OPERATIONAL PROCESS OF MEDIA FILTERS

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Abstract

An operational process analysis of a device answers two questions: what is it?...and what does it do? The acronym STAAR® stands for Smart Trickling Anaerobic Aerobic Recirculating, and it is an artificial media filter system. The STAAR is one example of a class of system called unsaturated media filters. Media can be natural or artificial. Each media category can be designed in single pass or recirculating modes. Recirculating mode is typically used to reduce total nitrogen in effluent using a well-established process called biological nitrogen reduction or BNR.

Biologically mediated nitrogen reduction consists of first encouraging the bacteria responsible for nitrification, followed by denitrification in distinct places in a wastewater treatment system. The irony of BNR is that although bacteria are used in both process steps, the preferred environments of the bacteria responsible are remarkably different. In the case of media filters, nitrification occurs by passing the effluent through an oxygen-rich porous media. The next step in the process, denitrification, is necessary to convert oxidized forms of nitrogen into inert nitrogen gas. The STAAR media filter uses a two-tank system and three centrifugal pumps to accomplish this task. In the first tank, a septic tank blends incoming wastewater flows and strains suspended solids out of the effluent before entering the second tank, called the processor tank. In the processor tank one pump aerates the effluent through thin-film diffusion, another pump transfers oxygenated effluent and sloughed solids back to the headworks of the septic tank. The pump back creates a fluctuating anaerobic anoxic aerobic environment with sufficient carbon for denitrifying bacteria to thrive. A third pump is used to discharge effluent to a soil treatment area provided by others.

Introduction

In this paper, a media filter is described which combines classical biological nutrient reduction with thin-film oxygen transfer by simple diffusion. The acronym STAAR stands for Smart Trickling Anaerobic Aerobic Recirculating, and it is an artificial media filter system. The term "operational process" is a fancy way of saying "This is what it is: and this is what it does". Someone describing the operational process will describe both the form and function of each unit process. STAAR is just one example of a class of systems called media filters. This paper will begin by explaining common features of these similar but not identical technologies, and then move on to unique aspects of the SeptiTech® STAAR system. Media filters are sometimes called by other names. Those alternate names include attached growth, fixed film, packed bed, biofilter

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or trickling filter. Two main media categories are natural (including mineral and fibrous materials found in nature) and man-made materials, usually plastic-based.

Each media category may be designed in single pass or recirculating modes. Recirculating mode is typically used to reduce total nitrogen in effluent using a well-established process called biological nitrogen reduction or BNR. More on that process later in this paper.

Certain physical properties are prized in a media filter. Top of the list is the square foot of surface area per cubic foot of media. This property has the technical name of specific surface area,

Both water and air are examples of a material state called a fluid. Fluids take the shape of whatever container holds them. When the denser fluid, known as a liquid, is placed in a container it settles to the bottom and sides of its container and forms a liquid /gas interface. That interface is called a free water surface (Evett & Liu, 1987). Both liquids and gasses must be allowed to flow freely through and around media to effectively treat the wastewater constituents.

Excess liquid drainage must also be a property of the media so it will not pond effluent on the surface, nor water log. However, residual moisture (i.e., dampness) is essential in a media. This property will keep the microbes alive until the next effluent dose arrives.

Media must also be structurally sound. Oatmeal flakes, for instance, would make a terrible media. Over long-term use (years), the weight of media may double as cell mass increases.

Media Filter Microbial Ecology

Once you have gained experience in advanced treatment systems, you'll realize it's all about the microbes. Let me compare an unsaturated media filter system to a popular alternative approach. In a suspended growth system, free-floating bacteria, ciliates, rotifers and various worms swim around in a liquid filled container. If fresh food isn't introduced regularly, hungry microorganisms will hunt down and eat each other. An example might be a home where the residents are away for multiple weeks at a time. If the lack of fresh food is extended beyond a handful of days, when two free-swimming microorganisms come in close contact, one will eat the other. Eventually you are left with one tough dude who has eaten all its neighbors (pin floc condition). Make no mistake, if a media filter is underfed, the attached microorganisms are just as hungry, they just can't reach their neighbors.

In a media filter, food must come to the microbes because the microbe is physically, permanently attached. The attached microbes can over time form a biofilm.

Microorganism that are commonly found as free-swimming forms have 'relatives' that are adapted to an attached lifestyle. These attached forms are more successful in an unsaturated media filter and eventually are the dominant life forms in the unsaturated media filter.

