

CONTROL OF VIRUSES IN DRINKING WATER WITH VISIBLE LIGHT-ACTIVATED TiO₂/PdO
PHOTOCATALYST: PERFORMANCE DYNAMICS ASSOCIATED WITH REGENERATION AND ACTIVATION

BY

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THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in Environmental Engineering in Civil Engineering
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2010

Urbana, Illinois

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Abstract

The need for cost-effective and socio-culturally accepted treatment of drinking water in areas without access to clean water has motivated exploration of alternative pathogen control strategies including point of use systems using solar disinfection. Photocatalytic materials, such as titanium dioxide, have been demonstrated to inactivate a variety of pathogens when irradiated with UVA light but the UVA fraction of sun light is limited. In this research, the performance of a visible light-activated palladium-modified, nitrogen-doped titanium oxide (TiON/PdO) photocatalyst against viruses was further characterized. For initial virus concentrations of 10^8 - 10^{11} pfu/ml, TiON/PdO, was able to achieve four-logs of viral surrogate MS2 phage removal, with both dark and photocatalytic effects. Sustained regeneration potential of the material was tested using ozonation, which has been shown to completely restore the removal capacity after repeated use without degradation. A “photocatalytic memory” effect previously seen with E.coli was further explored with MS2 phage. The sorptive affinity of the material for viruses, coupled with its potential to oxidize contaminants at its surface when illuminated by visible light, may provide a novel means to couple with solar disinfection to provide continuous and effective point of use treatment for areas in need.

Acknowledgements

I would like to thank Benito Marinas, my advisor, for all of his guiding advice and support during this project. Thanks for opening my eyes to the world of research. I would like to thank Marinas Group members, especially Marty Page for all of the help and training in the lab. I would like to thank my family, for always showing me that I could do anything I set my mind to and for supporting me throughout it all. Thanks, finally to Environmental Engineers of the Future and WaterCampws for funding for my work.

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1. Introduction

Over 1.1 billion people do not have access to clean water. Water problems can be mainly attributed to water contamination not water availability, however with global climate change, waters are changing and because water availability is decreasing, it is even more important to utilize best the water we do have [McCullagh et al., 2007]. In many cases, the majority of people in these situations are in developing countries which do not have the infrastructure or the capital to have large-scale water treatment systems. For these areas, point of use systems that can be built out of existing materials and are cost-effective to build and sustain are considered. One of the technologies that are used in developing countries currently is solar disinfection. There have been many studies done on how solar disinfection can be effective against a wide array of pathogens [Reed, 2004, McGuigan et al., 1999]. It is a great technique to use because it utilizes the sun's natural energy source and can be done in existing containers that a family or village might have. However, this technology is not regarded as an efficient system for controlling viruses in drinking water [Wegelin et al., 2003].

Photocatalysts have been explored in the last three decades as a possible alternative in water disinfection. Specifically, titanium dioxide (TiO_2) has been shown by numerous studies as a viable disinfectant for a variety of pathogens including bacteria and viruses [Blake et al., 1999, Cho et al., 2005, Dunlop et al., 2002, Horie et al., 1996, Ireland et al., 1993]. TiO_2 is activated by UV rays which make it a valuable technology to combine with solar disinfection [Fujishima and Honda, 1972, Shibata et al., 1998]. Since the 1980s studies combining TiO_2 with metals such as iron have been done showing an increased efficiency against pathogens [Sjorgen and Sierka, 1994]. Studies have also been done doping TiO_2 with nitrogen and other nonmetal dopants to extend the optical absorbance of TiO_2 into the visible light region [Li et al., 2008]. The N-doped TiO_2 can be activated not only by UV but also visible light giving an increased solar efficiency and improved stability [Asahi et al., 2001, Wong et al., 2001, Wong et al., 2006]. In a point of use based system this could be a very important factor because it will give more continuous disinfection capability. However, many of these studies are done with powdered TiO_2 or TiON which is inserted into the water and then has to be filtered out in order for the water to be utilized.

Recently, studies have been done showing the implementation of putting the TiON onto a glass fiber by a sol-gel process [Li et al., 2007]. The "fiber" is a system that does not leave any residue in the water and gives the opportunity for reuse of the material. In the previous study for this project a TiON/PdO fiber by a sol-gel process was developed that was shown to be effective against both bacteria and

viruses. [Li et al., 2008] More recently this material has been shown to have a “photocatalytic memory” effect against bacteria so that the material continued the disinfection up to 24 hours in the dark [Li et al., 2010].

This work focuses on the TiON/PdO material developed by Li et al. in previous studies. Unpublished preliminary studies had shown regeneration of the fiber was necessary to recover removal capacity. This study confirms that need and gives more understanding to the removal capacity of the fiber over time and what affects it. The “photocatalytic memory” effect that was formerly shown with E.coli is explored with MS2 phage. This study gives an enhanced understanding to the lifecycle and dynamics of the fiber when used to inactivate MS2 phage. With continued development this material could prove to be an effective improvement to the solar disinfection method in point of use technologies.

2. Materials and Methods

2.1 Materials

Carbonate buffer stock solution: 0.0825 g sodium bicarbonate NaHCO_3 (>99% purity) was placed in 1L volumetric flask which was filled to mark with distilled de-ionized (DDI) water and stirred to make 1 mM stock solution. The solution was autoclaved at 121°C and after cooling it was stored.

Sodium thiosulfate solution: 8.350 g anhydrous sodium thiosulfate, $\text{Na}_2\text{S}_2\text{O}_3$ (>98% purity) (Fisher Scientific, Itasca IL) was added to a 500 ml volumetric flask that was brought to volume with DDI water to produce a 1.67% solution [Rennecker, 1997].

Indigo stock solution: 0.770 g potassium indigo trisulfonate, $\text{C}_6\text{H}_7\text{N}_2\text{O}_{11}\text{S}_3\text{K}_3$ (Aldrich Chemical, St. Louis, MO), and 1.0 ml 85% HPLC grade concentrated phosphoric acid (Fisher Scientific, Itasca, IL) were added to a 1000 ml volumetric flask which was filled to the mark with DDI water and stirred. The solution was placed in an amber colored bottle and stored at 4°C [Rennecker, 1997].

Indigo Reagent I: (for ozone concentration of 0.25 – 1.5 mg/L): 50 ml indigo stock solution, 11.5 sodium di-hydrogen phosphate ($\text{NaH}_2\text{PO}_4 \cdot \text{H}_2\text{O}$) and 7.0 ml 85% concentrated phosphoric acid were added to 1000 ml volumetric flask which was brought to volume with DDI water and mixed afterward. The solution was transferred to an amber colored bottle and stored at 4°C [Rennecker, 1997].

Tween 80 solution: 1 ml of Tween 80 solution (Fisher Scientific, Itasca, IL) was added to a 1 L volumetric flask and filled to mark with DDI water and stirred to create a .1% solution.

Coliphage MS2: a nonpathogenic virus widely used as a model system for immunological studies was used for the virus control assessment portion of this study. MS2 phase is an icosahedral-shaped virus with a diameter of ~26.0 nm, and a well-characterized molecular structure [Adams, 1959; Van Duin, 1988].

TiON/PdO fiber: The fiber was provided as part of a WaterCAMPWS collaboration from the previous studies with this material [Li et al., 2008]. The process and materials used to create it are shown here as described in those studies. Titanium tetraisopropoxide (TTIP, 97%, Sigma-Aldrich, St. Louis, MO), tetramethylammonium hydroxide (TMA, 25 wt% in methanol, Sigma-Aldrich, St. Louis, MO), and palladium acetylacetonate ($\text{Pd}(\text{acac})_2$, 99%, Sigma-Aldrich, St. Louis, MO) were used in that study as sources of titanium, nitrogen, and palladium, respectively. Ethyl alcohol (EtOH, 100%, AAPER Alcohol and Chemical Co., Shelbyville, KY) and dichloromethane (CH_2Cl_2 , 99.6%, Sigma-Aldrich, St. Louis, MO) were used as solvents. Activated carbon glass fibers (ACGF), prepared in a nonwoven fabric form by a thermal activation process [Daley et al., 1996] were used as templates. The TiON/PdO precursor solution was prepared at room temperature by a sol-gel process. Initially, TMA was dissolved in EtOH at a mol ratio at 1:10. The solution was stirred for 5 min by a magnetic stirrer, and then TTIP was added into the solution at a TMA:TTIP molar ratio of 1:5. An appropriate amount of $\text{Pd}(\text{acac})_2$ was dissolved in CH_2Cl_2 , and then inserted into the TMA/TTIP/EtOH mixture to achieve a target Pd:Ti molar ratio at 0.5%. After stirring for 5 min, a homogeneous TiON/PdO precursor solution was attained. After, the ACGF template was soaked in the solution for 24 h. Upon removal from the precursor solution, the soaked template was promptly washed in EtOH before it was exposed to humidified ambient air to induce the hydrolysis of precursors. Following further hydrolysis and drying, the template was calcinated in air at 450 °C for 3 h to produce fine crystallites of TiON/PdO on the fiber surface. [Li et al., 2008]

2.2 MS2 Phage Stock Preparation

Coliphage MS2 (ATCC 15597-B1) and its bacterial host *E. coli* (ATCC 15597) were obtained from the American Type Culture Collection (Manassas, VA). *E. coli* cells were grown and maintained using slants and Tryptic Soy Broth suspensions, and stored at 4 °C. Both the original MS2 phage stock passed down from previous work [Li et al., 2008] and a new stock were prepared using the method as described in the previous study. Virus stocks were grown in *E. coli* suspensions and purified by sequential centrifugation, microfiltration (MF) and ultrafiltration (UF). Centrifugation at 3000 RPM was used to removal the cell debris, and the resulting supernatant was passed through a Polyethersulfone (PES) MF membrane with nominal pore size of 0.22 μm . The resulting filtrate and a 1 mM carbonate buffer

solution (CBS) volume of 2 L were passed through a PVDF ultrafiltration (UF) membrane with nominal molecular-weight cut-off of 50 kDa (HFM-100; Koch Membrane Systems, Wilmington, MA) in an Amicon Stirred Ultrafiltration 8400 cell. The concentrate retained by the UF membrane was diluted in 1 mM CBS to a final concentration of 10^{10} - 10^{11} plaque-forming-units (pfu/ml) to make a total volume of 100 ml. The solution was passed through a 0.22 μ m membrane and stored at 4° C [Li et al., 2008].

2.3 Photocatalytic Reactor

Photocatalytic experiments were conducted in a 100-ml, completely mixed reactor placed under a collimated beam from a 1000W xenon-arc lamp (Newport, Stratford, CT). The light source was equipped with a liquid filter (H_2O), a long pass (> 400 nm) filter, and a neutral density filter (10%T). The average intensity at the surface of the suspension was $I = 45 \text{ mW/cm}^2$, measured using a radiant power meter (Newport, Irvine, CA). Temperature was maintained around 25°C with a temperature-controlled water jacket surrounding the reaction vessel (Wilmaad-Labglass, Vineland, NJ). Mixing was achieved by magnetic stirring with minimal vortex formation, and it was done carefully to avoid contact between the magnetic stirrer and the TiON/PdO fiber sample [Li et al., 2008].

2.4 Experimental Methods

Several different procedures were used to assess the TiON/PdO fiber sample. The procedures provided a combination of varied experimental parameters and regeneration techniques of the material. This was done in order to more fully understand the dynamics and lifecycle of the material. Overall, six different pieces of the material were used in experimentation and there were multiple stages of the project.

To begin, several different regeneration methods were examined with a new piece of the material. The lifecycles of three older pieces were then tested using a combination of ozonation techniques to better understand how the regeneration of the material with this strong oxidizing agent affected the span of use. Finally, surfactant was used for removing organic matter previous to assessing how the material inactivated viruses under visible light photocatalysis and under dark condition following illumination. The experimental matrix shown in Table 1 below displays the outline of the experiments performed during this work.

Table 1. Experimental Matrix

Experiment	MS2 Stock	Regeneration Technique	Experiment Exposure	Fiber	Mass (g)	V (mL) virus	N _o (pfu/mL)	N _f (pfu/mL)	Virus abs./mass fiber
1	1	Ozone - Overnight (CBS)	Combined	old	0.109	0.35	1.91E+08	1.31E+07	5.71E+08
2		Ozone - Overnight (CBS)	Combined		0.0977	0.25	1.93E+08	-----	#VALUE!
3		None (brand new fiber)	Combined		0.0566	0.125	-----	-----	#VALUE!
4		None	Combined	new	0.0558	0.125	6.14E+07	3.92E+07	4.98E+07
5		UV irradiation	Combined		0.0558	0.125	5.10E+07	1.70E+07	7.61E+07
6		Monochloramine	Combined		0.0558	0.125	4.44E+07	9.54E+06	7.82E+07
7		Monochloramine	Combined		0.0558	0.125	4.77E+07	1.14E+06	1.04E+08
8		Ozone - Overnight (air)	Combined	1	0.0897	0.007	7.19E+06	1.44E+03	5.61E+05
9		Ozone - Overnight (air) *7 days	Combined	3	0.0468	0.007	3.41E+06	3.05E+06	5.28E+04
10		Ozone - Overnight (air)	Combined	2	0.0377	0.007	5.88E+06	1.39E+05	1.07E+06
11		Ozone - Overnight (air)	Combined	3	0.0468	0.007	1.27E+07	9.41E+06	4.89E+05
12		Ozone - Overnight (air)	Combined	2	0.0377	0.007	1.32E+07	1.31E+06	2.21E+06
13		Ozone - Overnight (air)	Combined	1	0.0897	0.007	1.11E+07	-----	#VALUE!
14		Ozone - Overnight (air)	Combined	2	0.0377	0.007	2.33E+07	1.37E+06	4.07E+06
15		Ozone - Overnight (air)	Combined	3	0.0468	0.007	7.32E+06	-----	#VALUE!
16		Ozone - Overnight (air)	Combined	1	0.0897	0.007	4.84E+06	7.84E+03	3.77E+05
17		Ozone - Overnight (air)	Combined	3	0.0468	0.007	6.67E+06	2.40E+06	6.38E+05
18		Ozone - Overnight (air)	Combined	2	0.0377	0.007	6.67E+06	3.09E+05	1.18E+06
19		Ozone - Overnight (air)	Combined	1	0.0897	0.007	6.01E+06	3.79E+04	4.66E+05
20		Ozone - Overnight (air)	Combined	2	0.0377	0.007	3.35E+06	1.32E+06	3.76E+05
21		Ozone - Overnight (air)	Combined	3	0.0468	0.007	2.14E+06	7.45E+05	2.08E+05
22		Surfactant	Combined	3	0.0468	0.007	2.30E+06	1.19E+06	1.66E+05
23		Surfactant	Combined	3	0.0468	0.007	5.36E+06	3.95E+06	2.10E+05
24		Surfactant	Combined	3	0.0468	0.007	1.90E+06	9.80E+05	1.37E+05
25		Ozone - Same Day	Combined	4	0.04	0.007	7.84E+05	0.00E+00	1.37E+05
26		Ozone (Same Day) + Surfactant	Combined	3	0.0377	0.007	8.24E+05	3.29E+04	1.47E+05
27		Ozone - Same Day	Light	3	0.0377	0.007	1.41E+06	9.93E+03	2.60E+05
28		Ozone - Same Day	Dark	3	0.0377	0.007	1.16E+06	0.00E+00	2.16E+05
29		Ozone - Same Day	Combined	3	0.0377	0.007	1.45E+06	1.71E+04	2.66E+05
30		Ozone - Same Day	Combined	3	0.0377	0.007	2.62E+06	6.54E+03	4.85E+05
31		Ozone - Same Day	Combined	2	0.0205	0.007	2.65E+06	-----	#VALUE!
32		Ozone - Same Day	Combined	1	0.0474	0.007	1.57E+06	0.00E+00	2.32E+05
33		Ozone - Same Day	Combined	3	0.0215	0.007	1.86E+06	0.00E+00	6.06E+05
34		Ozone - Same Day	Combined	2	0.0205	0.007	1.62E+06	4.84E+05	3.88E+05
35		Ozone - Same Day	Combined	1	0.0474	0.007	1.18E+06	0.00E+00	1.74E+05
36		Ozone - Same Day	Combined	3	0.0215	0.007	5.82E+05	0.00E+00	1.89E+05
37		Ozone - Same Day	Combined	2	0.0205	0.007	---	3.27E+03	#VALUE!
38	2	Ozone - Same Day	Light	1	0.0415	0.05	4.44E+08	0.00E+00	5.35E+08
39		Ozone - Same Day	Dark	1	0.0415	0.05	3.58E+08	8.63E+04	4.31E+08
40		Ozone - Same Day	Light	2	0.0194	0.05	5.49E+08	2.36E+05	1.41E+09
41		Ozone - Same Day	Dark	2	0.0194	0.05	8.10E+08	2.22E+07	2.03E+09
42		Ozone - Same Day	Light	1	0.0389	0.05	4.44E+08	1.31E+04	5.71E+08
43		Ozone - Same Day	Dark	1	0.0389	0.05	5.23E+08	1.31E+03	6.72E+08
44		Ozone - Same Day	Light	1	0.0389	0.05	6.14E+08	2.09E+04	7.90E+08
45		Ozone - Same Day	Dark	1	0.0253	0.05	6.93E+08	----	#VALUE!
46		Ozone - Same Day	Light	1	0.0253	0.05	2.19E+08	1.01E+06	4.31E+08
47		Ozone - Same Day	Dark	1	0.0253	0.05	3.26E+08	9.80E+06	6.25E+08
48		Ozone - Same Day	Light	1	0.026	0.05	4.28E+08	3.27E+05	8.23E+08
49		Ozone - Same Day	Dark	1	0.0246	0.05	4.23E+08	5.10E+05	8.58E+08
50		Ozone - Same Day	Light	1	0.0244	0.05	4.14E+08	1.02E+05	8.49E+08
51		Ozone - Same Day	Light	1	0.0239	0.05	5.23E+08	4.97E+06	1.08E+09
52		Ozone - Same Day	Light	3	0.0111	0.05	7.84E+08	----	#VALUE!
53				3	0.0103	0.05	0.00E+00	2.61E+00	-1.27E+01
54		Ozone - Light	Dark	3	0.0103	0.05	6.14E+08	3.87E+07	2.79E+09
55				3	0.0103	0.05	----	3.14E+01	#VALUE!
56		Ozone - Light	Light	3	0.0103	0.05	4.97E+08	-----	#VALUE!
57		Ozone - Light	Dark	4	0.0238	0.05	3.10E+08	1.74E+08	2.86E+08
58				4	0.0228	0.05	1.10E+02	1.74E+02	-1.40E+02
59		Ozone - Light	Light	4	0.0228	0.05	4.18E+08	8.10E+06	9.00E+08
60		Ozone - Light	Dark	4	0.0228	0.05	5.75E+08	-----	#VALUE!
61		Ozone - Light	Light	4	0.0226	0.05	5.23E+08	-----	#VALUE!

2.4.1 Experiment Preparation and Sampling

For each experiment, a piece of TiON/PdO fiber cloth was immersed in 25 ml of 1 mM carbonate buffer solution (CBS) inside the reactor. Magnetic stirring was applied for the entirety of the experiment. A predetermined volume (0.007 – 0.050 ml) of MS2 phage stock was added to the reactor at the start of an experiment. Sample volumes of 1 ml were withdrawn at various contact time intervals (up to 60-80 min) until completion of 5 hrs and quenched in 0.1% sodium thiosulfate solution and kept in ice bath prior to viability measurement.

2.4.2 Dark Treatment

Dark treatment experiments were performed to assess the removal taking place not involving photocatalysis. The reactor was set-up and prepared following the procedures given in the preceding section. After the addition of the MS2 phage to the solution the reactor was kept in complete darkness for 5 hours. Samples were withdrawn at consistent time intervals (60-90 min) and processed as described in Section 2.5.

2.4.3 Photocatalytic Treatment

Photocatalytic experiments were performed by placing the reactor in the collimated beam apparatus for 5 hours. Samples were withdrawn at consistent time intervals (60-90 min) and processed as described in Section 2.5.

2.4.4 Combined Treatment

Combined exposure experiments were performed to see the sequential result of the dark and photocatalysis effects. Dark exposure lasted up to 3 hours followed by 2-2.5 hours of light exposure. Samples were withdrawn at consistent time intervals (60-90 min) and processed as described in Section 2.5.

2.5 Viability Assessment

The viability of MS2 phage sample was assessed within 24-72 hours after the corresponding photocatalytic/dark experiment was performed. The soft agar overlay method as described in Lozier *et al* [2003] was used to determine the viability of all MS2 phage samples. For this method *E.coli* broth (TSB inoculated with *E.coli* and incubated at 37°C) and soft agar (0.8 g Difco granulated agar diluted in 100 ml of TBS broth) were prepared. After preparation the *E.coli* solution was stored at 4°C and the soft

agar was immersed in a water bath at 45°C. The MS2 phage samples were diluted using TBS broth for 10-fold dilutions in order to reach concentrations in the range of 15-300 pfu/ml. In the water bath, 3.5 ml of the soft agar solution was added to glass vials which were mixed with 0.9 ml of the diluted sample and 0.25 ml of *E.coli* broth. The mixtures were poured onto 15x100 mm Petri Dishes containing a fixed base of hard agar (1.5 g agar granulated in 100 ml TBS broth). When the soft agar had set the plates were placed upside down in 37°C incubator. After a time period of 18-20 hr, the plaques in each plate were counted. Plaque counts between 15 and 300 were assumed used to quantify the phage density in plaque forming unit per milliliter (pfu/ml). A plate containing only soft agar and *E. coli* broth was prepared as a blank to compare for possible contamination [Coronell, 2004].

2.6 Ozone Measurement

The air tank and cooling water were both turned on prior to the start of the ozone generator. The ozone generator would be started and given at least 3 minutes to pass prior to determining the ozone concentration. To measure the ozone concentration 1 mL of the Indigo Reactant 1 solution was added to the vial first. Then a syringe that was placed securely within the ozone reactor was used to remove a 1 mL sample of the ozonated DDI water. This sample was added to the indigo solution to make the indigo/water mixture. The spectrophotometer was auto-zeroed using a blank sample. The indigo solution was placed in the vial and after allowing the absorbance at 600 nm to equilibrate take the reading was taken. The indigo/water solution was then placed in vial and the absorbance reading for this sample was taken. Using the absorbance readings and the volumes determined in the procedure, the concentration was calculated (Equation 1). This procedure was repeated at least 3 times to ensure the accuracy of the measurement. The ozone was measured to be 2.0 mg/L in the ozone reactor using the conditions (Ozone generator control at 2 mg/L; ozone reactor filled to mark with 500 ml DDI) that were kept consistent throughout the entirety of the work done [Rennecker, 1997].

$$C(O_3) = \frac{48000}{23150} \times \frac{(Ind. Abs. \times \%Ind.) - Ind./Oz. Abs.}{\%Buffer} \quad (1)$$

Ind. Abs. = Absorbance of pure indigo solution at 600 nm

% Ind. = Fraction of Indigo in indigo/water mixture (Volume of indigo/Volume of mixture)

Ind./Oz.Abs. = Absorbance of indigo/ozonated water mixture

% Buffer = Fraction of water in indigo/water mixture: (Volume of sample/Volume of mixture)

2.7 Photocatalyst Regeneration and Cleaning Procedures

2.7.1 Ozone Regeneration

Several different methodologies for ozone regeneration were used during the course of this project. The ozonation process for each method was done as described. The preparation of the fiber after the ozone treatment step changed with each method and will be described subsequent sub-sections. Ozone regeneration was done in a batch reactor. The reactor was filled with 500 ml DDI initially and refilled periodically when the volume decreased from that amount and continuously fed with gaseous ozone. The ozone was generated by passing pure air through an ozone generator. A 5,000 ml equalization tank between the ozone generator and the reactor ensured a stable ozone concentration in the stock. The air tank and cooling water were both turned on prior to starting of the ozone generator. The ozone generator would be started and given at least 2 minutes to warm up or until bubbles were observed in the reactor. The TiON/PdO fiber piece was dropped into the reactor where it was mixed with the ozone according to the dispersion forces of the bubbles. The fiber was ozonated for 60-90 min. Prior to being deposited in the ozone reactor the fiber cloth sample was weighed. After the period of ozone regeneration the ozone generator would be shut off with the air continuing to bubble for an interlude of at least 10 minutes to allow all of the ozone to be removed before the fiber was removed from the reactor.

2.7.1.a Overnight Preparation (Immersed in CBS)

The TiON/PdO fiber was removed from the reactor and immediately put into a 50 ml centrifuge tube filled with 1 mM CBS. The tube was closed and completely covered with aluminum foil to allow for complete darkness. The container was then placed in a dark place until needed for photocatalytic/dark treatment experiment.

2.7.1.b Overnight Preparation (Wet in Air)

The TiON/PdO fiber was removed from the reactor and immediately stored in air inside a 50 ml centrifuge tube. The tube was closed and completely covered with aluminum foil to allow for complete darkness. The container was then placed in a dark place overnight until needed for photocatalytic/adsorption experiment. For many of experiments the time period between ozonation and corresponding experiment was overnight but could be as long as 8 days as shown in Table 1.

2.7.1.c Same Day Preparation (No holding period)

The TiON/PdO fiber was removed from the ozone regeneration reactor and placed in a weigh boat for transport. After approximately 2.5 minutes of transport time between the ozone reactor and the experimental reactor, the material was immersed into the solution inside the experimental reactor and the experiment proceeded as described previously.

2.7.1.d Light Preparation

The TiON/PdO fiber was removed from the ozone regeneration reactor and placed in a weigh boat for transport. After 2.5 minutes of transport time between the ozone reactor and the experimental reactor, the material was immersed in 25 ml of 1 mM CBS inside the experimental reactor. The light source as described previously was turned on for a period of 5 hours. The material then remained in the reactor and was left in darkness and completely covered with aluminum foil overnight until performing a disinfection experiment the following day.

2.7.2 Monochloramine Regeneration

A fresh monochloramine solution was prepared for each regeneration. 0.1 grams NH_4Cl was added to 50 ml CBS. Ten milliliters of this NH_4Cl solution was added to 50 ml CBS. The TiON/PdO fiber cloth was immersed in the solution inside the reaction vessel. In 50 milliliters of CBS 0.05 ml of Cl_2 stock (NaOCl) was added. The chlorine solution was slowly added into mixing NH_4Cl and material. There was 3 hours contact time with the monochloramine solution before the material was removed and immediately put into a 50 ml centrifuge tube filled with 1 mM CBS. The tube was closed and completely covered with aluminum foil to allow for complete darkness. The container was then placed in a dark place until needed for photocatalytic/adsorption experiment.

2.7.3 Free Chlorine Regeneration

A 0.05 ml volume of Cl_2 stock (NaOCl) was added to 50 milliliters of CBS. The resulting chlorine solution was slowly added to the reaction vessel already containing the TiON/PdO fiber cloth. The fiber cloth had 3 hours contact time with the free chlorine solution before the material was removed and immediately put into a 50 ml centrifuge tube filled with 1 mM CBS. The tube was closed and completely covered with aluminum foil to allow for complete darkness. The container was then placed in a dark place until needed for photocatalytic/dark experiment.

2.7.4 UV Regeneration

UV Regeneration was conducted using the same experimental conditions as described previously for the photocatalytic/dark experiments. Instead, the light source was equipped with a liquid filter (H_2O), a long pass ($> 324 \text{ nm}$) filter, and a neutral density filter (25%T). The TiON/PdO fiber was exposed to the UV light for a period of 5 hours. The fiber was removed from the reactor and stored in air inside a 50 ml centrifuge tube completely covered in aluminum foil. The tube was stored in a dark place overnight until needed for experimental purposes.

2.7.5 Surfactant Regeneration

Tween 80 (Fisher Scientific, Itasca, IL) was used as surfactant to clean the surface of the TiON/PdO fiber cloth samples. The surfactant solution was first used by gently rubbing TiON/PdO fiber and rinsing thoroughly first with DI and then DDI. The fiber was then stored in air inside a 50 ml centrifuge tube completely covered in aluminum foil overnight. An alternative approach was to place the TiON/PdO fiber in a 50 ml centrifuge tube filled with surfactant solution. The fiber was shaken vigorously and then soaked in the solution for a period of 70 minutes. The fiber was rinsed and stored as before. Finally the fiber was regenerated just using the rapid mixing approach with the surfactant solution and then rinsed and stored as described previously.

3. Results and Discussion

3.1 Regeneration

Preliminary studies were done (data not shown) that demonstrated the material's removal ability decreases dramatically when the material is used continuously without regeneration. The material was used in succession with the same conditions applied for each subsequent experiment. It was found that when compared to the material's initial removal, there was order of magnitude reduction in the removal of MS2 from solution. However, when the material was regenerated with ozone following procedures similar to those used for this study between experiments, the MS2 removal was restored to that of the original run.

After observing the need for regeneration of the fiber between uses, the effect of regeneration and how it restored the material's capacity to remove MS2 were explored. XPS analyses were done on the material with samples before and after ozonation. It was hypothesized that in order for regeneration to take place, the palladium must be oxidized back to its original state in PdO. This is following the studies

shown by Li et al. (2008) that the Pd^{2+} accepts the electrons released by the TiON when hit by visible light and reduces to Pd^0 . It would follow that when the experiment is taking place the palladium is taking up the electrons until its capacity is used. The activity of the fiber would then be related in some way to the total number of electrons the palladium can accept. In order to restore that capacity, the palladium must be restored back to Pd^{2+} by treatment with an oxidizing agent so it is available again to accept electrons. Figures 1 and 2 below show the results for the palladium states in the fiber before and after ozonation, respectively. It is confirmed by the XPS scans that palladium is in its Pd^0 form after experimentation but before ozonation, and its Pd^{2+} form after regeneration with ozone.

