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*Article*

# Sustainable Treatment and Reuse of Water using Decentralized Systems

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**Abstract:** As the scarcity of potable water increases, recycling of treated wastewater is increasing. Small-scale, decentralized treatment can be implemented to serve local populations by keeping water within their boundaries and within reach for reuse, particularly in less dense, non-urban communities. Availability of cellular networks and high-speed internet connectivity, along with significant reduction in cost, allows ongoing monitoring of decentralized treatment systems at a central location. In this paper a decentralized treatment system using micro nanobubble aeration, moving media and membranes is able to produce reusable water with low energy consumption, thereby allowing the use of solar energy in places with unreliable electrical supply. The treatment system, which uses no external chemicals, is able to operate unattended and deliver clear, disinfected water with non-detect suspended solids, BOD5 less than 10 mg/L and nutrients below 5 mg/L.

**Keywords:** sustainable; decentralized; wastewater; treatment; micro-nanobubbles; biomedia

## 1. Introduction

Wastewater has been treated in mainly two ways: (1) centralized treatment which collects wastewater from a large number of houses using a network of underground sewer pipes, and then treats it in a single plant; and (2) decentralized treatment which treats the wastewater separately for each house or a limited number of houses with the goal of returning the water back to the ground near the source(s). The major disadvantage of centralized treatment is installation and maintenance of a large collection system (sewer pipes) and inability to economically return the treated water back to its source(s). Most centralized treatment plants discharge the treated water into a creek, river or ocean, where it eventually becomes salt water. This has resulted in the decline of groundwater levels around the globe, resulting in water scarcity and famine.

Decentralized treatment allows the groundwater table to be replenished assuring availability of groundwater for future generations. However, the traditional decentralized system is a septic tank, which separates the solids but does not treat the wastewater. Wastewater is treated by the bacteria in the soil drain field. In recent years, soil drain fields gave begun to clog prematurely due to the accumulation of microplastics in the wastewater. In 2014 a national survey in the U.S. had reported that there were more than 2 million failed soil drain fields. Untreated wastewater from these failed fields have been contaminating drinking water wells for decades, which is jeopardizing the health of millions of people, that rely on well water for their daily needs.

In several European countries, such as Germany, The Netherlands, decentralized treatment systems for 1,000 people have been deployed that incorporate reuse of water, energy and resources [1,2]. The potential of centralized and decentralized wastewater management was studied in Bangkok [3] and it showed that decentralized approach was economical and conducive for sustainable urban growth. It also demonstrated that decentralized treatment was cost-competitive, since it had short sewer lines and simpler technology, which was easy to maintain. Treated water was used locally, mainly for irrigation

(30- 100%), while only 5% of treated water from centralized treatment was recycled and reused.

Currently both centralized treatments using large-scale wastewater treatment plants and decentralized systems, such as a septic tank, coexist, with decentralized approach being used mainly for rural areas. In the United States, about 60 million people use some form of onsite wastewater treatment systems of which about 20 million use the conventional septic tank system [4]. In Australia, about 12% of the population uses septic tank systems [5], while in Turkey, about 28% of municipalities are served by septic systems [6].

In recent years, on-site aerobic systems have also been used as decentralized treatment, for single family houses and sub-divisions. While these systems can treat the organic load in the influent wastewater, they usually don't effectively reduce the nitrogen and phosphorus, resulting in algal blooms in receiving water bodies. They are also unable to filter out microplastics, present in domestic wastewater, which eventually clog up the soil drain field.

## 2. Decentralized vs Centralized Treatment

Centralized treatment using an elaborate network of underground sewer pipes (collection system) followed by a large, central, wastewater treatment plant was the biggest blunder of mankind. It has resulted in the decline of ground water levels around the globe, including many countries, which suffer from water scarcity [7,8]. It poses the greatest impediment to water reuse, since piping the treated water back to the users would be uneconomical. In addition, maintaining the vast network of sewer pipes is very expensive and has resulted in raw wastewater leaking into the ground contaminating drinking water wells, with adverse health implications for millions of people [9].

Decentralized treatment, which treats the wastewater at or near the source, allows water reuse, at least as non-potable water, thereby preventing the decline of ground water levels, reduces the net consumption of fresh water, and avoids the high installation and maintenance costs of a large collection system [10]. With the growth of wireless connectivity and sensors, these decentralized treatment systems can relay their alarms wirelessly to a central location, which allows low-cost maintenance of the decentralized treatment systems by a single company or entity. Hence, the world should move from centralized treatment to decentralized treatment with centralized monitoring, as shown in Figure 1.

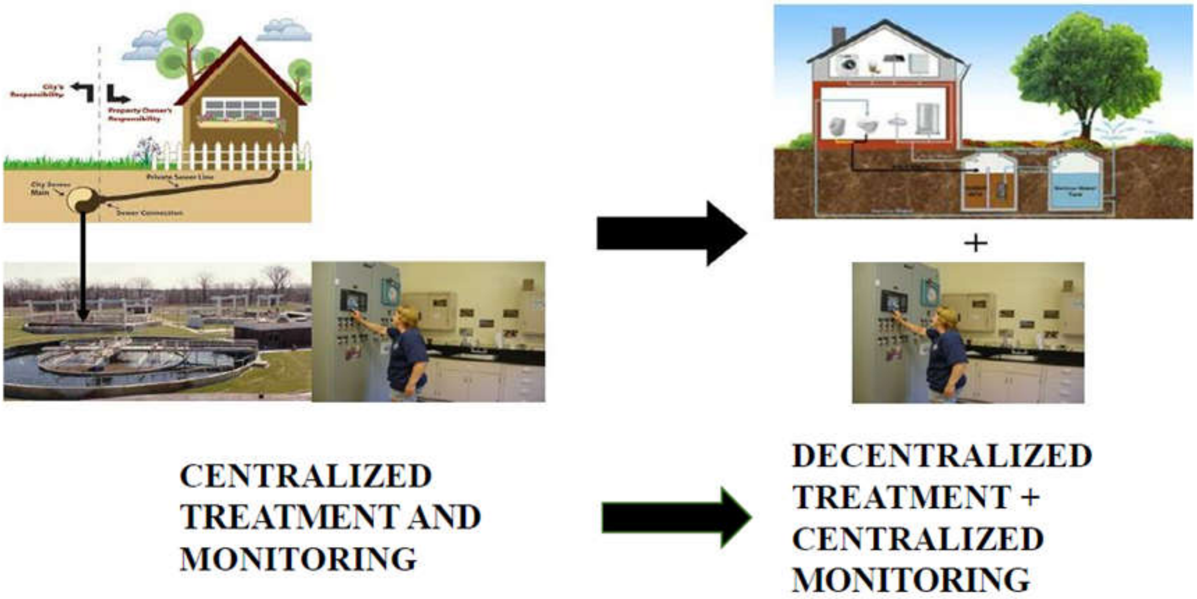

**Figure 1.** Centralized Treatment and Monitoring versus the future of Wastewater Treatment, which is Decentralized Treatment and Centralized Monitoring.

## 3. Background

Sustainable design requires that the energy consumption for wastewater treatment is minimized. In a typical wastewater treatment plant (WWTP) there are three stages of treatment and the percent energy consumption in each stage are shown in Figure 2 [11]. The first stage is physical treatment, in which the suspended solids are separated from the wastewater. This stage consumes about 25% of the total energy consumption. The second stage is biological treatment which includes aerobic and anaerobic treatment, which converts the organic matter to carbon dioxide, methane and ammonium nitrogen to nitrogen gas and nitrates/nitrites. This stage consumes about 60 -70% of the total energy consumption. The final stage is sludge handling and dewatering, which consumes 4.1 – 13.9% of the total energy consumption.

Clearly, there is substantial potential for energy reduction in the treatment process. It is well known that energy consumption for treatment per unit volume of wastewater decreases with increasing influent water flowrate. However, this does not account for the fact that smaller-scale wastewater treatment systems, as in the decentralized approach, can use renewable energy much more easily than large-scale wastewater treatment plants.

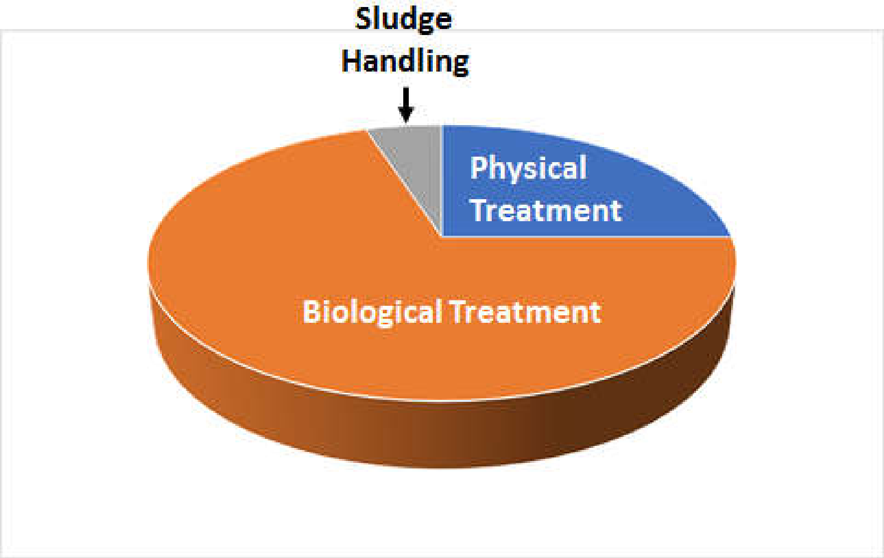

**Figure 2.** Percent energy consumption in a typical wastewater treatment plant (WWTP).

### *3.1. Wastewater Aeration*

Aeration is essential for biological treatment of wastewater under aerobic conditions. The goal of aeration is to maximize the concentration of dissolved oxygen in the aqueous phase, thereby promoting aerobic biological treatment. There are two main kinds of aeration systems: (1) natural aeration, which uses no energy and relies on oxygen transfer as the water moves through atmospheric air; and (2) engineered aeration, which can be of several kinds: (1) basin aeration; (2) surface aeration; and (3) in-line aeration. Furthermore, aeration can be achieved with either ambient air or with higher concentrations of oxygen separated from air.

Surface aeration often is unable to oxygenate the entire water column, unless the basin is shallow, which makes the footprint of the aeration basin very large. This stratification of oxygenated water at the top, results in anoxic conditions at the bottom of the basin. This results in the formation of methane gas, especially in lagoons, where low water velocity creates sedimentation of the suspended solids. Settled solids begin to accumulate at the bottom. Lagoons have to be dredged when the sediment thickness increases, and this waste sludge, often rich in nitrogen and phosphorus, has to be treated before disposal.

Most commonly used aeration method is basin aeration, wherein ambient air is bubbled from the bottom of the basin. Oxygen in the air bubbles dissolves into water as the

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bubbles rise through the water column. To achieve higher levels of oxygen transfer into the water, greater basin depths are used, which reduces the surface area of the basin. Fine bubble aeration is used to increase interfacial surface area between the air bubble and water. However, basin aeration requires the diffusers to be periodically cleaned, to maintain their higher oxygen transfer efficiency. Coarse bubble aeration is often used with fine bubbles to allow the water column to mix, in order to prevent stratification in the basin. Major disadvantage of bubble aeration using deep basins is the high cost of air compression, which makes aeration for biological treatment one of the highest energy consuming steps in wastewater treatment (reefer to Figure 2).

The oxygen transfer efficiency is measured in clean water, defined as Standard Oxygen Transfer Efficiency (SOTE) and the fouling potential of the aerators is defined by a parameter α, which is 1.0 for clean water. The actual oxygen transfer efficiency (OTE) is defined as the product of this parameter α with SOTE, measured in clean water. Table 1 lists the values of OTE versus bubble diameter. These values show that while ultrafine bubbles have a higher SOTE/ft compared to larger size bubbles, their fouling parameter, α, is also lower. Lower values of the fouling parameter give a lower OTE and increases the energy consumption.

**Table 1.** Oxygen Transfer Efficiency (OTE) versus Bubble Diameter in Basin Aeration.

| Diffuser Type | Typical SOTE (%/ft) | α (SOTE)/ft | OTE = α x SOTE | Energy Consumption Multiplier |
|---|---|---|---|---|
| **Coarse Bubble (> 4 mm)** | 0.90 | 0.75 | 0.675% | 1 |
| **Medium Bubble (2.5 mm – 4.0 mm)** | 1.40% | 0.60 | 0.84% | 0.756 |
| **Fine Bubble (1 mm – 2.5 mm)** | 2.1% | 0.49 | 1.03% | 0.476 |
| **Ultrafine Bubble (0.5 mm – 1.5 mm)** | 2.6% | 0.3 | 0.78% | 1.243 |

In recent years aeration using microbubbles and nanobubbles or micro-nano bubbles (MNB) have been developed and applied for wastewater treatment [12, 13]. The critical diameter separating bubble swelling and shrinkage is about 50–65 μm, as shown in Figure 3 [14]. Bubbles larger than the critical value will swell, while smaller bubbles will shrink. Furthermore, surface charge of the MNB's prevents them from coalescing to form larger bubbles. The bubble rise time for different size air bubbles is shown in Figure 4. With increasing bubble residence time, the oxygen transfer efficiency increases.

