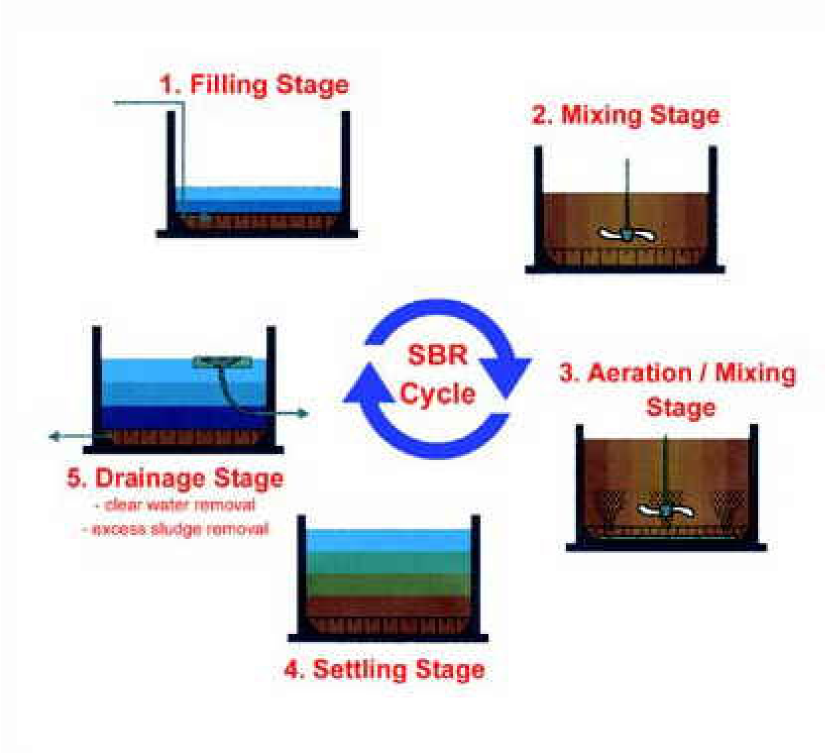



**Figure 2. Sequencing Batch Reactor Process Stages**

**Fixed film and attached growth systems**

One type of attached growth technology that is gaining popularity is the moving bed biofilm reactor, like PuraMax, which uses plastic media to provide a surface area for a biofilm to develop.

The reactors can be operated under aerobic conditions for biochemical oxygen demand (BOD) removal and nitrification or under anoxic conditions for denitrification as detailed in Figure 3. During operation the media carriers are kept in constant circulation. In an aerobic reactor the circulation is induced through the action of the air bubbles injected into the tank by a fine or coarse bubble diffuser system. In an anoxic reactor a submerged mixer is typically supplied.