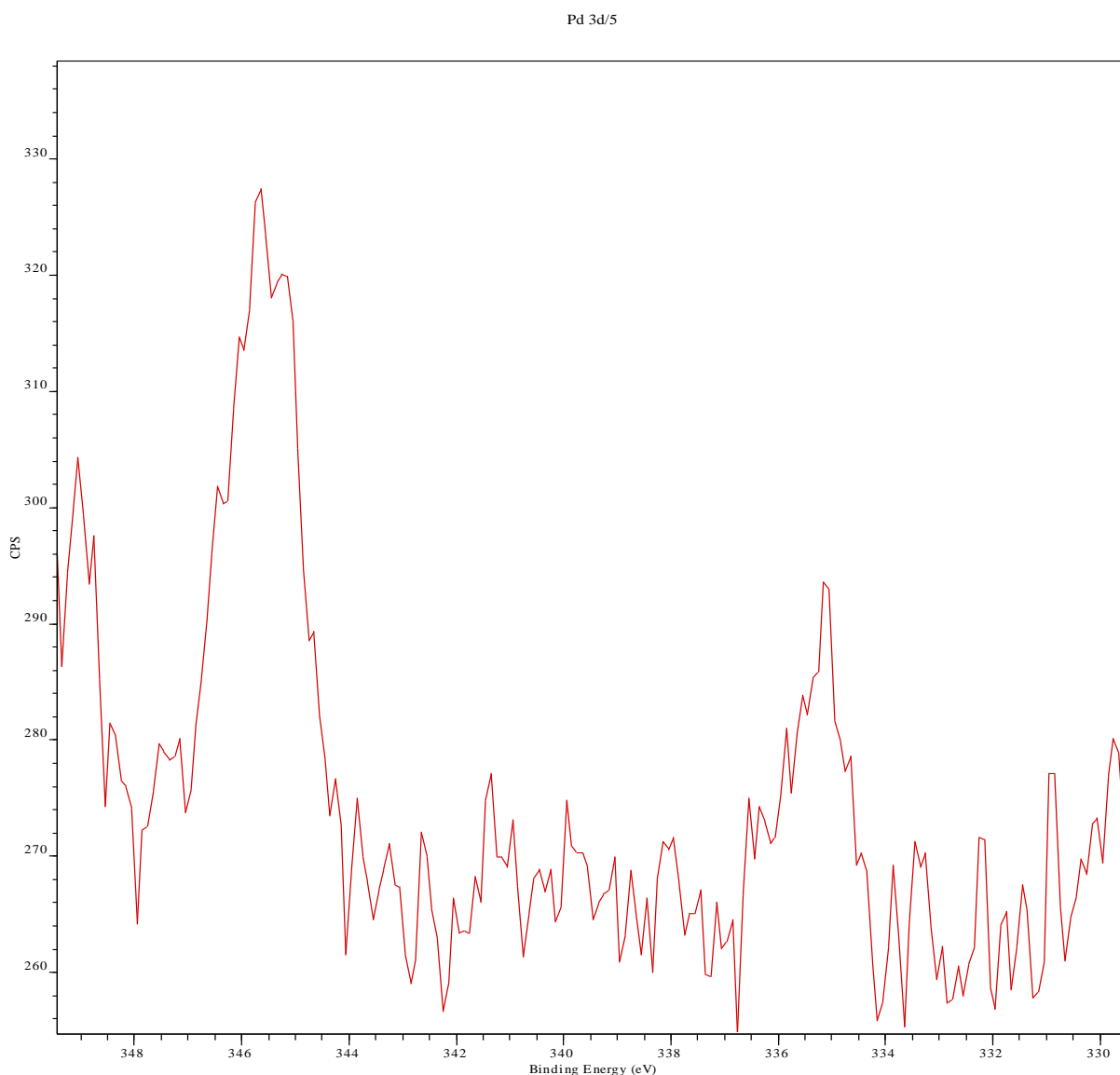


Figure 1. XPS analysis showing Pd valence state (Pd^0) after experimentation and before ozonation

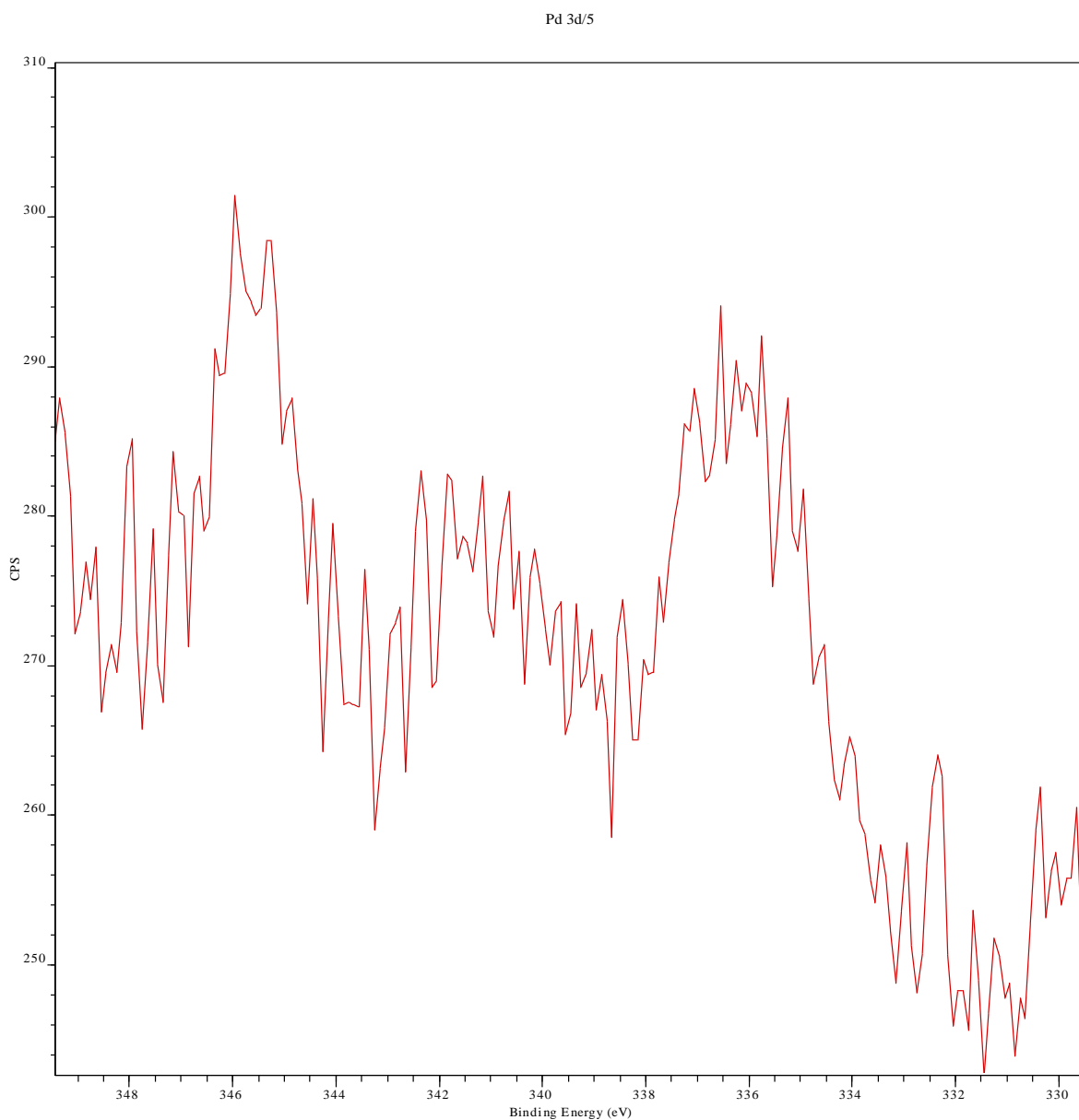


Figure 2. XPS analysis showing Pd valence state (Pd^{2+}) after ozonation

3.2 Lifecycle of Photocatalyst

While the regeneration with ozone was able to restore the removal ability of the material initially, this process was tested on a few samples repeatedly to test for any degradation over time of the material. The material was ozonated in general the day before at some point and left wet in air in darkness until the experiment was run the next day. After finding apparent degradation in the photocatalytic material over time as shown in Figure 3, the effect was tested to confirm that it was degradation of the material and not build-up on the surface of the material that was blocking any additional viruses from being

absorbed or getting to the surface. Tween 80 surfactant was used to clean the material and remove any “build-up” that occurred.

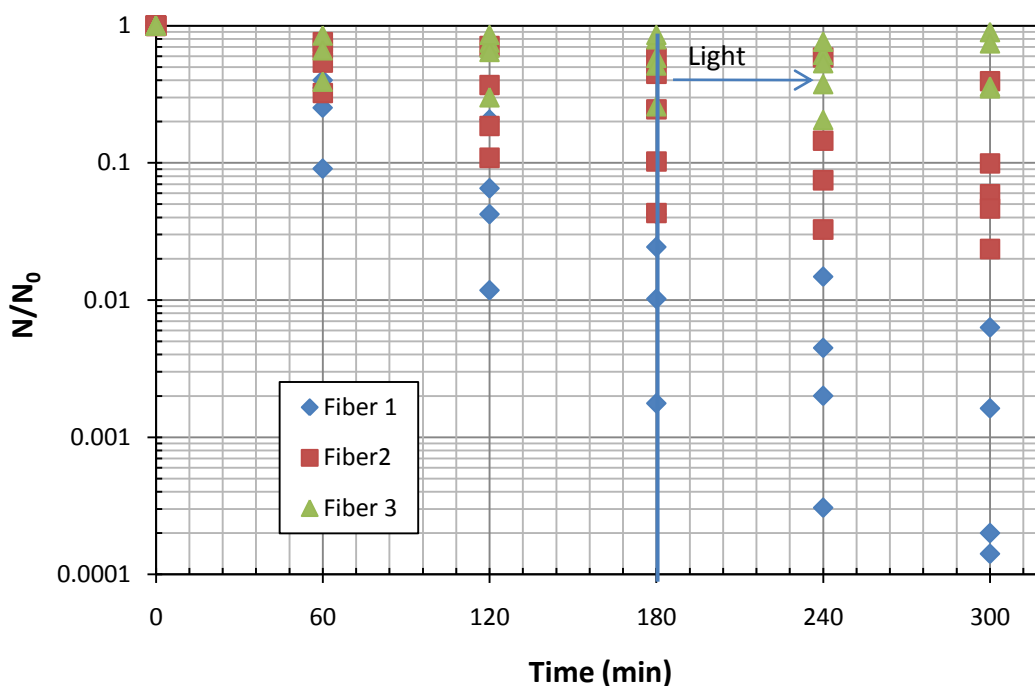


Figure 3. Comparison of fibers regenerated with sequential dark/photocatalytic treatment with ozone followed by overnight holding prior to treatment.

Since no progress was seen with just surfactant cleaning, an experiment was run with ozonation done first and then the surfactant cleaning in the morning of the experiment and then the experiment run directly afterward. The significant increase in removal was attributed to the ozonation done directly before. After it was found that the time between when the ozonation was done and when the experiment was run had a major influence on the material's performance, it was decided to pursue the same set of experiments as done before but with instead doing the ozonation in the morning for one hour with a set time between the ozonation and the experiment (2.5 min). The goal was once again to find if the material showed signs of degradation after several experiments. Figure 4 shows the results of the removal from this method with the different fibers. In these experiments there was a period of darkness for the first 3 hours of the experiment followed by 2 hours of light. By comparing the removal of Fiber s 1-3 in Figures 3 and 4 it is seen that with the change in the timing of the ozonation all three fibers generally show much improved removal abilities.

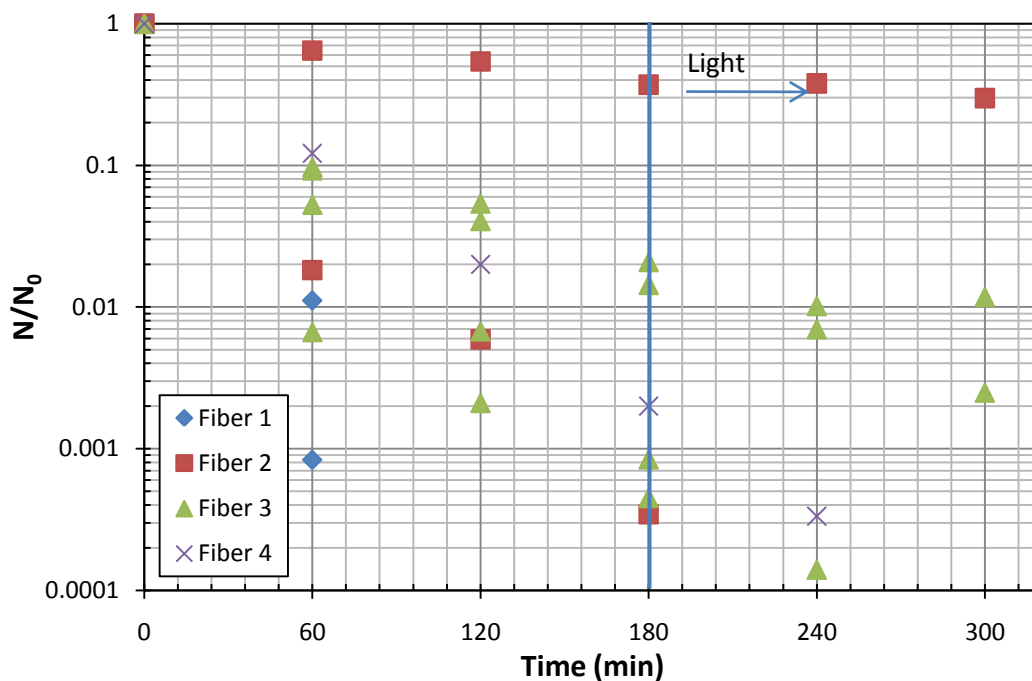


Figure 4. Comparison of sequential dark/photocatalysis treated with fibers regenerated with ozone the same day.

While Figures 3 and 4 seem to support that the catalyst is possibly degrading over time, Figures 5 and 6 below show the removal capacity normalized with respect to fiber mass for the same sets of experiments remains approximately constant. This demonstrates that the only thing that is being lost over time is the mass of the catalyst. When the removal is shown per gram of catalyst it can be easily seen that the material is not losing any of its original removal capacity. The material is shown to be sustainable with continued use over time with regeneration.

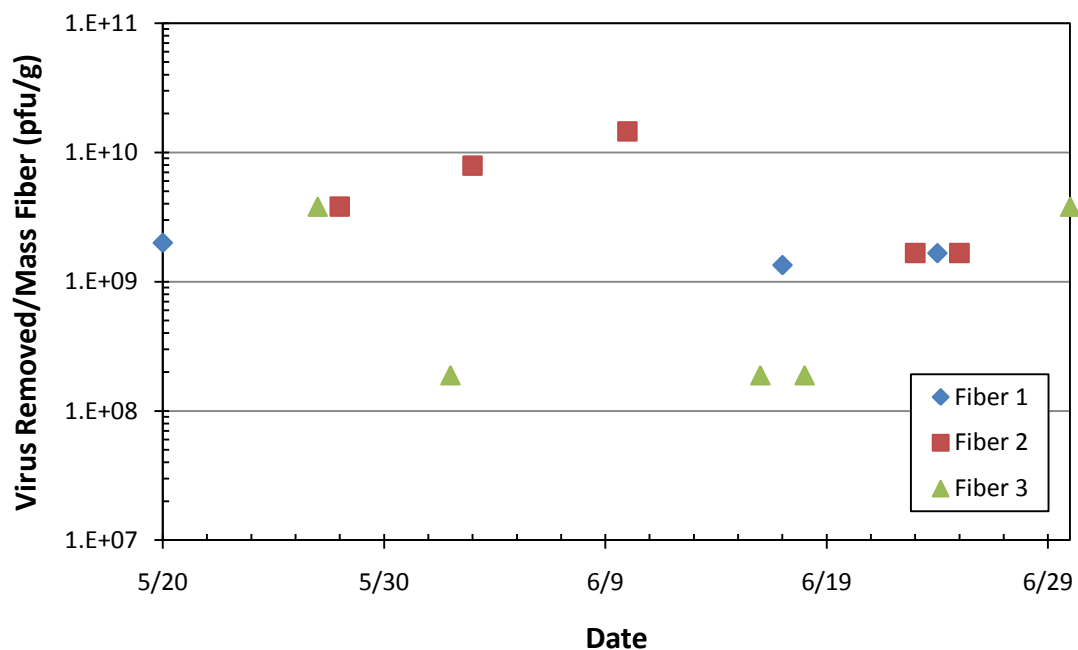


Figure 5. Comparison of overall removal capacity by fibers corresponding to Figure 3.

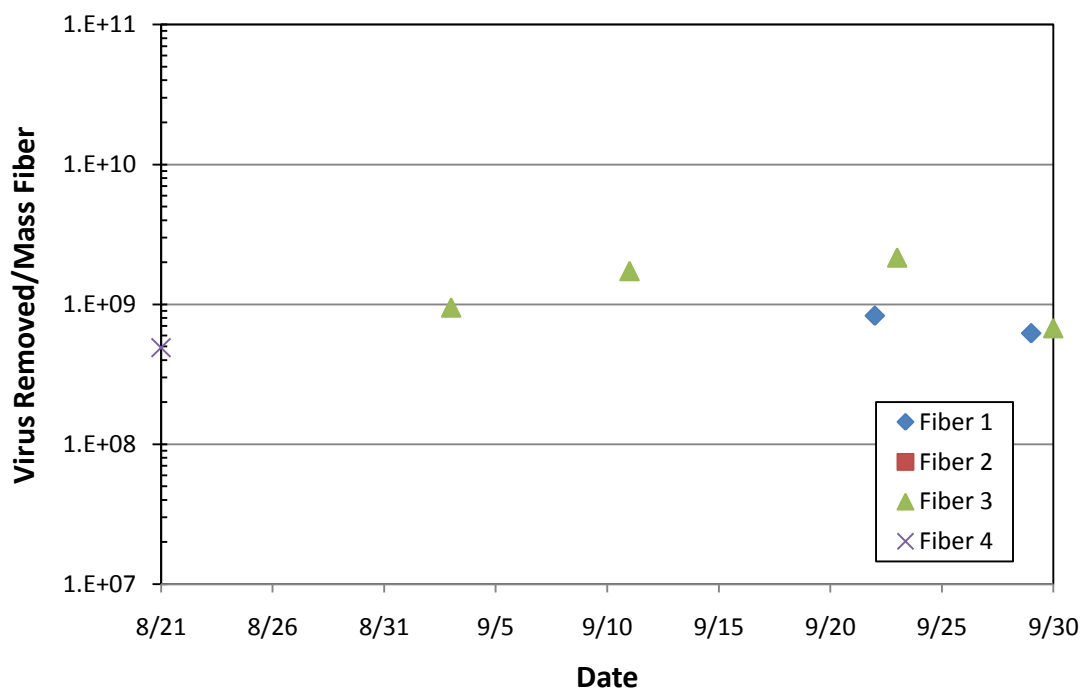


Figure 6. Comparison of overall removal capacity corresponding to Figure 4.

3.3 Exploration Of “Photocatalytic Memory” Effect For MS2 Removal

To allow the material to reach equilibrium with both the dark and photocatalytic effects, dark only and light only experiments were done, respectively. During these experiments there was a light experiment followed directly the next day by a dark experiment. On 11.2.09 there was 3 days between the previous light experiment and that day's dark experiment. It was observed that the removal capacity was decreased tremendously from previous data. This occurred again on 11.5.09 where there had been 2 days between the light experiment and the dark experiment. With these findings it was proposed that the “photocatalytic memory” of the material shown in Li et al. (2010) for E.coli also could be affecting MS2 removal. Additional experiments were set up to test the hypothesis formed from these results. Each experiment was 2 days. The first day the material was ozonated for one hour, transported to the reactor and illuminated for 5 hours in 25 mls CBS without virus addition. The cover was then put on the reactor and the fiber sat in reactor overnight in the CBS in darkness. The next day, 0.050 ml of the virus was added and the experiment took place in darkness. The light experiment used the same procedure except on the second day visible light was shown instead of darkness. These experiments were done with Fiber 3 first and then switched to Fiber 4 because the mass of Fiber 3 had decreased so much it was hard to handle properly. Figure 7 shows the results from experiments testing out the “photocatalytic memory” in relation to MS2 phage.

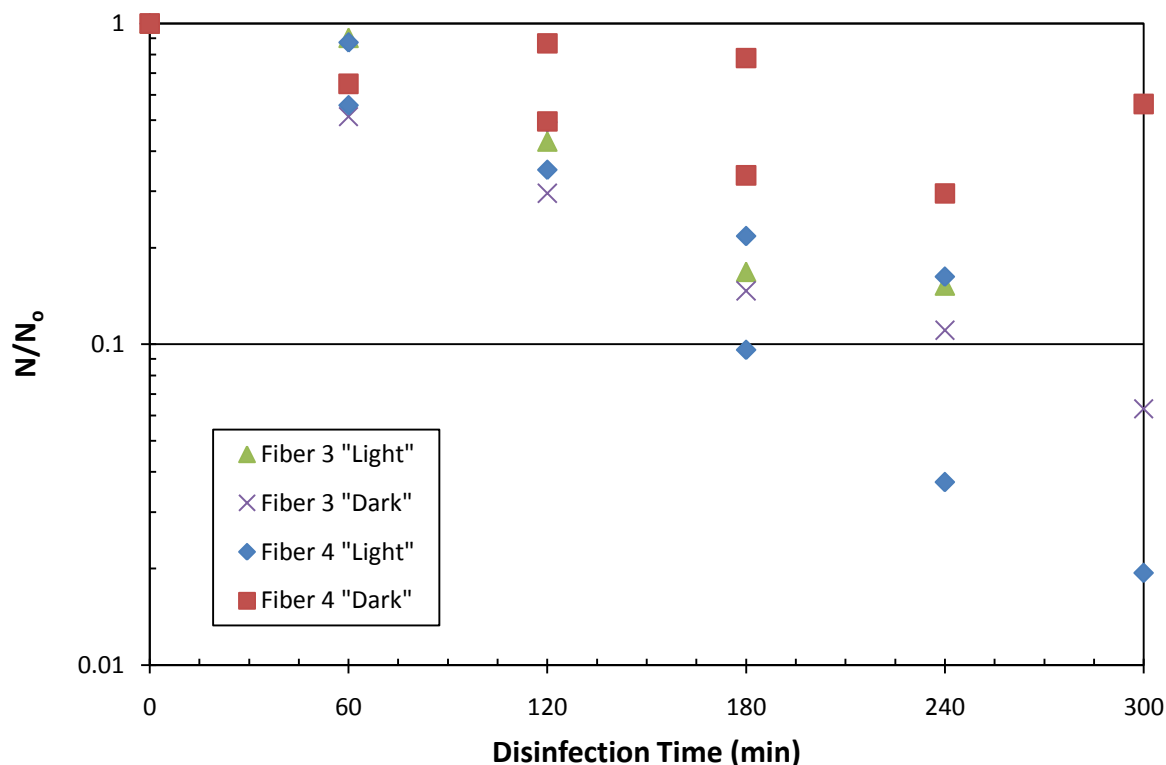


Figure 7. "Photocatalytic Memory" effect for MS2 removal.

Visible light is needed by the TiON/PdO fiber in order for the electrons to be released from the TiON. However, with the Pd^{2+} (PdO) as electron traps which prevent some recombining between the electrons and the holes, the visible light is not necessary for removal to take place. Li et al. (2010) explains that with the "photocatalytic memory" the Pd^0 slowly release the electrons over time which can react with oxygen and water to further produce oxidizing radicals and also allows the reactive holes created in the material to remain longer giving more opportunity to remove pathogens. Unlike that study, the material in this work was not new, but regenerated with ozone. As shown in the Figure 7, the material shows a definite capability for removing the virus under dark after about 18 hours since illumination. The results provide evidence that the "photocatalytic memory" shown with bacteria also takes place with viruses.

3.4 Difference In Viability Of MS2 Between Virus Stocks

It is interesting to observe the difference when the viruses removed from solution per gram of photocatalytic material are compared versus both the final count of MS2 in solution (N_f) and the initial count of viruses in solution (N_0). Figure 8 shows that for each virus stock used, the viruses removed/gram fiber was independent from N_f .

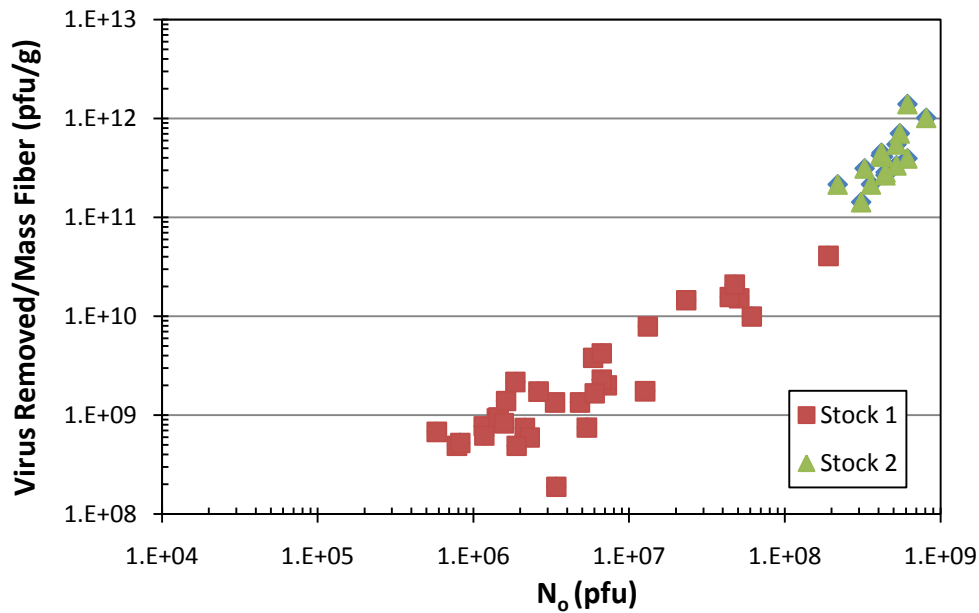


Figure 9. Virus Removed/mass fiber vs. N_o

Also, when looking at both Figure 8 and Figure 9, two distinct groups are shown. These two groups are showing the removal capacity for the two different stocks used during the course of the experiments. Since the main difference in the experiments is a different stock, the figures are showing an indirect relationship to the viability of the two respective stocks. Fibers 1-4 are used with both the old and new MS2 stock and because of the consistency of the removal capacity among different experimental conditions in both stocks, it is hypothesized that the capacity does not change with stock but rather the viability of the stock changes. Basically, the material removes the same number of viruses with each stock, but the newer stock reflects an increased removal capacity only because it has a higher viability. This would be consistent with viability not showing the total number of viruses in solution, but only the active viruses.

Figure 10 illustrates that there are slight differences in the removal capacities due to the variety of methods used for regeneration and experimentation but due to the spread of data for each type, there is nothing conclusive except the difference in the virus stocks as explained above.

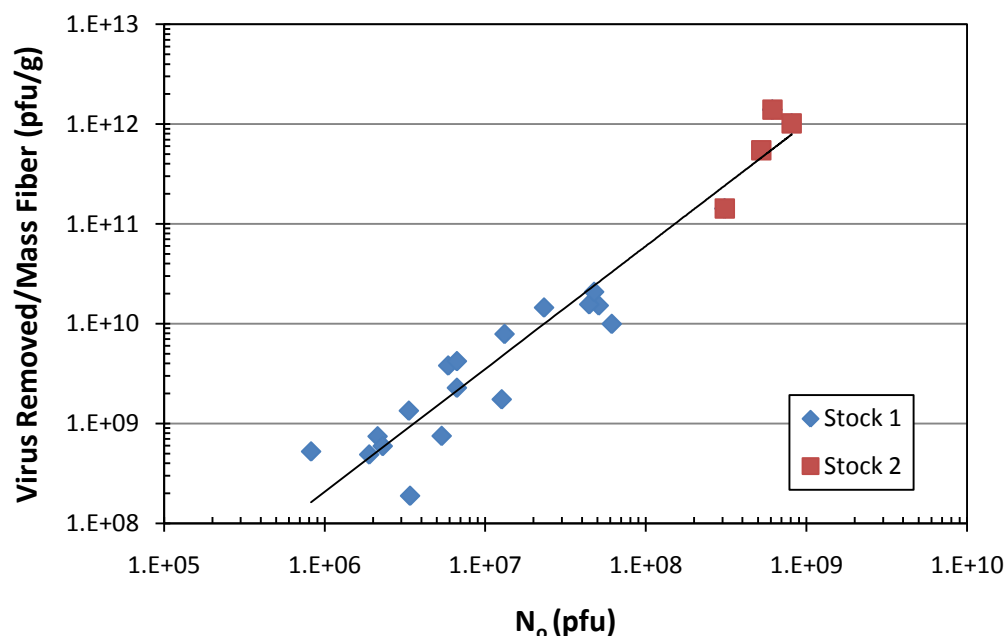


Figure 11. Virus removed/mass of fiber vs. N_o for experiments showing low removal.

4. Conclusions and Recommendations

Consistent with observations from preliminary studies regeneration was necessary for the TiON/PdO material to recover its removal capacity. This investigation has shown that using the fiber consecutively without regeneration between experiments resulted in a deterioration on the removal efficiency of MS2 phage. Comparatively, when the material was regenerated with ozone for approximately an hour the removal efficiency was restored.

XPS analyses of the material before and after ozonation confirmed that regeneration by ozonating changed the palladium valence state. Ozone oxidated the material, bringing the Pd^0 back to Pd^{2+} . By bringing the palladium back to its original state of PdO, palladium was able to capture the free electrons released by TiON under visible light illumination. Additionally, while it is not conclusive why the capacity of the fiber seems to sometimes increase past initial capacity after regeneration, this could be attributed to the strong oxidation power of ozone which could be elevating all palladium back to Pd^{2+} whereas when the original fiber was created not all Pd was as PdO.

The regeneration of the material was not optimized as a part of this work but by experimenting with a variety of regeneration methods more can be understood about this process. Comparing the results

from doing the ozonation the day before and the same day, it is shown that the time period between regeneration and use is an important variable to be considered. While there does not seem to be a considerable difference in the removal capacity of the fiber, there is as much as an additional 2-log removal in the same time period with all other variables remaining the same.

The surfactant study was not conclusive. Tween 80 did not seem to make a visible difference in either the amount of removal or the removal capacity of the fiber with or without regeneration. By performing experiments in both complete light and complete dark it can be concluded that with regeneration the fiber can remove viruses in either environment. Initially, it was believed that the regeneration by ozone was able to bring the palladium back to PdO which would then capture electrons resulting from electron-hole pairs, thus leaving the holes open for oxidative reactions. However, after doing a few experiments in complete dark more than 24 hours since the time of the complete light experiment it was shown that the MS2 removal decreased drastically. It was then proposed that in order for the electron-hole pairs to be produced the material must be shined with visible light after ozonation. This should become the optimal environment for the electron-hole pairs to form. All of the Pd will be Pd²⁺ giving space for the electrons to go once the photons from the light have caused them to shift from the TiON. The electron-hole pairs are then formed and the “holes” remained present until reduced by reaction with a virus or other compounds. The experiments done by ozonating the day before and then shining the material with visible light for 5 hours as pretreatment for the dark or light experiment the next day were able to explore that assumption. There was some degree of removal in both the light and dark experiments but not comparable to the removal seen when the experiment was done directly after ozonation. It is believed that by storing the material in CBS during the period between irradiation of visible light and the addition of the MS2 to the solution that the “holes” were filled by taking the electrons out of the water in the CBS. Additional work should be done with this set of experiments by allowing the material to be stored dry between the pretreatment and the experiment. Although, it is not conclusive this experiment does show that material does have some form of the “photocatalytic memory” effect that performs to equal or greater power on MS2 than as shown on E.coli in Li et al., (2010). The recommended course of regeneration as found from this study would be to ozonate directly before the experiment and irradiate with visible light to create the “holes” needed for removal then proceed immediately with experimentation.

Future work should be done to optimize the regeneration of the material and to determine if there is a more viable solution than ozonation of the material. Additional work should be completed to test the

length of time the material can remove viruses effectively before regeneration is needed and to find the capacity of the fiber. The material should also be tested with natural waters to understand if there will be a competition effects by NOM or other substances.

Solar disinfection is a cost-effective and culturally adaptable method for water treatment. To achieve a more advanced level of treatment the pairing of solar disinfection and photocatalysts might be a good solution. Unfortunately, many photocatalysts come mostly in powdered form and are not able to be re-used in treatment. This leads to a more complicated process that could lead to poor treatment and lack of acceptability. By utilizing a reusable fiber form and ability to effectively remove both bacteria and viruses in continuous conditions the TiON/PdO material shows much promise as new alternative in point of use technology.