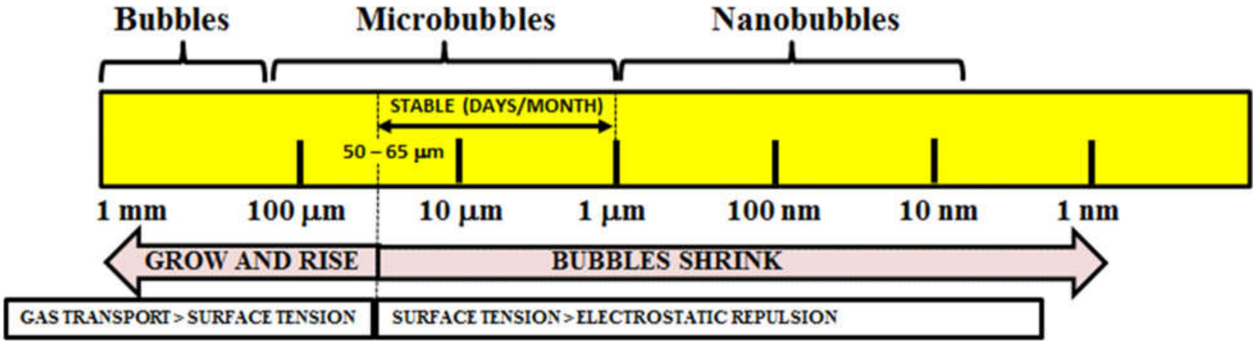


**Figure 3.** Stability of various air bubble sizes in wastewater.

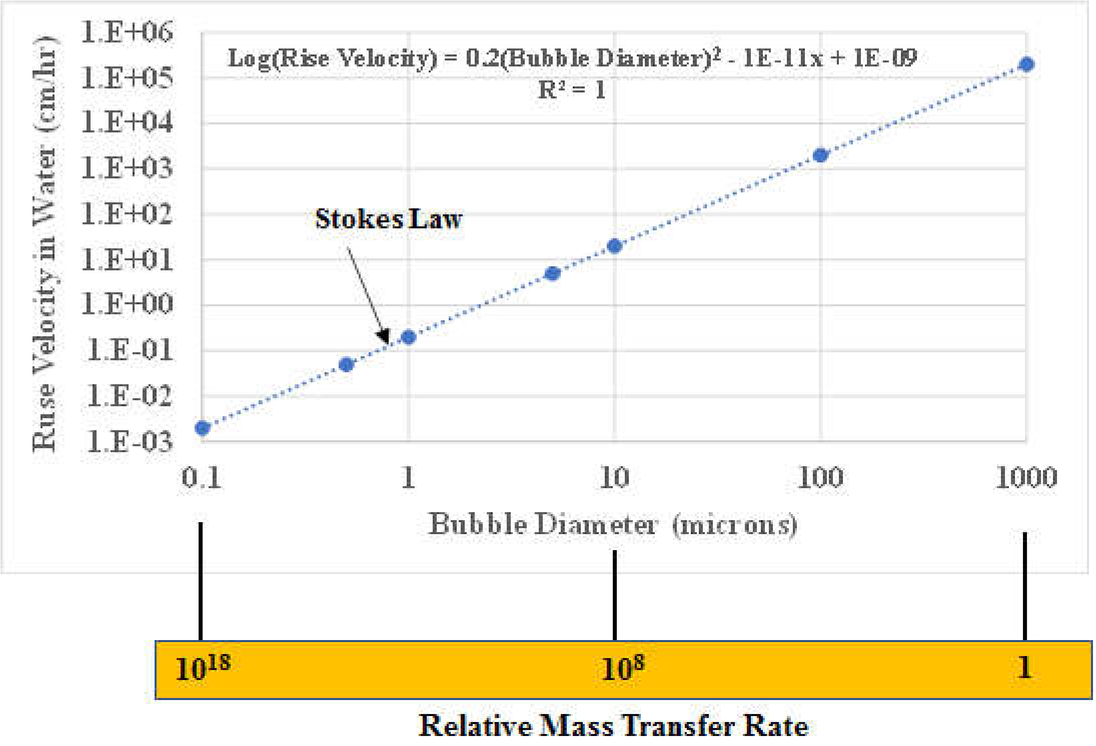


**Figure 4.** Rise Velocity for Micro and Nanobubbles in Water.

However, since air has an oxygen concentration of 21%, and mass transfer coefficients for oxygen and nitrogen are very similar, after oxygen in the bubble has been utilized, these nanobubbles of nitrogen serve no function in the bioreactor. In fact, they pose several disadvantages in a bioreactor system. Firstly, nanobubbles are capable of shearing biofilms from the surface of the biomedia, and the functioning of a bioreactor is based on the existence and maintenance of active biofilms. Secondly, the presence of nitrogen bubbles decreases the bulk density of water, which causes activated sludge flocs to float rather than remain immersed in the wastewater. Flotation of activated sludge also occurs due to surface attachment of nanobubbles to the microbial flocs. This also inhibits biological degradation in a suspended culture treatment system, like activated sludge basins.

Hence, the optimum bubble size for aeration is in the range of microbubbles, 1-100 mm range, which have a reasonable liquid residence time, ability to coalesce due to low surface charge and ability to deliver oxygen from the air at high oxygen transfer efficiencies.

Liquid mixing is also an important aspect of bioreactor effectiveness, and microbubbles do not possess sufficient drag to effectively mix the wastewater in the bioreactor. The most effective method of mixing the liquid in a bioreactor is to use recycle flow of water. In-line aeration achieves this goal of recycling water from the bioreactor and aerating this flow before it re-enters the bioreactor. The most common way of in-line aeration is achieved by using a venturi, which creates a negative pressure when water flow through a narrow region, as described by the Bernoulli equation. In a venturi in-line aeration system, air is introduced into the throat of the venturi, where the water velocity is high, and air is drawn in due to the negative pressure created by the high-water velocity. However, the main issue with venturi aeration is the air-water ratio which can be achieved. Biological treatment requires a specific air/water ratio as shown in Figure 5. This calculation assumes air at 1 atm, 25 deg C, various influent BOD in mg/L and 25% oxygen absorption efficiency. Clearly, for an influent BOD of 500 mg/L the air/water ratio required is 6.65, which is much greater than air/water ratio that can be achieved using a venturi. Hence, venturi’s alone cannot be effectively used for wastewater aeration since they are unable to provide sufficient dissolved oxygen in the water.

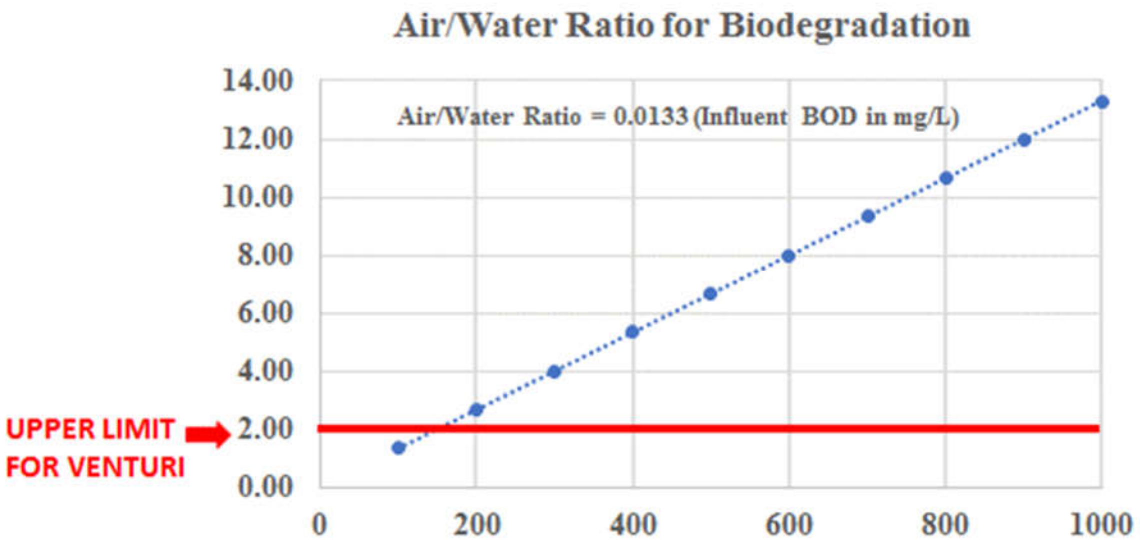


**Figure 5.** Air/Water Ratio needed for Biodegradation and Limit for Venturis.

Microbubble generation using microporous membranes is a simple, energy-efficient method for generating microbubbles wherein a high gas/liquid ratio, as required for biodegradation of wastewater, as shown in Figure 5. Bubble size depends on the shear stress exerted by the liquid flow and the hydrophobicity of the membrane [14,15]. This method allows the air/water ratio to be controlled independently, and the microbubbles can be generated in-line, thereby allowing the recycled liquid to mix the bioreactor. Furthermore, the gas and liquid phase pressure drops are small, compared to other methods of microbubble generation such as venturi, high pressure dissolution, etc.

### *3.2. Biomedia*

Wastewater treatment in domestic WWTPs is usually conducted using an activated sludge process, which uses suspended cultures. The main disadvantages of suspended cultures are low biomass concentration, typically 2,000 – 3,000 mg/L, high impact of biocidal chemicals, washout of the suspended biomass at high water flowrates, and net generation of biomass. Immobilized biomass or biofilms allow a substantially higher concentration of active biomass, typically 10,000 – 50,000 mg/L, less adverse impact of biocidal chemicals [16], no washout of the active biofilms, and robust performance even at low operating water temperatures. Immobilized biomass or biofilms are achieved using biomedia, which presents a high surface area for active biofilms to attach and grow on its surface. Various kinds of biomedia have been used, such as plastic pieces of various shapes and sizes, open-cell polyurethane foam pieces, porous ceramic media and even rocks. Biomedia can be used as moving media in the water phase or in a static packed bed with trickling flow of wastewater.

Flexible polyurethane foams have gained relevance as microbial carriers. Favorable properties of open-cell polyurethane foam as biomedia includes good mechanical properties, high porosity, large adsorption surface, resistance to organic solvents and microbial attack, and cost effectiveness [16]. In general, the high rates of sorption of positive charge and hydrophobic character of the polyurethane foam, allow interaction with most microbial cell surfaces [17,18].

One of the central issues with any biomedia, whether stationary or moving, is clogging due to biomass growth [32]. Most plastic medias currently on the market clog due to biomass growth, especially at high influent BOD levels. Also, the surface area in a biomedia can be sub-divided into two types: (1) protected; and (2) unprotected. Protected surface area represents surface area in a biomedia in which the biofilm is not subjected to any action which may slough-off the biofilm from the biomedia. The outside surface area of any biomedia which is subjected to either water velocity that exerts frictional force on the biofilm or where the biomedia can rub against each other to abrade the biofilm off the surface, is unprotected surface area. Biofilms in the protected areas of the biomedia tend to grow significantly thicker while biomedia's surface area in unprotected areas are unable to sustain any active biofilms. This allows the biomedia to begin to clog in the protected areas while having no biofilm in the unprotected areas, and this significantly reduces the total effective surface area of the biomedia.

Determining the maximum biofilm thickness is critical for any biomedia [32], since it determines the opening size for the protected areas. The maximum biofilm thickness must be 50% or less than the size of the openings in the protected areas of the biomedia. Using F as the influent flowrate in million gallons per day, $C_{in}$ mg/L as the maximum influent soluble BOD in most domestic wastewater treatment applications, 0.8 as the fraction of volatile suspended solids to the mixed liquor suspended solids, and Y (lb/lb) as the biomass yield, the total amount of biomass that will result from complete treatment of this wastewater is given by the following equation:

$$\text{Rate of biomass growth (lbs/day)} = (F \times C_{in} \times Y \times 8.34)/0.8 = 10.425F \times C_{in} \times Y \tag{1}$$

For steady state to be achieved in the bioreactor, the rate of growth of biomass must be equal to its decay rate. When this steady state is achieved, the biofilm thickness would have attained a constant value. This also assumes that there is no removal of biofilms due to slough-off from the protected areas of the biomedia.

At this steady-state condition, the decay rate of biomass is given by the kinetic decay rate constant, which is in the range of 0.025 – 0.075 $day^{-1}$, with an average value of 0.06 $day^{-1}$. Using this average decay rate and W lbs is the total amount of biomass in the bioreactor, we get the following equation when biomass growth and decay are equal:

$$0.06 \times W = 10.425F \times C_{in} \times Y \tag{2}$$

Using density of water (62.5 lbs/ft3) as density of biomass, we get the total volume of biomass in the bioreactor, VB ($ft^3$) as follows:

$$VB\ (ft^3) = \quad 2.78F \times C_{in} \times Y \tag{3}$$

If the fractional protected area of the biomedia (protected area/total surface area) is AB, and $A_{tot}$ is the total surface area of all the biomedia pieces in the bioreactor, then the maximum biofilm thickness is given by the volume of biomass dived by the total protected area, i.e.,

$$\text{Maximum biofilm thickness } t(ft) = VB\ (ft^3)/(AB \times A_{tot}) = 2.78F \times Cin \times Y/(AB \times A_{tot}) \tag{4}$$

The above equation gives the maximum biofilm thickness since we are assuming that all biomass growth is on the biomedia and there are no suspended cultures in the liquid phase. Clearly, if the maximum opening size dimension, t (ft) is less than or nearly equal to the maximum biofilm thickness, then the biomedia will clog.

$$t \leq 2.78F \times C_{in} \times Y/(AB \times A_{tot}) \quad \text{Biomedia will clog} \tag{5}$$

$$t >> 2.78F \times C_{in} \times Y/(AB \times A_{tot}) \quad \text{Biomedia will not clog} \tag{6}$$

### 3.3. *Treatment of Nutrients*

Several of the seventeen Sustainable Development Goals (SDGs) are related to managing nutrients in wastewater. Nutrients (nitrogen and phosphorus compounds), normally present in domestic wastewater, when released into water bodies result in the growth of toxic algal blooms. Nutrients also stimulate eutrophication in lakes and rivers, and ammonium-nitrogen in wastewater can deplete water bodies of dissolved oxygen, resulting in fish kills. Eutrophic conditions are a major risk to human health, resulting from consumption of shellfish contaminated with algal toxins or direct exposure to waterborne toxins. Algal blooms have caused major problems in water bodies used to supply drinking water, since chlorine, used to disinfect drinking water, reacts with organic compounds to form disinfection byproducts, which are potential carcinogens and regulated by the U.S. Environmental Protection Agency.

Release of nutrients from decentralized systems, such as a septic tank and even on-site aeration units has been well documented. While treatment of nutrients in centralized treatment systems has been well studied and will not be reviewed here.

Both phosphorus and nitrogenous compounds are encountered in wastewater in two general forms-inorganic and organic forms, which together make up total phosphorus (TP) or total nitrogen (TN). Complex phosphorus and nitrogenous compounds are found in soluble and insoluble states, and usually need to be converted into simple form such as orthophosphate or ammonia before use by most microorganisms.

Facultative anaerobic processes are found to be most effective for converting complex P or N into orthophosphate or ammonia. These processes involve various hydrolyzing enzymes from acclimatized microorganisms. However, these types of microorganisms usually grow slowly, are less competitive than other microorganisms and require certain special conditions.

After biological conversion, most of the N and P are in solution, and only a portion is assimilated into the biomass. Often, the goal is to reduce the N and P compounds from the water and wastewater to specified levels to meet discharge or reuse requirements. Several biological processes for removal of the N or P compounds are well known in the art. Such conventional systems typically involve suspended growth systems or sludge wasting methods. To biologically remove soluble P, there is need for a selection system that allows for growth and retention of the P-removal microbial consortia in the bioreactor system at a reasonable concentration. This biomass may then absorb the PO-P in relatively high concentrations in its microbial cells. After reaching the maximum capacity under favorable conditions, the biomass is typically removed from the system and disposed of as waste sludge before it can release the absorbed P into the solution again. Although this treatment method may remove $PO_4$-P, the phosphate removal biomass in the process varies considerably with the wastewater characteristics and operation, and it is very difficult to control. The disposal of significant amount of wasted biomass, or sludge, is also a great burden [56,57].