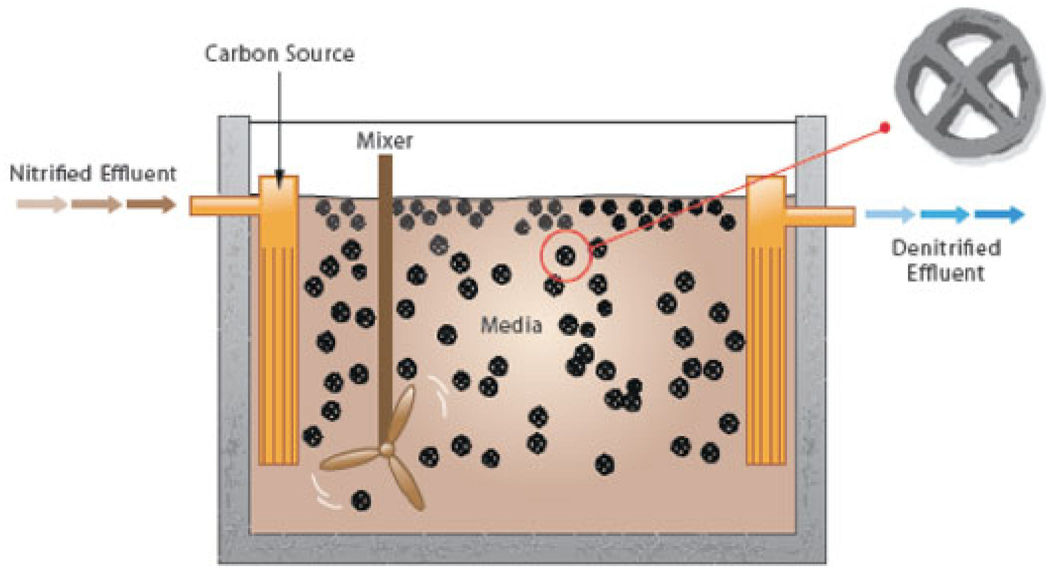



**Figure 3. Post Anoxic MBBR with Carbon Dose**

As MBBR's are primarily attached growth processes the design of the system is based on the specific surface area of the media and the size of the reactor. There are a number of different types of media available with different characteristics. The carriers can occupy up to 70% of the reactor volume. The biofilm on the media naturally sloughs off and is settled in a clarifier.

For denitrification the MBBR process can use either:

1. Recirculation which has similar limitations to the suspended growth activated sludge process
2. A post anoxic MBBR with external carbon dose
3. A combination of recirculation and post anoxic MBBR

For either an average or low nitrogen strength influent or a standard that requires a percentage reduction, recirculation or a post anoxic process would be sufficient. Where a high strength nitrogen influent or an absolute nitrogen standard below 10 mg/l is required a combination of recirculation and a post anoxic MBBR would be recommended.

Recirculating MBBR systems exhibit similar advantages and limitations to suspended growth activated sludge systems. MBBRs and post anoxic MBBR systems exhibit the following advantages and limitations

The advantages include:

- Small aeration reactor volumes for nitrification (due to the higher relative MLSS concentration)
- The carbon dosing is adjustable
- Resilience to shock loads as the nitrifiers are retained on the media
- Performs better than suspended growth activated sludge systems for intermittent flows and low strength influents

- Ease of operation compared to suspended growth activated sludge systems as there is no return activated sludge (RAS) system
- Low operation cost and maintenance requirements

Limitations:

- A post anoxic reactor may require re-oxygenation of the effluent where discharging to a surface water (6 mg/l is often specified)
- For on-site systems a non-toxic carbon source would be required. There are a number of chemicals commercially available.
- The carbon dose needs to be flow proportional to control the effluent BOD levels
- Alkalinity is not recovered as recirculation is not provided

A further variation on the attached growth process is the submerged aerated filter, like PuraSAF, which incorporates similar media but in a packed bed rather than moving bed configuration. The design of the system is detailed in figure 4.