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6. Appendix

Appendix A
Exploring Types of Regeneration

Experiment	Date
Old fiber regenerated with Ozone	1.12.09
Old fiber regenerated with Ozone	1.19.09
New piece of fiber untouched	1.23.09
New piece of fiber without regeneration	1.29.09
New piece of fiber with UV irradiation	2.5.09
New piece of fiber with monochloramine regeneration	2.15.09
New piece of fiber with monochloramine regeneration	2.20.09

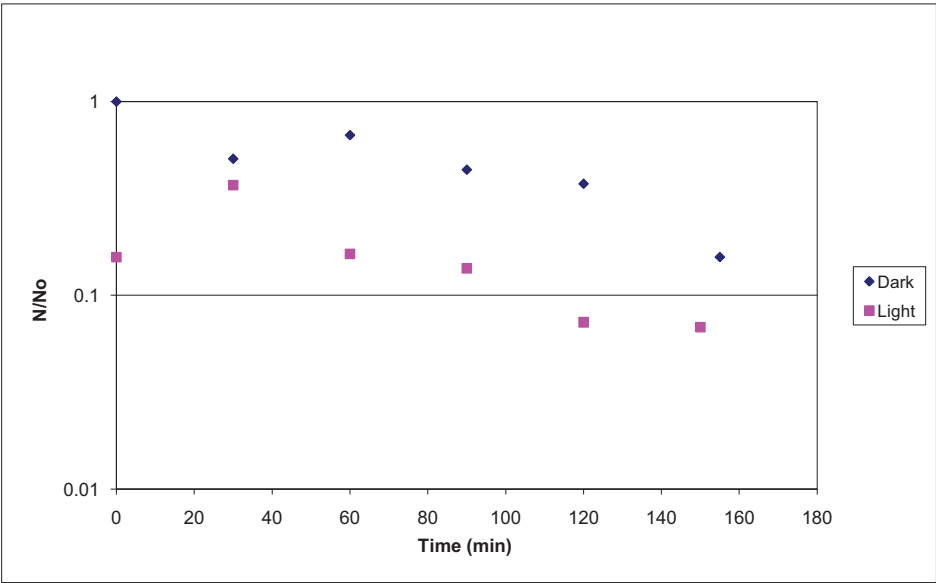
Date 1/12/2009 Old fiber regenerated with ozone

Experiment 1

pH
Temp 25
Buffer 1mM CBS
Mass Cat 0.109 grams
Volume 35 mL
Intensity ~450 W/m2
Filters > 400 nm, 10% Transmittance

Volume Virus Stock Added 0.35 mL

Plaques per 0.85 ml at 10^X dilution											pfu/ml		Time in	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	8	N	N/N ₀	Light (min)
dark	1	0						tntc	146	8	0	190849673.2	1	0
	2	30						tntc	74	9	0	96732026.14	0.506849	0
	3	60					tntc	tntc	98	8		128104575.2	0.671233	0
	4	90					tntc	tntc	65	9		84967320.26	0.445205	0
	5	120					tntc	tntc	55	5		71895424.84	0.376712	0
	6	155					tntc	tntc	23	3		30065359.48	0.157534	0
	7	185					tntc	tntc	54	7		70588235.29	0.369863	30
light	8	215				tntc	tntc	217	26			31176470.59	0.163356	60
	9	245				tntc	tntc	212	19			26274509.8	0.137671	90
	10	275			tntc	tntc	tntc	106				13856209.15	0.072603	120
	11	305			tntc	tntc	tntc	100				13071895.42	0.068493	150



Date 1/19/2009 Old fiber regenerated with ozone

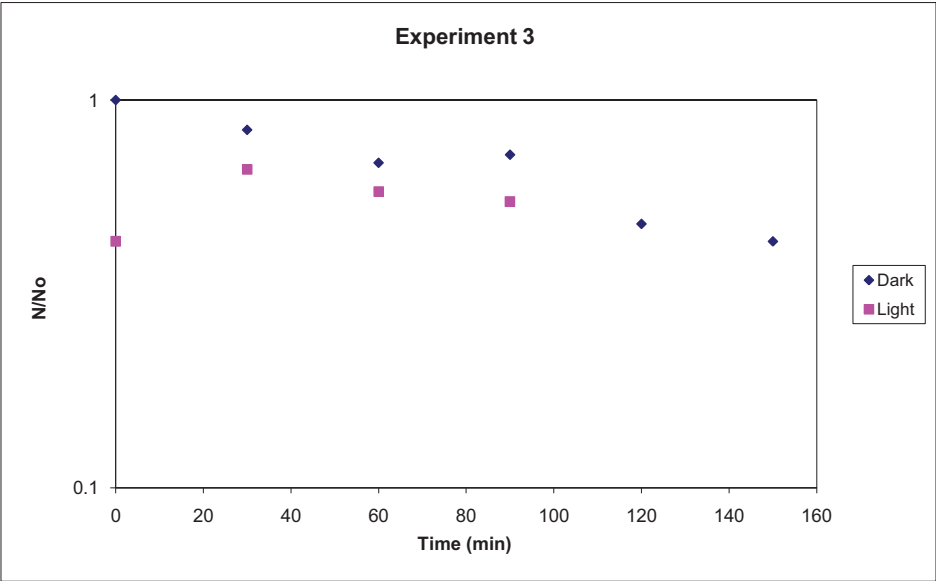
Experiment 2

pH
Temp 25
Buffer 1mM CBS oC
Mass Cat 0.0977 grams
Volume 25 mL
Intensity ~450 W/m2
Filters > 400 nm, 10% Transmittance

Volume Virus Stock Added 0.25 mL

1

Plaques per 0.85 ml at 10^X dilution											pfu/ml		Time in	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	8	N	N/N ₀	Light (min)
dark	1	0						tntc	148	15	2	193464052.3	1	0
	2	30						tntc	124	10	0	162091503.3	0.837838	0
	3	60					tntc	tntc	102	13		133333333.3	0.689189	0
	4	90					tntc	tntc	107	11		139869281	0.722973	0
	5	120					tntc	tntc	71	9		92810457.52	0.47973	0
	6	150					tntc	tntc	64	10		83660130.72	0.432432	0
	7	180					tntc	tntc	98	8		128104575.2	0.662162	30
light	8	210				tntc	tntc	tntc	86			112418300.7	0.581081	60
	9	240				tntc	tntc	tntc	81			105882352.9	0.547297	90
	10	270			tntc	tntc	tntc	tntc				0	0	120
	11	300			tntc	tntc	tntc	tntc				0	0	150



Date1/23/2009New fiber untouched

Experiment3

pH

Temp

Buffer

Mass Cat

Volume

Intensity

Filters

25

1mM CBS

0.0566

25

~450

> 400 nm, 10% Transmittance

oC

grams

mL

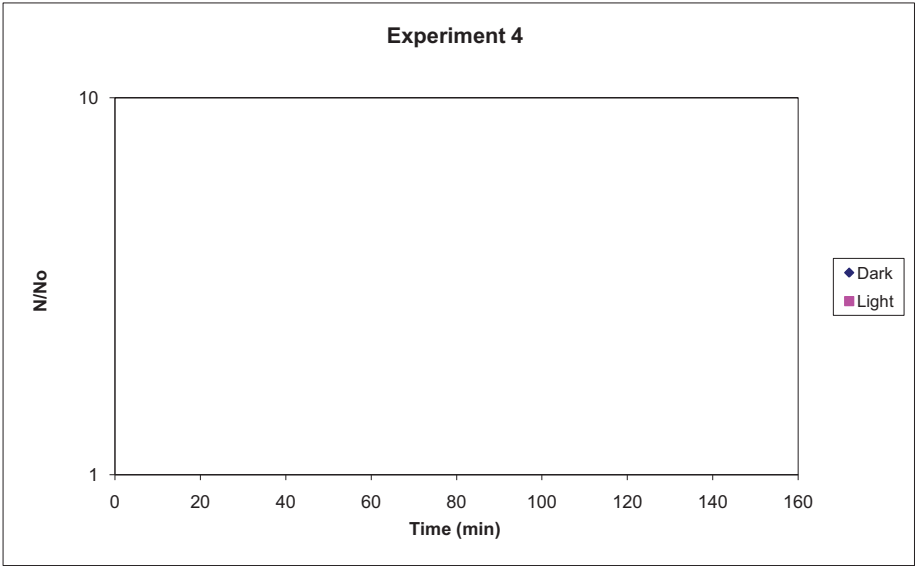
W/m2

Volume Virus Stock Added

0.125 mL

*experiment did not show results because e. coli was added to solution right after autoclave and were killed from the heat

Plaques per 0.85 ml at 10^X dilution												pfu/ml		Time in
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	8	N	N/N ₀	Light (min)
dark	1	0						--	--	--	--	#VALUE!	#VALUE!	0
	2	30						--	--	--	--	#VALUE!	#VALUE!	0
	3	60					--	--	--	--		#VALUE!	#VALUE!	0
	4	90					--	--	--	--		#VALUE!	#VALUE!	0
	5	120					--	--	--	--		#VALUE!	#VALUE!	0
	6	150					--	--	--	--		#VALUE!	#VALUE!	0
	7	180					--	--	--	--		#VALUE!	#VALUE!	30
	8	210				--	--	--	--			#VALUE!	#VALUE!	60
light	9	240				--	--	--	--			#VALUE!	#VALUE!	90
	10	270			--	--	--	--				0	#VALUE!	120
	11	300			--	--	--	--				0	#VALUE!	150



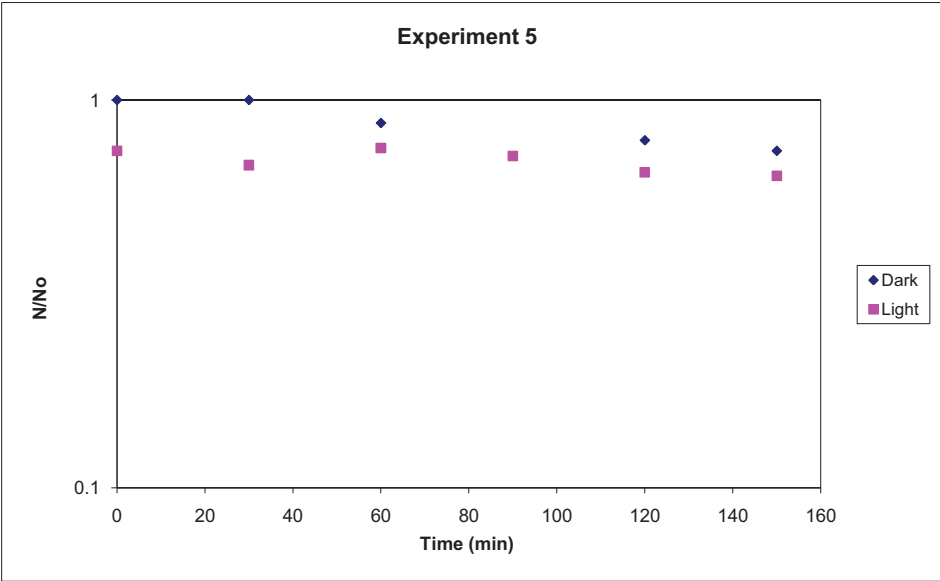
Date 1/29/2009 New fiber without regeneration

Experiment 4

pH
Temp 25 oC
Buffer 1mM CBS
Mass Cat 0.0558 grams
Volume 25 mL
Intensity ~450 W/m2
Filters > 400 nm, 10% Transmittance

Volume Virus Stock Added 0.125 mL

Plaques per 0.85 ml at 10^X dilution												pfu/ml		Time in
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	8	N	N/N ₀	Light (min)
dark	1	0						0	0	0	0	47712418.3	1	0
	2	30						tntc	47	--	8	61437908.5	1	0
	3	60					tntc	tntc	41	4		53594771.2	0.87234	0
	4	90					tntc	tntc	55	0		71895424.8	1.170213	0
	5	120					tntc	tntc	37	3		48366013.1	0.787234	0
	6	150					tntc	315	38	3		45424836.6	0.739362	0
	7	180					tntc	309	33	3		41764705.9	0.679787	30
light	8	210				tntc	tntc	327	38			46209150.3	0.752128	60
	9	240				tntc	tntc	335	34			44117647.1	0.718085	90
	10	270			tntc	tntc	tntc	306				40000000	0.651064	120
	11	300			tntc	tntc	tntc	300				39215686.3	0.638298	150



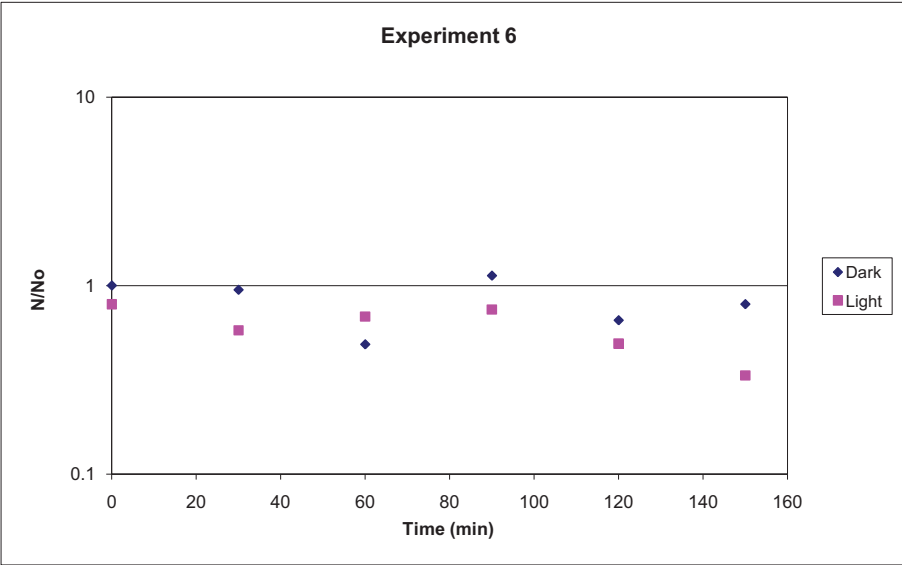
Date 2/5/2009 New fiber with UV irradiation

Experiment 5

pH 8.2
Temp 25 oC
Buffer 1mM CBS
Mass Cat 0.0558 grams
Volume 25 mL
Intensity ~450 W/m2
Filters > 400 nm, 10% Transmittance

Volume Virus Stock Added 0.125 mL

Plaques per 0.85 ml at 10 ^X dilution												pfu/ml		Time in
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	8	N	N/N ₀	Light (min)
dark	1	0						tntc	39	5	1	50980392.2	1	0
	2	30						tntc	37	4	0	48366013.1	0.948718	0
	3	60					tntc	tntc	19	0		24836601.3	0.487179	0
	4	90					tntc	tntc	44	6		57516339.9	1.128205	0
	5	120					tntc	260	25	3		33333333.3	0.653846	0
	6	150					tntc	241	38	3		40588235.3	0.796154	0
	7	180					tntc	232	22	3		29542483.7	0.579487	30
light	8	210				tntc	tntc	234	30			34901960.8	0.684615	60
	9	240				tntc	tntc	192	39			38039215.7	0.746154	90
	10	270			tntc	tntc	tntc	192				25098039.2	0.492308	120
	11	300			tntc	tntc	tntc	130				16993464.1	0.333333	150



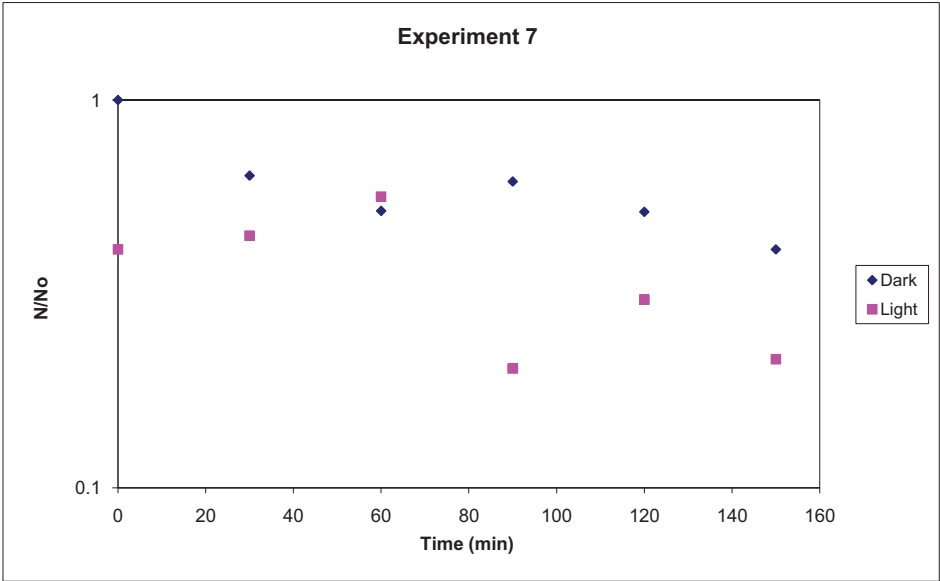
Date 2/15/2009 New fiber with monochloramine regeneration

Experiment 6

pH
Temp 25 oC
Buffer 1mM CBS
Mass Cat 0.0558 grams
Volume 25 mL
Intensity ~450 W/m2
Filters > 400 nm, 10% Transmittance

Volume Virus Stock Added 0.125 mL

Plaques per 0.85 ml at 10 ^X dilution											pfu/ml	Time in		
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	8	N	N/N ₀	Light (min)
dark	1	0						tntc	34	2	1	44444444.4	1	0
	2	30						217	14	1	0	28366013.1	0.638235	0
	3	60					tntc	202	15	1		23006535.9	0.517647	0
	4	90					tntc	219	20	1		27385620.9	0.616176	0
	5	120					tntc	140	21	3		22875817	0.514706	0
	6	150					tntc	130	15	1		18300653.6	0.411765	0
	7	180					tntc	152	13	1		19869281	0.447059	30
light	8	210				tntc	tntc	123	26			25032679.7	0.563235	60
	9	240				tntc	tntc	69	4			9019607.84	0.202941	90
	10	270			tntc	tntc	tntc	104				13594771.2	0.305882	120
	11	300			tntc	tntc	tntc	73				9542483.66	0.214706	150



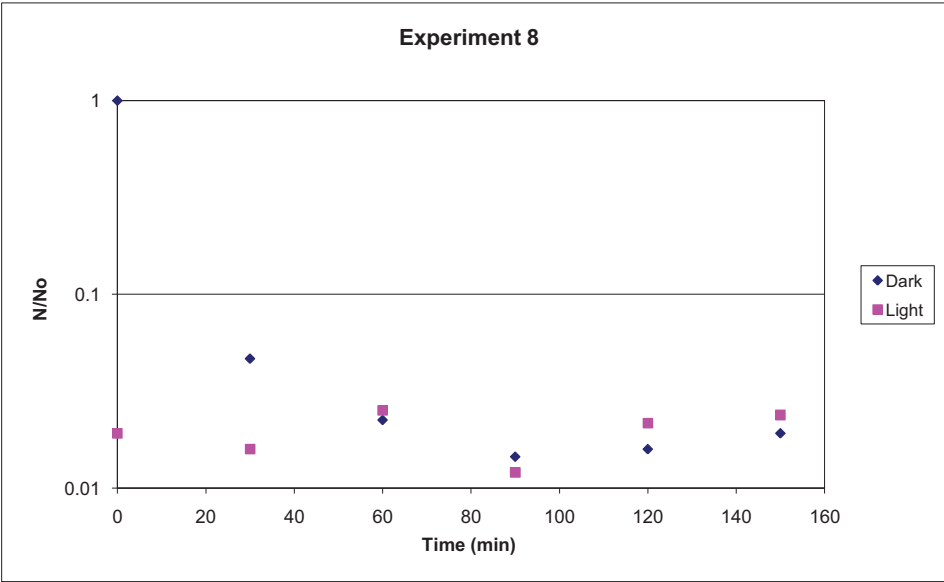
35 Date 2/20/2009 New fiber with monochloramine regeneration

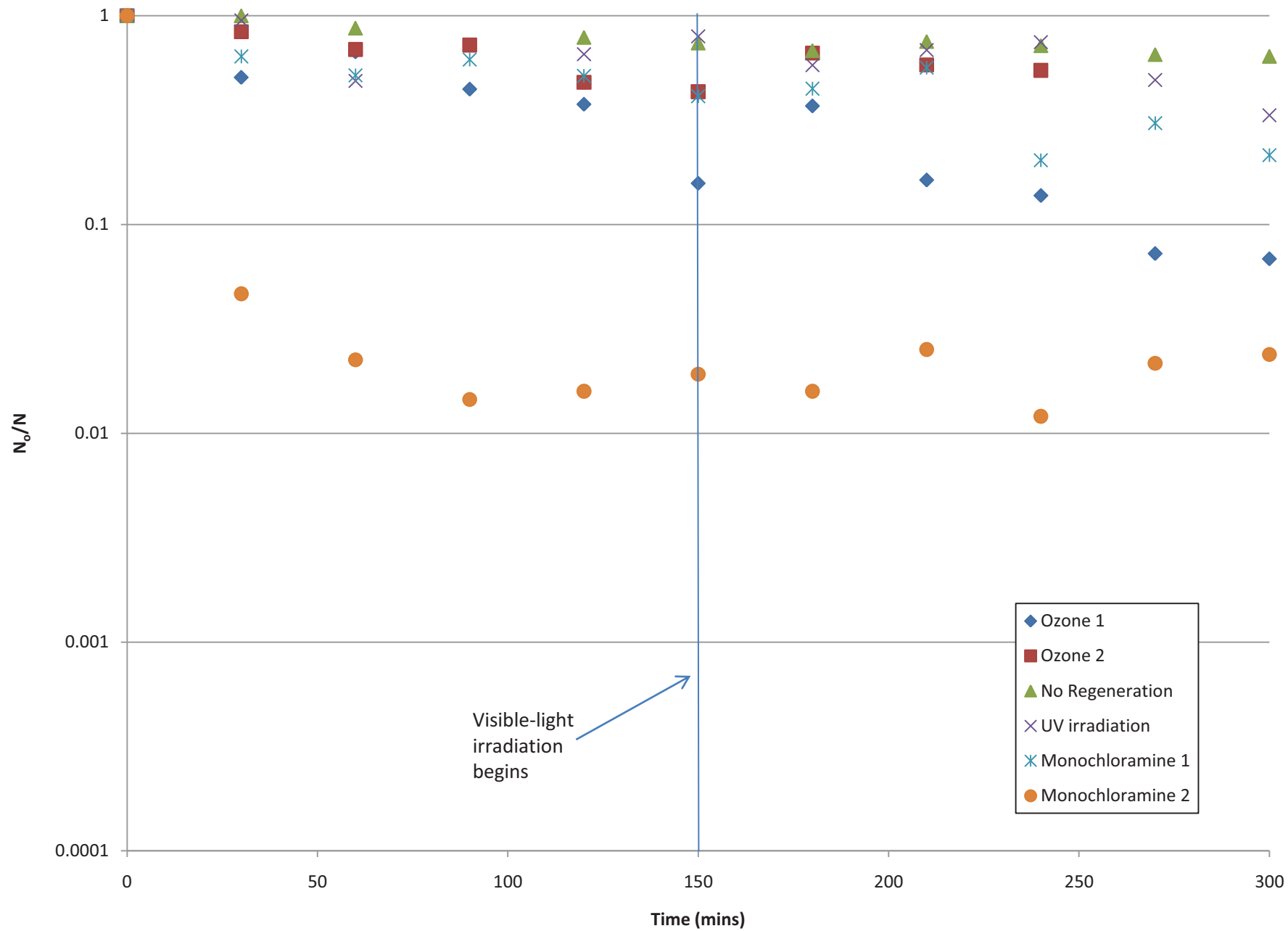
Experiment 7

pH
Temp 25 oC
Buffer 1mM CBS
Mass Cat 0.0558 grams
Volume 25 mL
Intensity ~450 W/m2
Filters > 400 nm, 10% Transmittance

Volume Virus Stock Added 0.125 mL

Plaques per 0.85 ml at 10 ^X dilution												pfu/ml	Time in	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	8	N	N/N ₀	Light (min)
dark	1	0						tntc	?	0	0	47712418.3	1	0
	2	30						17	?	?	0	2222222.22	0.046575	0
	3	60					82	?	5	2		1071895.42	0.022466	0
	4	90					53	?	?	0		692810.458	0.014521	0
	5	120					58	1	2	0		758169.935	0.01589	0
	6	150					70	6	0	0		915032.68	0.019178	0
	7	180					58	?	0	0		758169.935	0.01589	30
light	8	210				tntc	92	8	0			1202614.38	0.025205	60
	9	240				tntc	44	5	0			575163.399	0.012055	90
	10	270			tntc	tntc	79	1				1032679.74	0.021644	120
	11	300			tntc	tntc	87	4				1137254.9	0.023836	150





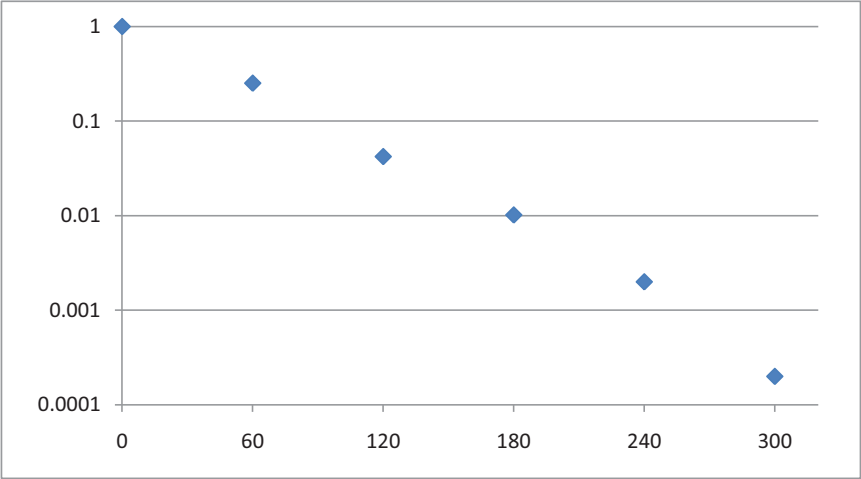
Appendix B**Regeneration Method: Ozone Day Before**

Fiber	Date	Notes
1	5.20.09	4-log removal
1	6.9.09	Contamination of hard agar
1	6.17.09	3-log removal
1	6.24.09	2.5-log removal
2	5.28.09	2-log removal
2	6.3.09	Contamination of hard agar
2	6.10.09	~1-log removal
2	6.23.09	~1-log removal
2	6.25.09	Less than 1-log removal
3	5.27.09	Less than 1-log removal
3	6.2.09	Fiber not in reactor for majority of experiment
3	6.16.09	Less than 1-log removal
3	6.18.09	Less than 1-log removal
3	6.30.09	Less than 1-log removal

38 Date 5/20/2009 Fiber 1 Experiment 8 Fiber 1 with ozone regeneration (ran day after ozonation)

pH 25 oC Volume Virus Stock Added 0.007 mL
Temp 25 oC
Buffer 1mM CBS
Mass Cat 0.0897 grams
Volume 25 mL
Intensity ~450 W/m2
Filters > 400 nm, 10% Transmittance

Plaques per 0.85 ml at 10^X dilution										pfu/ml	Time in		
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀	Light (min)
dark	1	0				tntc	350	55	5	1	7189542.5	1	0
	2	60				tntc	167	11	6	2	1810457.5	0.251818	0
	3	120				184	28	5	0	2	303267.97	0.042182	0
light	4	180			tntc	56	0	1	1		73202.614	0.010182	0
	5	240			50	17	1	2	2		14379.085	0.002	0
	6	300			11	0	1	1			1437.9085	0.0002	0



Date6/9/2009Ran Day after ozonation

Fiber1

Experiment13

pH

Temp25oC

Buffer1mM CBS

Mass Cat0.0897grams

Volume25mL

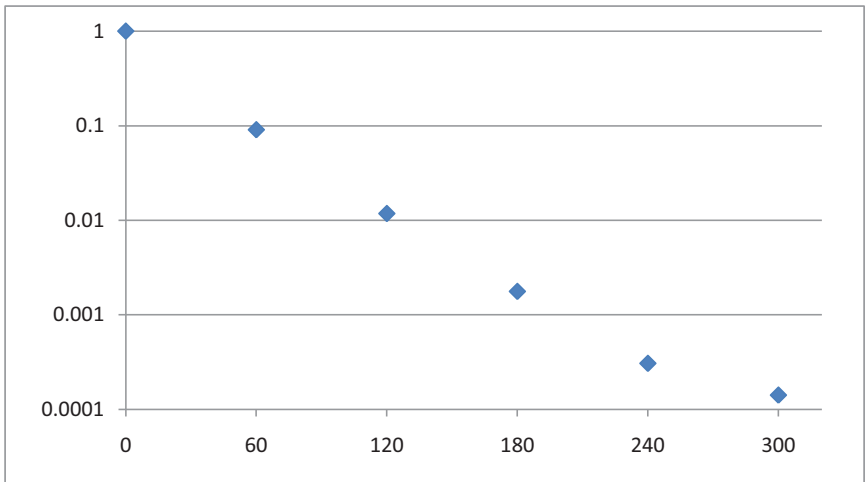
Intensity~450W/m2

Filters> 400 nm, 10% Transmittance

Volume Virus Stock Added0.007 mL

Plaques per 0.85 ml at 10^X dilution										pfu/ml	Time in		
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀	Light (min)
dark	1	0				tntc	tntc	85	70*	9	11111111	1	0
	2	60				?	77	5	11	7	1006535.9	0.090588	0
	3	120				100	28*	1	5	6	130718.95	0.011765	0
	4	180			150	36*	1	2	0		19607.843	0.001765	0
light	5	240			26	3	0	0	34*		3398.6928	0.000306	0
	6	300			12	0*	0	0			1568.6275	0.000141	0

*****Possible Contamination (*)



40

Date6/17/2009Fiber1Experiment16

Fiber1Experiment16

Fiber 1 with ozone regeneration (ran day after ozonation)

pHTempBufferMass CatVolumeIntensityFilters

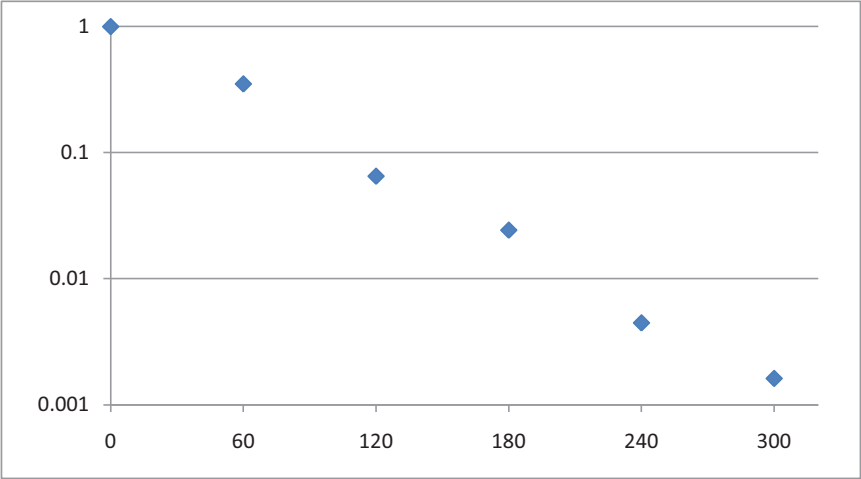
251mM CBS0.089725~450> 400 nm, 10% Transmittance

oCgrams mLW/m2

Volume Virus Stock Added

0.007 mL

Plaques per 0.85 ml at 10^X dilution											pfu/ml	Time in	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀	Light (min)
dark	1	0				tntc	300+	37	4	1	4836601.3	1	0
	2	60				tntc	110	15	1	0	1699346.4	0.351351	0
	3	120				262	22	4	0	0	315032.68	0.065135	0
	4	180			tntc	90	8	0	0		117647.06	0.024324	0
light	5	240			141	19	1	0	0		21633.987	0.004473	0
	6	300			60	4	1	0			7843.1373	0.001622	0