The chemistry of nitrogen is more complex because N can exist in seven oxidation states. Although many species of bacteria can change the oxidation states of N, they usually grow slowly and are much less competitive compared to heterotrophs. In addition, the biochemical processes for conversion of N are usually kinetic limiting processes. To improve the efficiency of these biological processes, it is desirable to selectively grow the desired species efficiently and in high density in the bioreactor and it is further desirable to provide the favorable growth conditions for these microorganisms to maximize N removal efficiency.

Previous studies have used the oxidation reduction potential (ORP) measurements to control the aerobic-anoxic cycles in order to achieve nitrification of ammonium-N into nitrates followed by denitrification to nitrogen gas [19,20,21]. Enhanced Biological Phosphorus Removal (EBPR) is also achieved during the anoxic phase [22].

Adsorption with chemical complexation is an alternative method of removing nutrients to veery low levels after biological treatment has achieved some reductions. Magnesium salts have been extensively used to remove phosphorus from wastewater. Water insoluble magnesium salts, such as magnesium and cerium carbonates have been used to complex phosphates in wastewater streams. Blast furnace slag (BF slag) is an industrial by-product from steel plants derived from the slag forming minerals, mainly limestone, during iron production in the blast furnace [23]. Both adsorption and precipitation mechanisms contribute to the phosphorus sorption by BF slag. Khelifi et al. [24] found adsorption processes to account for about 20% of the total removal of phosphate. Wollastonite has been investigated regarding its adsorption of positively charged metal ions [25-29]. Lind et al. [30] studied adsorption of ammonium in human urine on wollastonite, with about 50% of the ammonium in the solution being adsorbed to the wollastonite. In addition, wollastonite has been investigated regarding removal of phosphorus. Wollastonite was suggested as a filter material for phosphorus removal in con-structed wetlands in surveys [31,32]. Clinoptilolite has a high affinity for ammonium in solutions as studied by several researchers [33-36]. The ammonium adsorption capability of clinoptilolite makes it interesting for wastewater treatment applications [37 – 47]. Many factors influence the adsorbed amount of ammonium on clinoptilolite in practical applications. Filtralite-P™ which is light weight aggregate (LWA) clay mineral with a high Ca and Mg content was especially developed for P sorption. Batch experiments have shown high P sorption capacity of the material up to 12 g P kg⊚1 Filtralite-P™ (6.6 kg P $m^3$ Filtralite-P™) [48].

More than 200 reactive filter systems using Filtralite P have been constructed in Norway during recent years. About 70-80 compact reactive filter systems with Nordkalk Filtra P have been built in Finland during the last 2-3 years. A reactive filter system with blast furnace slag for small scale wastewater treatment was constructed in Luleå in 2005 [49]. A larger reactive filter system to treat urine separated wastewater was built in 2003 at a highway rest stop with toilet facilities in Ångersjön, Hudiksvall [50]. In one of the treatment lines, a filter bed with blast furnace slag for phosphorus sorption was located after a limestone filter [51]. In a Canadian system, designed for about 100 persons, blast furnace slag was investigated at an experimental plant with reactive filter beds to treat lagoon and wetland effluents [52]. In New Zealand, a pond system for a population of about 6,000 was upgraded with slag filters to increase the phosphorus removal [53].

The phosphorus treatment efficiencies of large Norwegian filter bed systems using about 40 $m^3$ of filter material have been high. Systems using porous filter materials with high phosphorus sorption capacity have consistently removed more than 90% of the phosphorus for more than 10 years. These systems were designed with a total surface area of 7-12 $m^2$/person [54]. The compact filter systems built in Finland using Nordkalk Filtra P reduced phosphorus concentrations of the wastewater by more than 90% during a period of 1-2 years. In these systems, a 1 $m^3$ tank filled with the Nordkalk Filtra P was loaded with wastewater from one family.

Recently, studies have been conducted using insoluble Mg carbonates and iron oxide, $Fe_3O_4$, for simultaneous recovery of nitrogen and phosphorus from domestic wastewaters [55]. Magnesium carbonate, which has low aqueous solubility, reacts with ozone water to form Magnesium Hydroxide. Magnesium Hydroxide reacts with nitrates, nitrites and ammonium-N to form Magnesium nitrate and Magnesium ammonium phosphate. Iron oxide reacts with phosphate to form iron phosphate. It also adsorbs nitrates, nitrites and phosphates. This combination of adsorption and chemical complexation removes N and P and is reliable able to achieve very low (less than 4 mg/L total nitrogen and < 1 mg/L of total P) in the effluent water.

### *3.4. Disinfection of Treated Water*

The goal of disinfection is to destroy and/or inactivate pathogenic organisms to minimize the spread of water-borne diseases. The dose of a disinfectant chemical, CT is defined as its concentration in water multiplied by the contact time between the disinfectant and wastewater. A very high concentration of disinfectant in contact with the pathogen for a very short time may result in the same effectiveness as a low concentration of disinfectant in contact with the wastewater for a long time. Pathogens are usually associated with solids, and with effective separation of total suspended solids, most of the pathogens are removed from the wastewater. When the treated water is discharged into a soil drain field, any residual of a chemical disinfectant is undesirable, since it prevents the active bacteria in the soil from effectively treating the water. However, with the use of advanced decentralized treatment systems, which effectively treat the wastewater before discharge, disinfectants such as chlorine, which can maintain a residual concentration, can harm the natural biota in the soil drain field.

The disinfectant chemical which has several advantages over other chemicals, such as chlorine, peracetic acid, etc. is ozone. Ozone can be produced on-site with oxygen from ambient air. The disinfecting mechanisms of dissolved ozone in water includes direct oxidation/destruction of the cell wall, damage to the cell constituents, such as nucleic acids, reactions with radical by-products of ozone decomposition, such as hydrogen peroxy and hydroxyl, and breakage of nitrogen-carbon bonds leading to depolymerization. Ozone eventually decomposes to oxygen and water, leaving no toxic by-products.

For decentralized treatment, ozone is a better disinfectant than UV light since UV light requires a high degree of filtration to separate the suspended solids. Typically, the concentration of ozone generated from dried, ambient air is in the rage of 30 – 60 mg/L in air. At maximum water temperature of 35 deg C the solubility of ozone from an ozone/air mixture will be in the range of 2.57 mg/L – 5.15 mg/L, compared to 8.37 mg/L – 16.7 mg/L at 10 deg C. Hence, water temperature has a significant impact on ozone solubility in water. At the higher temperature ozone absorption is substantially reduced.

The disinfection effectiveness of ozone compared to other chemicals is given in Table 2. For *E.Coli* reduction by 99%, the CT value (Concentration in water in mg/L x time in minutes), as given in the above table is 0.02 at a pH of 6-7, which is the pH of treated water. Earlier the ozone concentration of 3.15 mg/L was calculated in the treated water after ozone absorption, for 10% ozone absorption efficiency and 5 gms/hr ozone generating capacity operating at 80% of this generating capacity. Hence, to kill 99% of the organisms listed in the table above, the time needed will be 2.0/3.15 = 0.64 minutes.

**Table 2.** CT values (mg/min $l^{-1}$) for 99% inactivation at 5°C using Ozone. [58].

| Microorganism | Free Chlorine (pH 6-7) | Preformed Chloroamines (pH 8-9) | Chlorine dioxide (pH 6-7) | Ozone (pH 6-7) |
|---|---|---|---|---|
| *E. coli* | 0.034 – 0.05 | 95 – 180 | 0.4 – 0.75 | 0.02 |
| Poliovirus I | 1.1 – 2.5 | 7770 – 3740 | 0.2 – 6.7 | 0.1 – 0.2 |
| Rotavirus | 0.01 – 0.05 | 3810 – 6480 | 0.2 – 2.1 | 0.006 – 0.06 |
| Phage f2 | 0.08 – 0.18 | - | - | - |
| *G. lamblia cysts* | 47 - > 150 | - | - | 0.5 – 0.6 |
| *G. muris cysts* | 30 – 630 | 1400 | 7.2 – 18.5 | 1.8 – 2.0 |

## 4. Biofilms and Bioreactors

There are several types of bioreactors which have been used for wastewater treatment. While the various types of bioreactors will not be reviewed here, bioreactors can be described in terms of the biofilm characteristics, as shown in Figure 6. In Figure 6(a), biomedia in the liquid phase supports the active biofilm, and the contaminant, dissolved oxygen and nutrients diffuse from the bulk liquid phase into the biofilm. This situation occurs in liquid-phase bioreactors with either moving or stationary biomedia. In this case, there is a maximum thickness of biofilm which can be achieved, since the organic contaminants and dissolved oxygen are being consumed as a function of increasing biofilm depth At the maximum biofilm thickness, the organic contaminant(s) and/or dissolved oxygen concentration is reduced to zero. In Figure 6(b), there is trickling flow of wastewater on the surface of the active biofilm, supported by the biomedia. This is the case in Trickling Filters and packed bed bioreactors, in which the dissolved oxygen in the trickling flow of wastewater, contaminants and nutrients simultaneously diffuse into the biofilm. The biofilm thickness is also limited as in the case of Figure 6(a). In Figure 6(c) the wastewater flows on the biofilm side, which is supported on a porous membrane, and the oxygen, present in air, dissolves into the biofilm through the porous membrane. This occurs in Membrane-Assisted Biofilm Reactors (MABR), wherein dissolved oxygen and contaminant(s)/Nutrients diffuse into the biofilm in opposite directions. This results in thicker biofilms, since dissolved oxygen diffuses on the back side of the biofilm which is supported by the porous membrane. In this case, the maximum biofilm thickness is mainly limited by the diffusion flux of the contaminant(s) through the biofilm.

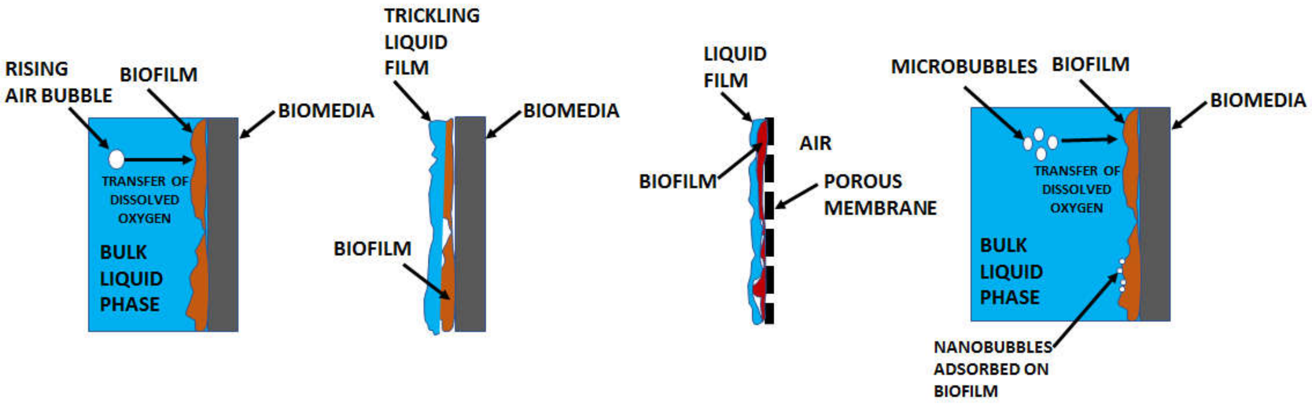
Figure 6(d) shows a moving biomedia bioreactor except in this case aeration is achieved using micro nanobubbles, rather than standard aeration. Microbubbles in the size range of 1 - 100 microns have a significantly higher surface area than fine bubble aeration and this allows a significantly higher oxygen transfer rate into the biofilm. In addition, nanobubbles, which are less than 1 micron in diameter, stay in the water for days and attach themselves to the biofilm surface, since the buoyancy force is cancelled by their weight, and they have a hydrophobic surface, which enables them to adsorb on the biofilm's surface.

Treatment of contaminants in the bulk liquid phase, as in Figure 6(a), is limited by the mixing of the liquid, which controls the mas transfer rates from the bulk liquid phase into the active biofilm, and the concentration of dissolved oxygen in the bulk liquid. However, in this case, the liquid residence time in the bioreactor can be designed since it depends on the volume of liquid in the bioreactor and the influent wastewater flowrate. By increasing the size of the bioreactor, the liquid residence time in the treatment system can be designed and implemented.

When the wastewater is trickled down the bed of biomedia, as shown in Figure 6(b), the liquid residence time is limited by the time it takes for the liquid to trickle down by gravity through the biomedia packing. To increase this liquid residence time in the packed bed, recycle of the effluent flow from the bottom of the packed bed to the spray heads located at the top, is conducted at the expense of electric power consumption by the recycle pumps. A high recycle ratio, which is the ratio of the recycle flowrate divided by the influent flowrate before addition of the recycle flow stream, makes the packed bed behave hydrodynamically as a completely mixed, liquid-phase bioreactor. However, the thin flowing liquid film on the surface of the biomedia, with immobilized active biofilms, allows higher mass transfer rates than in the moving bed bioreactor. In traditional trickling bed bioreactors, the air movement outside the trickling liquid film is achieved by natural convection caused by a temperature difference between the ambient air and the wastewater. However, in summertime, when the wastewater coming into the trickling beds is warm, this temperature difference is small, which causes stagnant air within the trickling flow bioreactor, resulting in poor oxygen transfer into the water.

The advantage of the Membrane Assisted Biofilm Reactor (MABR) is the availability of dissolved oxygen due to diffusion across the porous membrane and the high surface area of the membrane pores. However, aerobic biofilms produce polysaccharides (slime) which is likely to clog the membrane pores over time. The second big advantage is the power consumption needed to provide adequate dissolved oxygen in the wastewater. In moving biomedia bioreactors, wherein the biofilm immobilized on the biomedia's surface is completely submerged in the liquid, aeration consumes a significant amount of energy, as shown in Figure 2, since ambient air has to be compressed in order to bubble it at the bottom of the bioreactor. In trickling beds, although air flows under natural convection, recycle of the liquid consumes energy. However, in a MABR system, air flows on the other side of the membrane at very low pressure drop and the liquid trickles down under gravity or at a small pressure difference. When micro nanobubbles are generated at low energy consumption using porous membranes, high rates of oxygen transfer are achieved, with no membrane clogging issues as in the MABR case.

The use of micro nanobubbles for aeration in moving biomedia bioreactors is that the oxygen transfer rate is high due to the large number of bubbles and their large surface area. This maximizes the oxygen transfer rate into the water. As long as the energy consumption to create the micro nanobubbles I slow, this method of aeration is the most effective in providing dissolved oxygen without the issue of membrane clogging, as in the case of MABRs.