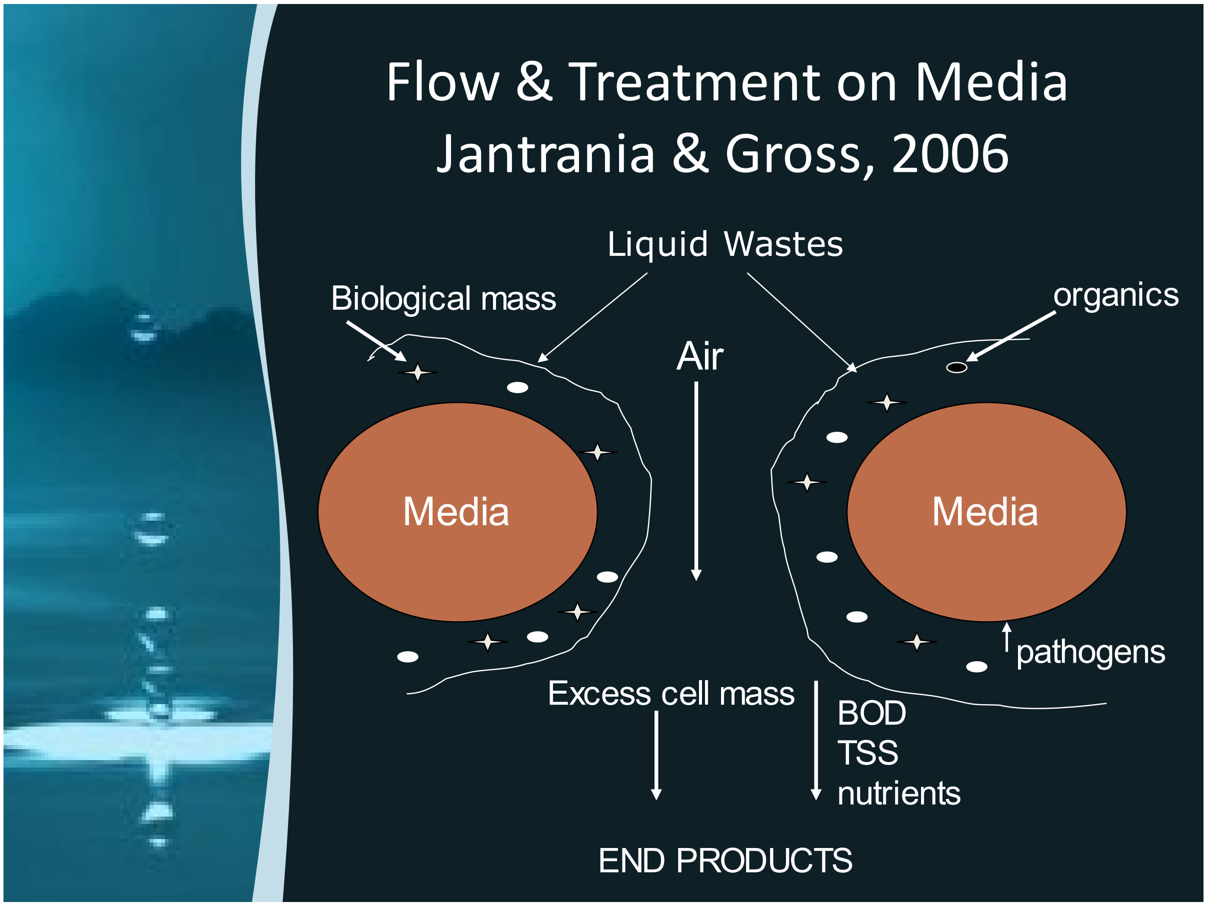

Figure 1. Flow path and treatment areas in a media filter.

This figure is from "Advanced Onsite wastewater systems technologies". Liquid wastes (i.e., effluent) wets the surface of the media leaving larger pores air-filled. The ovals in the figure can represent either spheres, grains or thin fibers in cross section. Natural spheres would be sand grains, artificial spheres might be plastic particles. Natural fibers could be peat moss, artificial fibers could be polypropylene filaments. The thin film is in close contact with air and oxygen diffuses from the air to the liquid. The oxygen gradient is favorable to dissolve into the liquid film as microbial growth within the film is removing oxygen as microbes attached to the media surface grow and reproduce. Excess cell mass (sloughed solids) will penetrate deeper into the unsaturated media filter over time with the assistance of gravity. Oxygen constantly diffuses from the interstitial space to the liquid film. The thinner the liquid film, the more efficient the oxygen transfer.