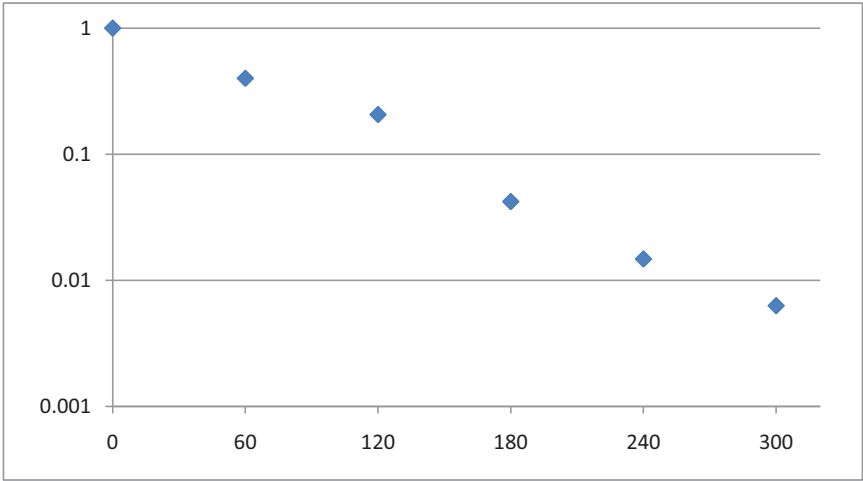
Date6/24/2009Fiber1Experiment19

Ran day after ozonation

pHTemp25 oCBuffer1mM CBSMass Cat0.0897 gramsVolume25 mLIntensity~450 W/m2Filters> 400 nm, 10% Transmittance

Volume Virus Stock Added0.007 mL

Plaques per 0.85 ml at 10^X dilution											pfu/ml	Time in	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀	Light (min)
dark	1	0				tntc	tntc	46	2	0	6013071.9	1	0
	2	60				tntc	168	20	2	0	2405228.8	0.4	0
	3	120				tntc	95	7	0	0	1241830.1	0.206522	0
	4	180			tntc	238	15	3	1		253594.77	0.042174	0
light	5	240			tntc	68	8	0	0		88888.889	0.014783	0
	6	300			304	29	2	0			37908.497	0.006304	0

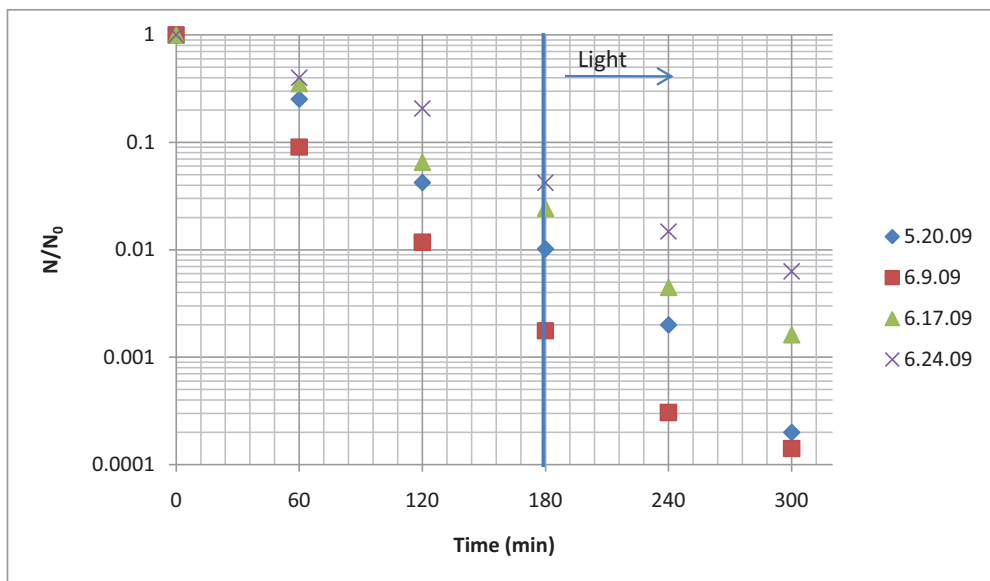


Date 7/13/2009 Ran day after ozonation
 Fiber 1
 Experiment

pH
 Temp 25 oC
 Buffer 1mM CBS
 Mass Cat 0.0897 grams
 Volume 25 mL
 Intensity ~450 W/m2
 Filters > 400 nm, 10% Transmittance

Volume Virus Stock Added 0.007 mL

Plaques per 0.85 ml at 10^X dilution											pfu/ml	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
dark	1	0				tntc	350	55	5	1	7189542.48	1
	2	60				tntc	167	11	6	2	1810457.52	0.251818
	3	120				184	28	5	0	2	303267.974	0.042182
	4	180			tntc	56	0	1	1		73202.6144	0.010182
light	5	240			50	17	1	2	2		14379.085	0.002
	6	300			11	0	1	1			1437.9085	0.0002
dark	1	0				tntc	tntc	85	70*	9	11111111.1	1
	2	60				?	77	5	11	7	1006535.95	0.090588
	3	120				100	28*	1	5	6	130718.954	0.011765
	4	180			150	36*	1	2	0		19607.8431	0.001765
light	5	240			26	3	0	0	34*		3398.69281	0.000306
	6	300			12	0*	0	0			1568.62745	0.000141
dark	1	0				tntc	300+	37	4	1	4836601.31	1
	2	60				tntc	110	15	1	0	1699346.41	0.351351
	3	120				262	22	4	0	0	315032.68	0.065135
	4	180			tntc	90	8	0	0		117647.059	0.024324
light	5	240			141	19	1	0	0		21633.9869	0.004473
	6	300			60	4	1	0			7843.13725	0.001622
dark	1	0				tntc	tntc	46	2	0	6013071.9	1
	2	60				tntc	168	20	2	0	2405228.76	0.4
	3	120				tntc	95	7	0	0	1241830.07	0.206522
	4	180			tntc	238	15	3	1		253594.771	0.042174
light	5	240			tntc	68	8	0	0		88888.8889	0.014783
	6	300			304	29	2	0			37908.4967	0.006304



Date
Fiber
Experiment

1

Ran day after ozonation

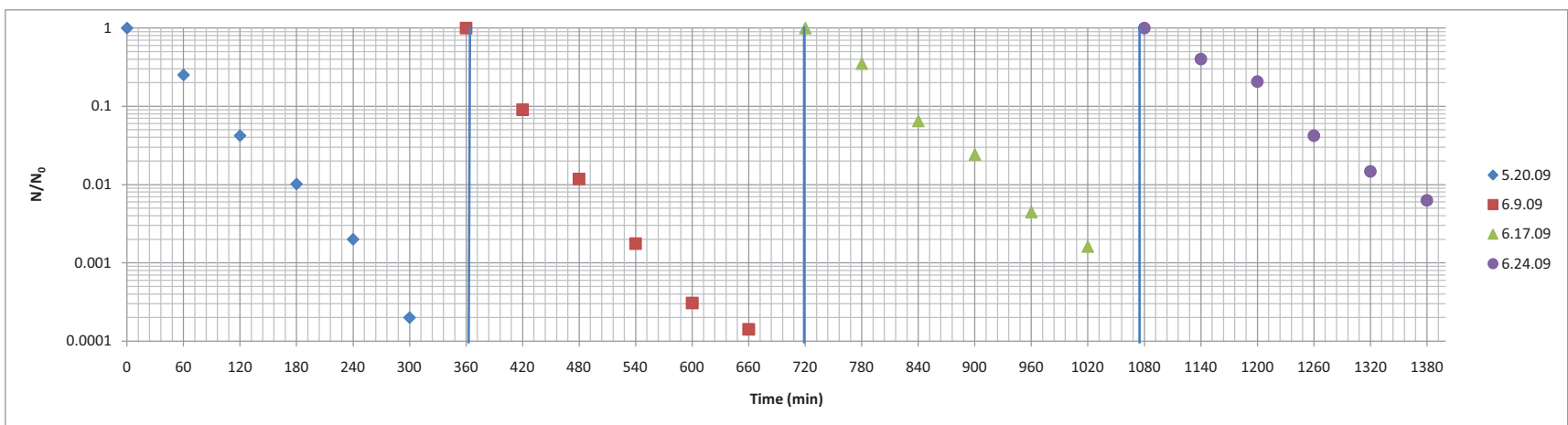
pH
Temp 25 oC
Buffer 1mM CBS
Mass Cat 0.0897 grams
Volume 25 mL
Intensity ~450 W/m2
Filters > 400 nm, 10% Transmittance

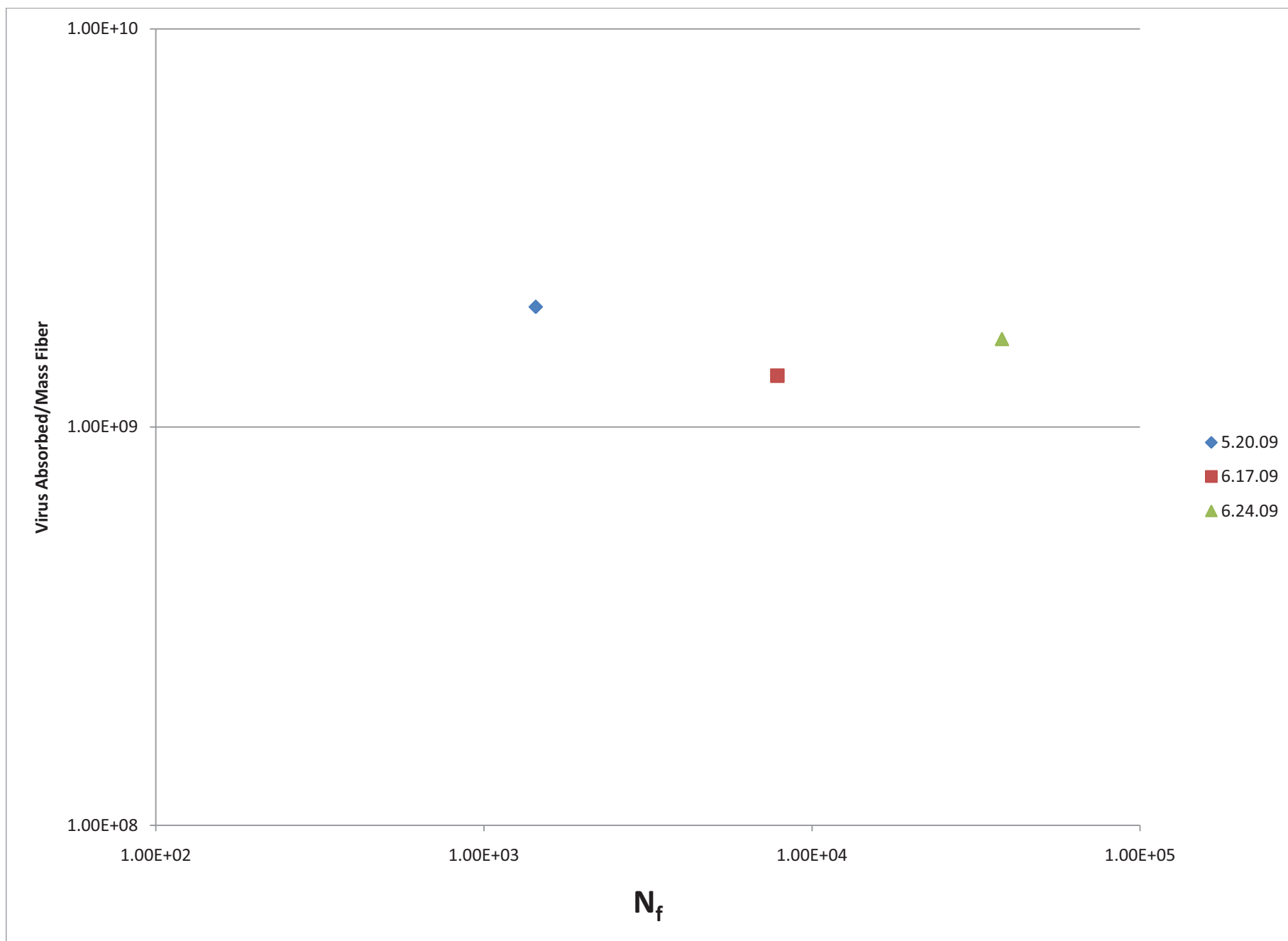
Volume Virus Stock Added

0.007 mL

Plaques per 0.85 ml at 10 ^{^X} dilution											
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	pfu/ml N
	1	0				tntc	350	55	5	1	7189542.48
dark	2	60				tntc	167	11	6	2	1810457.52
	3	120					184	28	5	0	303267.974
	4	180			tntc	56	0	1	1		73202.6144
light	5	240			50	17	1	2	2		14379.085
	6	300			11	0	1	1			1437.9085
	1	360				tntc	tntc	85	70*	9	11111111.1
dark	2	420				?	77	5	11	7	1006535.95
	3	480				100	28*	1	5	6	130718.954
	4	540			150	36*	1	2	0		19607.8431
light	5	600			26	3	0	0	34*		3398.69281
	6	660			12	0*	0	0			1568.62745
	1	720				tntc	300+	37	4	1	4836601.31
dark	2	780				tntc	110	15	1	0	1699346.41
	3	840				262	22	4	0	0	315032.68
	4	900			tntc	90	8	0	0		117647.059
light	5	960			141	19	1	0	0		21633.9869
	6	1020			60	4	1	0			7843.13725
	1	1080				tntc	tntc	46	2	0	6013071.9
dark	2	1140				tntc	168	20	2	0	2405228.76
	3	1200				tntc	95	7	0	0	1241830.07
	4	1260			tntc	238	15	3	1		253594.771
light	5	1320			tntc	68	8	0	0		88888.8889
	6	1380			304	29	2	0			37908.4967

N/N₀



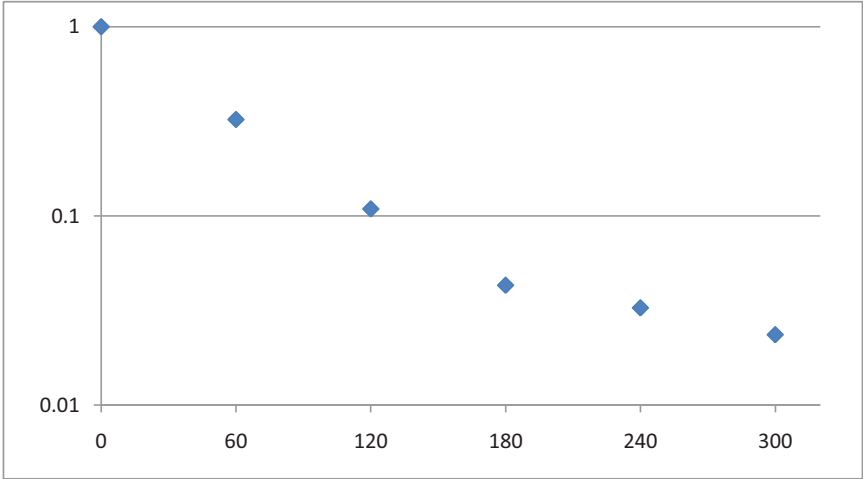


Date 5/28/2009
Fiber 2
Experiment 10

pH
Temp 25 oC
Buffer 1mM CBS
Mass Cat 0.0377 grams
Volume 25 mL
Intensity ~450 W/m2
Filters > 400 nm, 10% Transmittance

Volume Virus Stock Added 0.007 mL

Plaques per 0.85 ml at 10^X dilution										pfu/ml	Time in		
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀	Light (min)
dark	1	0				tntc	tntc	45	6	0	5882352.9	1	0
	2	60				tntc	121	17	0	1	1901960.8	0.323333	0
	3	120				tntc	49	6	0	35*	640522.88	0.108889	0
	4	180			tntc	247	14	3	1		252941.18	0.043	0
light	5	240			tntc	164	13	3	0		192156.86	0.032667	0
	6	300			tntc	106	4	3			138562.09	0.023556	0



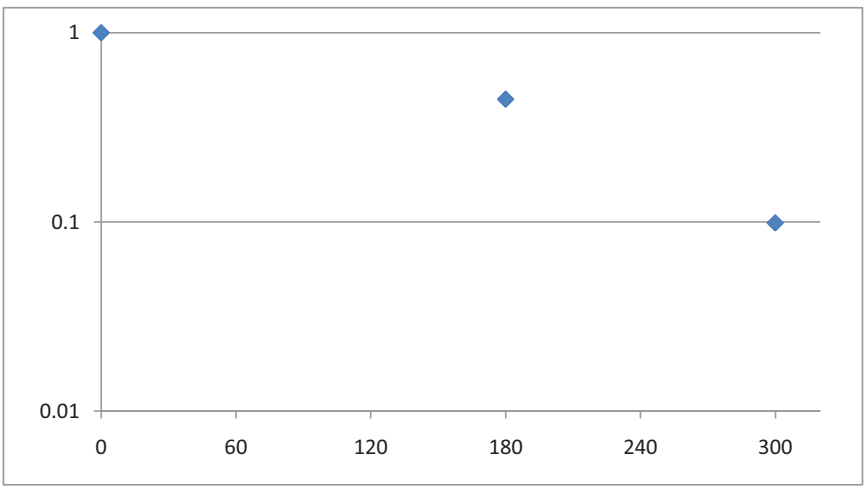
Date 6/3/2009 Ran Day after ozonation
Fiber 2
Experiment 12

pH
Temp 25 oC
Buffer 1mM CBS
Mass Cat 0.0377 grams
Volume 25 mL
Intensity ~450 W/m2
Filters > 400 nm, 10% Transmittance

Volume Virus Stock Added 0.007 mL

Plaques per 0.85 ml at 10^X dilution										pfu/ml	Time in		
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀	Light (min)
dark	1	0				XXX	tntc	101	5	1	13202614	1	0
	2	60				XXX	tntc	XXX	14	75*	#VALUE!	#VALUE!	0
	3	120				tntc	XXX	XXX	10	8	#VALUE!	#VALUE!	0
	4	180			tntc	XXX	XXX	45	10	2	5882352.9	0.445545	0
light	5	240			tntc	tntc	184	53*	6*		#VALUE!	#VALUE!	0
	6	300			XXX	tntc	108	10			1307189.5	0.09901	0

*****Contamination on hard agar plates



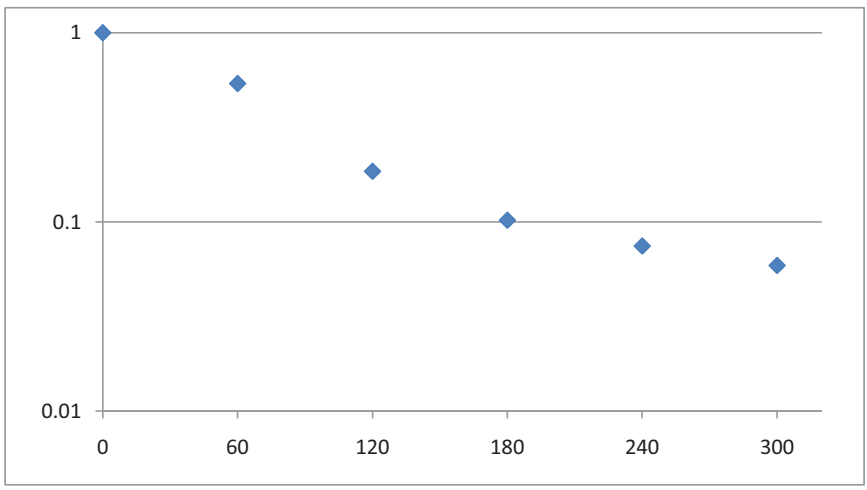
Date6/10/2009Fiber2Experiment14

Ran Day after ozonation

pHTemp25oCBuffer1mM CBSMass Cat0.0377gramsVolume25mLIntensity~450W/m2Filters> 400 nm, 10% Transmittance

Volume Virus Stock Added0.007 mL

Plaques per 0.85 ml at 10^X dilution										pfu/ml		Time in	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀	Light (min)
dark	1	0				tntc	tntc	126	23	35*	23267974	1	0
	2	60				tntc	300+	72	12	4/24*	12549020	0.539326	0
	3	120				tntc	313	33	cont.	cont.	4313725.5	0.185393	0
	4	180			tntc	tntc	182	cont.	cont.		2379085	0.102247	0
light	5	240			tntc	tntc	133	cont.	cont.		1738562.1	0.074719	0
	6	300		tntc	tntc	300+	105	9			1372549	0.058989	0



Date6/23/2009

Fiber2

Experiment18

Ran day after ozonation

pH

Temp25

Buffer1mM CBS

Mass Cat0.0377

Volume25

Intensity~450

Filters> 400 nm, 10% Transmittance

Volume Virus Stock Added

0.007 mL

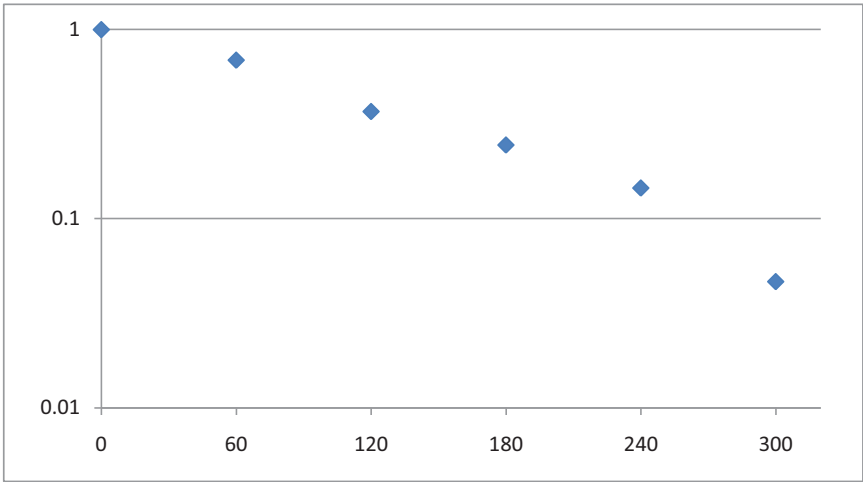
oC

grams

mL

W/m2

Plaques per 0.85 ml at 10^X dilution											pfu/ml	Time in	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀	Light (min)
dark	1	0				tntc	tntc	51	6	0	6666666.7	1	0
	2	60				tntc	323	38	5	1	4594771.2	0.689216	0
	3	120				tntc	166	21	0	0	2457516.3	0.368627	0
	4	180			tntc	tntc	110	14	2		1633986.9	0.245098	0
light	5	240			tntc	tntc	74	4	1		967320.26	0.145098	0
	6	300			tntc	203	27	3			309150.33	0.046373	0



Date6/25/2009

Fiber2

Experiment20

Ran day after ozonation

pH

Temp25

Buffer1mM CBS

Mass Cat0.0377

Volume25

Intensity~450

Filters> 400 nm, 10% Transmittance

Volume Virus Stock Added

0.007 mL

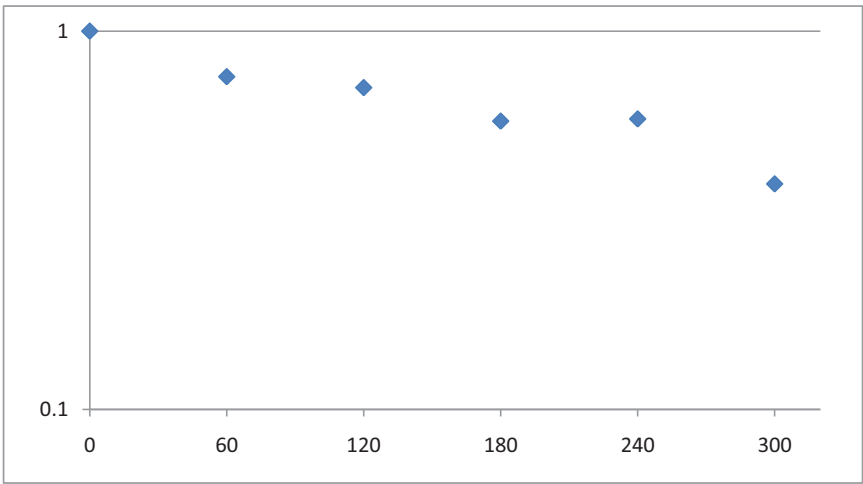
oC

grams

mL

W/m2

Plaques per 0.85 ml at 10^X dilution										pfu/ml	Time in		
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀	Light (min)
dark	1	0				tntc	242	27	1	1	3346405.2	1	0
	2	60				tntc	178	21	2	0	2535947.7	0.757813	0
	3	120				tntc	193	17	1	0	2372549	0.708984	0
	4	180			tntc	tntc	156	14	6		1934640.5	0.578125	0
light	5	240			tntc	tntc	150	15	1		1960784.3	0.585938	0
	6	300			tntc	tntc	101	13			1320261.4	0.394531	0

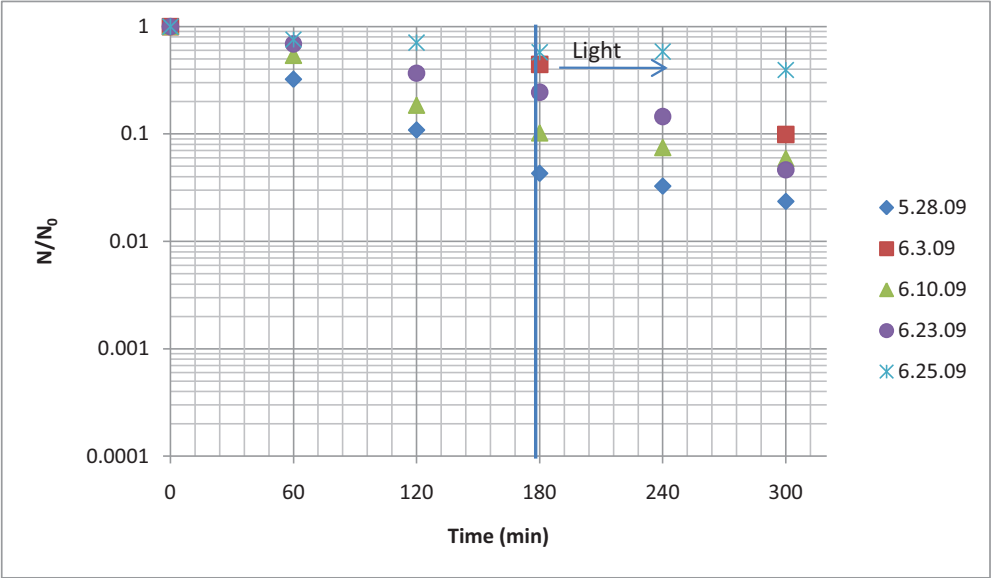


Date Various Ran day after ozonation
 Fiber 2
 Experiment

pH
 Temp 25 oC
 Buffer 1mM CBS
 Mass Cat 0.0377 grams
 Volume 25 mL
 Intensity ~450 W/m2
 Filters > 400 nm, 10% Transmittance

Volume Virus Stock Added 0.007 mL

Plaques per 0.85 ml at 10^X dilution										pfu/ml		
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
dark	1	0				tntc	tntc	45	6	0	5882352.94	1
	2	60				tntc	121	17	0	1	1901960.78	0.3233333
	3	120				tntc	49	6	0	35*	640522.876	0.1088889
	4	180			tntc	247	14	3	1		252941.176	0.043
light	5	240			tntc	164	13	3	0		192156.863	0.0326667
	6	300			tntc	106	4	3			138562.092	0.0235556
dark	1	0				XXX	tntc	101	5	1	13202614.4	1
	2	60				XXX	tntc	XXX	14	75*	#VALUE!	#VALUE!
	3	120				tntc	XXX	XXX	10	8	#VALUE!	#VALUE!
light	4	180			tntc	XXX	XXX	45	10	2	5882352.94	0.4455446
	5	240			tntc	tntc	184	53*	6*		#VALUE!	#VALUE!
	6	300			XXX	tntc	108	10			1307189.54	0.0990099
dark	1	0				tntc	tntc	126	23	35*	23267973.9	1
	2	60				tntc	300+	72	12	4/24*	12549019.6	0.5393258
	3	120				tntc	313	33	cont.	cont.	4313725.49	0.1853933
light	4	180			tntc	tntc	182	cont.	cont.		2379084.97	0.1022472
	5	240			tntc	tntc	133	cont.	cont.		1738562.09	0.0747191
	6	300		tntc	tntc	300+	105	9			1372549.02	0.0589888
dark	1	0				tntc	tntc	51	6	0	6666666.67	1
	2	60				tntc	323	38	5	1	4594771.24	0.6892157
	3	120				tntc	166	21	0	0	2457516.34	0.3686275
	4	180			tntc	tntc	110	14	2		1633986.93	0.245098
light	5	240			tntc	tntc	74	4	1		967320.261	0.145098
	6	300			tntc	203	27	3			309150.327	0.0463725
dark	1	0				tntc	242	27	1	1	3346405.23	1
	2	60				tntc	178	21	2	0	2535947.71	0.7578125
	3	120				tntc	193	17	1	0	2372549.02	0.7089844
light	4	180			tntc	tntc	156	14	6		1934640.52	0.578125
	5	240			tntc	tntc	150	15	1		1960784.31	0.5859375
	6	300			tntc	tntc	101	13			1320261.44	0.3945313