(a) Moving Biomedia in Bioreactor

(b) Packed Biomedia in Bioreactor with Wastewater Tricking Flow

(c) Biofilm supported by Porous Membrane with dissolved oxygen from the other side of Membrane

(d) Moving Biomedia in Bioreactor with Micro-Nanobubble Aeration

**Figure 6.** Biofilm Characteristics in Various Bioreactors.

The rate of biodegradation depends on three factors: (1) concentration of contaminant(s); (2) concentration of dissolved oxygen; and (3) concentration of nutrient(s). This is shown in Figure 7. The figure corresponding to Figures 7(a), 7(b) and 7(d), the concentration of the contaminant(s), nutrients and dissolved oxygen are high at the liquid-biofilm interface and declines within the depth of the biofilm. This results in a high biodegradation rate at the liquid-biofilm interface and declines as the concentrations of the contaminant(s), nutrients and dissolved oxygen decrease with increasing depth of the biofilm. In a MABR system, the highest concentration of dissolved oxygen is when the concentration of the contaminant(s) and nutrients is lowest, as shown in Figure 7 corresponding to Figure 6(c), which gives a lower biodegradation rate, since this rate is the product of all three concentrations. In Figure 7 corresponding to Figure 6(d), using micro nanobubble aeration, higher rates of biodegradation are achieved at the liquid-biofilm interface compared to cases in Figures 6(a) and 6(b), since the dissolved oxygen concentration is higher compared to fine bubble aeration in moving bed bioreactors and in trickling filters. The rate of biodegradation in the MABR system depends on the product of decreasing contaminant(s) and nutrient concentrations and varying dissolved oxygen concentration, as shown in Figure 7.

As discussed earlier, sustainability requires low energy consumption and high biodegradation rates. The highest biodegradation rate can be achieved in a moving bed bioreactor system using high surface area biomedia and micro nanobubble aeration to achieve high oxygen transfer and biodegradation rates.

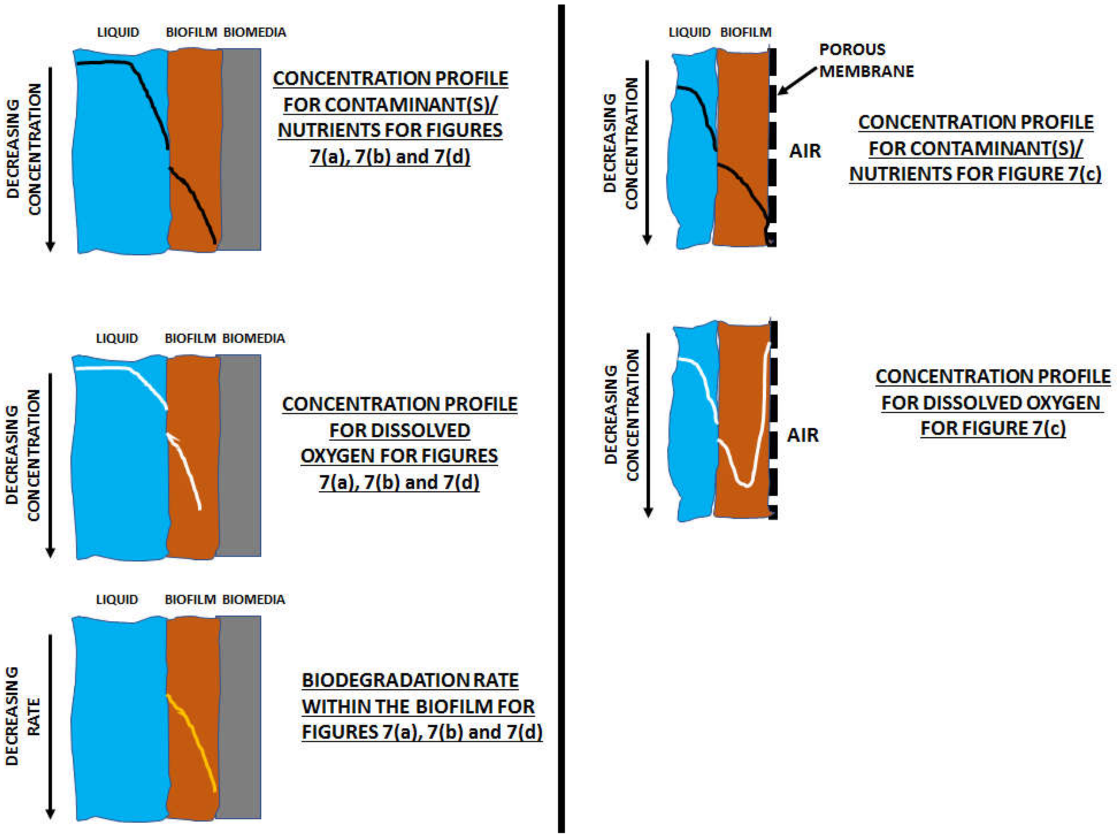


**Figure 7.** Concentration profiles for contaminant(s), nutrients and dissolved oxygen as a function of Biofilm thickness for cases shown in Figure 7.

## 5. Materials and Methods

### 5.1. Treatment System Tank

The septic tank used was Infiltrator's IM-1530 tank (infiltrator Water Technologies, CT), which has a working capacity of 1,537 gallons and a total volume of 1,787 gallons. Although it is supplied with a single baffle, this baffle was replaced by two baffles, which were inserted into the tank. The first baffle near the influent pipe had openings in the middle of the baffle, and the second baffle near the outlet had openings only at the bottom of the baffle. These baffles were made of ¼" thick High-Density Polyethylene (HDPE) and were sealed by a sealant with the tank walls. These two baffles produced three compartments with 300 gallons for the first and third compartment and 937 gallons for the center compartment. This tank had three 24" manways, and risers were provided on the first and third manway, with the second manway closed with a lid without any risers. This tank was installed below ground with the lids of the two manways above ground.

### 5.2. Aeration using Micro Nanobubbles

Aeration using micro nanobubbles (MNBs) is achieved using a silicon carbide monolith (JMFilmtec, China) with dimensions of 146 mm diameter with 524 channels, each 4.3 mm diameter, 1100 mm length of membrane, with area of 7.8 m2. The membrane had average pore size of 40 nm. Silicon carbide is a highly hydrophilic material (contact angle 0.3$^{o}$). Ambient air from the air pump (ET500, Blue Diamond, GA) was connected to the passages of the monolith membrane, while water from a recycle pump was pumped outside the monolith. Air pressure at 4 psi prevented water from flowing into the passages and the air bubbled into the water flow creating micro nanobubbles (MNBs) in the water. This recycle water was then injected about 12 inches below the water level in the center

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compartment. Water flow created mixing condition inside the compartment which allowed the moving biomedia to move around, while the micro nanobubbles provided dissolved oxygen in the water at high oxygen transfer efficiency.

### 5.3. Moving Biomedia

Moving biomedia used in this study was Biomesh Biomedia™, supplied by PRD Tech, Inc. (Cincinnati, OH), and consists of a piece of open-cell polyurethane foam packed inside a spherical, plastic mesh, as shown in Figure 8. The foam piece provides a very large surface area for immobilization of active biofilms, and the main characteristics of this biomedia are given in Table 3. The purpose of the spherical plastic mesh is to protect the open cell foam from catching suspended solids, biomass , present in the bioreactor water. The average opening of the 30 pores per inch (ppi) open-cell polyurethane foam was 130 microns and using the equations presented in this paper (eqn.6) the maximum biofilm thickness was calculated as 8 microns. Hence the selected biomedia will never clog.

**Table 3.** Characteristics of Biomesh Biomedia.

| Biomedia Characteristics | Value |
|---|---|
| Material | Non-toxic polypropylene, Black |
| Bulk Density with no biofilms | 3.5 lbs/ft3 |
| Surface Area for biofilms | 2,200 $ft^2/ft^3$ |
| Diameter | 2 inches |
| Maximum Temperature | 140 deg F |
| Typical volume % in Bioreactor | 10% – 25% |
| $BOD_5$ Oxidation Rate | 0.45 lbs $BOD_5/ft^3$.day |
| Ammonium Nitrification Rate | 0.02 lbs $NH_4$-N/$ft^3$.day |
| Denitrification Rate | 0.05 lbs $NO_x$-N/$ft^3$.day |

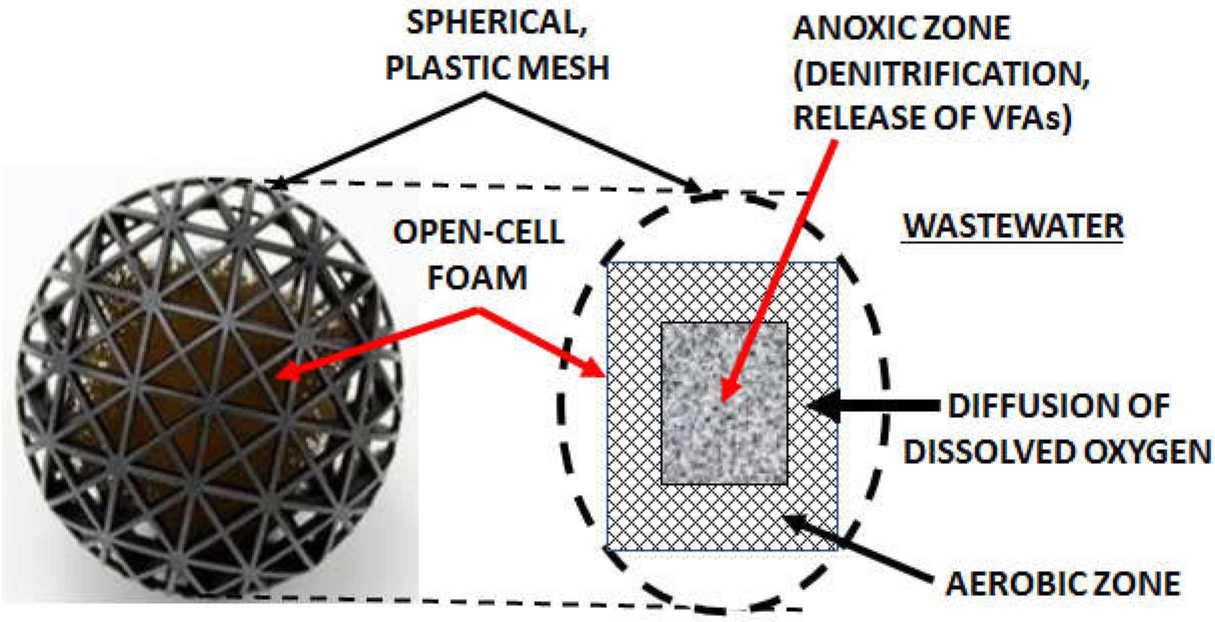


**Figure 8.** Photograph of Biomesh Biomedia™ and the formation of aerobic and anoxic zones within the open-cell foam piece, inside the plastic mesh.

### 5.4. Self-Cleaning Filter

Self-cleaning filter (NextGen Septic, LLC, Cincinnati, OH) consists of a 50-micron stainless-steel screen, which is continuously cleaned by rotating water jets inside the screen. These water jets are powered by the water flow. A submersible pump, capable of pumping 30 gallons per minute of water flow at a pressure of 40 psi is used in conjunction with this self-cleaning filter. The submersible pump draws its filtered water, passing through the screen, and part of this flow, about 4 gpm is recycled back to the rotating water jets, located inside the screen. The rest of the water flows into the stainless-steel microfiltration membrane, followed by the membrane aerator. The aerated water is then recycled back to the center compartment with moving biomedia.

### *5.5. Stainless-Steel Microfiltration Membrane*

A 1-inch diameter stainless steel sheet with an average pore size of 5 microns was rolled into a cylinder and installed with O-ring seals on both ends in a 2-inch PVC housing. Water to be filtered entered the housing at one end and then flowed outside the stainless-steel membrane tube and then exited at the other end. Filtered water which passed through the membrane was drawn out by a reversible pump at a maximum flowrate of 1 gallon per minute using a reversible pump. Periodically this pump was reversed to backflush the membrane from the inside to the outside into the flowing water through the housing, and this dislodged any deposited solids on the outer surface of the membrane and within the membrane pores. Unfiltered water which did not flow through the membrane was recycled back to the first compartment of the septic tank. Characteristics of this membrane, supplied by NextGen Septic (NextGen Septic, LLC, Cincinnati, OH) are summarized in Table 4.

**Table 4.** Characteristics of the Stainless-Stel Membrane.

| Membrane Characteristics | Value |
|---|---|
| Material of Membrane | 304 Stainless-Steel |
| Thickness of membrane | 0.10 mm |
| Average pore size of membrane | 5 microns |
| Length | 40 inches (157 mm) |
| Diameter | 1 inch (25 mm) |

### *5.6. Removal of Nutrients*

Nutrients (nitrogen and phosphorus) are removed biologically initially and subsequently by adsorption and chemical complexation. Nitrogen is removed in two ways: (1) Using the Anamox reaction, given below, which mainly occurs in the first compartment due to the recycle flow from the housing of the stainless-steel membrane unit

$$\mathbf{NH_4^+ + 1.32NO_2^- + 0.066HCO_3^- + 0.13H^+ \rightarrow 1.02N_2 + 0.26NO_3^- + 0.066CH_2O_{0.5}N0_{.15} + 2.03H_2O} \quad (7)$$

(2) Denitrification, which occurs in the anoxic zone of the moving biomedia, as shown in Figure 6. This anoxic sone is created when the blower is turned off, and the dissolved oxygen in the center compartment (bioreactor section) decreases below 2 mg/L. The aeration system is programmed by the PLC to run for a given length of time, which creates aerobic conditions and then is turned off for a certain time period. During the time period when the blower is turned off, and there is no aeration, anoxic conditions are created within the biomedia, which allows denitrification to occur.

By controlling the time period of aeration (blower switched on) and no aeration (blower turned off), we are able to manipulate the dissolved oxygen concentration in the moving biomedia within the bioreactor.

The chemical transformation during traditional nitrification and denitrification can be described by the following equations:

$$\text{Nitrification: } NH_4^+ + 1.5\ O_2 \rightarrow NO_2^- + H_2O + 2H^+ \quad (8)$$

$$NO_2^- + 0.5\ O_2 \rightarrow NO_3^- \quad (9)$$

$$\text{Denitrification: } NO_3^- + 4g\ COD + H^+ \rightarrow 0.5\ N_2 + 1.5g\ \text{biomass} \quad (10)$$

$$\text{Summary: } NH_4^+ + 2\ O_2 + 4g\ COD \rightarrow 0.5\ N_2 + H_2O + H^+ + 1.5g\ \text{biomass} \quad (11)$$

However, nitrification under controlled dissolved oxygen conditions (blower on) and denitrification under anaerobic conditions (blower switch off), can be chemically written as follows:

$$\text{Nitrification: } NH_4^+ + 1.5\ O_2 \rightarrow NO_2^- + H_2O + 2H^+ \quad (12)$$

$$\text{Denitrification: } NO_2^- + 2.4g\ COD + H^+ \rightarrow 0.5\ N_2 + 0.9g\ \text{biomass} \quad (13)$$

$$\text{Summary: } NH_4^+ + 1.5\ O_2 + 2.4g\ COD \rightarrow 0.5\ N_2 + H_2O + H^+ + 0.9g\ \text{biomass} \quad (14)$$

Compared to the traditional nitrification and denitrification process, the latter process of controlling the dissolved oxygen concentration during aeration followed by denitrification requires 40% of the carbon requirements, 25% of the oxygen requirements and produces 40% less biomass. Furthermore, denitrification of $NO^{2-}$ occurs significantly faster than standard denitrification.