On the first day the system is used, it does an excellent job of reducing Total Suspended Solids (TSS hereafter) concentrations because this is a mechanical process with no reliance on organisms. As the media filter matures, the physical filter transforms to a biological filter indicating that living things are now doing the bulk of the treatment. The entire class of media filters provides robust and stable performance for the reasons given above. Typical NSF 40 media filter test data shows

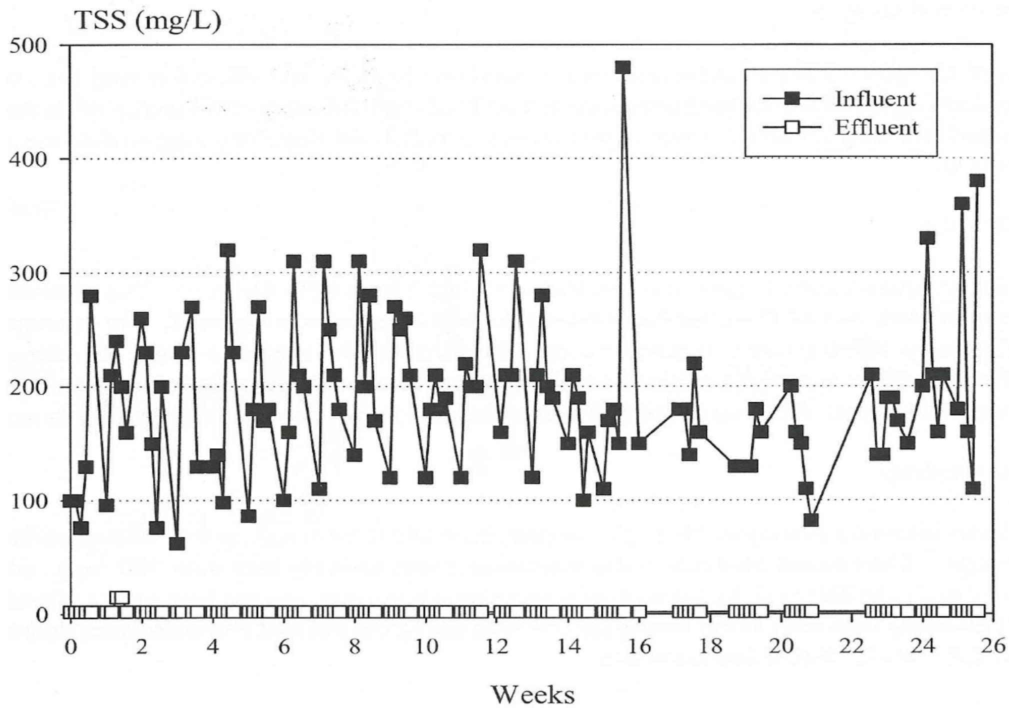

Figure 2. Influent and effluent concentrations of total suspended solids during 26-week test period.

