ABSTRACT

Nitrogen in raw wastewater is predominately in the forms of organic nitrogen and ammonium. Well developed aerobic treatment processes biologically convert these forms of nitrogen to nitrates (nitrification), the oxidized form of nitrogen. After this first step, biological nitrogen removal requires the reduction of nitrate to elemental nitrogen gas (denitrification) that is released to the atmosphere. This step requires the wastewater containing the nitrate to pass through an environment low in dissolved oxygen with a food source (in the form of carbon) for denitrifying bacteria. Aerobically treated wastewater does not normally have enough remaining carbon to support a bacterial population sufficient to accomplish good denitrification.

There are other ways that have been used to accomplish denitrification, but this research utilizes an inline, up-flow, anaerobic reactor/filter to accomplish nearly 100% denitrification. After the nitrification, the wastewater is introduced to the bottom of the upflow denitrification reactor using a pump controlled by a programmable timer. In this way, the feed pump can be adjusted from time to time to maintain the desired flow and contact time in the reactor. The media in the reactor is shredded bark mulch. This media serves two functions: 1) Serves as a carbon source for denitrifying bacteria; and 2) Provides surface area for denitrifying bacteria to attach themselves. Previous research has shown that shredded bark is a good material for this purpose. The reactor is an up-flow reactor to provide a saturated environment with very little dissolved oxygen, thereby forcing the bioculture to utilize the oxygen attached to the nitrate molecules and release nitrogen gas to the atmosphere.

Results from a year of operation have demonstrated the ability to reduce the total nitrogen content of domestic wastewater to 5.0 mg/l, or less, as an average. The results of this research have led to the design of a community treatment system to treat flows in excess of 100,000 GPD.

BACKGROUND

The Silver Lake area in Oceana County, Michigan is a prime tourist area in the far western side of the Lower Peninsula along Lake Michigan. The area is located among the picturesque sand dune shoreline of Lake Michigan, and is a very popular recreation area because it is one of the few places where the dunes are made accessible for off-road vehicles. The local community has become very concerned about the slow deterioration of the water quality of the lake, and nutrient contributions from onsite systems populating the shoreline are thought to be a contributing cause. Of course, the very permeable sandy soil throughout the area does support that conclusion.

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A local businessman that owns several commercial properties in the Silver Lake area has taken steps to build a privately owned and financed public wastewater collection and treatment system. Previous efforts over the last 30 or 40 years to construct a community sewer system around the lake have not been successful, primarily due to cost. This recreational area has experienced a lot of growth in the last couple of decades, and there is a growing urgency among local residents and businesses to protect the Lake from further deterioration. After all, it is this resource that attracts tourists to the area.

So, the local business leader purchased property and retained this writer to plan and design a private wastewater treatment facility to serve his properties and others that would be interested in connecting. The concept proposed is a STEP (Septic Tank Effluent Pumping) collection system with common pressure sewers to transmit the settled effluent to a central treatment facility over a mile from the lake and on much higher ground. After treatment, the wastewater is to be discharged back into the ground in large, open infiltration beds.

Treatment will occur in a series of aerated lagoon cells in which phosphorus will be precipitated from the wastewater stream by the addition of alum, mixing and then settling. The aerobic treatment that will occur in the lagoon cells over a number of weeks of residence time with aggressive aeration will do a very good job of nitrification (converting nearly 100% of the nitrogen to nitrate). This nitrate-nitrogen will then be reduced to nitrogen gas by passing the wastewater through an up-flow, anoxic/anaerobic saturated reactor with shredded bark mulch as the media. This research was then conducted to prove the concept that such a reactor will successfully remove nitrogen adequately.

For larger wastewater treatment facilities that discharge treated wastewater back into the groundwaters of the state, Michigan requires that the wastewater contain no more that 5.0 mg/l total inorganic nitrogen (TIN). This performance requirement can be measured either at the point of discharge, or in the groundwater near the property line. So, 5.0 mg/l is our performance target for this research.