Denitrification requires alkalinity and carbon source. The denitrification potential of wastewater is mainly governed by the available biodegradable organic carbon, commonly expressed as the C/N ratio (biodegradable COD/N or biological oxygen demand/nitrogen (BOD/N) ratio). The minimum C/N ratio to carry out denitrification in domestic wastewater has been inferred by several studies. Based on calculations, the minimum C/N ratio is 3.5–4.5 $gCODg^{-1}N$ and C/N values of approximately 6–11 $gCODg^{-1}N$ could allow proper N removal.

In the NextGen Septic system, the bioreactor is designed as an aerobic digester, in which the biomass growing due to biodegradation of carbon in the influent is also being aerobically digested to release nutrients, biodegradable soluble BOD and nitrates/nitrites. In the NextGen Septic system, solids and biomass which are unable get through the porous stainless-steel membrane gets recycled back to the pre-aeration tank, and this results in an almost infinite sludge age. This allows the biomass to reach a steady-state in which the growth rate of biomass is balanced by its decay rate. Typically, biomass growth rate is about 0.4 – 0.6 gms of biomass/gm of BOD treated and its decay rate is about 0.03 – 0.05 $day^{-1}$.

Aerobic digestion of sludge results in non-degradable solids, degradable portion of the Volatile Suspended Solids (VSS) and carbon dioxide and water. This process generates biodegradable material which provides carbon for denitrification in the bioreactor. The alkalinity requirements for nitrification can be detailed by the following equations:

Alkalinity buffering equation

$$H_20 + CO_2 \leftrightarrow H_2CO_3 \leftrightarrow HCO_3 + H^+ \leftrightarrow CO_3 + 2H+ \quad (15)$$

Nitrification equations

$$NH_4^+ + 1.5O_2 \longrightarrow 2H^+ + 2H_2O + NO_2^- \quad (16)$$

$$NO_2^- + 0.5O_2 \longrightarrow NO_3^- \quad (17)$$

$$NH_4^+ + 1.83\ O_2 + 1.98\ HCO3^- \longrightarrow 0.021\ C_5H_70_2N + 0.98\ NO_3^- + 1.041\ H_2O + 1.88\ H_2CO_3^- \quad (18)$$

$$NH_4+ + 1.9O_2 + 2HCO3^- \longrightarrow 1.9\ CO_2 + 2.9\ H_2O + 0.1\ CH_4 \quad (19)$$

The equilibrium concentration and subsequent dissociation of carbon dioxide, produced by the aerobic degradation of BOD and biomass, generates sufficient alkalinity needed for the nitrification. This equilibrium concentration of carbon dioxide is high especially when the aeration blower is tuned off during the aeration-no aeration cycle. If further alkalinity is needed, it will be supplied by adding sodium bicarbonate solution.

As discussed earlier, biological treatment can only reliably achieve total nitrogen concentrations which usually exceed current effluent standards. Hence, adsorption with chemical complexation has to be used to further reduce total nitrogen concentrations, especially in the wintertime, when biological kinetic rates decline. In this study a proprietary mixture of Magnesium Carbonate and Iron Oxide ($Fe_3O_4$) was pelletized into 6 mm diameter, 10 mm length pellets, which were packed in polypropylene mesh bags. These bags were packed at the bottom of a tank and could be easily removed and changed when completely spent. A total of 800 lbs of these pellets in mesh bags were placed at the bottom of the tank. Water after biological treatment and filtration flowed upwards through the section with these packed mesh bags, containing the pellets. Characteristics of these pellets is summarized in Table 5.

**Table 5.** Characteristics of Pellets for Nutrient Removal.

| Pellet Characteristics | Value |
|---|---|
| Pellet size | 6 mm diameter x 10 mm length |
| Pellet composition | Proprietary containing Magnesium Carbonate, Ferric Oxide, and other materials |
| Total phosphorus capacity | 20 gm P/kg pellets |
| Total Nitrogen capacity | 6 gm N/kg pellets |

Biological phosphorus removal occurs due to the growth of Phosphorus Accumulating Organisms (PAOs) and these organisms need anoxic conditions to proliferate [56,57]. This occurs during the time periods when the aeration is tuned off. However, this is effective only when excess biomass is wasted. Hence, the main mechanism for phosphorus removal is through adsorption and chemical complexation. Magnesium carbonates have been studied for phosphorus removal from domestic wastewaters [55].

### 5.6.1. Disinfection of Treated Water

An air pump (IP20-T 115V 60HZ MPU5205-N022, KNF Neuberger, Inc., NJ) is used to pump ambient air through an air dryer, which contains a regenerable desiccant to dry the air. Dried air then flows into an ozone generator (Model PZ4, Prozone Water Products, AL), which is a corona hybrid arc tube. Ozone concentration in the 5 LPM air flow is 30 mg/L. Water flow through a membrane aerator which allows the ozone from the ozone generator to create micro nano-bubbles and this ozonated water is then recycled back to the 300-gallon tank.

## 6. Sustainable Treatment Process (NextGen Septic)

A sustainable biological treatment process (NextGen Septic), shown in Figure 9, was operated for over 2 years. The treatment process consists of the septic tank (Infiltrator Water Technologies, CT) with three compartments, using two baffles. Wastewater from a single-family house entered the first compartment through a 4-inch pipe, which released this flow at the bottom of the compartment. Solids in this influent flow settled down, and any fats/oils/grease (FOGs) floated at the surface of the water. The first baffle separating the first and second compartments had openings at the center of the baffle to allow the water to flow into the second compartment. The design and operating conditions for the treatment process are summarized in Table 6.

The second compartment is the bioreactor section where the water is aerated and Biomesh Biomedia™ moves around the compartment, mixed by the recycle water flow. This recycled flow also contains micro nano-bubbles, which provide dissolved oxygen in the water. The recycle flow of aerated water is introduced near the top of the water, which generates a cyclic motion of the water going down to the bottom of the tank and then flowing upwards at the opposite end of the compartment. The micro nano- bubbles get dispersed in the entire water column. Biological oxidation of the organic load and conversion of ammonium-N to nitrates and nitrites occurs in the outer section of each moving biomedia while denitrification occurs simultaneously within the inner section.

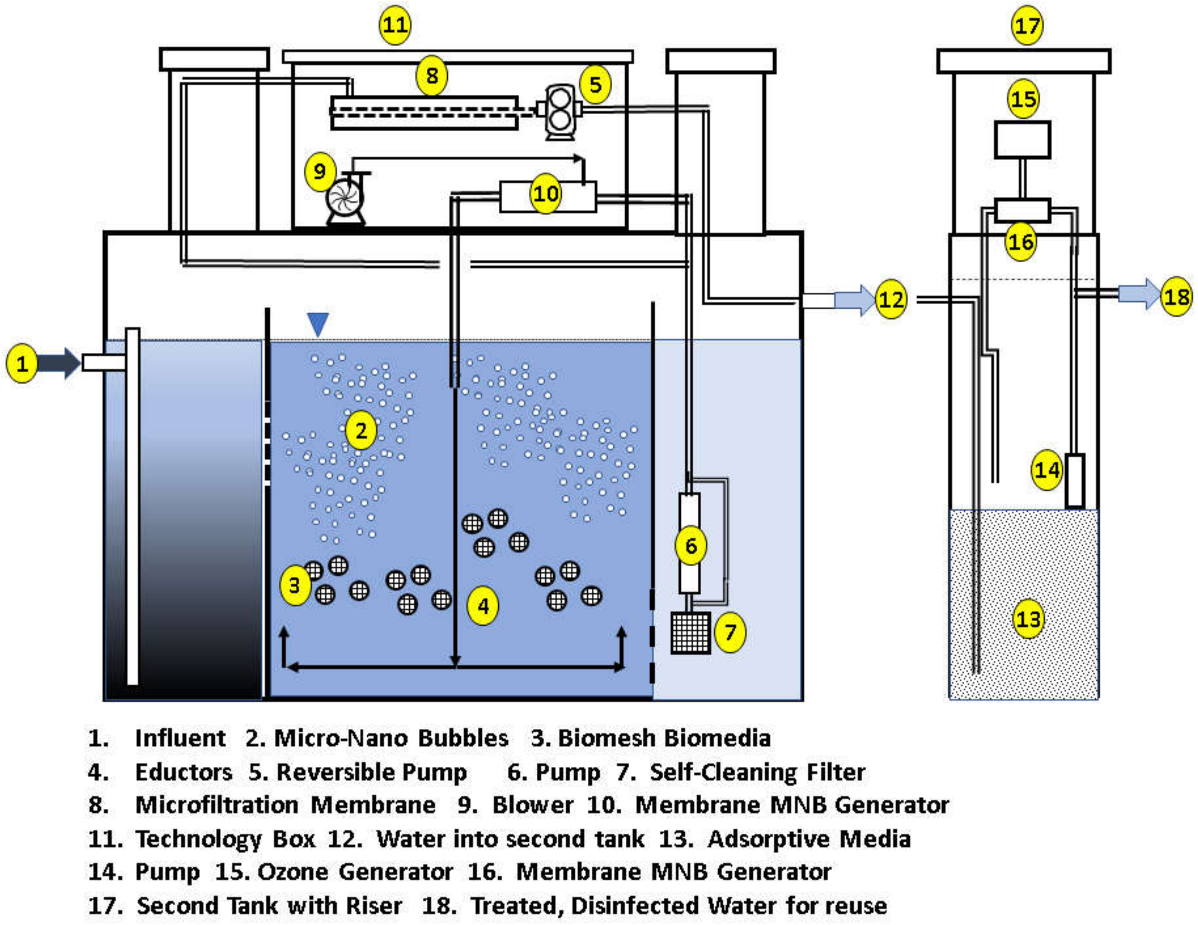


**Figure 9.** NextGen Septic – a sustainable, decentralized treatment process for domestic wastewater.

The water then flows into the third compartment through the slots at the bottom of the second baffle. In this compartment, there is a submersible pump which draws the water through a self-cleaning filter equipped with a 50-micron screen. Filtered water then flows into the membrane aerator, that injects micro nano-bubbles into this recycled water flow.

Some of this filtered water from the self-cleaning filter is pumped into the housing of the stainless-steel membrane, which has an average pore size of 5 microns. The permeate from this membrane is drawn in by a reversible pump that pumps the water into the bottom of the second tank. This tank has a total volume of 300 gallons and contains adsorbent with chemical complexation media to remove nutrients in the biologically treated water. Periodically, this reversible pump is reversed to back flush the membrane. Water that does not permeate through the membrane is recycled back to the first compartment of the septic tank.

**Table 6.** Design and Operating Conditions for the NextGen Septic Treatment Process.

| Operating Parameter | Value |
|---|---|
| Influent flowrate | 500 – 1,000 gallons per day |
| Maximum influent BOD- 5day | 900 mg/L |
| Maximum Ammonium-N | 65 mg/L |
| Maximum influent suspended solids (TSS) | 300 mg/L |
| Operating temperatures | 15 – 30°C |
| Aeration flowrate | 500 LPM |
| Recycle flow of water | 25 gallons per minute (gpm) |
| Flowrate of water through MNB generator | 10 gpm |
| Flowrate of water through stainless-steel membrane | 15 gpm |
| Time period of membrane back flush | Every 25 minutes |
| Amount of adsorbent media in second tank | 800 lbs |
| Ozone concentration in air flow | 30 mg/L |
| Air flow from pump to ozone generator | 5 LPM |
| Volume of moving biomedia in bioreactor | 80 gallons |

The second tank contains the proprietary media to adsorb and complex the nitrogen and phosphorus which has not been biologically treated in the bioreactor section. This happens when the water rises from the bottom of the 300-gallon tank through the mesh bags of the adsorbent material.

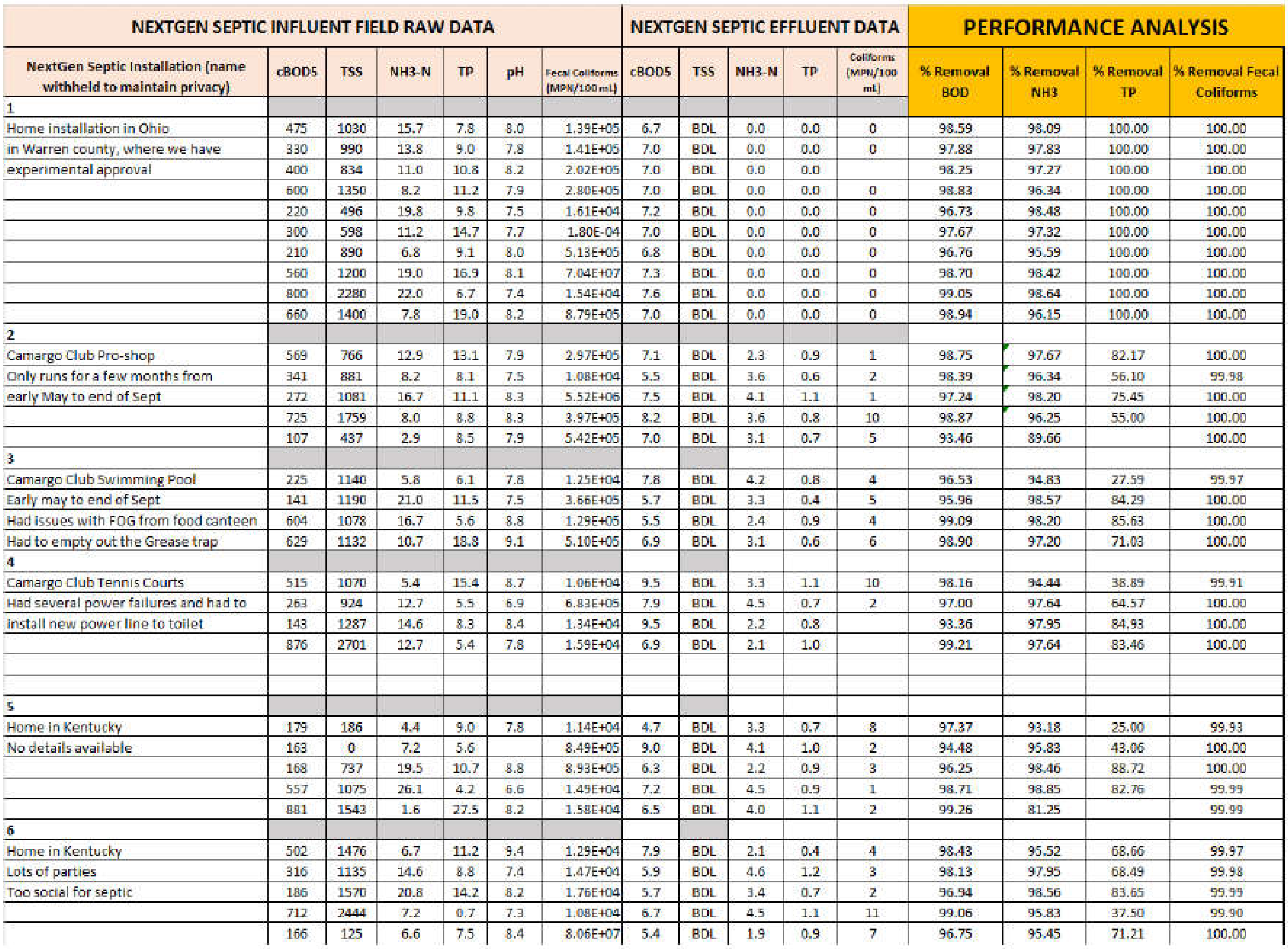
Water above the adsorbent media is aerated with ozone using a membrane aerator. The membrane aerator dissolves the ozone in the water at very high efficiency creating ozonated water above the adsorbent media. This water also flows out of the treatment system as treated, disinfected water.