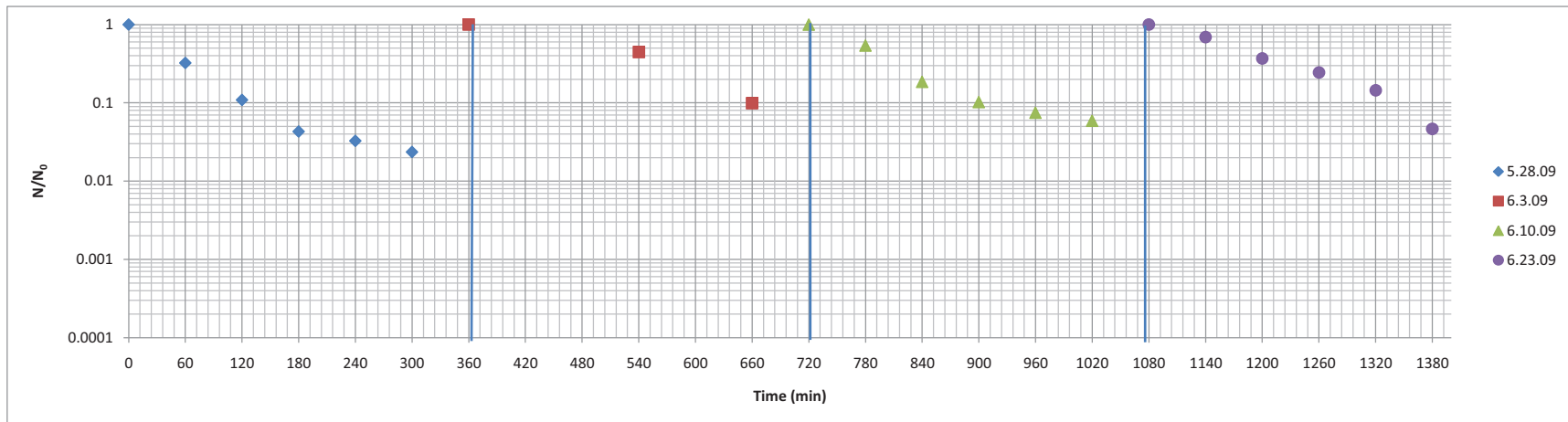


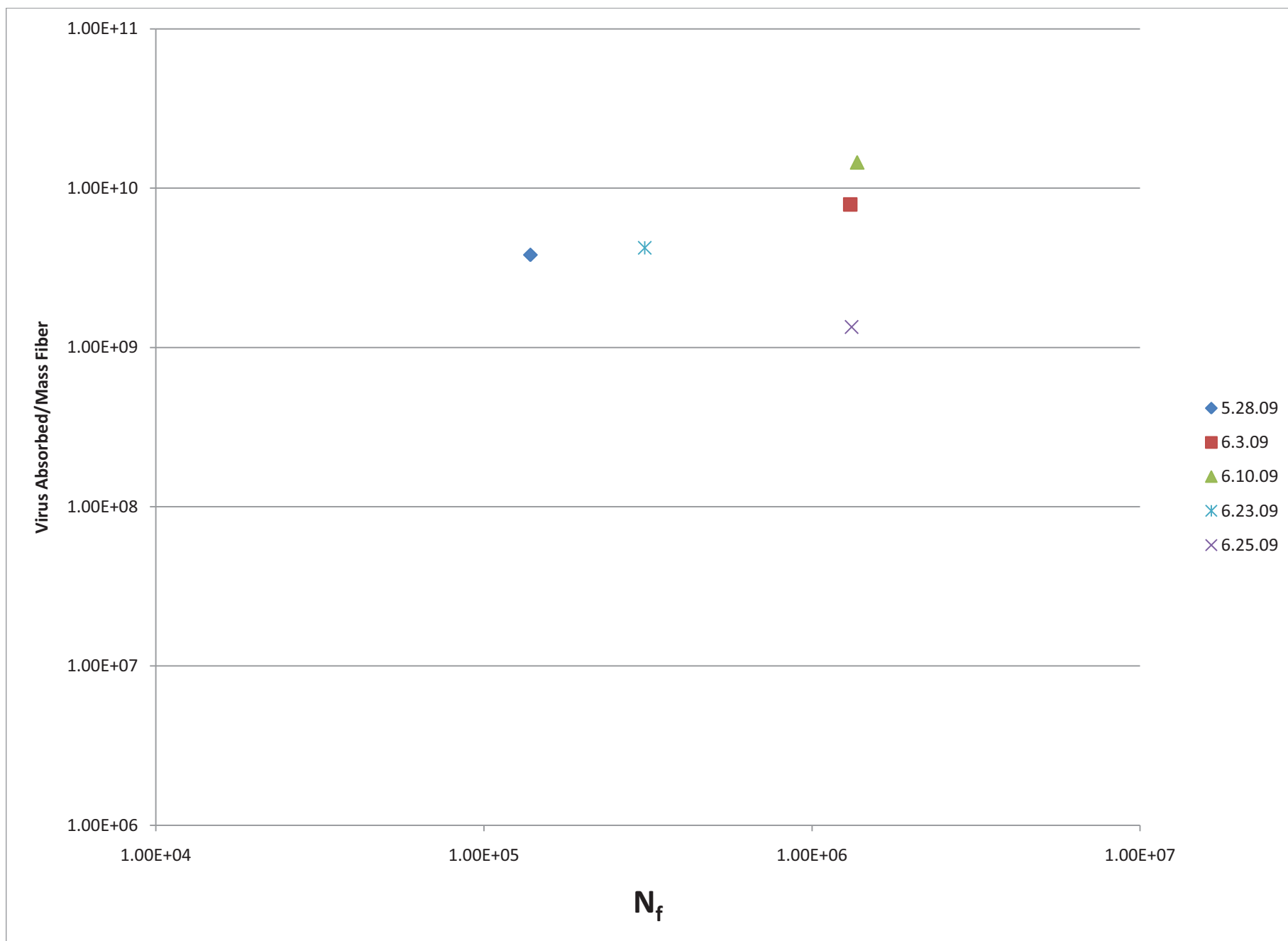
Date Various
Fiber 2
Experiment Ran day after ozonation

pH
Temp 25 oC
Buffer 1mM CBS
Mass Cat 0.0377 grams
Volume 25 mL
Intensity ~450 W/m2
Filters > 400 nm, 10% Transmittance

Volume Virus Stock Added 0.007 mL

Plaques per 0.85 ml at 10^X dilution											pfu/ml	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
dark	1	0				tntc	tntc	45	6	0	5882352.94	1
	2	60				tntc	tntc	121	17	0	1901960.78	0.3233333
	3	120					tntc	49	6	0	640522.876	0.1088889
	4	180			tntc	247	14	3	1	35*	252941.176	0.043
light	5	240			tntc	164	13	3	0		192156.863	0.0326667
	6	300			tntc	106	4	3			138562.092	0.0235556
	1	360				XXX	tntc	101	5	1	13202614.4	1
	2	420				XXX	tntc	XXX	14	75*	#VALUE!	#VALUE!
dark	3	480				tntc	tntc	XXX	10	8	#VALUE!	#VALUE!
	4	540			tntc	XXX	XXX	45	10	2	5882352.94	0.4455446
	5	600			tntc	tntc	184	53*	6*		#VALUE!	#VALUE!
	6	660			XXX	tntc	108	10			1307189.54	0.0990099
light	1	720				tntc	tntc	126	23	35*	23267973.9	1
	2	780				tntc	300+	72	12	4/24*	12549019.6	0.5393258
	3	840				tntc	313	33	cont.	cont.	4313725.49	0.1853933
	4	900			tntc	tntc	182	cont.	cont.		2379084.97	0.1022472
dark	5	960			tntc	tntc	133	cont.	cont.		1738562.09	0.0747191
	6	1020		tntc	tntc	300+	105	9			1372549.02	0.0589888
	1	1080				tntc	tntc	51	6	0	6666666.67	1
	2	1140				tntc	323	38	5	1	4594771.24	0.6892157
light	3	1200				tntc	166	21	0	0	2457516.34	0.3686275
	4	1260			tntc	tntc	110	14	2		1633986.93	0.245098
	5	1320			tntc	tntc	74	4	1		967320.261	0.145098
	6	1380			tntc	203	27	3			309150.327	0.0463725



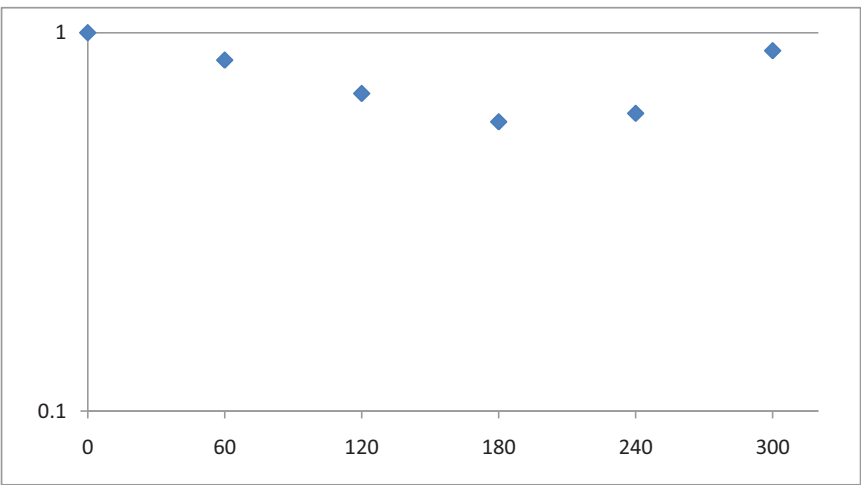


Date 5/27/2009 Fiber 3 with ozone regeneration (ran 8 days after ozonation)
Fiber 3
Experiment 9

pH
Temp 25 oC
Buffer 1mM CBS
Mass Cat 0.0468 grams
Volume 25 mL
Intensity ~450 W/m2
Filters > 400 nm, 10% Transmittance

Volume Virus Stock Added 0.007 mL

Plaques per 0.85 ml at 10^X dilution											pfu/ml	Time in	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀	Light (min)
dark	1	0				tntc	231	29	4	1	3405228.8	1	0
	2	60				tntc	171	27	11	0	2882352.9	0.846449	0
	3	120				tntc	180	18	2	1	2352941.2	0.690979	0
	4	180			tntc	tntc	133	17	2		1980392.2	0.581574	0
light	5	240			tntc	tntc	139	18	2		2084967.3	0.612284	0
	6	300			tntc	tntc	167	30			3052287.6	0.896353	0



Date6/2/2009Ran Day after ozonation

Fiber3

Experiment11

pH

Temp25oC

Buffer1mM CBS

Mass Cat0.0468grams

Volume25mL

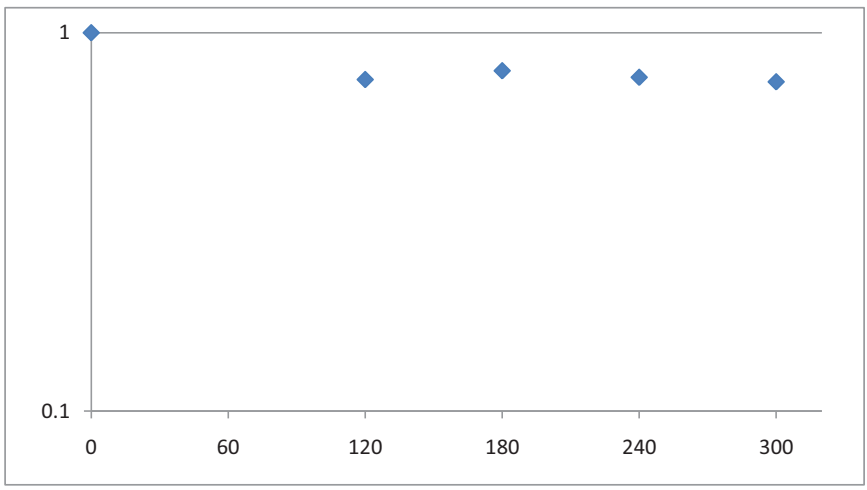
Intensity~450W/m2

Filters> 400 nm, 10% Transmittance

Volume Virus Stock Added0.007 mL

Plaques per 0.85 ml at 10^X dilution											pfu/ml	Time in	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀	Light (min)
dark	1	0				tntc	tntc	97	9	3	12679739	1	0
	2	60				tntc	tntc	98	11	1	12810458	1.010309	0
	3	120				tntc	tntc	73	10	cont.	9542483.7	0.752577	0
	4	180			tntc	tntc	tntc	77	6	2	10065359	0.793814	0
light	5	240			tntc	tntc	tntc	74	7		9673202.6	0.762887	0
	6	300			tntc	tntc	tntc	72			9411764.7	0.742268	0

*****Fiber not in reactor for samples 1-4



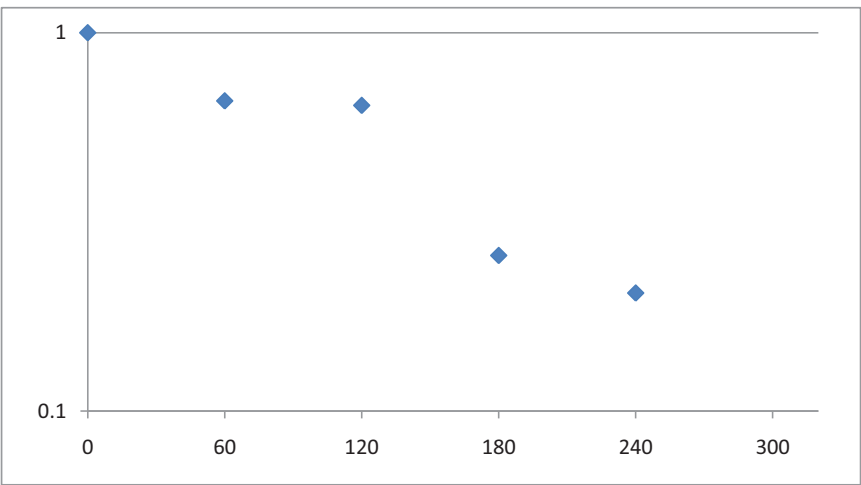
Date6/16/2009Fiber3Experiment15

Ran Day after ozonation

pHTemp25oCBuffer1mM CBSMass Cat0.0468gramsVolume25mLIntensity~450W/m2Filters> 400 nm, 10% Transmittance

Volume Virus Stock Added0.007 mL

Plaques per 0.85 ml at 10^X dilution											pfu/ml	Time in	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀	Light (min)
dark	1	0				tntc	tntc	56	6	3	7320261.4	1	0
	2	60				tntc	tntc	37	12	9	4836601.3	0.660714	0
	3	120				tntc	tntc	36	1	0	4705882.4	0.642857	0
	4	180			tntc	tntc	159	13	2		1888888.9	0.258036	0
light	5	240			tntc	tntc	100	13	8*		1503268	0.205357	0
	6	300		tntc	tntc	tntc	cont.	cont.			#VALUE!	#VALUE!	0

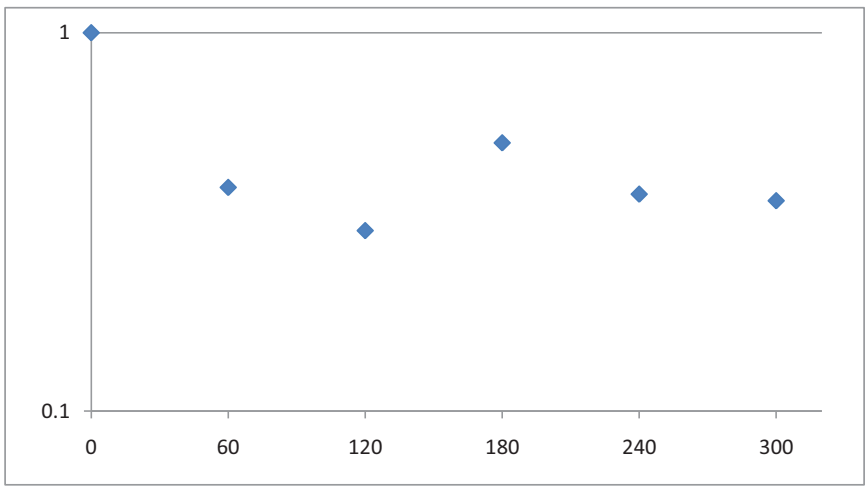


Date 6/18/2009 Ran day after ozonation
Fiber 3
Experiment 17

pH
Temp 25 oC
Buffer 1mM CBS
Mass Cat 0.0468 grams
Volume 25 mL
Intensity ~450 W/m2
Filters > 400 nm, 10% Transmittance

Volume Virus Stock Added 0.007 mL

Plaques per 0.85 ml at 10^X dilution											pfu/ml	Time in	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀	Light (min)
dark	1	0				tntc	tntc	51	10	3	6666666.7	1	0
	2	60				tntc	218	18	6	0	2601307.2	0.390196	0
	3	120				tntc	146	16	0	1	2000000	0.3	0
	4	180			tntc	tntc	262	26	3		3411764.7	0.511765	0
light	5	240			tntc	tntc	192	19	4		2496732	0.37451	0
	6	300			tntc	tntc	177	19			2398692.8	0.359804	0



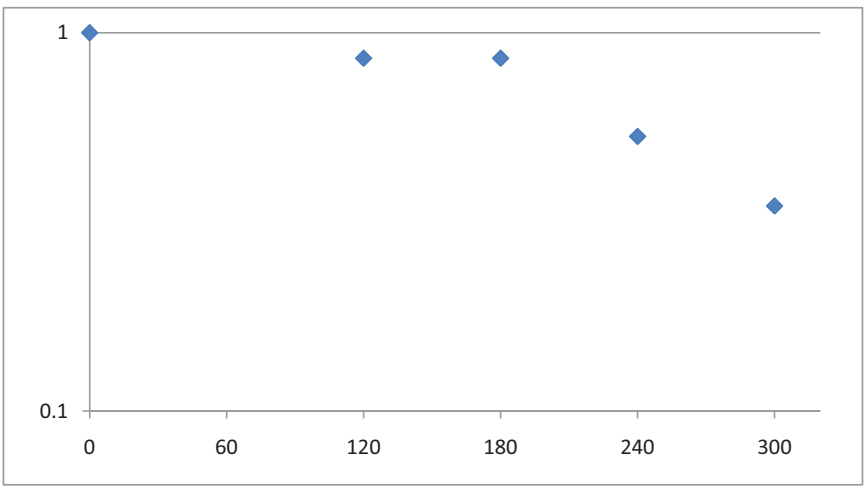
Date6/30/2009Fiber3Experiment21

Ran day after ozonation

pHTemp25 oCBuffer1mM CBSMass Cat0.0468 gramsVolume25 mLIntensity~450 W/m2Filters> 400 nm, 10% Transmittance

Volume Virus Stock Added0.007 mL

Plaques per 0.85 ml at 10^X dilution											pfu/ml	Time in	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀	Light (min)
dark	1	0				tntc	127	20	3	0	2137254.9	1	0
	2	60				tntc	164	24	2	0	2640522.9	1.235474	0
	3	120				tntc	140	14	1	0	1830065.4	0.856269	0
	4	180			tntc	tntc	140	14	3		1830065.4	0.856269	0
light	5	240			tntc	tntc	87	9	0		1137254.9	0.53211	0
	6	300			tntc	tntc	57	7			745098.04	0.348624	0

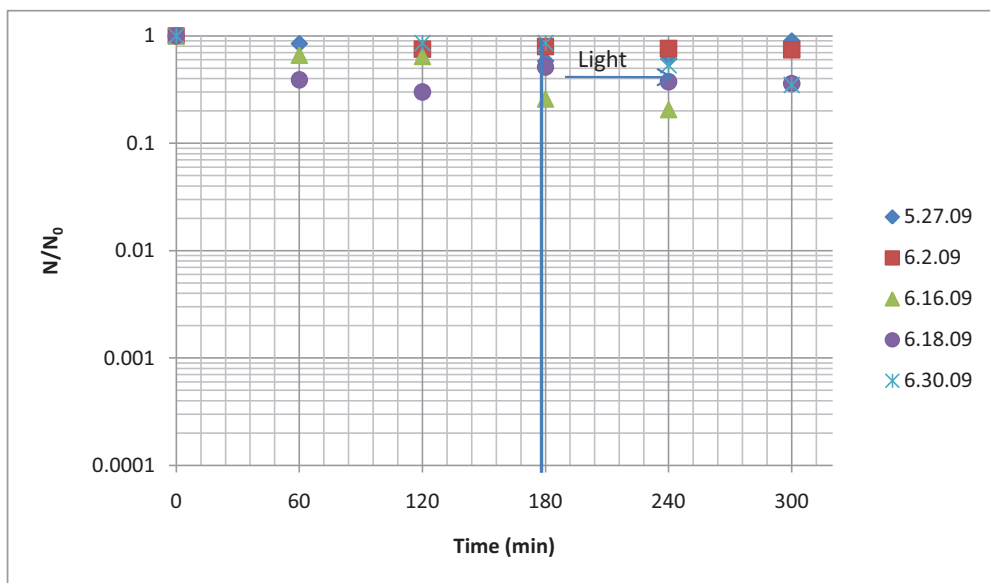


Date 7/13/2009 **Ran day after ozonation**
Fiber 3
Experiment

pH
Temp 25 oC
Buffer 1mM CBS
Mass Cat 0.0468 grams
Volume 25 mL
Intensity ~450 W/m2
Filters > 400 nm, 10% Transmittance

Volume Virus Stock Added 0.007 mL

Plaques per 0.85 ml at 10^X dilution										pfu/ml		
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
dark	1	0				tntc	231	29	4	1	3405228.76	1
	2	60				tntc	171	27	11	0	2882352.94	0.8464491
	3	120				tntc	180	18	2	1	2352941.18	0.6909789
	4	180			tntc	tntc	133	17	2		1980392.16	0.5815739
	5	240			tntc	tntc	139	18	2		2084967.32	0.6122841
	6	300			tntc	tntc	167	30			3052287.58	0.8963532
dark	1	0				tntc	tntc	97	9	3	12679738.6	1
	2	60				tntc	tntc	98	11	1	12810457.5	1.0103093
	3	120				tntc	tntc	73	10	cont.	9542483.66	0.7525773
	4	180			tntc	tntc	tntc	77	6	2	10065359.5	0.7938144
	5	240			tntc	tntc	tntc	74	7		9673202.61	0.7628866
	6	300			tntc	tntc	tntc	72			9411764.71	0.742268
dark	1	0				tntc	tntc	56	6	3	7320261.44	1
	2	60				tntc	tntc	37	12	9	4836601.31	0.6607143
	3	120				tntc	tntc	36	1	0	4705882.35	0.6428571
	4	180			tntc	tntc	159	13	2		1888888.89	0.2580357
	5	240			tntc	tntc	100	13	8*		1503267.97	0.2053571
	6	300		tntc	tntc	tntc	cont.	cont.			#VALUE!	#VALUE!
dark	1	0				tntc	tntc	51	10	3	6666666.67	1
	2	60				tntc	218	18	6	0	2601307.19	0.3901961
	3	120				tntc	146	16	0	1	2000000	0.3
	4	180			tntc	tntc	262	26	3		3411764.71	0.5117647
	5	240			tntc	tntc	192	19	4		2496732.03	0.3745098
	6	300			tntc	tntc	177	19			2398692.81	0.3598039
dark	1	0				tntc	127	20	3	0	2137254.9	1
	2	60				tntc	164	24	2	0	2640522.88	1.235474
	3	120				tntc	140	14	1	0	1830065.36	0.8562691
	4	180			tntc	tntc	140	14	3		1830065.36	0.8562691
	5	240			tntc	tntc	87	9	0		1137254.9	0.5321101
	6	300			tntc	tntc	57	7			745098.039	0.3486239

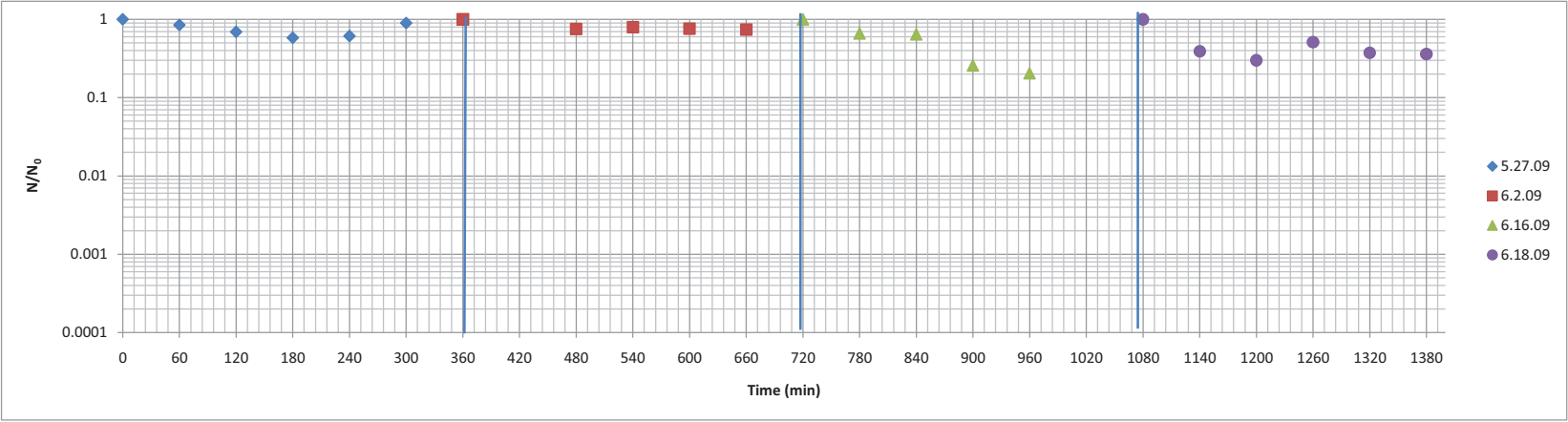


Date 7/13/2009 Ran day after ozonation
 Fiber 3
 Experiment

pH
 Temp 25 oC
 Buffer 1mM CBS
 Mass Cat 0.0468 grams
 Volume 25 mL
 Intensity ~450 W/m2
 Filters > 400 nm, 10% Transmittance

Volume Virus Stock Added 0.007 mL

Plaques per 0.85 ml at 10 ⁴ X dilution											pfu/ml	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
	1	0				tntc	231	29	4	1	3405228.76	1
dark	2	60				tntc	171	27	11	0	2882352.94	0.8464491
	3	120				tntc	180	18	2	1	2352941.18	0.6909789
	4	180			tntc	tntc	133	17	2		1980392.16	0.5815739
light	5	240			tntc	tntc	139	18	2		2084967.32	0.6122841
	6	300			tntc	tntc	167	30			3052287.58	0.8963532
	1	360				tntc	tntc	97	9	3	12679738.6	1
dark	2	420				tntc	tntc	98	11	1	12810457.5	1.0103093
	3	480				tntc	tntc	73	10	cont.	9542483.66	0.7525773
	4	540			tntc	tntc	tntc	77	6	2	10065359.5	0.7938144
light	5	600			tntc	tntc	tntc	74	7		9673202.61	0.7628866
	6	660			tntc	tntc	tntc	72			9411764.71	0.742268
	1	720				tntc	tntc	56	6	3	7320261.44	1
dark	2	780				tntc	tntc	37	12	9	4836601.31	0.6607143
	3	840				tntc	tntc	36	1	0	4705882.35	0.6428571
	4	900			tntc	tntc	159	13	2		1888888.89	0.2580357
light	5	960			tntc	tntc	100	13	8*		1503267.97	0.2053571
	6	1020		tntc	tntc	tntc	cont.	cont.			#VALUE!	#VALUE!
	1	1080				tntc	tntc	51	10	3	6666666.67	1
dark	2	1140				tntc	218	18	6	0	2601307.19	0.3901961
	3	1200				tntc	146	16	0	1	2000000	0.3
	4	1260			tntc	tntc	262	26	3		3411764.71	0.5117647
light	5	1320			tntc	tntc	192	19	4		2496732.03	0.3745098
	6	1380			tntc	tntc	177	19			2398692.81	0.3598039



Date 7/13/2009 **Ran day after ozonation**
Fiber 3
Experiment

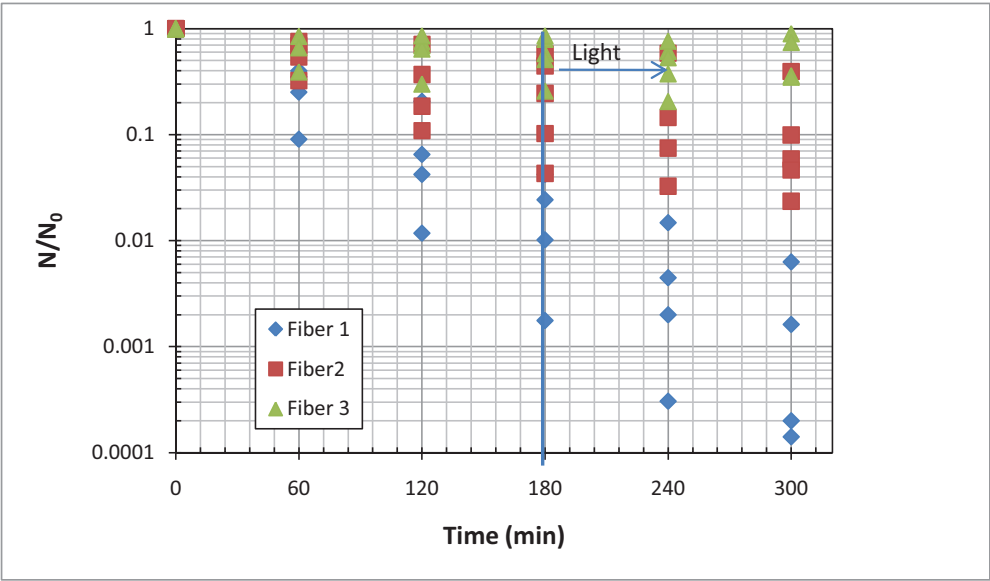
pH
Temp 25 oC
Buffer 1mM CBS
Mass Cat 0.0468 grams
Volume 25 mL
Intensity ~450 W/m2
Filters > 400 nm, 10% Transmittance