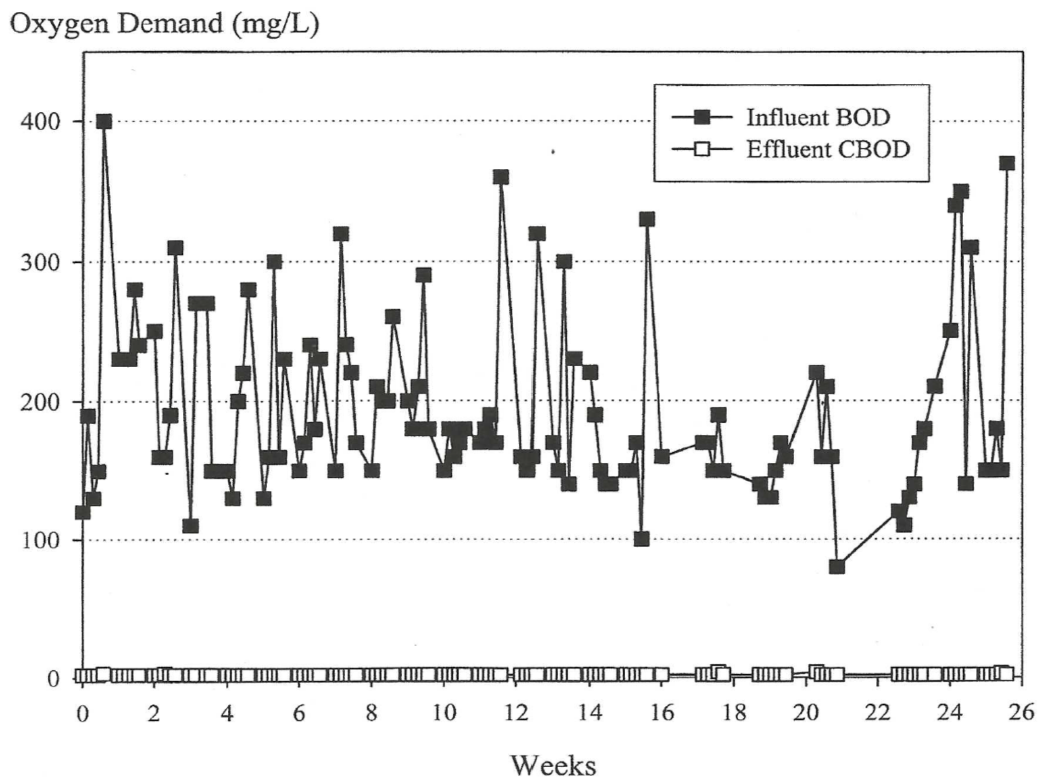

Figure 3. Influent concentrations of 5-day biochemical oxygen demand (BOD_5) and effluent concentrations of 5-day carbonaceous biochemical oxygen demand ($CBOD_5$) during 26-week test period.

consistently low concentrations of TSS and $CBOD_5$ leaving the filter despite highly variable inputs of TSS and BOD_5 (Figures 2 and 3 on previous page).

NSF/ANSI Standard 40 samples are usually collected 5 days a week (Monday through Friday). The concentration of TSS influent (Figure 2 black squares) varies substantially over the six-month testing period. The average influent TSS for STAAR® was ~180 mg/L, with a standard deviation (measuring the spread of data) of 64 mg/L. The average effluent TSS was 5 mg/L with a standard deviation of 3 mg/L. Where there are breaks in the data (easier to see by focusing on the clear boxes just above the horizontal axis), the standard conducts stress testing, starting after week 16. The stress tests are Wash Day stress, Working Parent stress, Power/equipment failure stress and vacation stress. Sampling occurs during recovery periods following each stress.

Figure 3 demonstrates similar performance to Figure 2. Both of these graphs are typically what an unsaturated media filter ANSI NSF Standard 40 performance looks like. For STAAR the average influent BOD was ~200 mg/L, with a standard deviation (measuring the spread of data) of 62 mg/L. The average effluent CBOD was 12 mg/L with a standard deviation of 8 mg/L. Testing of a 500 gpd STAAR unit was performed in Massachusetts.

Operational Process of STAAR

The operation process of the system begins with a two-compartment septic/recirculation tank accepting influent wastewater from the facility. The size of the tank is at least 1.5 times the daily flow estimate. The septic/recirculation tank is equipped with an effluent filter appropriately sized for the daily flow.

This tank is compartmentalized to prevent short circuiting of flows. The size of the tank ensures blending of multiple types of sewage inputs so a consistent composition is sent to the next tank. Flow is by hydraulic displacement. If 10 gallons enters this tank, the liquid level in the tank rises above the invert of the outlet and, if no further flow enters the tank, 10 gallons will slowly exit the tank. The purpose of the effluent filter is not to protect the next step in the treatment train. Instead, it is used to keep carbon in the septic/recirculation tank for denitrifying bacteria to consume. The BioMicrobics® SaniTEE® is preferred because the filter can be cleaned in place (without having to be removed) ensuring the dislodged particulate matter stays in the Septic/Recirculation tank.

The next tank is called the processor tank. The processor tank does the lion's share of the treatment. BOD is greatly reduced through aeration using thin films and biological processes such as microbial predation and population growth. TSS reduction is primarily a physical straining of particulates out of the thin film physically. Through repeated doses of effluent excess cell mass on a bead is transferred deeper into the media over time. Eventually spent solids are sloughed through the bottom of the media bags and drop into the lower liquid layer. The piping is Poly Vinyl Chloride (shown in RED in figure 4) is used for the four purposes shown on the figure. Pipe diameters are shown for typical residential use. The plan view of the installation is two about evenly sized tanks.

Three different centrifugal pumps are used in the processor tank, each with a distinct task. The recirculation pump is dual function. It takes liquid from the mid depth of the tank and sprays it over

1 mm diameter polyethylene bead media while simultaneously drawing in outside air through use of an air intake snorkel and venturi. Another pump called the return pump is located in the floor of the tank. When this pump is activated, it gathers up sloughed solids from the floor of the processor tank and sends it back to the headworks of the septic/recirculation tank along with a volume of aerobic water. The third pump is a discharge pump. Its purpose is to send treated water to a soil treatment system provided by others.