## 7. Results and Discussion

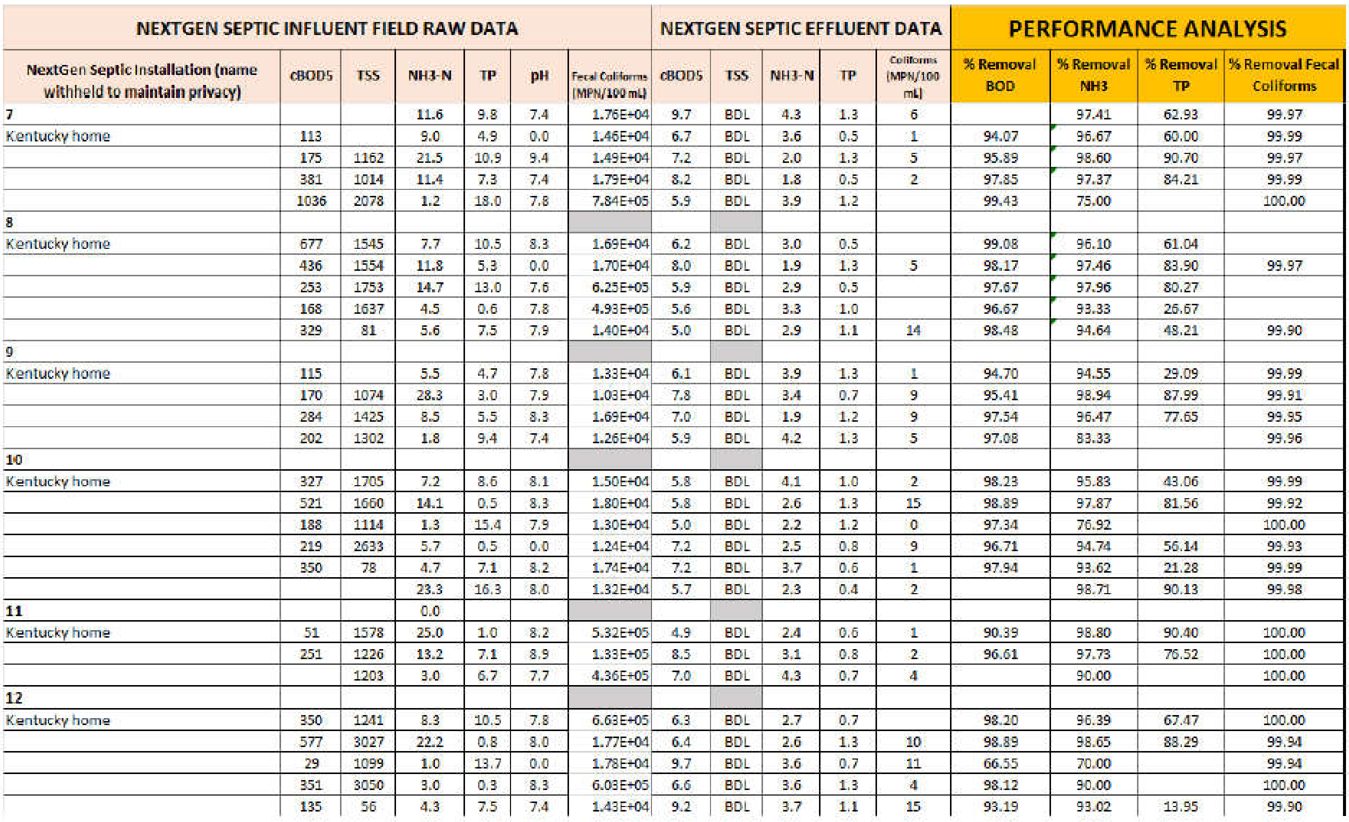
The NextGen Septic treatment system was installed at 27 single-family houses in Northern Kentucky and sampled over a period of 2 years. Samples were taken from the influent and effluent flowrates, every month at different times of the day. The average of the results for each house is summarized in Table 7. Analytical methods used for the various parameters were as follows: Phosphorus EPA 200.7; Turbidity Method SM 21308-11; Total Suspended Solids Method SM 25400; BOD – 5 day Method SM 5210B; Total Kjeldahl Nitrogen Method SM 4500-Norg D-11; Total Organic Carbon SM 5310C-11; E. Coli Method SM 9223B [58].

Field data shows that the NextGen Septic treatment system is capable of treating the raw wastewater adequately for surface discharge to existing water bodies or percolation into the soil.

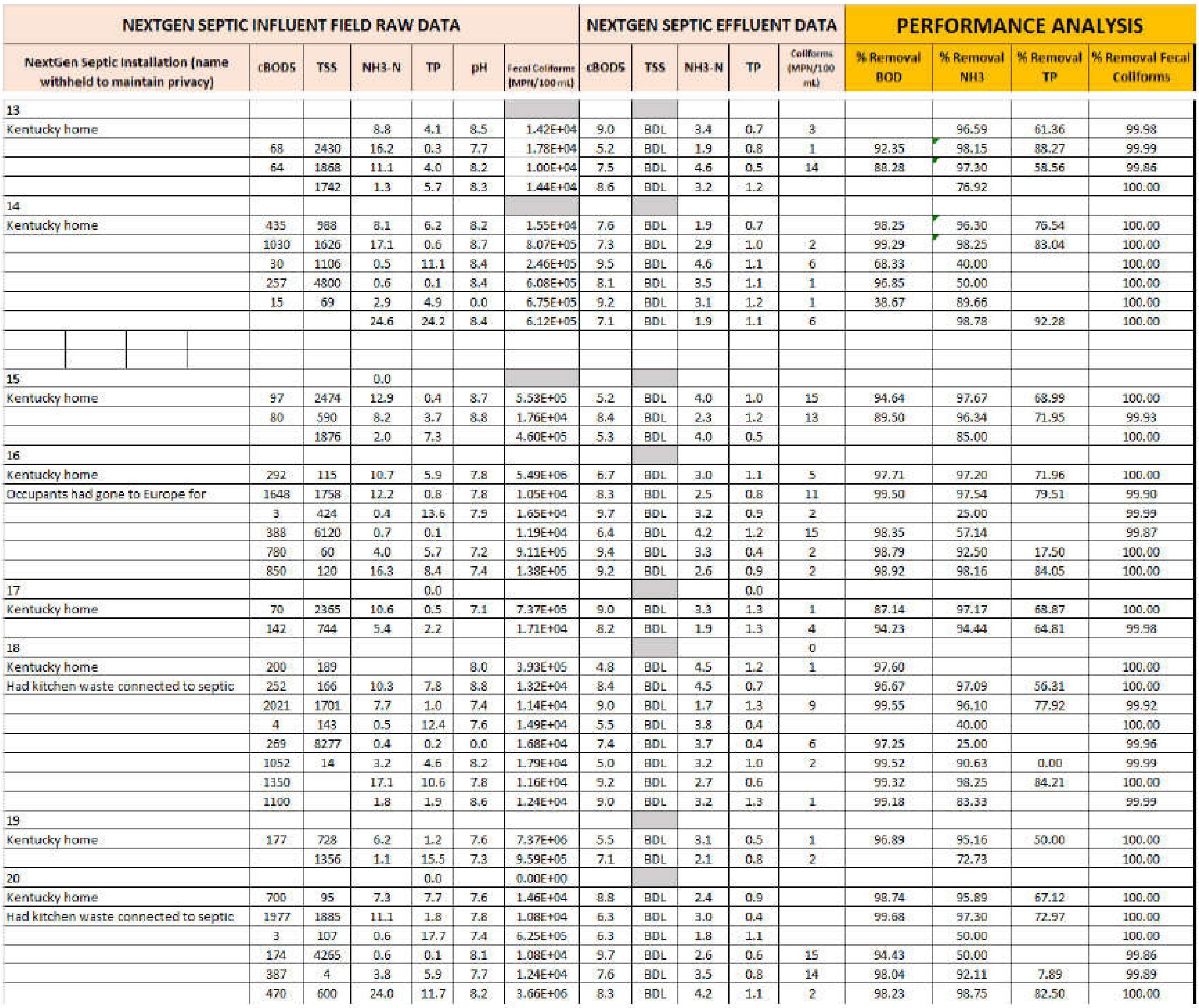
**Table 7.** Summary of Field Data for the NextGen Septic Treatment System installed at 27 houses in Northern Kentucky.