**STUDY FOR “PROOF OF CONCEPT” FOR NITROGEN REMOVAL**

**Background** – The processes involved in total nitrogen removal from a wastewater stream have been well known for decades (Advanced Wastewater Treatment, Culp and Culp, 1971). A quick summary of this 2-step process is as follows:

Nitrogen in raw wastewater is predominately in the forms of organic nitrogen and ammonium. Well developed aerobic treatment processes (like the proposed aerated lagoons) biologically convert these forms of nitrogen to nitrates, the oxidized form of nitrogen. This part of the process is called the “nitrification” step. Aerated lagoon cells are capable of nearly 100% conversion with adequate residence time. The only exception to this is when the water temperature drops below 45 to 50 degrees F. Colder temperatures slow the bacterial action significantly. Fortunately, incoming flow during the winter months at Silver Lake will be next to zero. This will allow flow to be stored for treatment when the temperature warms in the spring.
After the nitrification step, the treatment system will have a denitrification step. Denitrification requires the wastewater containing the nitrate to pass through an environment low in dissolved oxygen (anaerobic/anoxic) with a food source (in the form of carbon) for denitrifying bacteria. The wastewater following the aerobic nitrification step will not contain enough remaining carbon to feed the bacteria, so a food source must be added. There are other ways to accomplish denitrification, but this concept is to accomplish nearly 100% denitrification with an inline, up-flow, anaerobic reactor/filter. After the nitrification, the wastewater will be delivered to the bottom of the upflow denitrification reactor using pumps controlled by programmable timers. In this way, the feed pumps can be adjusted from time to time to maintain the desired flow and contact time in the reactor. The media in the reactor is to be shredded bark mulch. This media is to serve two functions: 1) Serve as a carbon source for denitrifying bacteria; and 2) Provide surface area for denitrifying bacteria to attach themselves. Research has shown that shredded bark has been found as a good material for this purpose. The reactor is also to be an up-flow reactor to provide a saturated, anoxic environment forcing the bio-culture to utilize the oxygen attached to the nitrate molecules and release nitrogen gas to the atmosphere.

**APPARATUS FOR THIS STUDY**

SCS Systems, LLC operates a wastewater treatment facility for Brookfield Township, Eaton County, MI. This treatment facility uses recirculating aerobic packed-bed filters to highly treat septic tank effluent from a S.T.E.P. collection system serving homes around Narrow Lake. The wastewater is highly nitrified in the process. This study is taking this nitrified effluent and passing it through an up-flow shredded bark mulch reactor/filter using a timer activated supply pump and valve assembly. The volume of the empty bed is known (~75 gallons), and the nitrified effluent feed is controlled by a programmable timer activating a motorized valve on the feed line. The source of the nitrified effluent is a pressure tank fed by a pump in an effluent storage tank. It was designed to supply wash-down water for the treatment facility.

The reactor chamber is a round H.D.P.E. cylindrical container of approximately 24” in diameter and about 4 feet tall, manufactured as a pump vault. It has a hopper bottom that forms the bottom 10” to 12” of the vault. A ¾” threaded bulkhead fitting was placed in the side of the hopper bottom for the wastewater feed location. Another ¾” threaded bulkhead fitting was placed near the top of the container as the overflow point. A sampling tap was installed in the feed plumbing so that samples can be drawn before the reactor. A P-trap was plumbed with a sample tap in the overflow piping so that a sample of the overflow can be collected at any time. Below are some pictures of the pilot study apparatus.
VIEW OF THE TEST APPARATUS SHOWING THE TEST CONTAINER AND THE FEED CONTROL VALVES

WASTEWATER FEED CONTROL APPARATUS

Container with media

Low voltage motorized valve controlled by programmable timer

Incoming wastewater feed

Transformer

Power from programmable timer

Incoming sampling tap

Pressure control valve
SOURCE OF NITRIFIED WASTEWATER EFFLUENT FROM EXISTING TREATMENT WORKS AT NARROW LAKE

Test container containing media

Overflow trap with treated effluent

Filtered effluent discharge

Sampling tap for treated effluent

Pressure tank for existing treated wastewater

Feed hose to test apparatus
FILLING OF THE TEST CONTAINER

Hopper bottom filled with 6A stone
(Stone used as a distribution media)

FILLING OF THE TEST CONTAINER

Porous plastic geotextile mesh placed
over stone as a separator

FILLING OF THE TEST CONTAINER

Shredded bark mulch place over
plastic mesh and stone
FILLING OF THE TEST CONTAINER

Test container filled with bark mulch up to just below the overflow – a total media depth of 2.75’ (33”)

Another layer of plastic mesh placed over bark mulch, and then covered with a thin layer of stone on top (to hold down mulch)

Ball Point Pen

Overflow bulkhead fitting

Media Size
SAMPLING AND TESTING SCHEDULE

This study has been up and running since the first week of December, 2015. Sampling began on December 30th of 2016 and continued for a full year through the end of 2016. The apparatus is still in place and performing at this time, but only a couple of random samples have been collected in 2017 to verify that the reactor is still performing.