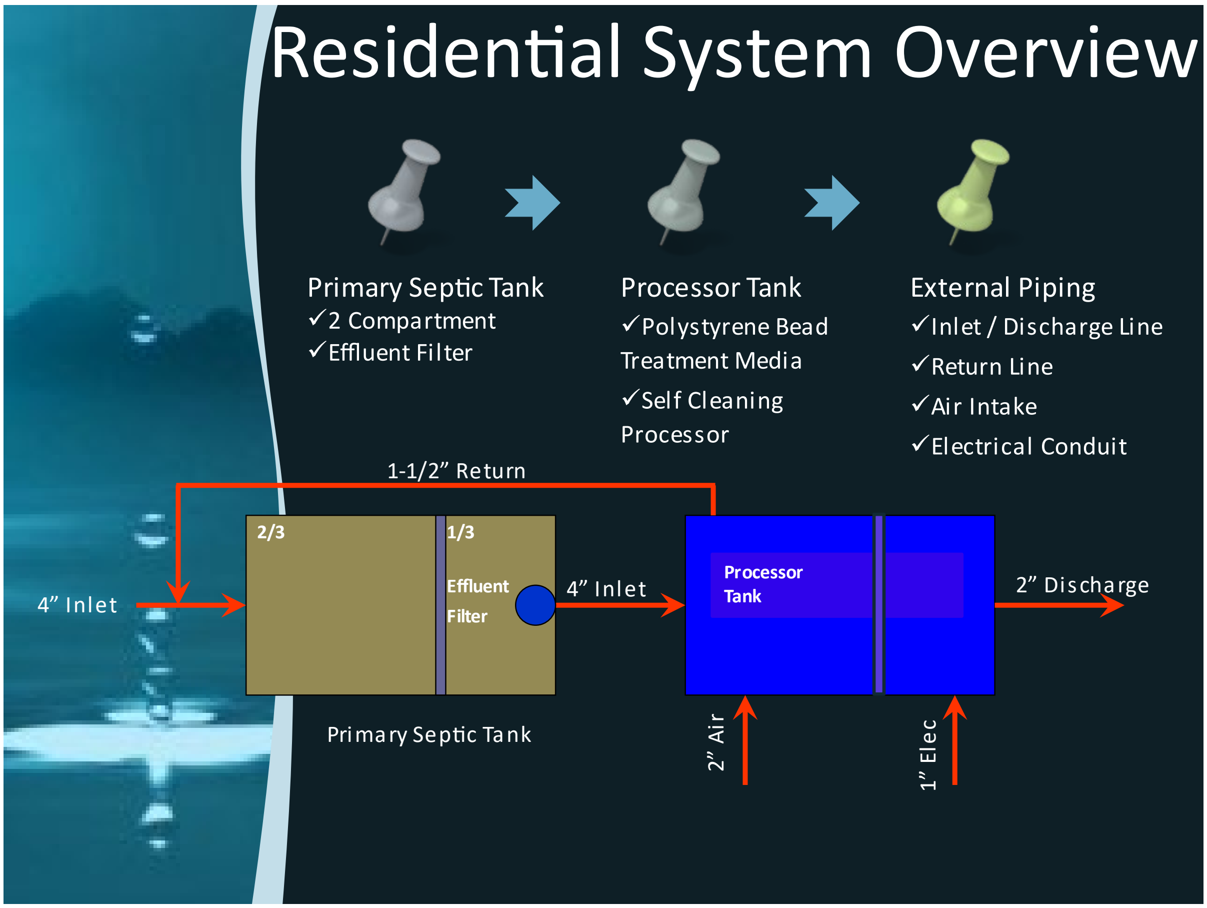

Figure 4. Plan view of typical STARR® two-tank layout.

Biological Nitrogen Removal

Nitrogen removal is another subject entirely. Nitrogen removal is carried out by sequentially first nitrifying then denitrifying the wastewater. All steps in the process are carried out by bacteria. The genera *Nitrosomonas*, *Nitrospira* and *Nitrobacter* do the work of nitrification. *Nitrosomonas*' role is to take in ammonium (NH_4) and convert it to nitrite (NO_2). *Nitrosomonas'* actions are rate limiting to nitrification. That means that if *Nitrosomonas* isn't on the playground, no one else can play. As soon as nitrite is formed, *Nitrospira* and *Nitrobacter* jump on the nitrite and quickly convert it to nitrate (NO_3).

What kind of environment is welcoming to nitrifiers? No carbon (they don't need it, they don't want it). Nitrifying bacteria are autotrophic. Autotrophic translates to "Self-Feeder". They prefer aerobic, dark environments (*Nitrosomonas* does not grow well in direct sunlight), with close to neutral pH. The water temperature should be at or above 50^{o}F (10^{o}C). There should be no solvents in the water (a single drop of acetone in a liter of water kills all the nitrifiers). In summary, these are super finicky bacteria.