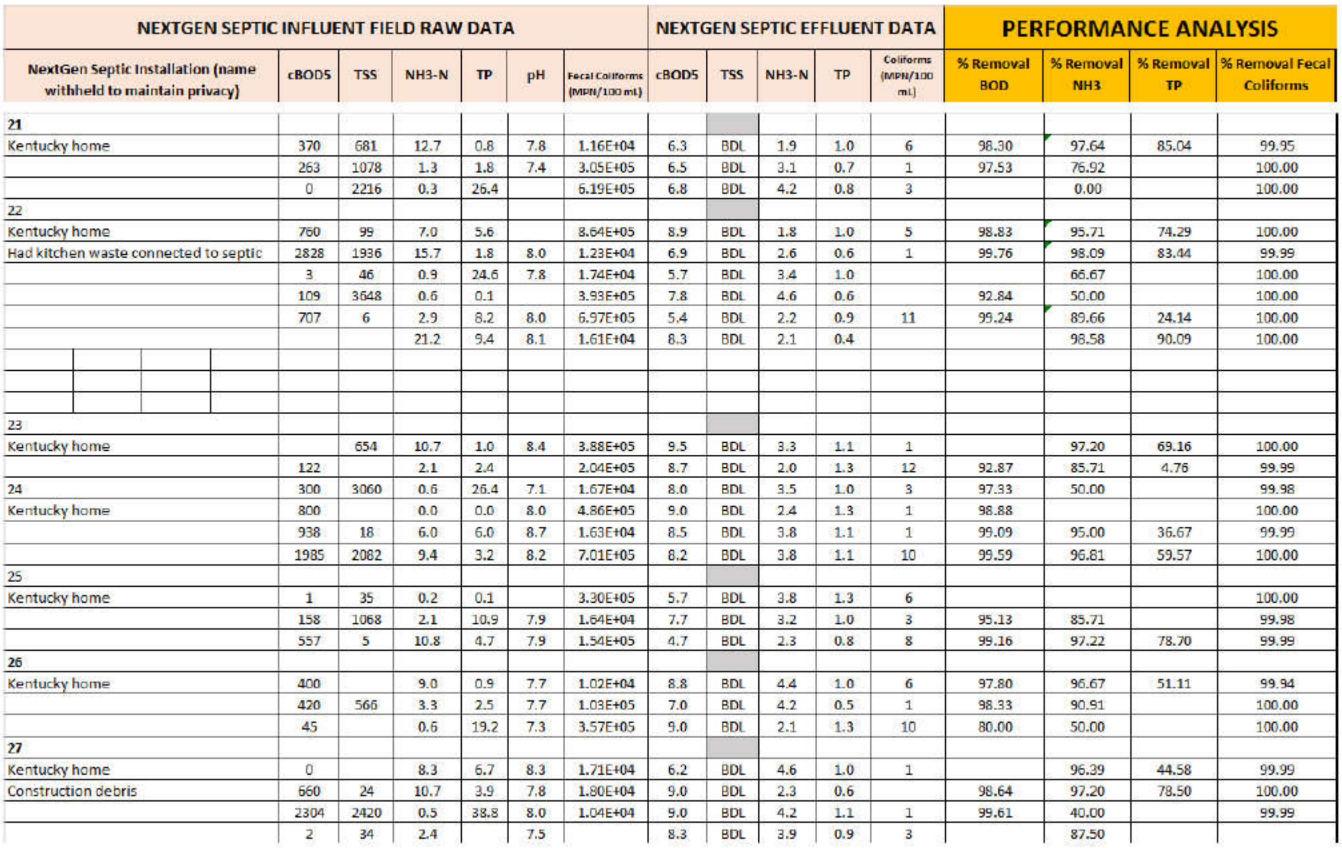
| NEXTGEN SEPTIC INFLUENT FIELD RAW DATA | | | | | | | NEXTGEN SEPTIC EFFLUENT DATA | | | | | PERFORMANCE ANALYSIS | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NextGen Septic Installation (name withheld to maintain privacy) | cBOD5 | TSS | NH3-N | TP | pH | Fecal Coliforms (MPN/100 mL) | cBOD5 | TSS | NH3-N | TP | Coliforms (MPN/100 mL) | % Removal BOD | % Removal NH3 | % Removal TP | % Removal Fecal Coliforms |
| 1 | | | | | | | | | | | | | | | |
| Home installation in Ohio | 475 | 1030 | 15.7 | 7.8 | 8.0 | 1.39E+05 | 6.7 | BDL | 0.0 | 0.0 | 0 | 98.59 | 98.09 | 100.00 | 100.00 |
| in Warren county, where we have | 330 | 990 | 13.8 | 9.0 | 7.8 | 1.41E+05 | 7.0 | BDL | 0.0 | 0.0 | 0 | 97.88 | 97.83 | 100.00 | 100.00 |
| experimental approval | 400 | 834 | 11.0 | 10.8 | 8.2 | 2.02E+05 | 7.0 | BDL | 0.0 | 0.0 | | 98.25 | 97.27 | 100.00 | 100.00 |
| | 600 | 1350 | 8.2 | 11.2 | 7.9 | 2.80E+05 | 7.0 | BDL | 0.0 | 0.0 | 0 | 98.83 | 96.34 | 100.00 | 100.00 |
| | 220 | 496 | 19.8 | 9.8 | 7.5 | 1.61E+04 | 7.2 | BDL | 0.0 | 0.0 | 0 | 96.73 | 98.48 | 100.00 | 100.00 |
| | 300 | 598 | 11.2 | 14.7 | 7.7 | 1.80E-04 | 7.0 | BDL | 0.0 | 0.0 | 0 | 97.67 | 97.32 | 100.00 | 100.00 |
| | 210 | 890 | 6.8 | 9.1 | 8.0 | 5.13E+05 | 6.8 | BDL | 0.0 | 0.0 | 0 | 96.76 | 95.59 | 100.00 | 100.00 |
| | 560 | 1200 | 19.0 | 16.9 | 8.1 | 7.04E+07 | 7.3 | BDL | 0.0 | 0.0 | 0 | 98.70 | 98.42 | 100.00 | 100.00 |
| | 800 | 2280 | 22.0 | 6.7 | 7.4 | 1.54E+04 | 7.6 | BDL | 0.0 | 0.0 | 0 | 99.05 | 98.64 | 100.00 | 100.00 |
| | 660 | 1400 | 7.8 | 19.0 | 8.2 | 8.79E+05 | 7.0 | BDL | 0.0 | 0.0 | 0 | 98.94 | 96.15 | 100.00 | 100.00 |
| 2 | | | | | | | | | | | | | | | |
| Camargo Club Pro-shop | 569 | 766 | 12.9 | 13.1 | 7.9 | 2.97E+05 | 7.1 | BDL | 2.3 | 0.9 | 1 | 98.75 | 97.67 | 82.17 | 100.00 |
| Only runs for a few months from | 341 | 881 | 8.2 | 8.1 | 7.5 | 1.08E+04 | 5.5 | BDL | 3.6 | 0.6 | 2 | 98.39 | 96.34 | 56.10 | 99.98 |
| early May to end of Sept | 272 | 1081 | 16.7 | 11.1 | 8.3 | 5.52E+06 | 7.5 | BDL | 4.1 | 1.1 | 1 | 97.24 | 98.20 | 75.45 | 100.00 |
| | 725 | 1759 | 8.0 | 8.8 | 8.3 | 3.97E+05 | 8.2 | BDL | 3.6 | 0.8 | 10 | 98.87 | 96.25 | 55.00 | 100.00 |
| | 107 | 437 | 2.9 | 8.5 | 7.9 | 5.42E+05 | 7.0 | BDL | 3.1 | 0.7 | 5 | 93.46 | 89.66 | | 100.00 |
| 3 | | | | | | | | | | | | | | | |
| Camargo Club Swimming Pool | 225 | 1140 | 5.8 | 6.1 | 7.8 | 1.25E+04 | 7.8 | BDL | 4.2 | 0.8 | 4 | 96.53 | 94.83 | 27.59 | 99.97 |
| Early may to end of Sept | 141 | 1190 | 21.0 | 11.5 | 7.5 | 3.66E+05 | 5.7 | BDL | 3.3 | 0.4 | 5 | 95.96 | 98.57 | 84.29 | 100.00 |
| Had issues with FOG from food canteen | 604 | 1078 | 16.7 | 5.6 | 8.8 | 1.29E+05 | 5.5 | BDL | 2.4 | 0.9 | 4 | 99.09 | 98.20 | 85.63 | 100.00 |
| Had to empty out the Grease trap | 629 | 1132 | 10.7 | 18.8 | 9.1 | 5.10E+05 | 6.9 | BDL | 3.1 | 0.6 | 6 | 98.90 | 97.20 | 71.03 | 100.00 |
| 4 | | | | | | | | | | | | | | | |
| Camargo Club Tennis Courts | 515 | 1070 | 5.4 | 15.4 | 8.7 | 1.06E+04 | 9.5 | BDL | 3.3 | 1.1 | 10 | 98.16 | 94.44 | 38.89 | 99.91 |
| Had several power failures and had to | 263 | 924 | 12.7 | 5.5 | 6.9 | 6.83E+05 | 7.9 | BDL | 4.5 | 0.7 | 2 | 97.00 | 97.64 | 64.57 | 100.00 |
| install new power line to toilet | 143 | 1287 | 14.6 | 8.3 | 8.4 | 1.34E+04 | 9.5 | BDL | 2.2 | 0.8 | | 93.36 | 97.95 | 84.93 | 100.00 |
| | 876 | 2701 | 12.7 | 5.4 | 7.8 | 1.59E+04 | 6.9 | BDL | 2.1 | 1.0 | | 99.21 | 97.64 | 83.46 | 100.00 |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| 5 | | | | | | | | | | | | | | | |
| Home in Kentucky | 179 | 186 | 4.4 | 9.0 | 7.8 | 1.14E+04 | 4.7 | BDL | 3.3 | 0.7 | 8 | 97.37 | 93.18 | 25.00 | 99.93 |
| No details available | 163 | 0 | 7.2 | 5.6 | | 8.49E+05 | 9.0 | BDL | 4.1 | 1.0 | 2 | 94.48 | 95.83 | 43.06 | 100.00 |
| | 168 | 737 | 19.5 | 10.7 | 8.8 | 8.93E+05 | 6.3 | BDL | 2.2 | 0.9 | 3 | 96.25 | 98.46 | 88.72 | 100.00 |
| | 557 | 1075 | 26.1 | 4.2 | 6.6 | 1.49E+04 | 7.2 | BDL | 4.5 | 0.9 | 1 | 98.71 | 98.85 | 82.76 | 99.99 |
| | 881 | 1543 | 1.6 | 27.5 | 8.2 | 1.58E+04 | 6.5 | BDL | 4.0 | 1.1 | 2 | 99.26 | 81.25 | | 99.99 |
| 6 | | | | | | | | | | | | | | | |
| Home in Kentucky | 502 | 1476 | 6.7 | 11.2 | 9.4 | 1.29E+04 | 7.9 | BDL | 2.1 | 0.4 | 4 | 98.43 | 95.52 | 68.66 | 99.97 |
| Lots of parties | 316 | 1135 | 14.6 | 8.8 | 7.4 | 1.47E+04 | 5.9 | BDL | 4.6 | 1.2 | 3 | 98.13 | 97.95 | 68.49 | 99.98 |
| Too social for septic | 186 | 1570 | 20.8 | 14.2 | 8.2 | 1.76E+04 | 5.7 | BDL | 3.4 | 0.7 | 2 | 96.94 | 98.56 | 83.65 | 99.99 |
| | 712 | 2444 | 7.2 | 0.7 | 7.3 | 1.08E+04 | 6.7 | BDL | 4.5 | 1.1 | 11 | 99.06 | 95.83 | 37.50 | 99.90 |
| | 166 | 125 | 6.6 | 7.5 | 8.4 | 8.06E+07 | 5.4 | BDL | 1.9 | 0.9 | 7 | 96.75 | 95.45 | 71.21 | 100.00 |



| NEXTGEN SEPTIC INFLUENT FIELD RAW DATA | | | | | | | NEXTGEN SEPTIC EFFLUENT DATA | | | | | PERFORMANCE ANALYSIS | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **NextGen Septic Installation (name withheld to maintain privacy)** | **cBOD5** | **TSS** | **NH3-N** | **TP** | **pH** | **Fecal Coliforms (MPN/100 mL)** | **cBOD5** | **TSS** | **NH3-N** | **TP** | **Coliforms (MPN/100 mL)** | **% Removal BOD** | **% Removal NH3** | **% Removal TP** | **% Removal Fecal Coliforms** |
| **7** | | | 11.6 | 9.8 | 7.4 | 1.76E+04 | 9.7 | BDL | 4.3 | 1.3 | 6 | | 97.41 | 62.93 | 99.97 |
| Kentucky home | 113 | | 9.0 | 4.9 | 0.0 | 1.46E+04 | 6.7 | BDL | 3.6 | 0.5 | 1 | 94.07 | 96.67 | 60.00 | 99.99 |
| | 175 | 1162 | 21.5 | 10.9 | 9.4 | 1.49E+04 | 7.2 | BDL | 2.0 | 1.3 | 5 | 95.89 | 98.60 | 90.70 | 99.97 |
| | 381 | 1014 | 11.4 | 7.3 | 7.4 | 1.79E+04 | 8.2 | BDL | 1.8 | 0.5 | 2 | 97.85 | 97.37 | 84.21 | 99.99 |
| | 1036 | 2078 | 1.2 | 18.0 | 7.8 | 7.84E+05 | 5.9 | BDL | 3.9 | 1.2 | | 99.43 | 75.00 | | 100.00 |
| **8** | | | | | | | | | | | | | | | |
| Kentucky home | 677 | 1545 | 7.7 | 10.5 | 8.3 | 1.69E+04 | 6.2 | BDL | 3.0 | 0.5 | | 99.08 | 96.10 | 61.04 | |
| | 436 | 1554 | 11.8 | 5.3 | 0.0 | 1.70E+04 | 8.0 | BDL | 1.9 | 1.3 | 5 | 98.17 | 97.46 | 83.90 | 99.97 |
| | 253 | 1753 | 14.7 | 13.0 | 7.6 | 6.25E+05 | 5.9 | BDL | 2.9 | 0.5 | | 97.67 | 97.96 | 80.27 | |
| | 168 | 1637 | 4.5 | 0.6 | 7.8 | 4.93E+05 | 5.6 | BDL | 3.3 | 1.0 | | 96.67 | 93.33 | 26.67 | |
| | 329 | 81 | 5.6 | 7.5 | 7.9 | 1.40E+04 | 5.0 | BDL | 2.9 | 1.1 | 14 | 98.48 | 94.64 | 48.21 | 99.90 |
| 9 | | | | | | | | | | | | | | | |
| Kentucky home | 115 | | 5.5 | 4.7 | 7.8 | 1.33E+04 | 6.1 | BDL | 3.9 | 1.3 | 1 | 94.70 | 94.55 | 29.09 | 99.99 |
| | 170 | 1074 | 28.3 | 3.0 | 7.9 | 1.03E+04 | 7.8 | BDL | 3.4 | 0.7 | 9 | 95.41 | 98.94 | 87.99 | 99.91 |
| | 284 | 1425 | 8.5 | 5.5 | 8.3 | 1.69E+04 | 7.0 | BDL | 1.9 | 1.2 | 9 | 97.54 | 96.47 | 77.65 | 99.95 |
| | 202 | 1302 | 1.8 | 9.4 | 7.4 | 1.26E+04 | 5.9 | BDL | 4.2 | 1.3 | 5 | 97.08 | 83.33 | | 99.96 |
| **10** | | | | | | | | | | | | | | | |
| Kentucky home | 327 | 1705 | 7.2 | 8.6 | 8.1 | 1.50E+04 | 5.8 | BDL | 4.1 | 1.0 | 2 | 98.23 | 95.83 | 43.06 | 99.99 |
| | 521 | 1660 | 14.1 | 0.5 | 8.3 | 1.80E+04 | 5.8 | BDL | 2.6 | 1.3 | 15 | 98.89 | 97.87 | 81.56 | 99.92 |
| | 188 | 1114 | 1.3 | 15.4 | 7.9 | 1.30E+04 | 5.0 | BDL | 2.2 | 1.2 | 0 | 97.34 | 76.92 | | 100.00 |
| | 219 | 2633 | 5.7 | 0.5 | 0.0 | 1.24E+04 | 7.2 | BDL | 2.5 | 0.8 | 9 | 96.71 | 94.74 | 56.14 | 99.93 |
| | 350 | 78 | 4.7 | 7.1 | 8.2 | 1.74E+04 | 7.2 | BDL | 3.7 | 0.6 | 1 | 97.94 | 93.62 | 21.28 | 99.99 |
| | | | 23.3 | 16.3 | 8.0 | 1.32E+04 | 5.7 | BDL | 2.3 | 0.4 | 2 | | 98.71 | 90.13 | 99.98 |
| **11** | | | 0.0 | | | | | | | | | | | | |
| Kentucky home | 51 | 1578 | 25.0 | 1.0 | 8.2 | 5.32E+05 | 4.9 | BDL | 2.4 | 0.6 | 1 | 90.39 | 98.80 | 90.40 | 100.00 |
| | 251 | 1226 | 13.2 | 7.1 | 8.9 | 1.33E+05 | 8.5 | BDL | 3.1 | 0.8 | 2 | 96.61 | 97.73 | 76.52 | 100.00 |
| | | 1203 | 3.0 | 6.7 | 7.7 | 4.36E+05 | 7.0 | BDL | 4.3 | 0.7 | 4 | | 90.00 | | 100.00 |
| **12** | | | | | | | | | | | | | | | |
| Kentucky home | 350 | 1241 | 8.3 | 10.5 | 7.8 | 6.63E+05 | 6.3 | BDL | 2.7 | 0.7 | | 98.20 | 96.39 | 67.47 | 100.00 |
| | 577 | 3027 | 22.2 | 0.8 | 8.0 | 1.77E+04 | 6.4 | BDL | 2.6 | 1.3 | 10 | 98.89 | 98.65 | 88.29 | 99.94 |
| | 29 | 1099 | 1.0 | 13.7 | 0.0 | 1.78E+04 | 9.7 | BDL | 3.6 | 0.7 | 11 | 66.55 | 70.00 | | 99.94 |
| | 351 | 3050 | 3.0 | 0.3 | 8.3 | 6.03E+05 | 6.6 | BDL | 3.6 | 1.3 | 4 | 98.12 | 90.00 | | 100.00 |
| | 135 | 56 | 4.3 | 7.5 | 7.4 | 1.43E+04 | 9.2 | BDL | 3.7 | 1.1 | 15 | 93.19 | 93.02 | 13.95 | 99.90 |