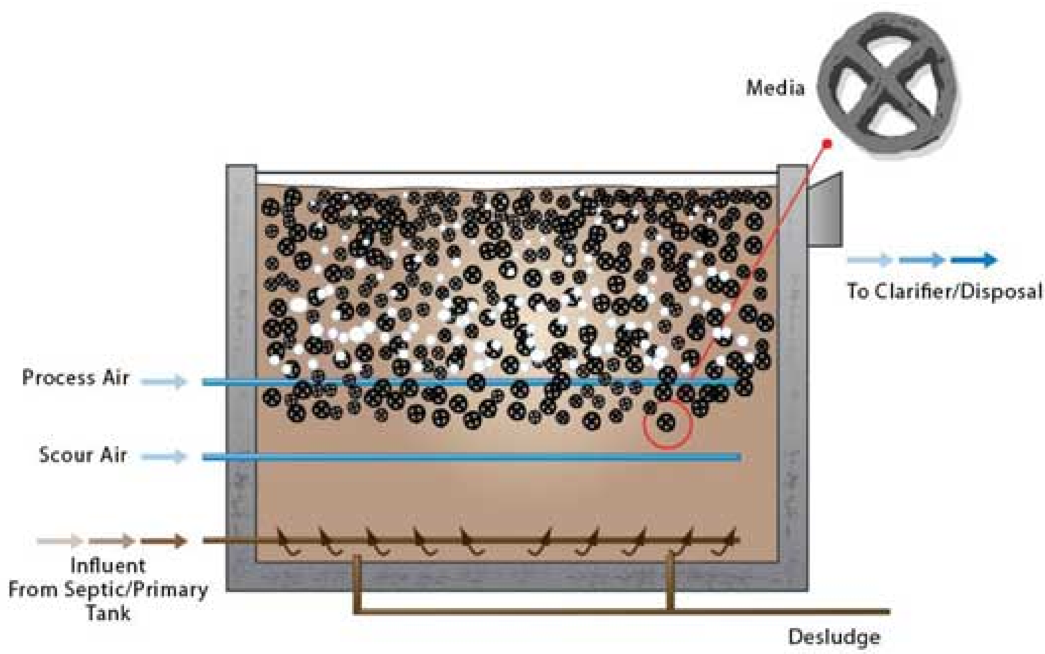



**Figure 4. Submerged Aerated Filter**

The submerged aerated filter has a number of advantages over the MBBR including a smaller footprint and lower energy cost however the system is more complex due to the scour system for desludging the media.

**Media Biofilters**

There are a number of biofilter technologies, like Puraflo®, available using a variety of media including peat, sand, textile, coir and foam. Depending on the manufacturers design the biofilter may be a single pass system or may incorporate recirculation as part of the standard design to meet even secondary treatment biochemical oxygen demand (BOD) standards.

One type of biofilter commonly used in the on-site industry incorporates peat media. Single pass peat systems can incorporate recirculation to achieve up to 70% reduction in the influent nitrogen load. Recirculation will however increase the footprint and cost of the system so post anoxic denitrification is often the most cost effective solution. A typical layout is detailed in figure 5.

Where a post anoxic denitrification system is employed the chemical dosing needs to be controlled proportional to the flow otherwise the added BOD may exceed the BOD effluent standard. Incorporation of a time dosed system is a good engineering solution with the additional benefit of balancing the flow to the subsequent treatment stages. A level of 10mg/l BOD and 10 mg/l total nitrogen can be achieved from peat biofilter systems incorporating a post anoxic system.

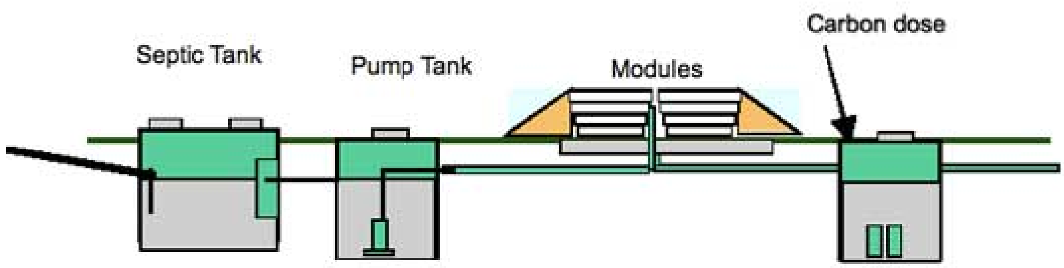



**Figure 5. Single pass media biofilter incorporating post anoxic denitrification**

Peat media biofilter systems exhibit a number of advantages and limitations

Advantages:

- Naturally nitrifies making the systems attractive for ammonia standards
- Standard design incorporates flow equalization and time dosing
- Excellent for intermittent flows
- Low operational and maintenance requirements

Limitations:

- The footprint size is relatively large making biofilter systems more suitable for single house and cluster systems
- A post anoxic reactor may require re-oxygenation of the effluent where discharging to a surface water
- For onsite systems a non-toxic carbon source would be required. There are a number of chemicals commercially available.