Because these bacteria are autotrophic, they have more in common with a plant than they do a paramecium (figure 5). They have no mouth nor anus. They have organelles inside their cells that trap a portion of the energy released when Nitrogen containing chemicals are transformed.

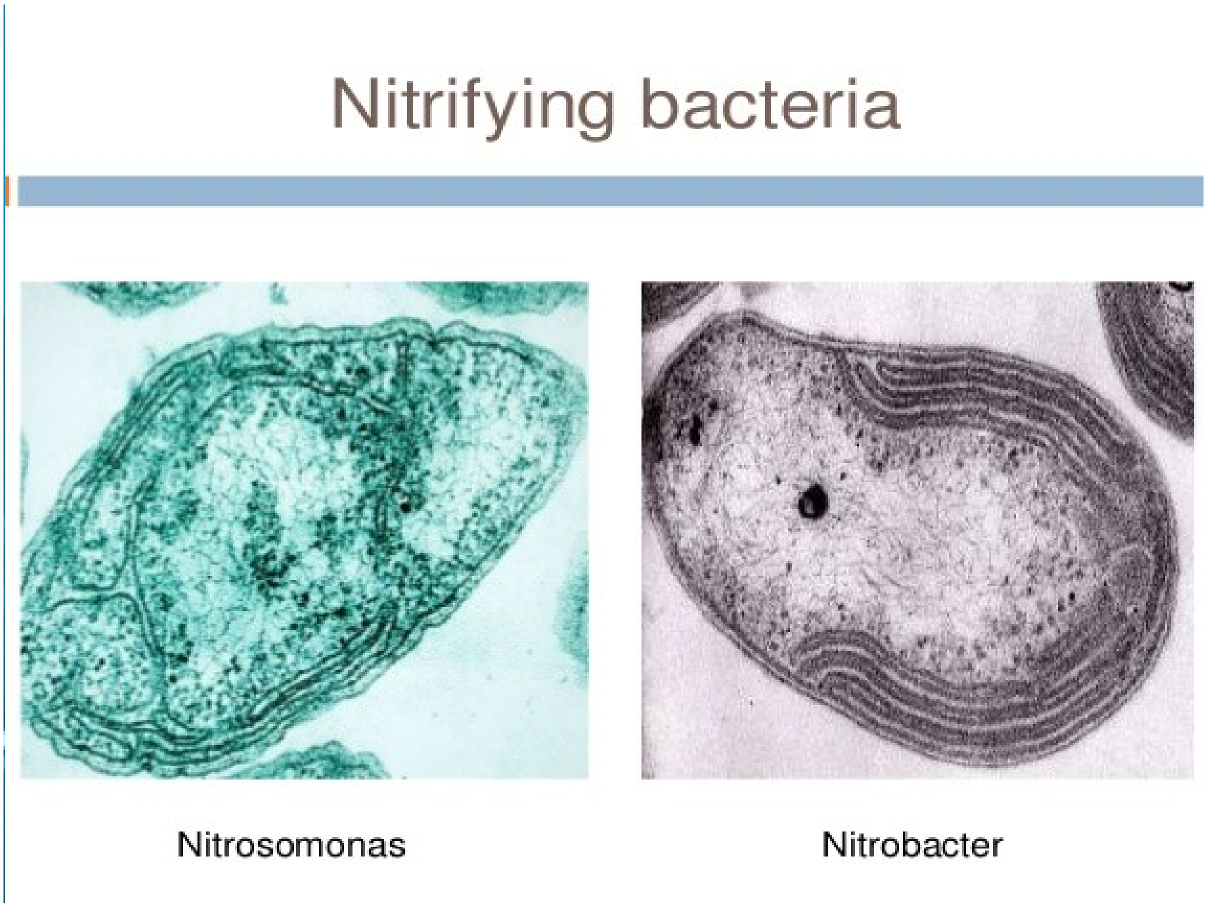

Figure 5. Microscopic view of two nitrifying bacteria.

Denitrification is the second part of Biological Nitrogen Reduction. Denitrification must happen following nitrification. This step is also bacterially mediated. Typical genera of denitrifiers are *Pseudomonas*, *Achromobacter*, *Bacillus* and *Micrococcus*. These bacteria are also specialized but could not be further from nitrifiers in their environmental preferences.