During the test run, frequent grab samples were drawn for both influent and effluent from the test apparatus, and tested for the following parameters:

- TKN
- Ammonia
- Nitrite
- Nitrate
- BOD
- Phosphorus

In addition, D.O., pH and water temperature were also carefully measured in the pool of effluent on top of the test container during the collection of each sample.

CONTACT TIME

This study did not allow the evaluation of numerous contact times or types of media. That will need to be the subject of study for others in the future. Initially, the programmable timer was set to provide an empty-bed contact time of 48 hours. We did try adjusting the contact time upward to about 3 days in mid-summer of 2016, but any difference in results seemed insignificant. A lot of the research that has already been done in similar situations has demonstrated that shorter contact times also produced good results. In fact, Camilo, et al (2013) concluded in similar research with wood chips, bark mulch and straw as media, that 1.7 days was enough residence time to get 100% nitrogen removal. However, in our study no attempt was made to account for the reduction of residence time due to space occupied by the media. So, 2 days of “empty-bed residence time” would only be 1 day of actual residence time if the media had only 50% void space.

RESULTS

Table 1 below shows the summary of results of all samples collected for influent and effluent nitrate and TIN. This even includes the early samples collected during the start-up period in the colder winter months when the water temperature of the effluent was frequently below 50º F.

Some may wonder whether the 5-day BOD increased during the study. It did . . . but only from an average influent of 3.0 mg/l to an average of 10.1 mg/l in the effluent. This is still considered a highly treated effluent to apply to any soil dispersal system.
**Table 1**

<table>
<thead>
<tr>
<th>Nitrogen Removal Demonstration</th>
<th>All Data</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Influent Nitrate mg/l</td>
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<tr>
<td>High</td>
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<tr>
<td>Average</td>
<td>28.5</td>
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<tr>
<td>Low</td>
<td>12.0</td>
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<tr>
<td>Number of Samples</td>
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</tbody>
</table>

* As a reference, the DEQ groundwater discharge limit for T.I.N. is 5.0 mg/l and the national drinking water standard for Nitrate is 10.0 mg/l.

**KEEPING THE RESULTS OF THIS STUDY IN PERSPECTIVE**

It is important to understand what we can learn from this and other similar studies like this. For instance:

1. We and others have demonstrated that total nitrogen can be removed from domestic wastewater by good aerobic processes followed by anaerobic/anoxic processes.

2. Several research efforts have now proven that nearly all of the nitrogen in wastewater can be removed with the use of a bio-degradable woody fiber media as a carbon source in an environment devoid of free dissolved oxygen.

3. By using a pump to feed the wastewater from the bottom of a container in an up-flow manner, we not only create anoxic conditions, but also force continuous flow up through the media in a fluidized bed methodology. We have learned from another experience that gravity-fed downflow methods tend to clog in a relatively short period of time.

4. Shredded bark mulch and perhaps other similar media can be used to remove TIN from well nitrified wastewater effluent down to an average of 5.0 mg/l, or less, with an empty-bed contact time of 2 to 3 days.
5. An additional option that could be designed into a denitrification reactor is the ability to provide recirculation of the effluent back through the reactor, if necessary. This will mean that the biology in the media would have more than one opportunity to remove nitrogen from the treatment flow stream.

**CAUTION** - We must understand that the biological colonies that nitrify and denitrify slow their metabolism when the water temperatures drop during colder months in cold climates. Since they become less efficient in the winter, performance will diminish. This will not be a problem in our application at Silver Lake because of the highly seasonal occupancy of the area, but it may be a factor in applications elsewhere.

Designers and operators should also be aware that these types of bacterial populations are also slow-growers, and do not compete well with aerobic bacterial populations that feed on carbon. It may therefore take several months for the development of a sufficient bacterial population to reach peak efficiency. This does limit the effectiveness of activated sludge processes, and sludge age must be carefully managed.

**CONCLUSIONS**

The information gained from this study demonstrate that the proposed treatment system at Silver Lake can be designed to meet the expected performance requirements of the Michigan Department of Environmental Quality of less than 5.0 mg/l TIN at the “end of pipe”.

**REFERENCES**