**Membrane bioreactors**

Membrane Bioreactors (MBR), like PuraM, are a combination of suspended growth activated sludge processes and membrane filtration. The membrane submersed in the bioreactor is used for solids/liquid separation replacing the clarifiers.

Because of the long sludge retention times required by the membrane design nitrification will almost certainly occur assuming sufficient oxygen and alkalinity are available and adequate pH levels and wastewater temperatures are maintained.

Denitrification requires recirculation to an anoxic zone to treat the nitrified MLSS. Hydraulic retention time in the anoxic basin is based on influent nitrogen loading, operating temperature, available carbon to consume oxygen in the recycled MLSS and nitrogen removal requirements for the plant.

For more information about nitrogen reduction in wastewater, please call us at 800-787-2356 or send us an email at info@bnm-us.com/

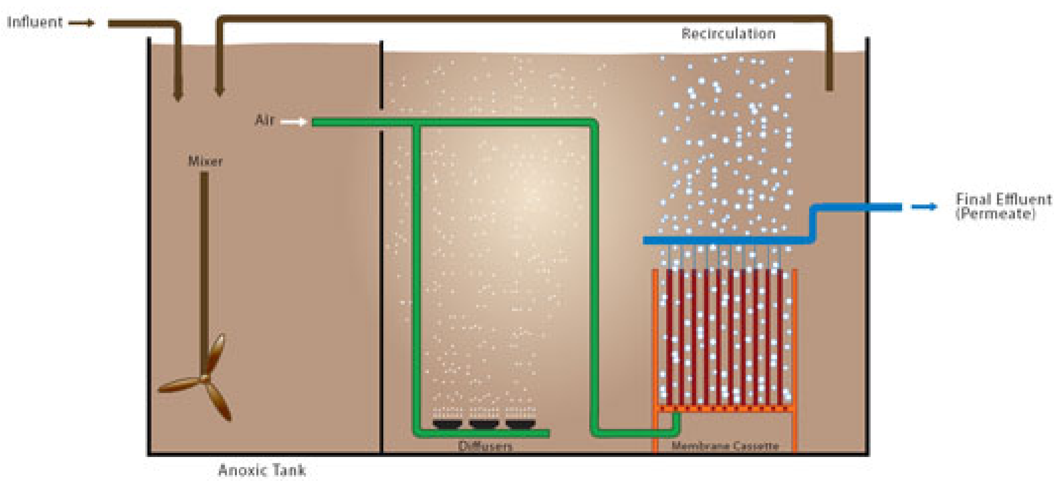



**Figure 6. Denitrifying Membrane Bioreactor**

As the membrane design allows recirculation of the nitrified MLSS, rather than the effluent, and the MLSS concentration is maintained at approximately 12,000 mg/l the mixed liquor recycle ratio can be increased significantly without significant increase in costs.

The advantages of MBR systems over traditional activated sludge processes generally include:

- Highest effluent quality when properly designed. Membrane systems are often chosen where a BOD of less than 5 mg/l is combined with total nitrogen levels less than 10 mg/l.
- Secondary clarifiers and tertiary filters can be eliminated, thereby reducing plant footprint area.
- Unlike clarifiers, the quality of solids separation is not dependent on the mixed liquor suspended solids (MLSS) concentration or characteristics. Since elevated mixed liquor concentrations are possible, the aeration basin volume can be reduced, further reducing plant footprint.

- Long solids retention times can be achieved, sludge production is reduced as a result.
- A barrier against bacteria & pathogens, including chlorine-resistant organisms such as cryptosporidium and giardia, is provided.
- Membranes are a cost effective solution where strict ammonia and total nitrogen standards are required

Limitations:

- MBR systems may have higher energy costs
- A higher degree of operational input may be required
- The anoxic tank needs to be designed for the relatively high levels of dissolved oxygen (DO) in the mixed liquor recycle

If you would like more information on nitrogen reduction in wastewater treatment, please call us at 800-787-2356 or send us an email at info@anua-us.com.