Most bacteria are obligate to one environment. *Nitrosomonas* is an obligate aerobe, meaning it cannot survive without oxygen. Other bacteria (such as those in a conventional septic tank) are obligate anaerobes, some find even small amounts of oxygen toxic. A third group of bacteria are facultative in nature. They can live with or without oxygen because they have metabolic pathways to deal with either circumstance. In a baseball analogy, facultative bacteria they are switch hitters. Having two metabolic pathways cost the organism having them, so in a consistently aerobic or anaerobic environment, facultative bacteria will be outcompeted by obligates. The only time they have the upper hand (i.e., they can outcompete competitors) is when conditions are varied between aerobic and anaerobic so lots of anoxic conditions in between the two end states are around.

Anoxic is to oxygen content as dusk and dawn are to light level. In anoxic conditions there is no free oxygen but oxygen containing compounds (carbon dioxide, nitrate) are available. Denitrifying bacteria breathe the oxygen off of nitrate (NO_3 remember?) and release nitrogen gas (N_2). Nitrogen gas makes up 78% of the earth's atmosphere. The septic/recirculation tank will effervesce nitrogen bubbles during denitrification. Denitrifying bacteria need carbon to eat, and sewage solids can provide that. As their populations grow, they will consume the sludge and scum, making the need for tank pumping less frequent. These bacteria are much easier to please

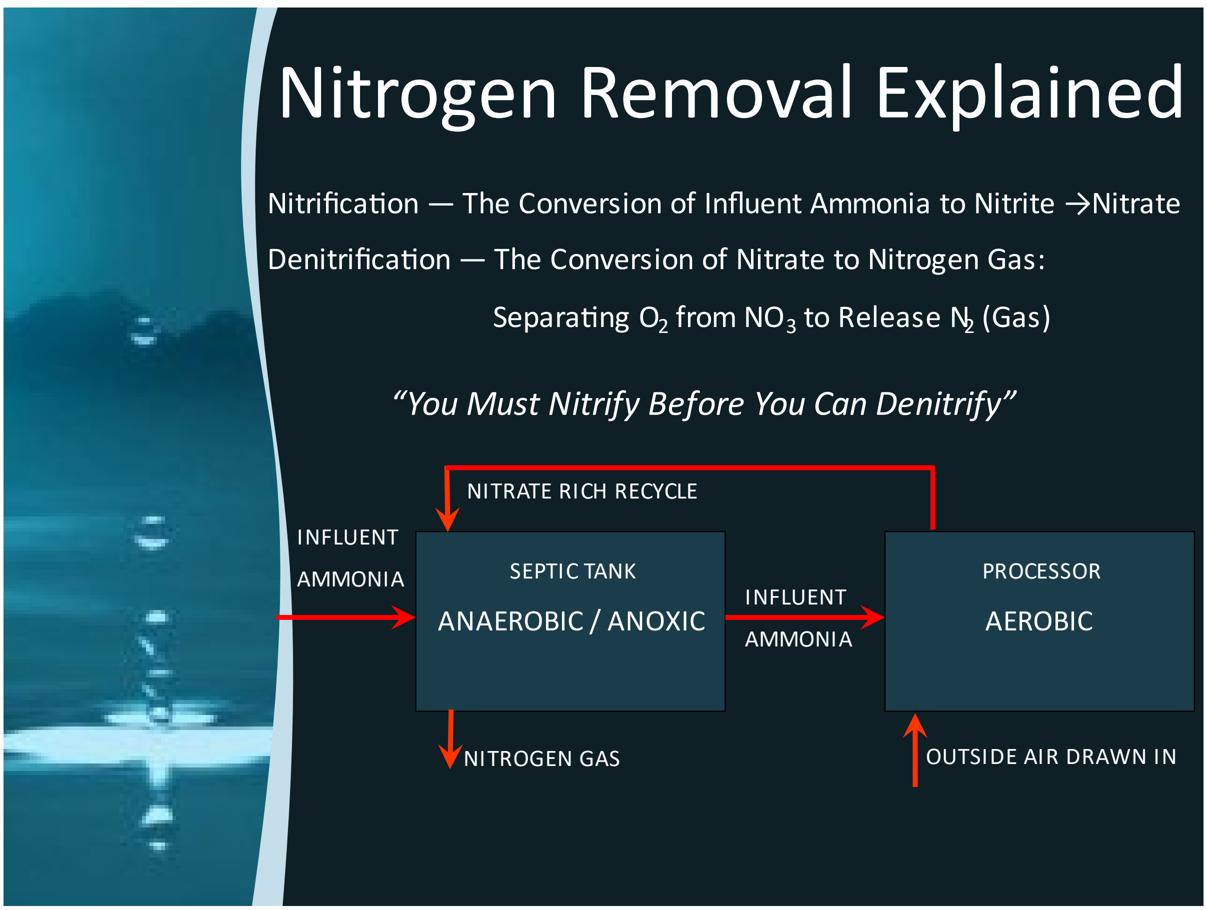

Figure 6. Steps in nitrogen removal with primary nitrogen compound in each location

so long as anoxic conditions and lots of carbon are around, they will thrive. With STAAR® the return pump discharge brings oxygenated water and sloughed solids back to the septic tank where the denitrifiers live. These denitrifying bacteria need the carbon to eat and the fluctuating anaerobic/aerobic environment to ensure anoxic conditions to thrive.