| NEXTGEN SEPTIC INFLUENT FIELD RAW DATA | | | | | | | NEXTGEN SEPTIC EFFLUENT DATA | | | | | PERFORMANCE ANALYSIS | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NextGen Septic installation (name withheld to maintain privacy) | cBOD5 | TSS | NH3-N | TP | pH | Fecal Coliforms (MPN/100 mL) | cBOD5 | TSS | NH3-N | TP | Coliforms (MPN/100 mL) | % Removal BOD | % Removal NH3 | % Removal TP | % Removal Fecal Coliforms |
| 13 | | | | | | | | | | | | | | | |
| Kentucky home | | | 8.8 | 4.1 | 8.5 | 1.42E+04 | 9.0 | BDL | 3.4 | 0.7 | 3 | | 96.59 | 61.36 | 99.98 |
| | 68 | 2430 | 16.2 | 0.3 | 7.7 | 1.78E+04 | 5.2 | BDL | 1.9 | 0.8 | 1 | 92.35 | 98.15 | 88.27 | 99.99 |
| | 64 | 1868 | 11.1 | 4.0 | 8.2 | 1.00E+04 | 7.5 | BDL | 4.6 | 0.5 | 14 | 88.28 | 97.30 | 58.56 | 99.86 |
| | | 1742 | 1.3 | 5.7 | 8.3 | 1.44E+04 | 8.6 | BDL | 3.2 | 1.2 | | | 76.92 | | 100.00 |
| 14 | | | | | | | | | | | | | | | |
| Kentucky home | 435 | 988 | 8.1 | 6.2 | 8.2 | 1.55E+04 | 7.6 | BDL | 1.9 | 0.7 | | 98.25 | 96.30 | 76.54 | 100.00 |
| | 1030 | 1626 | 17.1 | 0.6 | 8.7 | 8.07E+05 | 7.3 | BDL | 2.9 | 1.0 | 2 | 99.29 | 98.25 | 83.04 | 100.00 |
| | 30 | 1106 | 0.5 | 11.1 | 8.4 | 2.46E+05 | 9.5 | BDL | 4.6 | 1.1 | 6 | 68.33 | 40.00 | | 100.00 |
| | 257 | 4800 | 0.6 | 0.1 | 8.4 | 6.08E+05 | 8.1 | BDL | 3.5 | 1.1 | 1 | 96.85 | 50.00 | | 100.00 |
| | 15 | 69 | 2.9 | 4.9 | 0.0 | 6.75E+05 | 9.2 | BDL | 3.1 | 1.2 | 1 | 38.67 | 89.66 | | 100.00 |
| | | | 24.6 | 24.2 | 8.4 | 6.12E+05 | 7.1 | BDL | 1.9 | 1.1 | 6 | | 98.78 | 92.28 | 100.00 |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| 15 | | | 0.0 | | | | | | | | | | | | |
| Kentucky home | 97 | 2474 | 12.9 | 0.4 | 8.7 | 5.53E+05 | 5.2 | BDL | 4.0 | 1.0 | 15 | 94.64 | 97.67 | 68.99 | 100.00 |
| | 80 | 590 | 8.2 | 3.7 | 8.8 | 1.76E+04 | 8.4 | BDL | 2.3 | 1.2 | 13 | 89.50 | 96.34 | 71.95 | 99.93 |
| | | 1876 | 2.0 | 7.3 | | 4.60E+05 | 5.3 | BDL | 4.0 | 0.5 | | | 85.00 | | 100.00 |
| 16 | | | | | | | | | | | | | | | |
| Kentucky home | 292 | 115 | 10.7 | 5.9 | 7.8 | 5.49E+06 | 6.7 | BDL | 3.0 | 1.1 | 5 | 97.71 | 97.20 | 71.96 | 100.00 |
| Occupants had gone to Europe for | 1648 | 1758 | 12.2 | 0.8 | 7.8 | 1.05E+04 | 8.3 | BDL | 2.5 | 0.8 | 11 | 99.50 | 97.54 | 79.51 | 99.90 |
| | 3 | 424 | 0.4 | 13.6 | 7.9 | 1.65E+04 | 9.7 | BDL | 3.2 | 0.9 | 2 | | 25.00 | | 99.99 |
| | 388 | 6120 | 0.7 | 0.1 | | 1.19E+04 | 6.4 | BDL | 4.2 | 1.2 | 15 | 98.35 | 57.14 | | 99.87 |
| | 780 | 60 | 4.0 | 5.7 | 7.2 | 9.11E+05 | 9.4 | BDL | 3.3 | 0.4 | 2 | 98.79 | 92.50 | 17.50 | 100.00 |
| | 850 | 120 | 16.3 | 8.4 | 7.4 | 1.38E+05 | 9.2 | BDL | 2.6 | 0.9 | 2 | 98.92 | 98.16 | 84.05 | 100.00 |
| 17 | | | | 0.0 | | | | | | 0.0 | | | | | |
| Kentucky home | 70 | 2365 | 10.6 | 0.5 | 7.1 | 7.37E+05 | 9.0 | BDL | 3.3 | 1.3 | 1 | 87.14 | 97.17 | 68.87 | 100.00 |
| | 142 | 744 | 5.4 | 2.2 | | 1.71E+04 | 8.2 | BDL | 1.9 | 1.3 | 4 | 94.23 | 94.44 | 64.81 | 99.98 |
| 18 | | | | | | | | | | | 0 | | | | |
| Kentucky home | 200 | 189 | | | 8.0 | 3.93E+05 | 4.8 | BDL | 4.5 | 1.2 | 1 | 97.60 | | | 100.00 |
| Had kitchen waste connected to septic | 252 | 166 | 10.3 | 7.8 | 8.8 | 1.32E+04 | 8.4 | BDL | 4.5 | 0.7 | | 96.67 | 97.09 | 56.31 | 100.00 |
| | 2021 | 1701 | 7.7 | 1.0 | 7.4 | 1.14E+04 | 9.0 | BDL | 1.7 | 1.3 | 9 | 99.55 | 96.10 | 77.92 | 99.92 |
| | 4 | 143 | 0.5 | 12.4 | 7.6 | 1.49E+04 | 5.5 | BDL | 3.8 | 0.4 | | | 40.00 | | 100.00 |
| | 269 | 8277 | 0.4 | 0.2 | 0.0 | 1.68E+04 | 7.4 | BDL | 3.7 | 0.4 | 6 | 97.25 | 25.00 | | 99.96 |
| | 1052 | 14 | 3.2 | 4.6 | 8.2 | 1.79E+04 | 5.0 | BDL | 3.2 | 1.0 | 2 | 99.52 | 90.63 | 0.00 | 99.99 |
| | 1350 | | 17.1 | 10.6 | 7.8 | 1.16E+04 | 9.2 | BDL | 2.7 | 0.6 | | 99.32 | 98.25 | 84.21 | 100.00 |
| | 1100 | | 1.8 | 1.9 | 8.6 | 1.24E+04 | 9.0 | BDL | 3.2 | 1.3 | 1 | 99.18 | 83.33 | | 99.99 |
| 19 | | | | | | | | | | | | | | | |
| Kentucky home | 177 | 728 | 6.2 | 1.2 | 7.6 | 7.37E+06 | 5.5 | BDL | 3.1 | 0.5 | 1 | 96.89 | 95.16 | 50.00 | 100.00 |
| | | 1356 | 1.1 | 15.5 | 7.3 | 9.59E+05 | 7.1 | BDL | 2.1 | 0.8 | 2 | | 72.73 | | 100.00 |
| 20 | | | | 0.0 | | 0.00E+00 | | | | | | | | | |
| Kentucky home | 700 | 95 | 7.3 | 7.7 | 7.6 | 1.46E+04 | 8.8 | BDL | 2.4 | 0.9 | | 98.74 | 95.89 | 67.12 | 100.00 |
| Had kitchen waste connected to septic | 1977 | 1885 | 11.1 | 1.8 | 7.8 | 1.08E+04 | 6.3 | BDL | 3.0 | 0.4 | | 99.68 | 97.30 | 72.97 | 100.00 |
| | 3 | 107 | 0.6 | 17.7 | 7.4 | 6.25E+05 | 6.3 | BDL | 1.8 | 1.1 | | | 50.00 | | 100.00 |
| | 174 | 4265 | 0.6 | 0.1 | 8.1 | 1.08E+04 | 9.7 | BDL | 2.6 | 0.6 | 15 | 94.43 | 50.00 | | 99.86 |
| | 387 | 4 | 3.8 | 5.9 | 7.7 | 1.24E+04 | 7.6 | BDL | 3.5 | 0.8 | 14 | 98.04 | 92.11 | 7.89 | 99.89 |
| | 470 | 600 | 24.0 | 11.7 | 8.2 | 3.66E+06 | 8.3 | BDL | 4.2 | 1.1 | 2 | 98.23 | 98.75 | 82.50 | 100.00 |



| NEXTGEN SEPTIC INFLUENT FIELD RAW DATA | | | | | | | NEXTGEN SEPTIC EFFLUENT DATA | | | | | PERFORMANCE ANALYSIS | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NextGen Septic Installation (name withheld to maintain privacy) | cBOD5 | TSS | NH3-N | TP | pH | Fecal Coliforms (MPN/100 mL) | cBOD5 | TSS | NH3-N | TP | Coliforms (MPN/100 mL) | % Removal BOD | % Removal NH3 | % Removal TP | % Removal Fecal Coliforms |
| 21 | | | | | | | | | | | | | | | |
| Kentucky home | 370 | 681 | 12.7 | 0.8 | 7.8 | 1.16E+04 | 6.3 | BDL | 1.9 | 1.0 | 6 | 98.30 | 97.64 | 85.04 | 99.95 |
| | 263 | 1078 | 1.3 | 1.8 | 7.4 | 3.05E+05 | 6.5 | BDL | 3.1 | 0.7 | 1 | 97.53 | 76.92 | | 100.00 |
| | 0 | 2216 | 0.3 | 26.4 | | 6.19E+05 | 6.8 | BDL | 4.2 | 0.8 | 3 | | 0.00 | | 100.00 |
| 22 | | | | | | | | | | | | | | | |
| Kentucky home | 760 | 99 | 7.0 | 5.6 | | 8.64E+05 | 8.9 | BDL | 1.8 | 1.0 | 5 | 98.83 | 95.71 | 74.29 | 100.00 |
| Had kitchen waste connected to septic | 2828 | 1936 | 15.7 | 1.8 | 8.0 | 1.23E+04 | 6.9 | BDL | 2.6 | 0.6 | 1 | 99.76 | 98.09 | 83.44 | 99.99 |
| | 3 | 46 | 0.9 | 24.6 | 7.8 | 1.74E+04 | 5.7 | BDL | 3.4 | 1.0 | | | 66.67 | | 100.00 |
| | 109 | 3648 | 0.6 | 0.1 | | 3.93E+05 | 7.8 | BDL | 4.6 | 0.6 | | 92.84 | 50.00 | | 100.00 |
| | 707 | 6 | 2.9 | 8.2 | 8.0 | 6.97E+05 | 5.4 | BDL | 2.2 | 0.9 | 11 | 99.24 | 89.66 | 24.14 | 100.00 |
| | | | 21.2 | 9.4 | 8.1 | 1.61E+04 | 8.3 | BDL | 2.1 | 0.4 | | | 98.58 | 90.09 | 100.00 |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| 23 | | | | | | | | | | | | | | | |
| Kentucky home | | 654 | 10.7 | 1.0 | 8.4 | 3.88E+05 | 9.5 | BDL | 3.3 | 1.1 | 1 | | 97.20 | 69.16 | 100.00 |
| | 122 | | 2.1 | 2.4 | | 2.04E+05 | 8.7 | BDL | 2.0 | 1.3 | 12 | 92.87 | 85.71 | 4.76 | 99.99 |
| 24 | 300 | 3060 | 0.6 | 26.4 | 7.1 | 1.67E+04 | 8.0 | BDL | 3.5 | 1.0 | 3 | 97.33 | 50.00 | | 99.98 |
| Kentucky home | 800 | | 0.0 | 0.0 | 8.0 | 4.86E+05 | 9.0 | BDL | 2.4 | 1.3 | 1 | 98.88 | | | 100.00 |
| | 938 | 18 | 6.0 | 6.0 | 8.7 | 1.63E+04 | 8.5 | BDL | 3.8 | 1.1 | 1 | 99.09 | 95.00 | 36.67 | 99.99 |
| | 1985 | 2082 | 9.4 | 3.2 | 8.2 | 7.01E+05 | 8.2 | BDL | 3.8 | 1.1 | 10 | 99.59 | 96.81 | 59.57 | 100.00 |
| 25 | | | | | | | | | | | | | | | |
| Kentucky home | 1 | 35 | 0.2 | 0.1 | | 3.30E+05 | 5.7 | BDL | 3.8 | 1.3 | 6 | | | | 100.00 |
| | 158 | 1068 | 2.1 | 10.9 | 7.9 | 1.64E+04 | 7.7 | BDL | 3.2 | 1.0 | 3 | 95.13 | 85.71 | | 99.98 |
| | 557 | 5 | 10.8 | 4.7 | 7.9 | 1.54E+05 | 4.7 | BDL | 2.3 | 0.8 | 8 | 99.16 | 97.22 | 78.70 | 99.99 |
| 26 | | | | | | | | | | | | | | | |
| Kentucky home | 400 | | 9.0 | 0.9 | 7.7 | 1.02E+04 | 8.8 | BDL | 4.4 | 1.0 | 6 | 97.80 | 96.67 | 51.11 | 99.94 |
| | 420 | 566 | 3.3 | 2.5 | 7.7 | 1.03E+05 | 7.0 | BDL | 4.2 | 0.5 | 1 | 98.33 | 90.91 | | 100.00 |
| | 45 | | 0.6 | 19.2 | 7.3 | 3.57E+05 | 9.0 | BDL | 2.1 | 1.3 | 10 | 80.00 | 50.00 | | 100.00 |
| 27 | | | | | | | | | | | | | | | |
| Kentucky home | 0 | | 8.3 | 6.7 | 8.3 | 1.71E+04 | 6.2 | BDL | 4.6 | 1.0 | 1 | | 96.39 | 44.58 | 99.99 |
| Construction debris | 660 | 24 | 10.7 | 3.9 | 7.8 | 1.80E+04 | 9.0 | BDL | 2.3 | 0.6 | | 98.64 | 97.20 | 78.50 | 100.00 |
| | 2304 | 2420 | 0.5 | 38.8 | 8.0 | 1.04E+04 | 9.0 | BDL | 4.2 | 1.1 | 1 | 99.61 | 40.00 | | 99.99 |
| | 2 | 34 | 2.4 | | 7.5 | | 8.3 | BDL | 3.9 | 0.9 | 3 | | 87.50 | | |

## 8. Conclusions

Decentralized treatment is the future of wastewater treatment. While centralized treatment dominates the current status of wastewater treatment, it has several disadvantages, the most important being that it takes groundwater and eventually discharges it into a creek or river, which ends up in the ocean. This converts fresh water into salt water resulting in the global decline of groundwater levels. Currently, the most common decentralized treatment system is a septic tank, followed by an aerobic treatment unit. These systems are unable to treat nutrients, causing toxic algal blooms in water bodies. They are also incapable of preventing the release of microplastics into the receiving water bodies and/or the soil drain field, causing it to clog prematurely. Sustainable wastewater treatment requires minimum energy consumption and using renewable energy. In this paper, an on-site, decentralized, sustainable wastewater treatment is presented, NextGen Septic, which uses micro-nanobubble aeration and high surface area Biomesh Biomedia™ to effectively treat the wastewater. In addition, it uses self-cleaning filters and membranes to filter the water resulting in non-detect suspended solids, low turbidity, with low level of contaminants. It can be scaled up for on-site wastewater treatment for RV sites, housing sub-divisions, etc.

## References

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