Volume Virus Stock Added 0.007 mL

Plaques per 0.85 ml at 10^X dilution											pfu/ml	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
dark	1	0				tntc	231	29	4	1	3405228.76	1
	2	60				tntc	171	27	11	0	2882352.94	0.8464491
	3	120				tntc	180	18	2	1	2352941.18	0.6909789
	4	180			tntc	tntc	133	17	2		1980392.16	0.5815739
light	5	240			tntc	tntc	139	18	2		2084967.32	0.6122841
	6	300			tntc	tntc	167	30			3052287.58	0.8963532
dark	1	0				tntc	tntc	97	9	3	12679738.6	1
	2	60				tntc	tntc	98	11	1	12810457.5	1.0103093
	3	120				tntc	tntc	73	10	cont.	9542483.66	0.7525773
	4	180			tntc	tntc	tntc	77	6	2	10065359.5	0.7938144
light	5	240			tntc	tntc	tntc	74	7		9673202.61	0.7628866
	6	300			tntc	tntc	tntc	72			9411764.71	0.742268
dark	1	0				tntc	tntc	56	6	3	7320261.44	1
	2	60				tntc	tntc	37	12	9	4836601.31	0.6607143
	3	120				tntc	tntc	36	1	0	4705882.35	0.6428571
	4	180			tntc	tntc	159	13	2		1888888.89	0.2580357
light	5	240			tntc	tntc	100	13	8*		1503267.97	0.2053571
	6	300		tntc	tntc	tntc	cont.	cont.			#VALUE!	#VALUE!
dark	1	0				tntc	tntc	51	10	3	6666666.67	1
	2	60				tntc	218	18	6	0	2601307.19	0.3901961
	3	120				tntc	146	16	0	1	2000000	0.3
	4	180			tntc	tntc	262	26	3		3411764.71	0.5117647
light	5	240			tntc	tntc	192	19	4		2496732.03	0.3745098
	6	300			tntc	tntc	177	19			2398692.81	0.3598039
dark	1	0				tntc	127	20	3	0	2137254.9	1
	2	60				tntc	164	24	2	0	2640522.88	1.235474
	3	120				tntc	140	14	1	0	1830065.36	0.8562691
	4	180			tntc	tntc	140	14	3		1830065.36	0.8562691
light	5	240			tntc	tntc	87	9	0		1137254.9	0.5321101

light	6	300	tntc	tntc	57	7			745098.039	0.3486239
	1	0		tntc	tntc	45	6	0	5882352.94	1
dark	2	60		tntc	121	17	0	1	1901960.78	0.3233333
	3	120		tntc	49	6	0	35*	640522.876	0.1088889
	4	180	tntc	247	14	3	1		252941.176	0.043
light	5	240	tntc	164	13	3	0		192156.863	0.0326667
	6	300	tntc	106	4	3			138562.092	0.0235556
	1	0		XXX	tntc	101	5	1	13202614.4	1
dark	2	60		XXX	tntc	XXX	14	75*	#VALUE!	#VALUE!
	3	120		tntc	XXX	XXX	10	8	#VALUE!	#VALUE!
	4	180	tntc	XXX	XXX	45	10	2	5882352.94	0.4455446
light	5	240	tntc	tntc	184	53*	6*		#VALUE!	#VALUE!
	6	300	XXX	tntc	108	10			1307189.54	0.0990099
	1	0		tntc	tntc	126	23	35*	23267973.9	1
dark	2	60		tntc	300+	72	12	4/24*	12549019.6	0.5393258
	3	120		tntc	313	33	cont.	cont.	4313725.49	0.1853933
	4	180	tntc	tntc	182	cont.	cont.		2379084.97	0.1022472
light	5	240	tntc	tntc	133	cont.	cont.		1738562.09	0.0747191
	6	300	tntc	tntc	300+	105	9		1372549.02	0.0589888
	1	0		tntc	tntc	51	6	0	6666666.67	1
dark	2	60		tntc	323	38	5	1	4594771.24	0.6892157
	3	120		tntc	166	21	0	0	2457516.34	0.3686275
	4	180	tntc	tntc	110	14	2		1633986.93	0.245098
light	5	240	tntc	tntc	74	4	1		967320.261	0.145098
	6	300	tntc	203	27	3			309150.327	0.0463725
	1	0		tntc	242	27	1	1	3346405.23	1
dark	2	60		tntc	178	21	2	0	2535947.71	0.7578125
	3	120		tntc	193	17	1	0	2372549.02	0.7089844
	4	180	tntc	tntc	156	14	6		1934640.52	0.578125
light	5	240	tntc	tntc	150	15	1		1960784.31	0.5859375
	6	300	tntc	tntc	101	13			1320261.44	0.3945313
	1	0		tntc	350	55	5	1	7189542.48	1
dark	2	60		tntc	167	11	6	2	1810457.52	0.2518182
	3	120			184	28	5	2	303267.974	0.0421818
	4	180	tntc	56	0	1	1		73202.6144	0.0101818
light	5	240	50	17	1	2	2		14379.085	0.002
	6	300	11	0	1	1			1437.9085	0.0002
	1	0		tntc	tntc	85	70*	9	11111111.1	1
dark	2	60		?	77	5	11	7	1006535.95	0.0905882
	3	120		100	28*	1	5	6	130718.954	0.0117647
	4	180	150	36*	1	2	0		19607.8431	0.0017647
light	5	240	26	3	0	0	34*		3398.69281	0.0003059
	6	300	12	0*	0	0			1568.62745	0.0001412
	1	0		tntc	300+	37	4	1	4836601.31	1

dark	2	60		tntc	110	15	1	0	1699346.41	0.3513514
	3	120			262	22	4	0	315032.68	0.0651351
	4	180	tntc	90	8	0	0		117647.059	0.0243243
light	5	240		141	19	1	0	0	21633.9869	0.004473
	6	300		60	4	1	0		7843.13725	0.0016216
	1	0		tntc	tntc	46	2	0	6013071.9	1
dark	2	60		tntc	168	20	2	0	2405228.76	0.4
	3	120		tntc	95	7	0	0	1241830.07	0.2065217
	4	180	tntc	238	15	3	1		253594.771	0.0421739
light	5	240	tntc	68	8	0	0		88888.8889	0.0147826
	6	300	304	29	2	0			37908.4967	0.0063043



Appendix C**Cleaning Method: Surfactant**

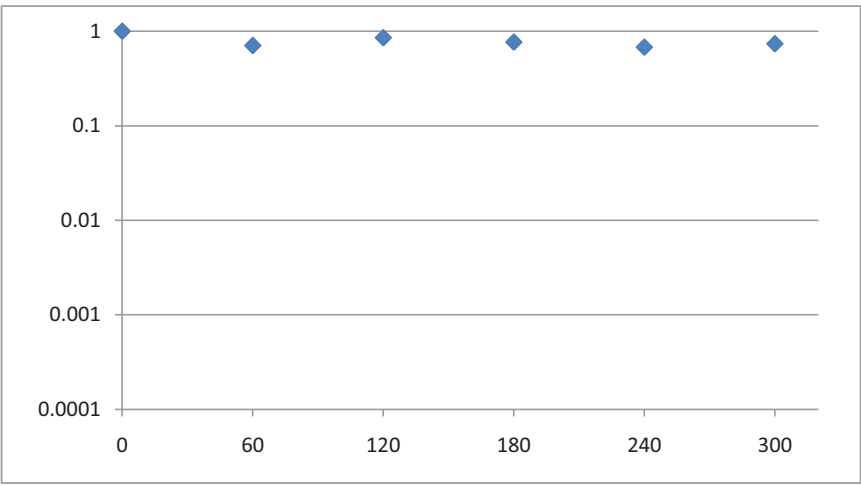
Experiment	Date	Fiber	Notes
Cleaned with Tween 80 surfactant solution (normal)- ran day after	7.21.09	3	Saw little to no removal
Cleaned with Tween 80 surfactant solution (soak for hour)- ran day after	7.30.09	3	Saw little to no removal
Cleaned with Tween 80 surfactant solution (rapid)- ran day after	8.6.09	3	Saw little to no removal
Ozonated (1hr) then Cleaned with Tween 80 surfactant solution (normal)- ran directly after	8.25.09	3	1.5-log removal

Date 7/30/2009 Cleaned with Tween 80 surfactant solution - ran day after
Fiber 3
Experiment 23

pH
Temp 25 oC
Buffer 1mM CBS
Mass Cat 0.0468 grams
Volume 25 mL
Intensity ~450 W/m2
Filters > 400 nm, 10% Transmittance

Volume Virus Stock Added 0.007 mL

Plaques per 0.85 ml at 10^X dilution											pfu/ml	Time in	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀	Light (min)
dark	1	0				tntc	tntc	41	4	1	5359477.1	1	0
	2	60				tntc	341	29	1	0	3790849.7	0.707317	0
	3	120				tntc	329	35	4	1	4575163.4	0.853659	0
	4	180			tntc	tntc	290	34	3		4117647.1	0.768293	0
light	5	240			tntc	tntc	277	28	8		3640522.9	0.679268	0
	6	300			tntc	tntc	265	34			3954248.4	0.737805	0

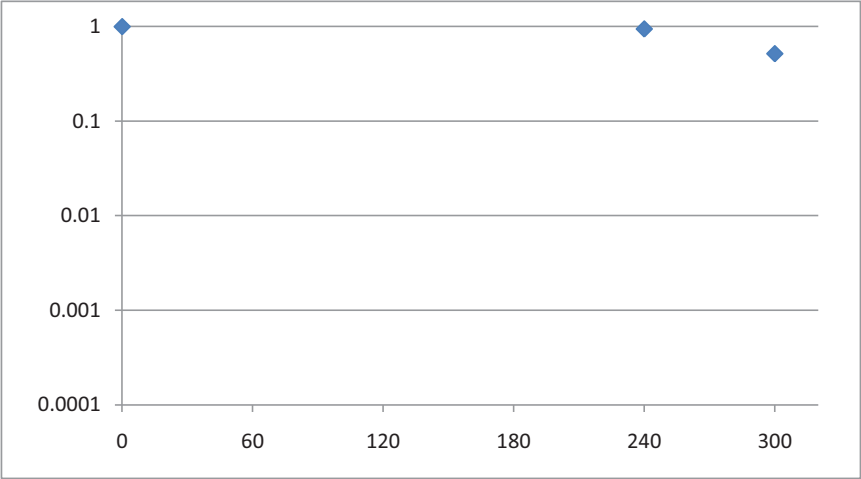


72 Date 7/30/2009 Cleaned with Tween 80 surfactant solution - ran day after
Fiber 3
Experiment 24

pH
Temp 25 oC
Buffer 1mM CBS
Mass Cat 0.0468 grams
Volume 25 mL
Intensity ~450 W/m2
Filters > 400 nm, 10% Transmittance

Volume Virus Stock Added 0.007 mL

Plaques per 0.85 ml at 10^X dilution											pfu/ml	Time in	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀	Light (min)
dark	1	0				tntc	145	12	3	0	1895424.8	1	0
	2	60				tntc	168	22	4	0	2535947.7	1.337931	0
	3	120				tntc	155	24	4	0	2581699.3	1.362069	0
	4	180			tntc	tntc	165	16	2		2124183	1.12069	0
light	5	240			tntc	tntc	137	9	-		1790849.7	0.944828	0
	6	300			tntc	tntc	75	7			980392.16	0.517241	0

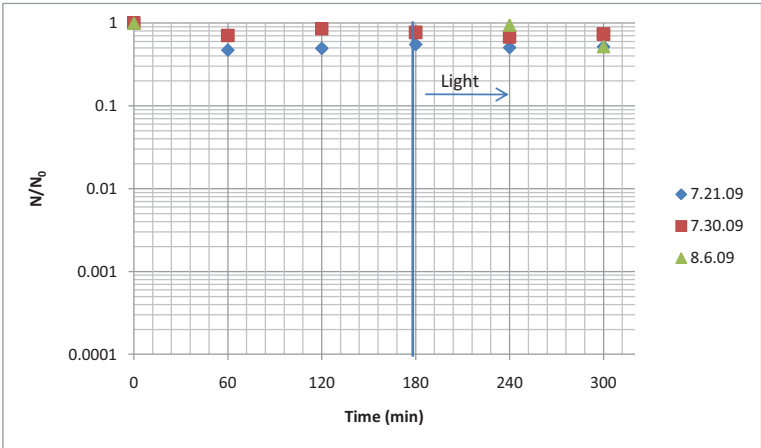


Date Various
Fiber 3
Experiment Cleaned with Tween 80 surfactant solution - ran day after

pH
Temp 25 oC
Buffer 1mM CBS
Mass Cat 0.0468 grams
Volume 25 mL
Intensity ~450 W/m2
Filters > 400 nm, 10% Transmittance

Volume Virus Stock Added 0.007 mL

Plaques per 0.85 ml at 10^X dilution											pfu/ml	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
dark	1	0				tntc	202	15	5	0	2300653.6	1
	2	60				tntc	83	14	0	0	1084967.3	0.471591
	3	120				tntc	87	12	1	0	1137254.9	0.494318
	4	180			tntc	tntc	97	8	1		1267973.9	0.551136
light	5	240			tntc	tntc	89	14	0		1163398.7	0.505682
	6	300			tntc	tntc	91	10			1189542.5	0.517045
dark	1	0				tntc	tntc	41	4	1	5359477.1	1
	2	60				tntc	341	29	1	0	3790849.7	0.707317
	3	120				tntc	329	35	4	1	4575163.4	0.853659
	4	180			tntc	tntc	290	34	3		4117647.1	0.768293
light	5	240			tntc	tntc	277	28	8		3640522.9	0.679268
	6	300			tntc	tntc	265	34			3954248.4	0.737805
dark	1	0				tntc	145	12	3	0	1895424.8	1
	2	60				tntc	168	22	4	0	2535947.7	1.337931
	3	120				tntc	155	24	4	0	2581699.3	1.362069
	4	180			tntc	tntc	165	16	2		2124183	1.12069
light	5	240			tntc	tntc	137	9	-		1790849.7	0.944828
	6	300			tntc	tntc	75	7			980392.16	0.517241



Date8/25/2009Ozonated Morning of experiment - did surfactant right after - normal experiment

Fiber3

Experiment25

pH

Temp25oC

Buffer1mM CBS

Mass Cat0.0377grams

Volume25mL

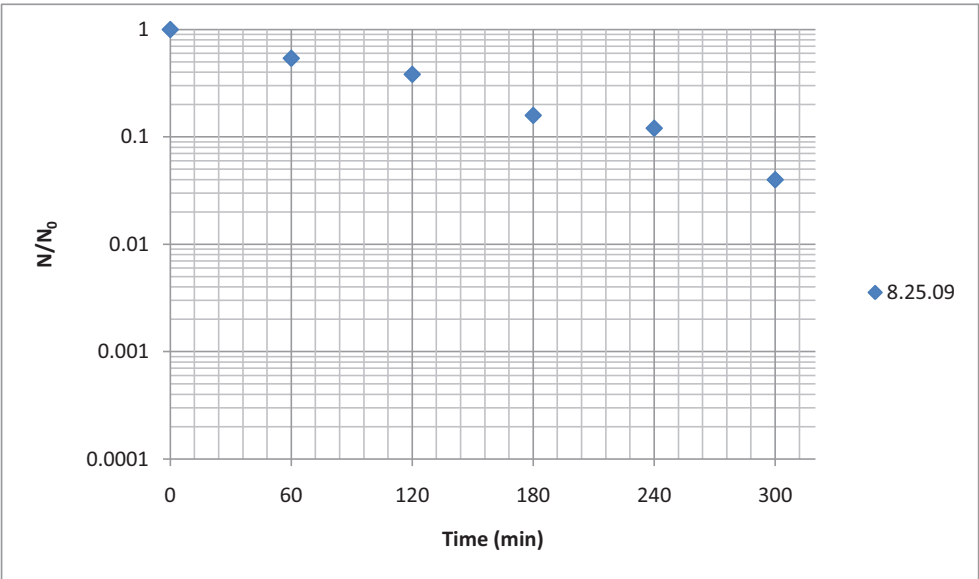
Intensity~450W/m2

Filters> 400 nm, 10% Transmittance

Volume Virus Stock Added

0.007 mL

Plaques per 0.85 ml at 10^X dilution										pfu/ml		
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
dark	1	0				tntc	63	8	3	0	823529.41	1
	2	60				tntc	34	2	0	0	444444.44	0.539683
	3	120				192	29	1	0	0	315032.68	0.38254
	4	180			tntc	100	10	1	0		130718.95	0.15873
light	5	240			tntc	76	9	0	0		99346.405	0.120635
	6	300			254	25	3	0			32941.176	0.04

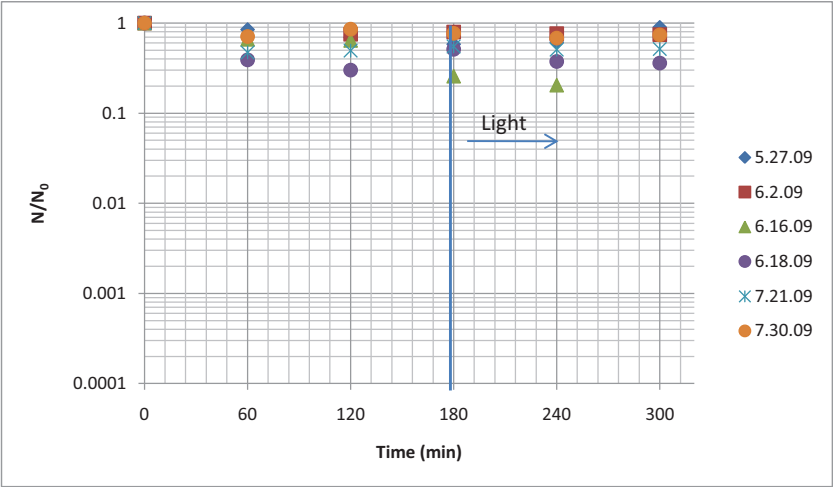


Date Various
Fiber 3
Experiment Ran day after ozonation

pH 25
Temp oC
Buffer 1mM CBS
Mass Cat 0.0468 grams
Volume 25 mL
Intensity ~450 W/m2
Filters > 400 nm, 10% Transmittance

Volume Virus Stock Added 0.007 mL

Plaques per 0.85 ml at 10 ⁴ X dilution										pfu/ml		
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
dark	1	0				tntc	231	29	4	1	3405228.76	1
	2	60				tntc	171	27	11	0	2882352.94	0.8464491
	3	120				tntc	180	18	2	1	2352941.18	0.6909789
	4	180			tntc	tntc	133	17	2		1980392.16	0.5815739
light	5	240			tntc	tntc	139	18	2		2084967.32	0.6122841
	6	300			tntc	tntc	167	30			3052287.58	0.8963532
	1	0				tntc	tntc	97	9	3	12679738.6	1
dark	2	60				tntc	tntc	98	11	1	12810457.5	1.0103093
	3	120				tntc	tntc	73	10	cont.	9542483.66	0.7525773
	4	180			tntc	tntc	tntc	77	6	2	10065359.5	0.7938144
light	5	240			tntc	tntc	tntc	74	7		9673202.61	0.7628866
	6	300			tntc	tntc	tntc	72			9411764.71	0.742268
	1	0				tntc	tntc	56	6	3	7320261.44	1
dark	2	60				tntc	tntc	37	12	9	4836601.31	0.6607143
	3	120				tntc	tntc	36	1	0	4705882.35	0.6428571
	4	180			tntc	tntc	159	13	2		1888888.89	0.2580357
light	5	240			tntc	tntc	100	13	8*		1503267.97	0.2053571
	6	300		tntc	tntc	tntc	cont.	cont.			#VALUE!	#VALUE!
	1	0				tntc	tntc	51	10	3	6666666.67	1
dark	2	60				tntc	218	18	6	0	2601307.19	0.3901961
	3	120				tntc	146	16	0	1	2000000	0.3
	4	180			tntc	tntc	262	26	3		3411764.71	0.5117647
light	5	240			tntc	tntc	192	19	4		2496732.03	0.3745098
	6	300			tntc	tntc	177	19			2398692.81	0.3598039
	1	0				tntc	202	15	5	0	2300653.59	1
dark	2	60				tntc	83	14	0	0	1084967.32	0.4715909
	3	120				tntc	87	12	1	0	1137254.9	0.4943182
	4	180			tntc	tntc	97	8	1		1267973.86	0.5511364
light	5	240			tntc	tntc	89	14	0		1163398.69	0.5056818
	6	300			tntc	tntc	91	10			1189542.48	0.5170455
	1	0				tntc	tntc	41	4	1	5359477.12	1
dark	2	60				tntc	341	29	1	0	3790849.67	0.7073171
	3	120				tntc	329	35	4	1	4575163.4	0.8536585
	4	180			tntc	tntc	290	34	3		4117647.06	0.7682927
light	5	240			tntc	tntc	277	28	8		3640522.88	0.6792683
	6	300			tntc	tntc	265	34			3954248.37	0.7378049



Appendix D**Regeneration Method: Ozone Same Day**

Fiber	Date	Notes
1	9.22.09	Removal to zero
1	9.29.09	Removal to zero
2	9.21.09	4-log removal
2	9.24.09	Less than 1-log removal
2	10.1.09	Contamination
3	9.3.09	2-log removal
3	9.11.09	3-log removal
3	9.23.09	4-log removal
3	9.30.09	4-log removal
4	8.21.09	~4-log removal

78

Date9/22/2009

Fiber1

Experiment32

Ozonation morning of experiment (1 hr)
Transport time from ozonation to reactor (2.5 min)

pH~7.6

Temp25

Buffer1mM CBS

Mass Cat0.0474

Volume25

Intensity~450

Filters> 400 nm, 10% Transmittance

Volume Virus Stock Added0.007 mL

oC

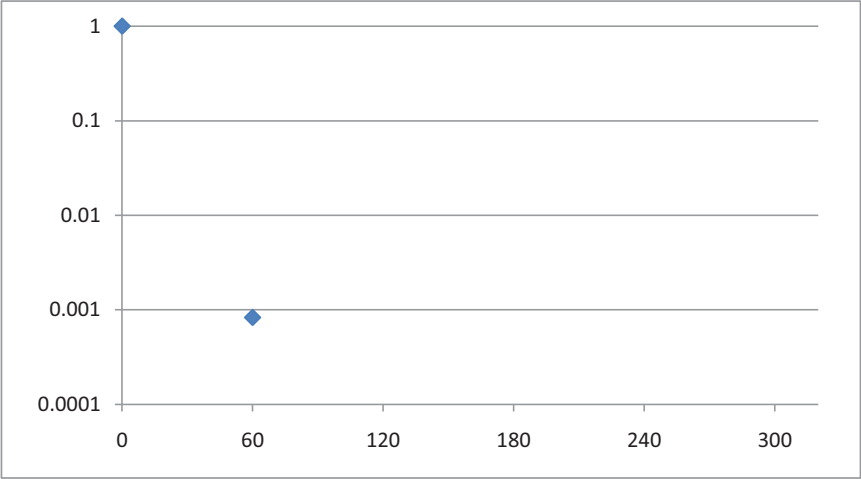
grams

mL

W/m2

> 400 nm, 10% Transmittance

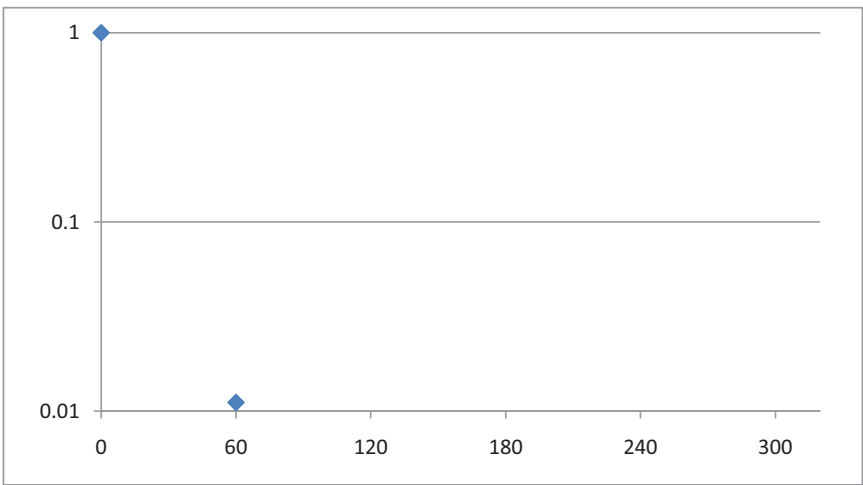
Plaques per 0.85 ml at 10^X dilution											pfu/ml	Time in	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀	Light (min)
dark	1	0				tntc	104	12	2		1568627.5	1	0
	2	60				1	0	0	0		1307.1895	0.000833	0
	3	120				0	0	0	9		0	0	0
	4	180			0	0	0	0			0	0	0
light	5	240			1	0	0	0			0	0	0
	6	300			0	0	0	0			0	0	0



Date 9/29/2009 Ozonation morning of experiment (1 hr)
Fiber 1 Transport time from ozonation to reactor (2.5 min)
Experiment 35

pH ~7.6 **Volume Virus Stock Added** 0.007 mL
Temp 25 oC
Buffer 1mM CBS
Mass Cat 0.0474 grams
Volume 25 mL
Intensity ~450 W/m2
Filters > 400 nm, 10% Transmittance

Plaques per 0.85 ml at 10^X dilution											pfu/ml	Time in	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀	Light (min)
dark	1	0				tntc	50	9	0		1176470.6	1	0
	2	60				10	1	0	0		13071.895	0.011111	0
	3	120				1	0	0	9		0	0	0
	4	180			0	0	2	0			0	0	0
light	5	240			0	0	0	0			0	0	0
	6	300			0	0	0	0			0	0	0



Date
Fiber
Experiment

1

Ozonation Morning of

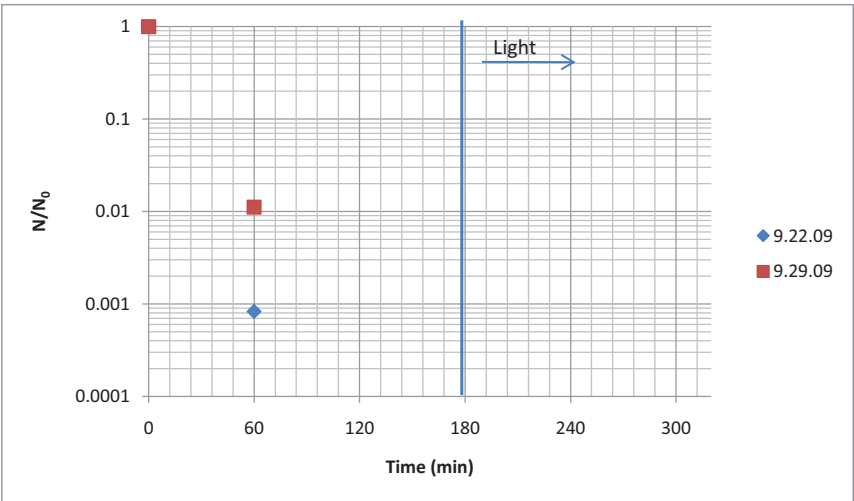
pH
Temp
Buffer
Mass Cat
Volume
Intensity
Filters

25
1mM CBS
0.0474
25
~450
> 400 nm, 10% Transmittance

oC
grams
mL
W/m2

Volume Virus Stock Added0.007 mL

Plaques per 0.85 ml at 10^X dilution											pfu/ml	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
dark	1	0				tntc	104	12	2		1568627.5	1
	2	60				1	0	0	0		1307.1895	0.000833
	3	120				0	0	0	9		0	0
	4	180			0	0	0	0			0	0
light	5	240		1	0	0	0	0			0	0
	6	300		0	0	0	0	0			0	0
dark	1	0				tntc	50	9	0		1176470.6	1
	2	60				10	1	0	0		13071.895	0.011111
	3	120				1	0	0	9		0	0
	4	180		0	0	0	2	0			0	0
light	5	240		0	0	0	0	0			0	0
	6	300		0	0	0	0	0			0	0



Date

Fiber

Experiment

9/21/2009

2

31

Ozonation morning of experiment (1 hr)

pH

Temp

Buffer

Mass Cat

Volume

Intensity

Filters

~7.6

25

1mM CBS

~.0205

25

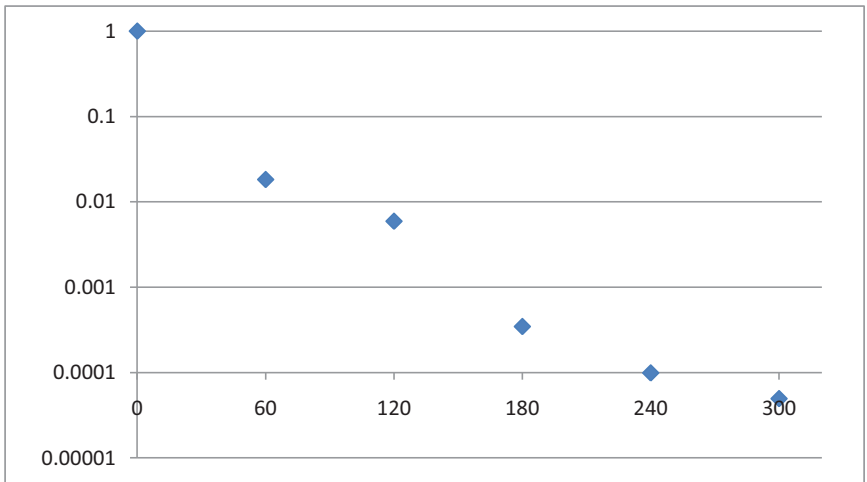
~450

> 400 nm, 10% Transmittance

Volume Virus Stock Added

0.007 mL

Plaques per 0.85 ml at 10^X dilution											pfu/ml	Time in	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀	Light (min)
dark	1	0				tntc	186	22	2		2653594.8	1	0
	2	60				37	5	0	0		48366.013	0.018227	0
	3	120				12	0	0	0		15686.275	0.005911	0
	4	180			7	1	0	0			915.03268	0.000345	0
light	5	240			2	0	0	0			261.43791	9.85E-05	0
	6	300			1	0	0	0			130.71895	4.93E-05	0



Date

Fiber

Experiment

9/24/2009

2

34

Ozonation morning of experiment (1 hr)

pH

Temp

Buffer

Mass Cat

Volume

Intensity

Filters

~7.6

25

1mM CBS

~.0205

25

~450

> 400 nm, 10% Transmittance

Volume Virus Stock Added

0.007 mL

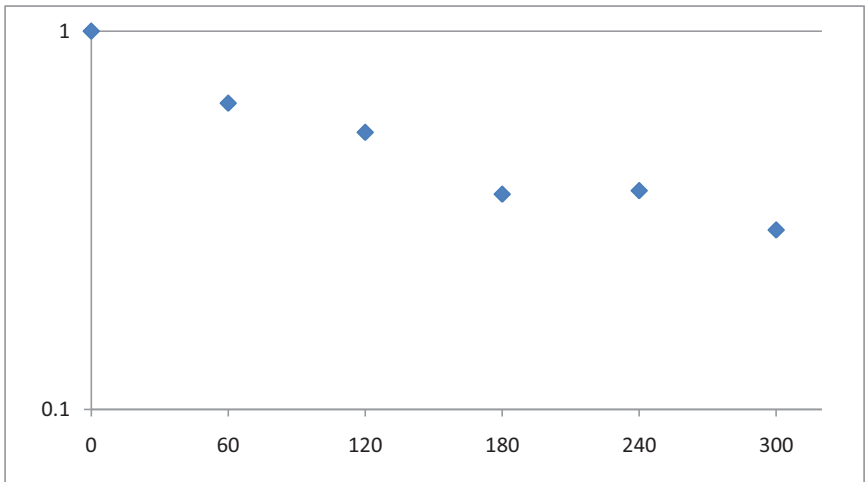
oC

grams

mL

W/m2

Plaques per 0.85 ml at 10^X dilution											pfu/ml	Time in	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀	Light (min)
dark	1	0				tntc	124	3	0		1620915	1	0
	2	60				tntc	80	8	1		1045751.6	0.645161	0
	3	120				tntc	67	5	0		875816.99	0.540323	0
	4	180			tntc	tntc	46	9			601307.19	0.370968	0
light	5	240			tntc	tntc	47	9			614379.08	0.379032	0
	6	300			tntc	tntc	37	2			483660.13	0.298387	0