Operation and Management

Operation and management are very important in an unsaturated media filter. With STAAR®, service providers only need to assess the solids content of the septic/recirculation tank using a sludge-judge or similar device. That is because the return pump has collected the sloughed solids from the media in the processor tank and placed them back in the first tank. Check the media surface to ensure effluent is not being concentrated in one area. The media filter should have a forest floor smell and not obnoxious odors.

Control panels should be accessed at every O&M visit. Data trends should be analyzed based on readings obtained. The Consortium of Institutes for Decentralized Wastewater Treatment (2008) put together a valuable checklist for media filters. I am not suggesting service providers use the checklist as provided. If there is something that will always be n/a for a service provider, the item should be removed from *the company's* checklist. Checklists are valuable because they make service personnel assess the system in a logical sequence (not skipping around) and they make them write it down observations while they are providing the service.

Form 7-1. Operational checklist: Media filter (MF).

Service provided on: Date:________ Time:______________ Reference #:______________________

Service provided by: Company: ______________________ Employee: ______________________

Date of last service: ______________________________ By: ❑ You ❑ Other:______________

Date of last inspection: ___________________________

1. Type of media filter:

Single pass:	❑ Sand	❑ Foam	❑ Peat	❑ Other: ____________
Recirculating:	❑ Sand/gravel	❑ Foam	❑ Textile	❑ Other: ____________
Trickling filter:	❑ Gravel	❑ Plastic	❑ Textile	❑ Other: ____________
Upflow filter:	❑ Gravel	❑ Plastic	❑ Wood chips	❑ Other: ____________

   a. Manufacturer: ______________________ Model #: ______________________
   b. Distribution method: ❑ Pressure distribution ❑ Gravity distribution

2. Conditions at media filter
   a. Evaluate presence of odor within 10 ft of perimeter of system:
      ❑ None ❑ Mild ❑ Strong ❑ Chemical ❑ Sour
   b. Source of odor, if present: ______________________

3. Cover
   a. Type of cover: ❑ Free access ❑ Buried ❑ Lid
   b. Filter cover intact. Yes_____No_____
   c. Method of securing cover: ______________
   d. Distribution component accessible. Yes_____No_____
   e. Surface water/infiltration into components. Yes_____No_____

4. Venting/Air supply: ❑ Passive ❑ Active ❑ Not present
   a. Supply: ❑ Aspirator ❑ Compressor ❑ Blower ❑ Free air (go to 4.g)
   b. Operation: ❑ Continuous ❑ Timed (On______min, Off ______ min)
   c. Air supply unit operating properly. Yes_____No_____
   d. Pressure at air supply unit: ____________psi
   e. Air flow at air supply unit: ____________cfm
   f. Air filter/screen: ❑ Cleaned ❑ Replaced
   g. Venting appears operable. Yes ____No____

Notes

2. ❑ Acceptable ❑ Unacceptable

3. ❑ Acceptable ❑ Unacceptable

4. ❑ Acceptable ❑ Unacceptable

5. Media surface
   a. Biomat on surface. Yes_____No_____
   b. Uniform gravity distribution. N.A._____Yes_____No_____
   c. Uniform spray pattern. N.A._____Yes_____No_____
   d. Ponding in/on media. Yes_____No_____
   e. Plugging/clogging of distribution components. Yes_____No_____
   f. Media appears to be settling. Yes_____No_____
   g. Appropriate maintenance performed. Yes_____No_____
   h. Pest activity at surface. Yes_____No_____

5. ❑ Acceptable ❑ Unacceptable

6. Effluent quality
   a. Turbidity: __________NTU
   b. Oily film on the surface of effluent. Yes_____No_____
   c. DO at outlet: __________mg/L
   d. pH at outlet: __________
   e. Temperature at outlet: __________
   f. Bypass or overflow noticed. Yes_____No_____
   g. Effluent odor after passing through media filter:
      ❑ None ❑ Mild ❑ Strong
   h. Effluent color after passing through media filter:
      ❑ Clear ❑ Brown ❑ Black

6. ❑ Acceptable ❑ Unacceptable

Figure 7. Operational checklist for media filters (CIDWT, 2008)

Acknowledgements

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