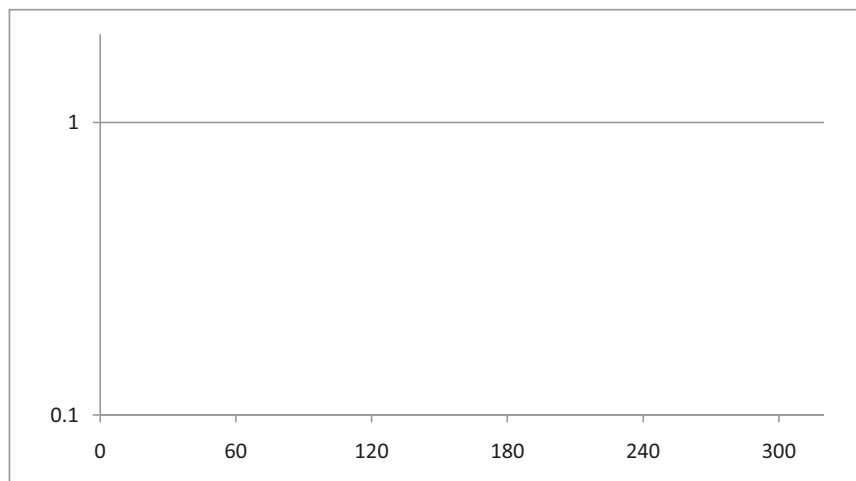


Date 10/1/2009 Ozonation morning of experiment (1 hr)
 Fiber 2
 Experiment 37

pH ~7.6
 Temp 25 oC
 Buffer 1mM CBS
 Mass Cat ~.0205 grams
 Volume 25 mL
 Intensity ~450 W/m2
 Filters > 400 nm, 10% Transmittance

Volume Virus Stock Added 0.007 mL

Plaques per 0.85 ml at 10^X dilution											pfu/ml		Time in
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀	Light (min)
dark	1	0				tntc	0?	4	0		#VALUE!	#VALUE!	0
	2	60				100	11	1	0		130718.95	#VALUE!	0
	3	120				17	4	0	0		22222.222	#VALUE!	0
	4	180			94	9	0	0			12287.582	#VALUE!	0
light	5	240			57	5	0	0			7450.9804	#VALUE!	0
	6	300			25	1	0	0			3267.9739	#VALUE!	0

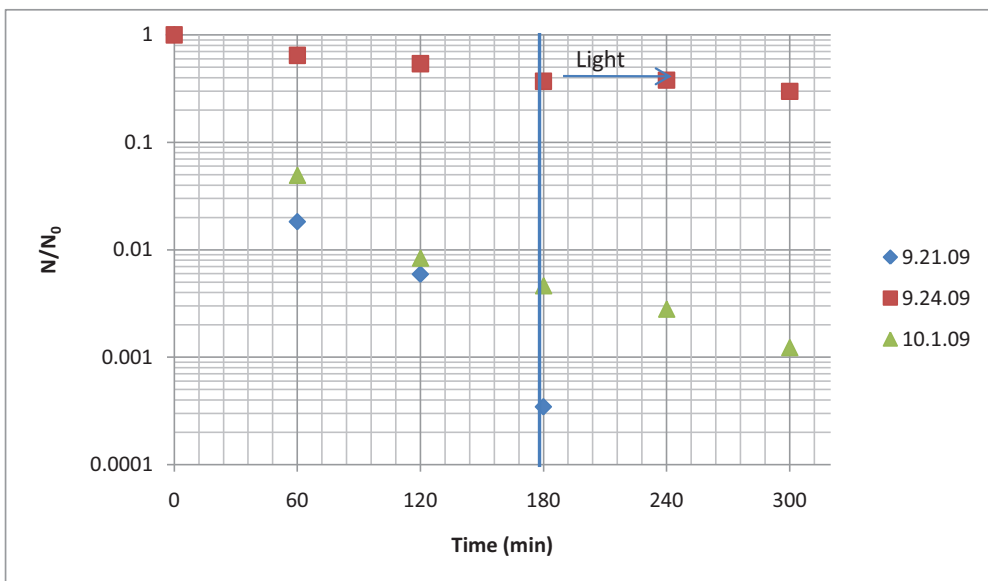


Date Ozonation morning of
 Fiber 2
 Experiment

pH
 Temp 25 oC
 Buffer 1mM CBS
 Mass Cat ~.0205 grams
 Volume 25 mL
 Intensity ~450 W/m2
 Filters > 400 nm, 10% Transmittance

Volume Virus Stock Added 0.007 mL

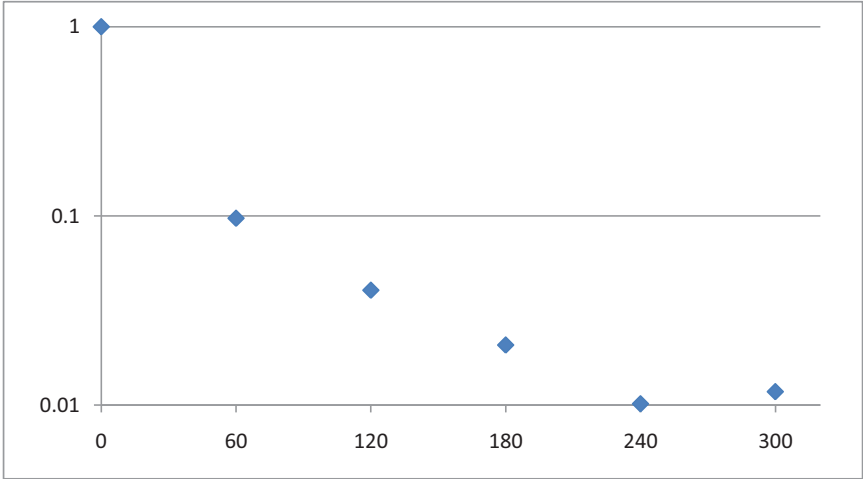
Plaques per 0.85 ml at 10^X dilution										pfu/ml		
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
dark	1	0				tntc	186	22	2		2653594.8	1
	2	60				37	5	0	0		48366.013	0.018226601
	3	120				12	0	0	0		15686.275	0.00591133
	4	180			7	1	0	0			915.03268	0.000344828
light	5	240			2	0	0	0			261.43791	9.85222E-05
	6	300			1	0	0	0			130.71895	4.92611E-05
dark	1	0				tntc	124	3	0		1620915	1
	2	60				tntc	80	8	1		1045751.6	0.64516129
	3	120				tntc	67	5	0		875816.99	0.540322581
light	4	180			tntc	tntc	46	9			601307.19	0.370967742
	5	240			tntc	tntc	47	9			614379.08	0.379032258
	6	300			tntc	tntc	37	2			483660.13	0.298387097
dark	1	0				tntc	0?	4	0		#VALUE!	#VALUE!
	2	60				100	11	1	0		130718.95	0.049261084
	3	120				17	4	0	0		22222.222	0.008374384
light	4	180			94	9	0	0			12287.582	0.004630542
	5	240			57	5	0	0			7450.9804	0.002807882
	6	300			25	1	0	0			3267.9739	0.001231527



88 **Date** 9/3/2009 ozonation done in "dark" morning of (1 hr)
 Fiber 3
 Experiment 29

pH ~7.6 **Volume Virus Stock Added** 0.007 mL
 Temp 25 oC
 Buffer 1mM CBS
 Mass Cat 0.0377 grams
 Volume 25 mL
 Intensity ~450 W/m2
 Filters > 400 nm, 10% Transmittance

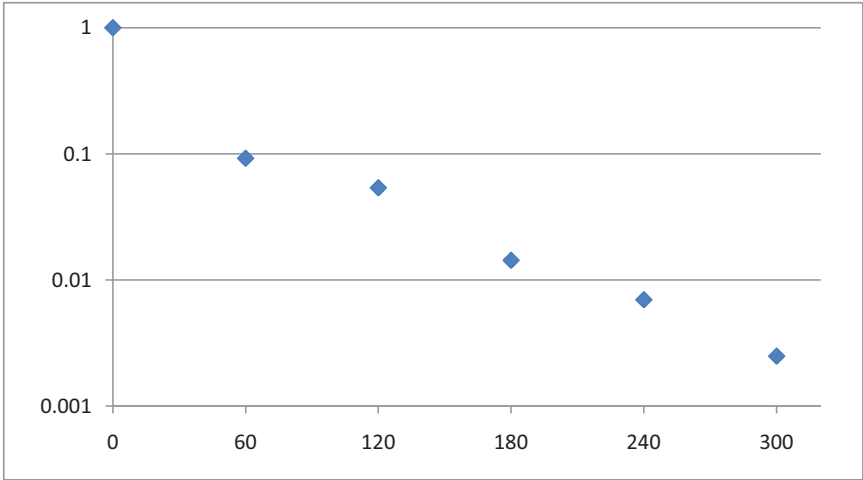
Plaques per 0.85 ml at 10^X dilution											pfu/ml	Time in	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀	Light (min)
dark	1	0				tntc	111	5	0	0	1450980.4	1	0
	2	60				108	4	0	0	0	141176.47	0.097297	0
	3	120				45	7	0	0	0	58823.529	0.040541	0
	4	180			212	25	2	0	0		30196.078	0.020811	0
light	5	240			113	10	2	0	0		14771.242	0.01018	0
	6	300			131	4	1	0			17124.183	0.011802	0



Date 9/11/2009 ozonation done in "dark" morning of (1 hr)
Fiber 3
Experiment 30

pH ~7.6 Volume Virus Stock Added 0.007 mL
Temp 25 oC
Buffer 1mM CBS
Mass Cat 0.0377 grams
Volume 25 mL
Intensity ~450 W/m2
Filters > 400 nm, 10% Transmittance

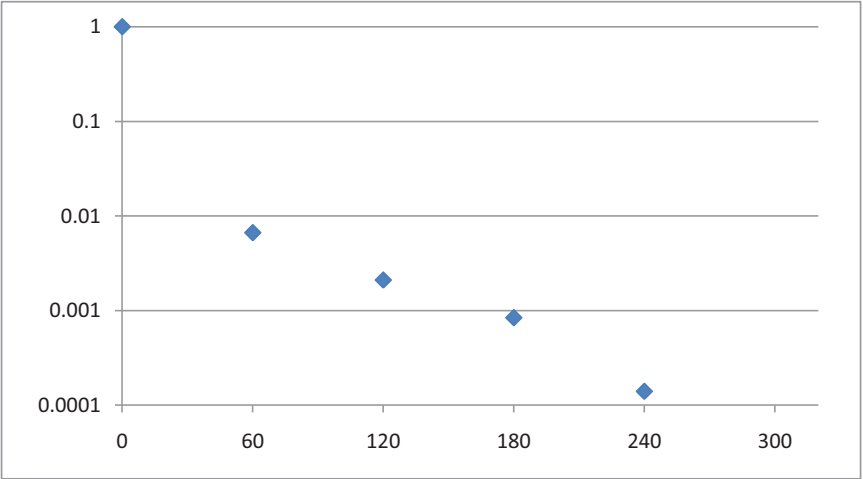
Plaques per 0.85 ml at 10^X dilution											pfu/ml	Time in	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀	Light (min)
dark	1	0				tntc	201	20	4		2620915	1	0
	2	60				180	19	2	0		241830.07	0.092269	0
	3	120				108	9	1	0		141176.47	0.053865	0
	4	180			275	30	4	0	0		37581.699	0.014339	0
light	5	240			140	14	1	0			18300.654	0.006983	0
	6	300		tntc	50	6	1	0			6535.9477	0.002494	0



88 **Date** 9/23/2009 ozonation done in "dark" morning of (1 hr)
 Fiber 3 transport time from ozonation to reactor (2.5 mins)
 Experiment 33

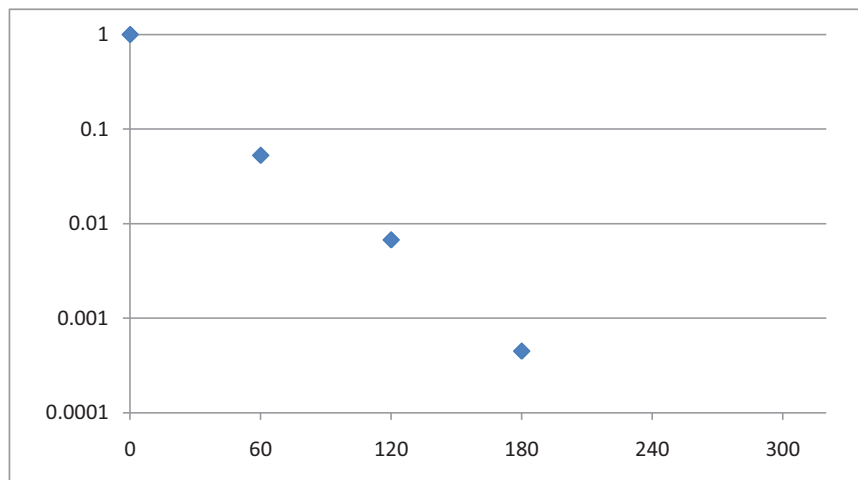
pH ~7.6 **Volume Virus Stock Added** 0.007 mL
 Temp 25 oC
 Buffer 1mM CBS
 Mass Cat 0.0215 grams
 Volume 25 mL
 Intensity ~450 W/m2
 Filters > 400 nm, 10% Transmittance

Plaques per 0.85 ml at 10^X dilution											pfu/ml	Time in	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀	Light (min)
dark	1	0				tntc	155	13	0		1862745.1	1	0
	2	60				9	1	0	0		12418.301	0.006667	0
	3	120				3	2	0	0		3921.5686	0.002105	0
	4	180			4	2	0	0			1568.6275	0.000842	0
light	5	240			2	0	0	0			261.43791	0.00014	0
	6	300			0	0	0	0			0	0	0



Date 9/30/2009 ozonation done in "dark" morning of (1 hr)
Fiber 3 transport time from ozonation to reactor (2.5 mins)
Experiment 36 Had to turn off stirrer after sample 5 b/c fiber had gotten into same zone as stirrer
 *MS2 vial left out in room temp for entire day before this experiment
pH ~7.6
Temp 25 oC
Buffer 1mM CBS
Mass Cat 0.0215 grams
Volume 25 mL
Intensity ~450 W/m²
Filters > 400 nm, 10% Transmittance
Volume Virus Stock Added 0.007 mL

Dark or light	Sample	Time (min)	Plaques per 0.85 ml at 10 ^X dilution							pfu/ml <i>N</i>	<i>N/N₀</i>	Time in Light (min)
			0	1	2	3	4	5	6			
	1	0				tntc	49	4	1	581699.35	1	0
dark	2	60				17	3	1	0	30718.954	0.052809	0
	3	120				3	0	1	0	3921.5686	0.006742	0
	4	180			4	0	0	0		261.43791	0.000449	0
light	5	240			0	0	0	0		0	0	0
	6	300			0	0	0	1		0	0	0

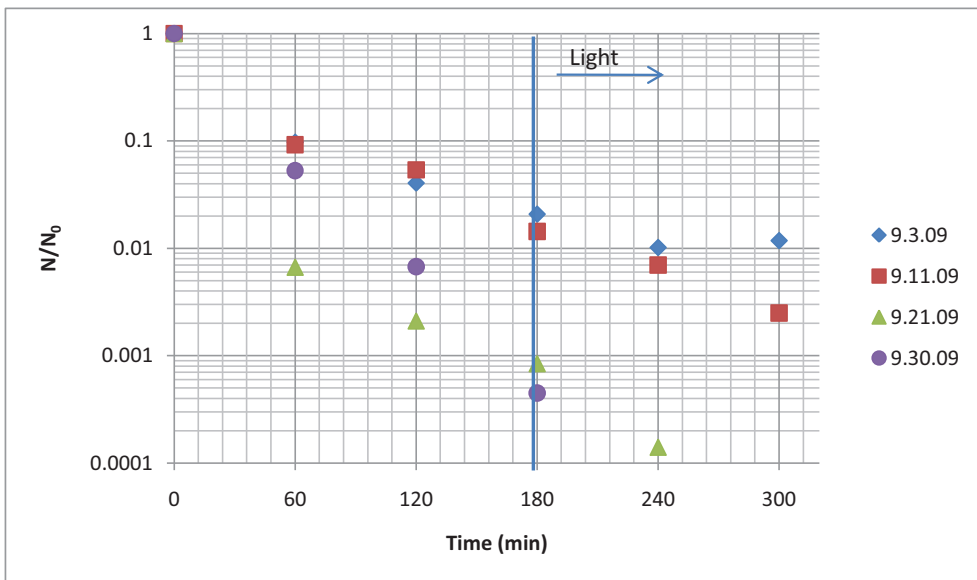


Date Various
Fiber 3
Experiment Ozonation morning of

pH ~7.6
Temp 25 oC
Buffer 1mM CBS
Mass Cat Various grams
Volume 25 mL
Intensity ~450 W/m²
Filters > 400 nm, 10% Transmittance

Plaques per 0.85 ml at 10⁴X dilution

Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	pfu/ml N	N/N ₀
	1	0				tntc	111	5	0	0	1450980.4	1
dark	2	60				108	4	0	0	0	141176.47	0.097297
	3	120				45	7	0	0	0	58823.529	0.040541
	4	180			212	25	2	0	0		30196.078	0.020811
light	5	240			113	10	2	0	0		14771.242	0.01018
	6	300			131	4	1	0			17124.183	0.011802
	1	0				tntc	201	20	4		2620915	1
dark	2	60				180	19	2	0		241830.07	0.092269
	3	120				108	9	1	0		141176.47	0.053865
	4	180			275	30	4	0	0		37581.699	0.014339
light	5	240			140	14	1	0			18300.654	0.006983
	6	300		tntc	50	6	1	0			6535.9477	0.002494
	1	0				tntc	155	13	0		1862745.1	1
dark	2	60				9	1	0	0		12418.301	0.006667
	3	120				3	2	0	0		3921.5686	0.002105
	4	180			4	2	0	0			1568.6275	0.000842
light	5	240			2	0	0	0			261.43791	0.00014
	6	300			0	0	0	0			0	0
	1	0				tntc	49	4	1		581699.35	1
dark	2	60				17	3	1	0		30718.954	0.052809
	3	120				3	0	1	0		3921.5686	0.006742
	4	180			4	0	0	0			261.43791	0.000449
light	5	240			0	0	0	0			0	0
	6	300			0	0	0	1			0	0



82

Date

Fiber

Experiment

8/21/2009

4

26

Ozonated Morning of experiment

pH

Temp

Buffer

Mass Cat

Volume

Intensity

Filters

25

1mM CBS

0.04

25

~450

> 400 nm, 10% Transmittance

oC

grams

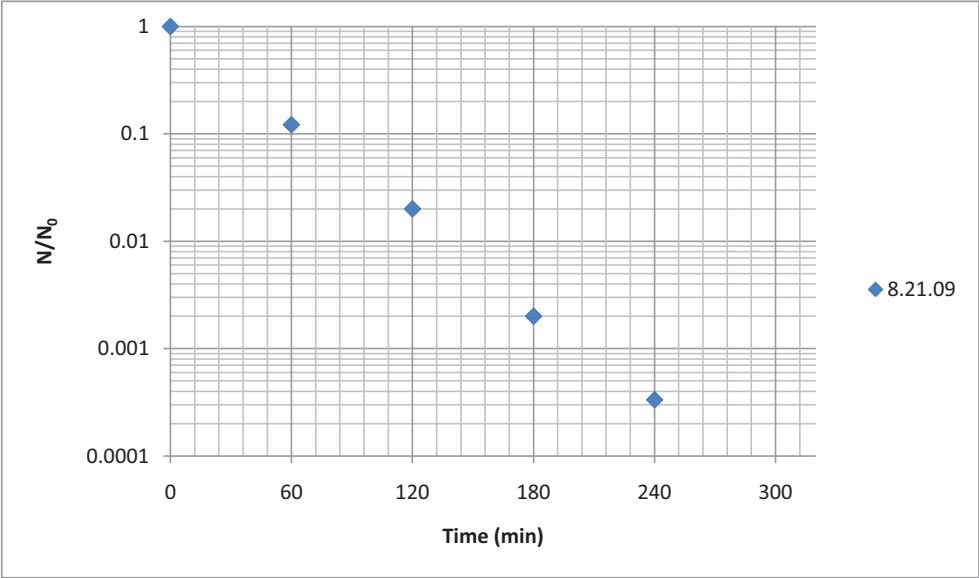
mL

W/m2

Volume Virus Stock Added

0.007 mL

Plaques per 0.85 ml at 10^X dilution											pfu/ml	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
dark	1	0				tntc	60	6	1	0	784313.73	1
	2	60				73	8	0	0	0	95424.837	0.121667
	3	120				12	0	0	0	0	15686.275	0.02
	4	180			12	2	1	0	0		1568.6275	0.002
light	5	240			2	1	0	0	0		261.43791	0.000333
	6	300			0	0	0	0			0	0



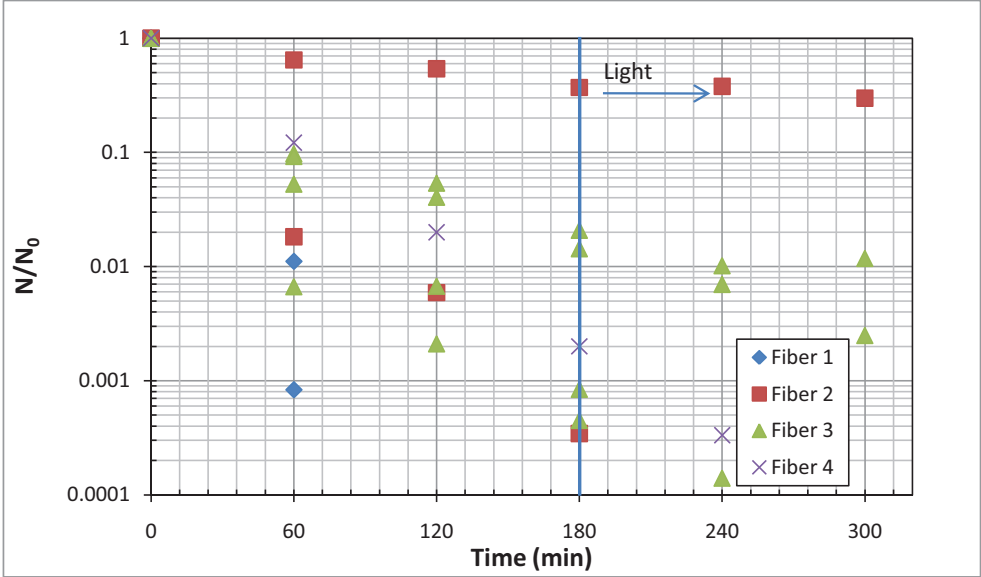
Date Various
Fiber 3
Experiment Ozonation morning of

pH ~7.6
Temp 25 oC
Buffer 1mM CBS
Mass Cat Various grams
Volume 25 mL
Intensity ~450 W/m2
Filters > 400 nm, 10% Transmittance

Plaques per 0.85 ml at 10^X dilution

Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	pfu/ml N	N/N ₀
	1	0				tntc	111	5	0	0	1450980.4	1
dark	2	60				108	4	0	0	0	141176.47	0.097297
	3	120				45	7	0	0	0	58823.529	0.040541
	4	180			212	25	2	0	0		30196.078	0.020811
light	5	240			113	10	2	0	0		14771.242	0.01018
	6	300			131	4	1	0			17124.183	0.011802
	1	0				tntc	201	20	4		2620915	1
dark	2	60				180	19	2	0		241830.07	0.092269
	3	120				108	9	1	0		141176.47	0.053865
	4	180			275	30	4	0	0		37581.699	0.014339
light	5	240			140	14	1	0			18300.654	0.006983
	6	300		tntc	50	6	1	0			6535.9477	0.002494
	1	0				tntc	155	13	0		1862745.1	1
dark	2	60				9	1	0	0		12418.301	0.006667
	3	120				3	2	0	0		3921.5686	0.002105
	4	180			4	2	0	0			1568.6275	0.000842
light	5	240			2	0	0	0			261.43791	0.00014
	6	300			0	0	0	0			0	0
	1	0				tntc	49	4	1		581699.35	1
dark	2	60				17	3	1	0		30718.954	0.052809
	3	120				3	0	1	0		3921.5686	0.006742
	4	180			4	0	0	0			261.43791	0.000449
light	5	240			0	0	0	0			0	0
	6	300			0	0	0	1			0	0

dark	1	0		tntc	186	22	2		2653594.8	1
	2	60		37	5	0	0		48366.013	0.018227
	3	120		12	0	0	0		15686.275	0.005911
	4	180	7	1	0	0			915.03268	0.000345
	5	240	2	0	0	0			261.43791	9.85E-05
	6	300	1	0	0	0			130.71895	4.93E-05
dark	1	0		tntc	124	3	0		1620915	1
	2	60		tntc	80	8	1		1045751.6	0.645161
	3	120		tntc	67	5	0		875816.99	0.540323
	4	180		tntc	46	9			601307.19	0.370968
	5	240	tntc	tntc	47	9			614379.08	0.379032
	6	300	tntc	tntc	37	2			483660.13	0.298387
dark	1	0		tntc	0?	4	0		#VALUE!	#VALUE!
	2	60		100	11	1	0		130718.95	#VALUE!
	3	120		17	4	0	0		22222.222	#VALUE!
	4	180	94	9	0	0			12287.582	#VALUE!
	5	240	57	5	0	0			7450.9804	#VALUE!
	6	300	25	1	0	0			3267.9739	#VALUE!
dark	1	0		tntc	104	12	2		1568627.5	1
	2	60		1	0	0	0		1307.1895	0.000833
	3	120		0	0	0	9		0	0
	4	180	0	0	0	0			0	0
	5	240	1	0	0	0			0	0
	6	300	0	0	0	0			0	0
dark	1	0		tntc	50	9	0		1176470.6	1
	2	60		10	1	0	0		13071.895	0.011111
	3	120		1	0	0	9		0	0
	4	180	0	0	2	0			0	0
	5	240	0	0	0	0			0	0
	6	300	0	0	0	0			0	0
dark	1	0		tntc	60	6	1	0	784313.73	1
	2	60		73	8	0	0	0	95424.837	0.121667
	3	120		12	0	0	0	0	15686.275	0.02
	4	180	12	2	1	0	0		1568.6275	0.002
	5	240	2	1	0	0	0		261.43791	0.000333
	6	300	0	0	0	0			0	0



Appendix E

Regeneration Method: Ozone Same Day with Dark/Light Methods

Complete Dark and Light experiments were done to try to reach equilibrium for adsorptive and photocatalytic removal, respectively

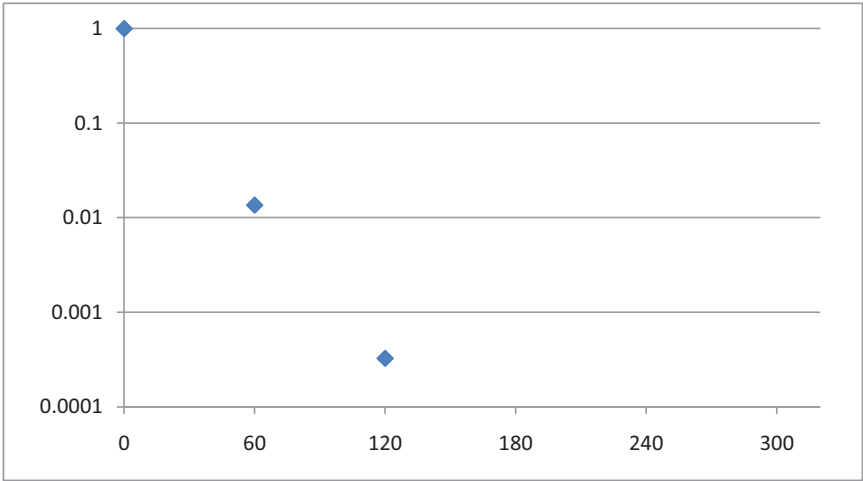
Fiber	Date	L/D	Notes
1	10.19.09	Light	Removal to zero
1	10.20.09	Dark	4-log removal
1	10.27.09	Light	4.5-log removal
1	10.28.09	Dark	~6-log removal
1	10.29.09	Light	~5-log removal
1	11.2.09	Dark	1-log removal
1	11.3.09	Light	2.5-log removal - significant mass loss
1	11.5.09	Dark	1.5-log removal
1	11.10.09	Light	3-log removal
1	11.11.09	Dark	3-log removal
1	11.12.09	Light	3.5-log removal
1	11.17.09	Light	2-log removal - significant mass loss
2	10.22.09	Light	3.5-log removal
2	10.23.09	Dark	1.5-log removal - pipettor failure
3	8.31.09	Light	2-log removal
3	9.1.09	Dark	Removal to zero
3	11.19.09	Light	1-log removal

*Done with Stock 2

Date 10.19.09 Ozonation morning of experiment (1 hr)
Fiber 1 Transport time from ozonation to reactor (2.5 min)
Experiment 38 In Light entire time

pH ~8.8 **Volume Virus Stock Added** 0.05 mL
Temp 25 oC
Buffer 1mM CBS
Mass Cat 0.0415 grams
Volume 25 mL
Intensity ~450 W/m2
Filters > 400 nm, 10% Transmittance

Plaques per 0.85 ml at 10^X dilution											pfu/ml	
light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
	1	0					tntc	tntc	289	39	443790850	1
	2	60					tntc	46	5	0	6013071.9	0.013549
	3	120					11	1	0	0	143790.85	0.000324
	4	180				6	0	0	0		0	0
	5	240				1	0	0	0		0	0
	6	300				0	0	0	0		0	0



86

Date

Fiber

Experiment

10.20.09

1

39

Ozonation morning of experiment (1 hr)

Transport time from ozonation to reactor (2.5 min)

In Dark entire time

pH

Temp

Buffer

Mass Cat

Volume

Intensity

Filters

~8.8

25

1mM CBS

0.0415

25

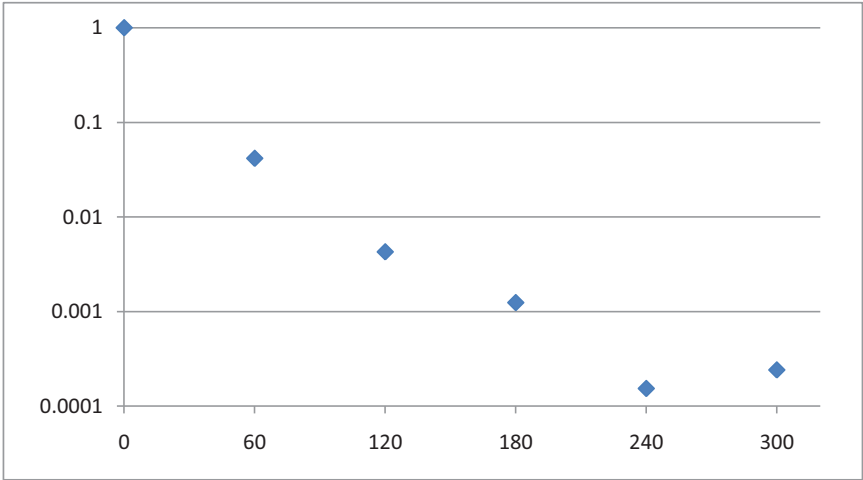
~450

> 400 nm, 10% Transmittance

Volume Virus Stock Added

0.05 mL

Plaques per 0.85 ml at 10^X dilution											pfu/ml	
	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
dark	1	0					tntc	tntc	268	28	358169935	1
	2	60					tntc	114	11	0	14901961	0.041606
	3	120					117	6	0		1529411.8	0.00427
	4	180				330	34	3			444444.44	0.001241
	5	240				42	9	3			54901.961	0.000153
	6	300				66	3	0			86274.51	0.000241



66

Date

Fiber

Experiment

pH

Temp

Buffer

Mass Cat

Volume

Intensity

Filters

10.27.09

1

42

~8.8

25

1mM CBS

0.0389

25

~450

> 400 nm, 10% Transmittance

Ozonation morning of experiment (1 hr)

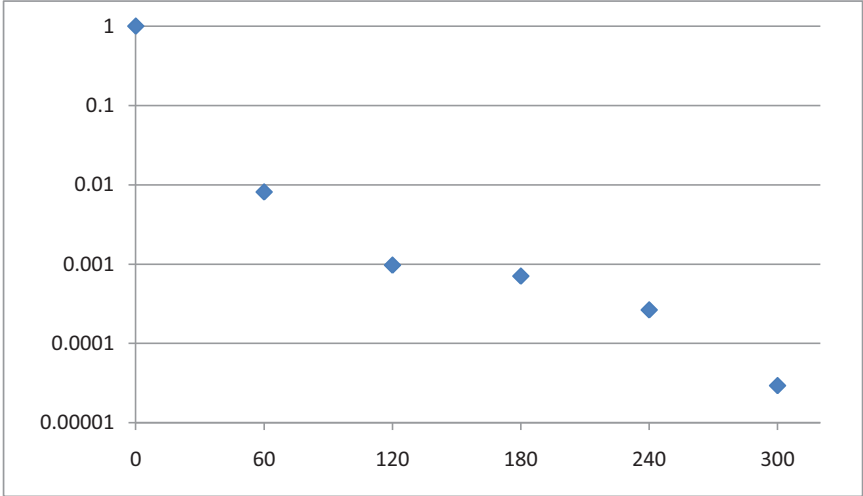
Transport time from ozonation to reactor (2.5 min)

In light entire time

Volume Virus Stock Added

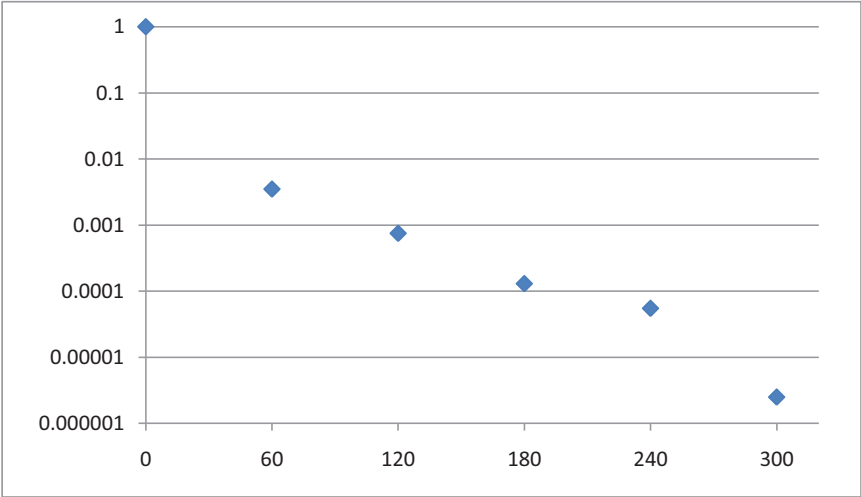
0.05 mL

Plaques per 0.85 ml at 10^X dilution											pfu/ml	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
light	1	0					tntc	tntc	306	34	444444444	1
	2	60					276	21	1	0	3607843.1	0.008118
	3	120					33	2	1	0	431372.55	0.000971
	4	180				240	5	1	0		313725.49	0.000706
	5	240				90	15	0	0		117647.06	0.000265
	6	300			100	10	0	0			13071.895	2.94E-05



Date	10.28.09	Ozonation morning of experiment (1 hr)	Plates counted at 20 hours
Fiber	1	Transport time from ozonation to reactor (2.5 min)	
Experiment	43	In Dark entire time	
pH	~8.8	Volume Virus Stock Added	0.05 mL
Temp	25		
Buffer	1mM CBS		
Mass Cat	0.0389	grams	
Volume	25	mL	
Intensity	~450	W/m2	
Filters	> 400 nm, 10% Transmittance		

Plaques per 0.85 ml at 10^X dilution											pfu/ml	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
dark	1	0					tntc	tntc	tntc	40	522875817	1
	2	60					140	10	1	0	1830065.4	0.0035
	3	120					30	3	1	0	392156.86	0.00075
	4	180				52	5	0	1		67973.856	0.00013
	5	240				22	0	0	0		28758.17	0.000055
	6	300			33	1	0	0			1307.1895	2.5E-06

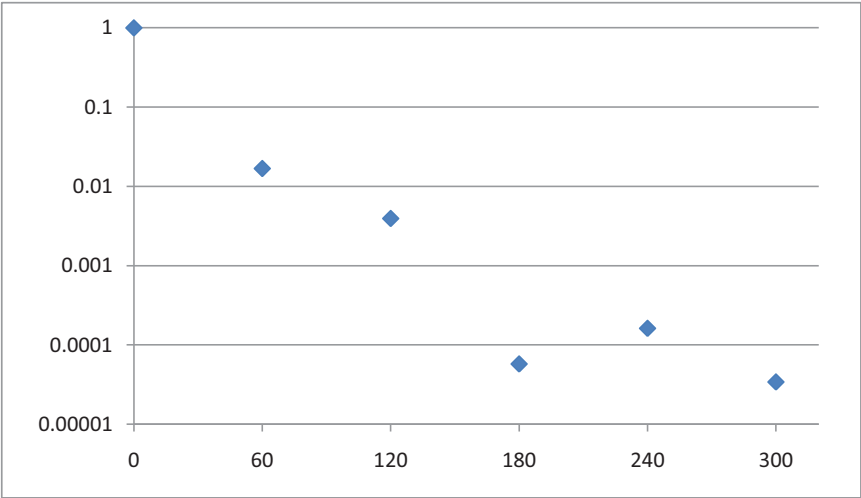


Date 10.29.09 Ozonation morning of experiment (1 hr)
Fiber 1 Transport time from ozonation to reactor (2.5 min)
Experiment 44 In light entire time

Plates counted at 20.5 hours

pH ~9.0 **Volume Virus Stock Added** 0.05 mL
Temp 25 oC
Buffer 1mM CBS
Mass Cat 0.0389 grams
Volume 25 mL
Intensity ~450 W/m2
Filters > 400 nm, 10% Transmittance

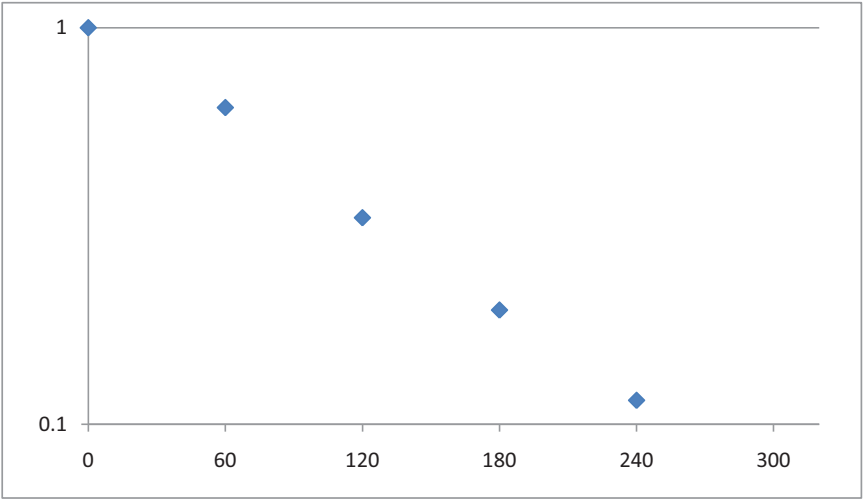
Plaques per 0.85 ml at 10^X dilution											pfu/ml	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
light	1	0					tntc	tntc	tntc	47	614379085	1
	2	60					tntc	79	4	0	10326797	0.016809
	3	120					170	20	7	0	2418300.7	0.003936
	4	180				27	7	3	0		35294.118	5.74E-05
	5	240				76	0	0	0		99346.405	0.000162
	6	300			134	16	0	0			20915.033	3.4E-05



Date	11.2.09	Ozonation morning of experiment (1 hr)	
Fiber	1	Transport time from ozonation to reactor (2.5 min)	
Experiment	45	In Dark entire time	
pH	~9	Volume Virus Stock Added	0.05 mL
Temp	25	oC	
Buffer	1mM CBS		
Mass Cat	0.0253	grams	
Volume	25	mL	
Intensity	~450	W/m2	
Filters	> 400 nm, 10% Transmittance		

Plates counted at 19 hours
Time between last light experiment and this experiment = 3 days

		Plaques per 0.85 ml at 10^X dilution									pfu/ml	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
dark	1	0					tntc	tntc	tntc	53	692810458	1
	2	60					tntc	tntc	287	38	435947712	0.629245
	3	120					tntc	tntc	176	9	230065359	0.332075
	4	180				tntc	tntc	tntc	103		134640523	0.19434
	5	240				tntc	tntc	tntc	61		79738562	0.115094
	6	300			tntc	tntc	tntc	tntc			0	0



Date11.3.09

Fiber1

Experiment46

pH~9

Temp25

Buffer1mM CBS

Mass Cat0.0253

Volume25

Intensity~450

Filters> 400 nm, 10% Transmittance

Ozonation morning of experiment (1 hr)

Transport time from ozonation to reactor (2.5 min)

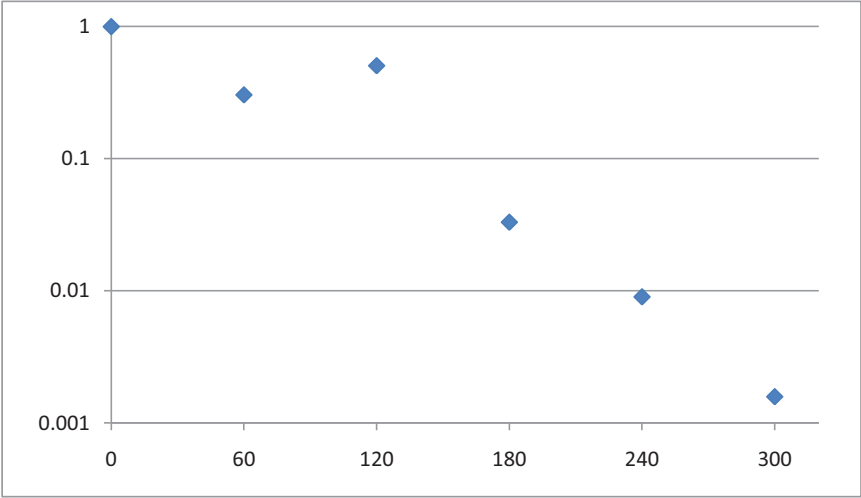
In light entire time

Volume Virus Stock Added

0.05 mL

CONTAMINATED!

Plaques per 0.85 ml at 10^X dilution											pfu/ml	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
light	1	0					tntc	tntc	tntc	133	1.739E+09	1
	2	60					tntc	195	tntc	79	529084967	0.304323
	3	120					tntc	58	143	187	879651416	0.505965
	4	180				tntc	tntc	16	88		57516340	0.033083
	5	240				287	62	30	44		15655882	0.009005
	6	300			tntc	185	192	42			2747276.7	0.00158



Date

Fiber

Experiment

pH

Temp

Buffer

Mass Cat

Volume

Intensity

Filters

11.3.09

1

46

~9

25

1mM CBS

0.0253

25

~450

> 400 nm, 10% Transmittance

Ozonation morning of experiment (1 hr)

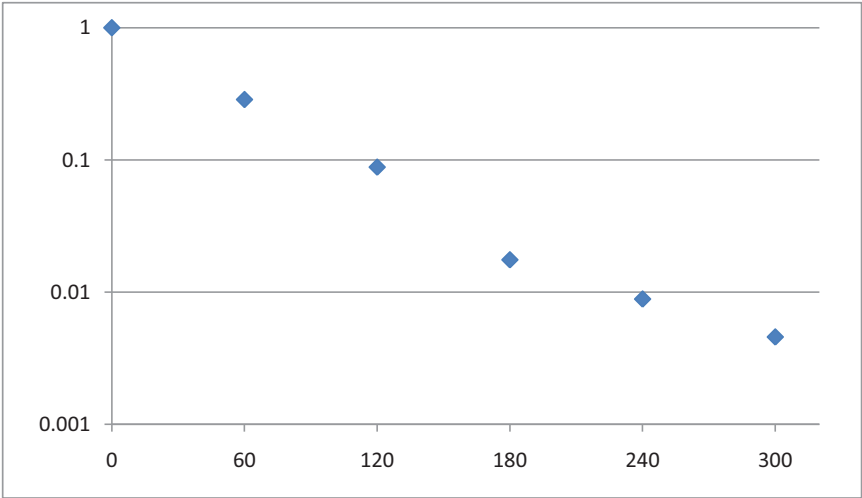
Transport time from ozonation to reactor (2.5 min)

In light entire time

Volume Virus Stock Added

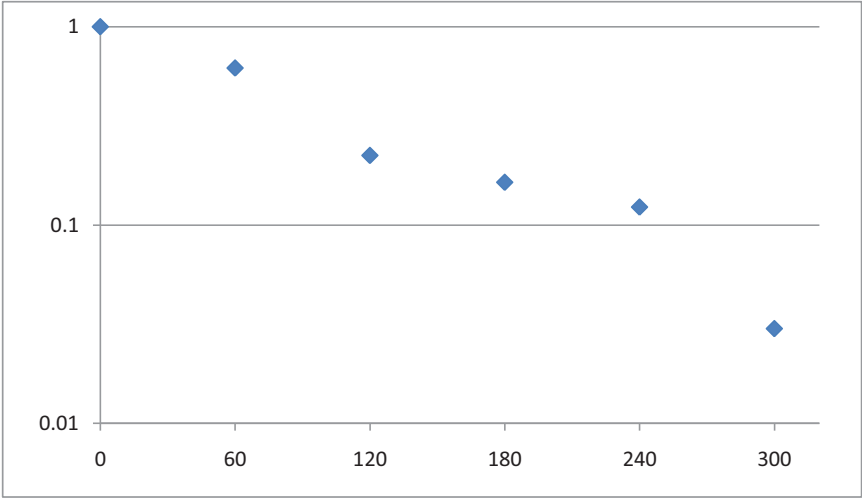
0.05 mL

		Plaques per 0.85 ml at 10^X dilution							pfu/ml	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7
light	1	0					tntc	tntc	165	17
	2	60					tntc	tntc	48	5
	3	120					tntc	146	15	1
	4	180				tntc	300	29	3	
	5	240				tntc	149	12	4	
	6	300			tntc	tntc	77	6		
									218954248	1
									62745098	0.286567
									19346405	0.088358
									3856209.2	0.017612
									1947712.4	0.008896
									1006535.9	0.004597



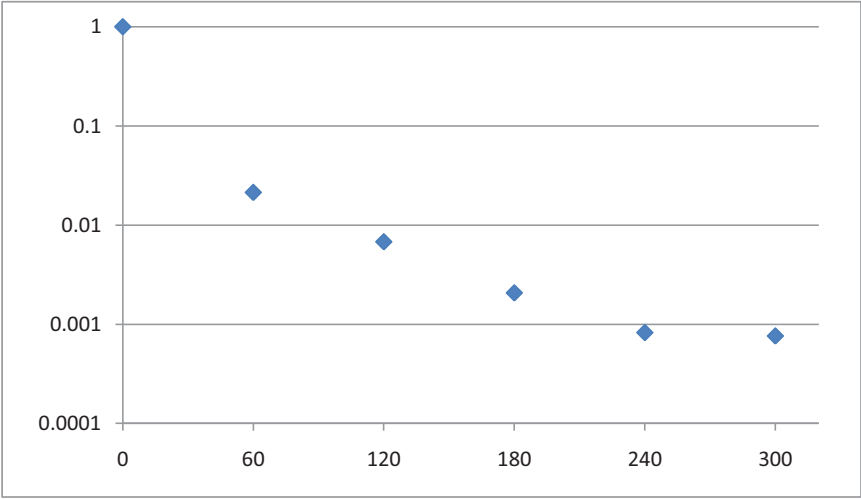
Date	11.5.09	Ozonation morning of experiment (1 hr)	
Fiber	1	Transport time from ozonation to reactor (2.5 min)	
Experiment	47	In dark entire time	
pH	~9	Volume Virus Stock Added	0.05 mL
Temp	25	oC	
Buffer	1mM CBS		
Mass Cat	0.0253	grams	
Volume	25	mL	
Intensity	~450	W/m2	
Filters	> 400 nm, 10% Transmittance		

		Plaques per 0.85 ml at 10^X dilution									pfu/ml	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
dark	1	0					tntc	tntc	239	26	326143791	1
	2	60					tntc	tntc	99	21	201960784	0.619238
	3	120					tntc	tntc	56	7	73202614	0.224449
	4	180				tntc	tntc	tntc	41		53594771	0.164329
	5	240				tntc	tntc	185	43		40196078	0.123246
	6	300			tntc	tntc	tntc	75			9803921.6	0.03006



Date	11.10.09	Ozonation morning of experiment (1 hr)	
Fiber	1	Transport time from ozonation to reactor (2.5 min)	
Experiment	48	In light entire time	
pH	~7.9	Volume Virus Stock Added	0.05 mL
Temp	25	oC	
Buffer	1mM CBS		
Mass Cat	0.026	grams	
Volume	25	mL	
Intensity	~450	W/m2	
Filters	> 400 nm, 10% Transmittance		

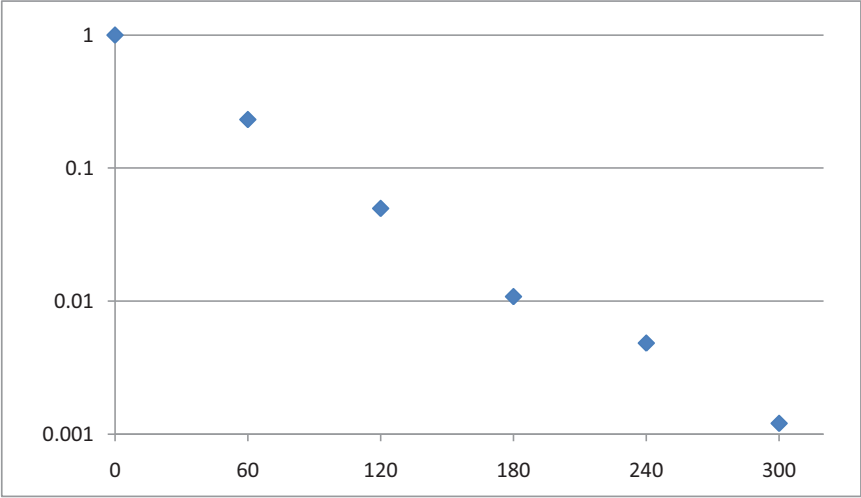
Plaques per 0.85 ml at 10^X dilution											pfu/ml	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
light	1	0					tntc	tntc	295	36	428104575	1
	2	60					tntc	70	4	2	9150326.8	0.021374
	3	120					215	23	2	0	2908496.7	0.006794
	4	180				tntc	68	0	0		888888.89	0.002076
	5	240				221	32	12	0		353594.77	0.000826
	6	300			tntc	tntc	25	2			326797.39	0.000763



Date 11.11.09 Ozonation morning of experiment (1 hr)
Fiber 1 Transport time from ozonation to reactor (2.5 min)
Experiment 49 In dark entire time

pH ~7.9 **Volume Virus Stock Added** 0.05 mL
Temp 25 oC
Buffer 1mM CBS
Mass Cat 0.0246 grams
Volume 25 mL
Intensity ~450 W/m2
Filters > 400 nm, 10% Transmittance

		Plaques per 0.85 ml at 10^X dilution									pfu/ml	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
dark	1	0					tntc	tntc	287	36	422875817	1
	2	60					tntc	tntc	75	7	98039216	0.231839
	3	120					tntc	172	15	2	21045752	0.049768
	4	180				tntc	tntc	35	4		4575163.4	0.010819
	5	240				tntc	133	18	0		2045751.6	0.004838
	6	300			tntc	tntc	39	4			509803.92	0.001206



Date

Fiber

Experiment

pH

Temp

Buffer

Mass Cat

Volume

Intensity

Filters

11.12.09

1

50

~7.9

25

1mM CBS

0.0244

25

~450

> 400 nm, 10% Transmittance

Ozonation morning of experiment (1 hr)

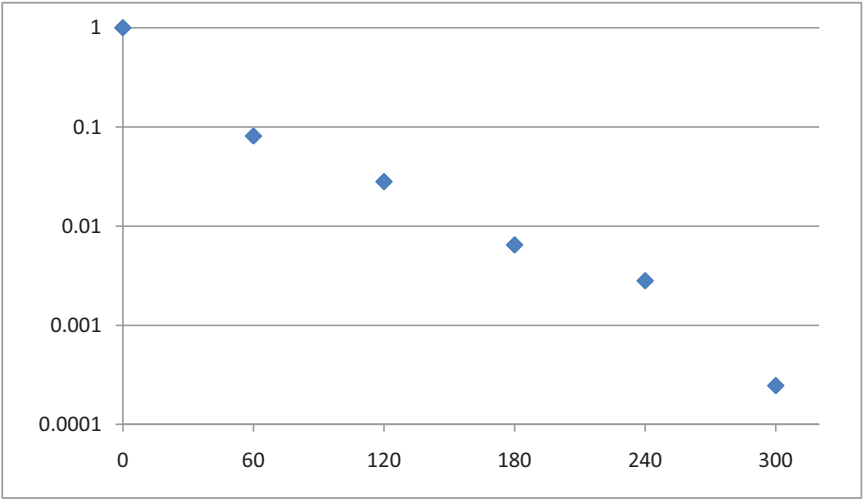
Transport time from ozonation to reactor (2.5 min)

In light entire time

Volume Virus Stock Added

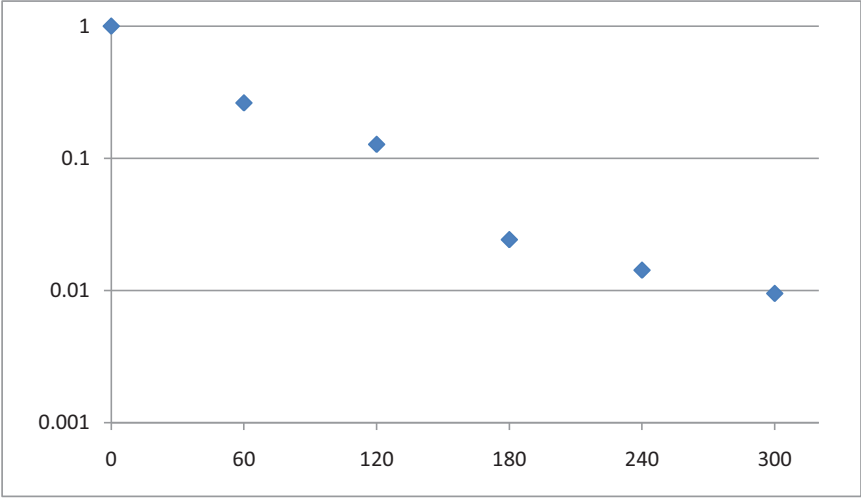
0.05 mL

		Plaques per 0.85 ml at 10^X dilution										pfu/ml	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7		N	N/N ₀
light	1	0					tntc	tntc	264	37		414379085	1
	2	60					tntc	263	25	8		33529412	0.080915
	3	120					tntc	89	10	1		11633987	0.028076
	4	180				tntc	179	23	3			2673202.6	0.006451
	5	240				tntc	89	4	1			1163398.7	0.002808
	6	300			tntc	78	9	1				101960.78	0.000246



Date	11.17.09	Ozonation morning of experiment (1 hr)	
Fiber	1	Transport time from ozonation to reactor (2.5 min)	
Experiment	51	In light entire time	
pH	~7.9	Volume Virus Stock Added 0.05 mL	
Temp	25	oC	
Buffer	1mM CBS		
Mass Cat	0.0239	grams	Loss significant mass during experiment
Volume	25	mL	
Intensity	~450	W/m2	
Filters	> 400 nm, 10% Transmittance		

Plaques per 0.85 ml at 10^X dilution											pfu/ml	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
light	1	0					tntc	tntc	tntc	40	522875817	1
	2	60					tntc	tntc	105	11	137254902	0.2625
	3	120					tntc	tntc	51	3	66666667	0.1275
	4	180				tntc	tntc	97	10		12679739	0.02425
	5	240				tntc	tntc	57	2		7450980.4	0.01425
	6	300			tntc	tntc	316	38			4967320.3	0.0095

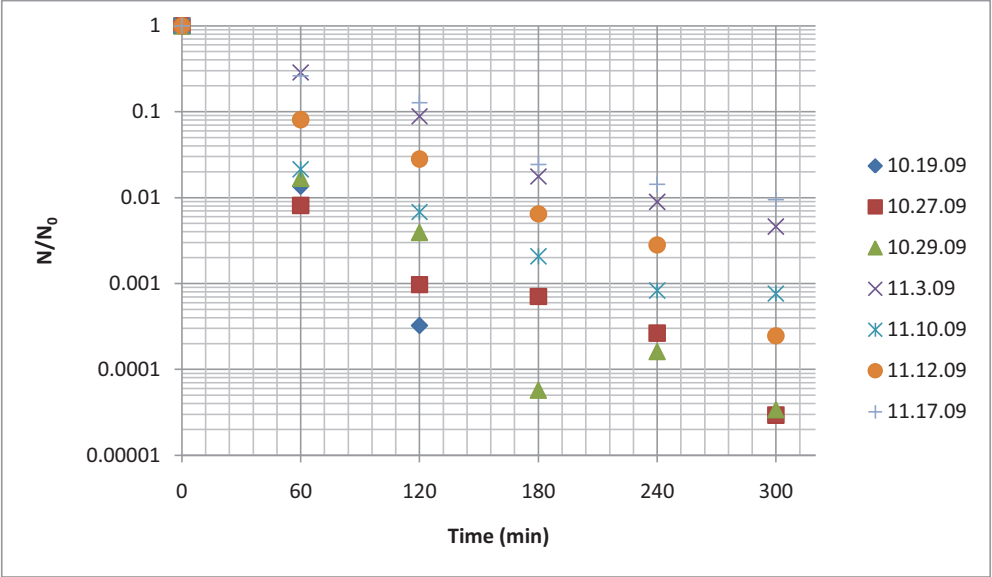


Date Various
Fiber 1
Experiment Ozonation morning of (1 hr)
Transport time (2.5 min)
Experiment entire in light

pH ~8.8-9
Temp 25 oC
Buffer 1mM CBS
Mass Cat Various grams
Volume 25 mL
Intensity ~450 W/m2
Filters > 400 nm, 10% Transmittance
Volume Virus Stock Added 0.05 mL

Plaques per 0.85 ml at 10^X dilution									pfu/ml		
Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
1	0					tntc	tntc	289	39	443790849.7	1
2	60					tntc	46	5	0	6013071.895	0.013549337
3	120					11	1	0	0	143790.8497	0.000324006
4	180				6	0	0	0		0	0
5	240				1	0	0	0			0
6	300				0	0	0	0		0	0
1	0					tntc	tntc	306	34	444444444.4	1
2	60					276	21	1	0	3607843.137	0.008117647
3	120					33	2	1	0	431372.549	0.000970588
4	180				240	5	1	0		313725.4902	0.000705882
5	240				90	15	0	0		117647.0588	0.000264706
6	300			100	10	0	0			13071.89542	2.94118E-05
1	0					tntc	tntc	tntc	47	614379085	1
2	60					tntc	79	4	0	10326797.39	0.016808511
3	120					170	20	7	0	2418300.654	0.00393617
4	180				27	7	3	0		35294.11765	5.74468E-05
5	240				76	0	0	0		99346.40523	0.000161702
6	300			134	16	0	0			20915.03268	3.40426E-05
1	0					tntc	tntc	165	17	218954248.4	1
2	60					tntc	tntc	48	5	62745098.04	0.286567164
3	120					tntc	146	15	1	19346405.23	0.088358209
4	180				tntc	300	29	3		3856209.15	0.01761194
5	240				tntc	149	12	4		1947712.418	0.008895522
6	300			tntc	tntc	77	6			1006535.948	0.004597015
1	0					tntc	tntc	295	36	428104575.2	1
2	60					tntc	70	4	2	9150326.797	0.021374046
3	120					215	23	2	0	2908496.732	0.006793893
4	180				tntc	68	0	0		888888.8889	0.002076336
5	240				221	32	12	0		353594.7712	0.000825954
6	300			tntc	tntc	25	2			326797.3856	0.000763359

1	0			tntc	tntc	264	37	414379085	1	
2	60			tntc	tntc	263	25	8	33529411.76	0.080914826
3	120			tntc	tntc	89	10	1	11633986.93	0.02807571
4	180			tntc	tntc	179	23	3	2673202.614	0.006451104
5	240			tntc	tntc	89	4	1	1163398.693	0.002807571
6	300		tntc	78	9	1			101960.7843	0.000246057
1	0			tntc	tntc	tntc	40		522875817	1
2	60			tntc	tntc	tntc	105	11	137254902	0.2625
3	120			tntc	tntc	tntc	51	3	66666666.67	0.1275
4	180			tntc	tntc	tntc	97	10	12679738.56	0.02425
5	240			tntc	tntc	tntc	57	2	7450980.392	0.01425
6	300		tntc	tntc	316	38			4967320.261	0.0095

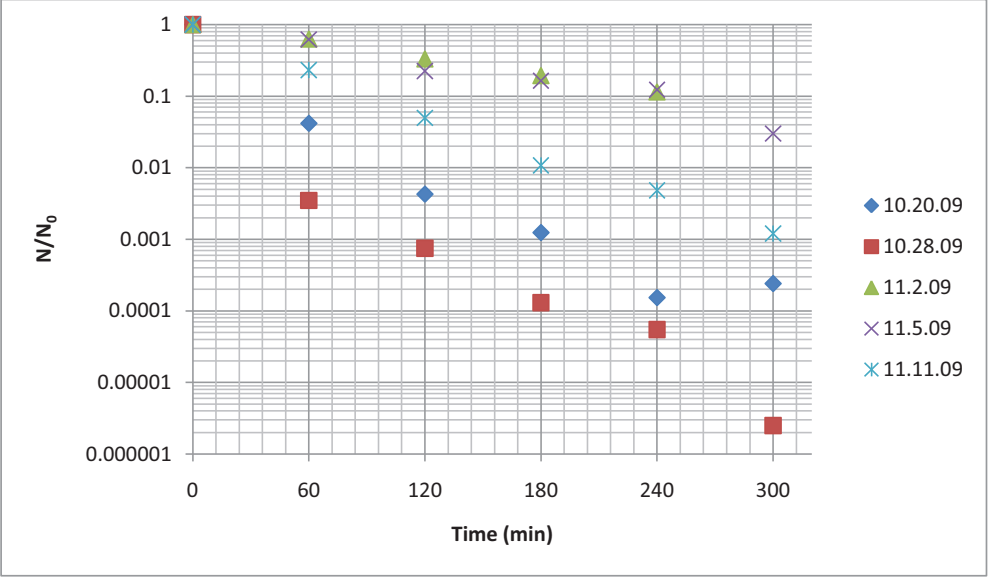


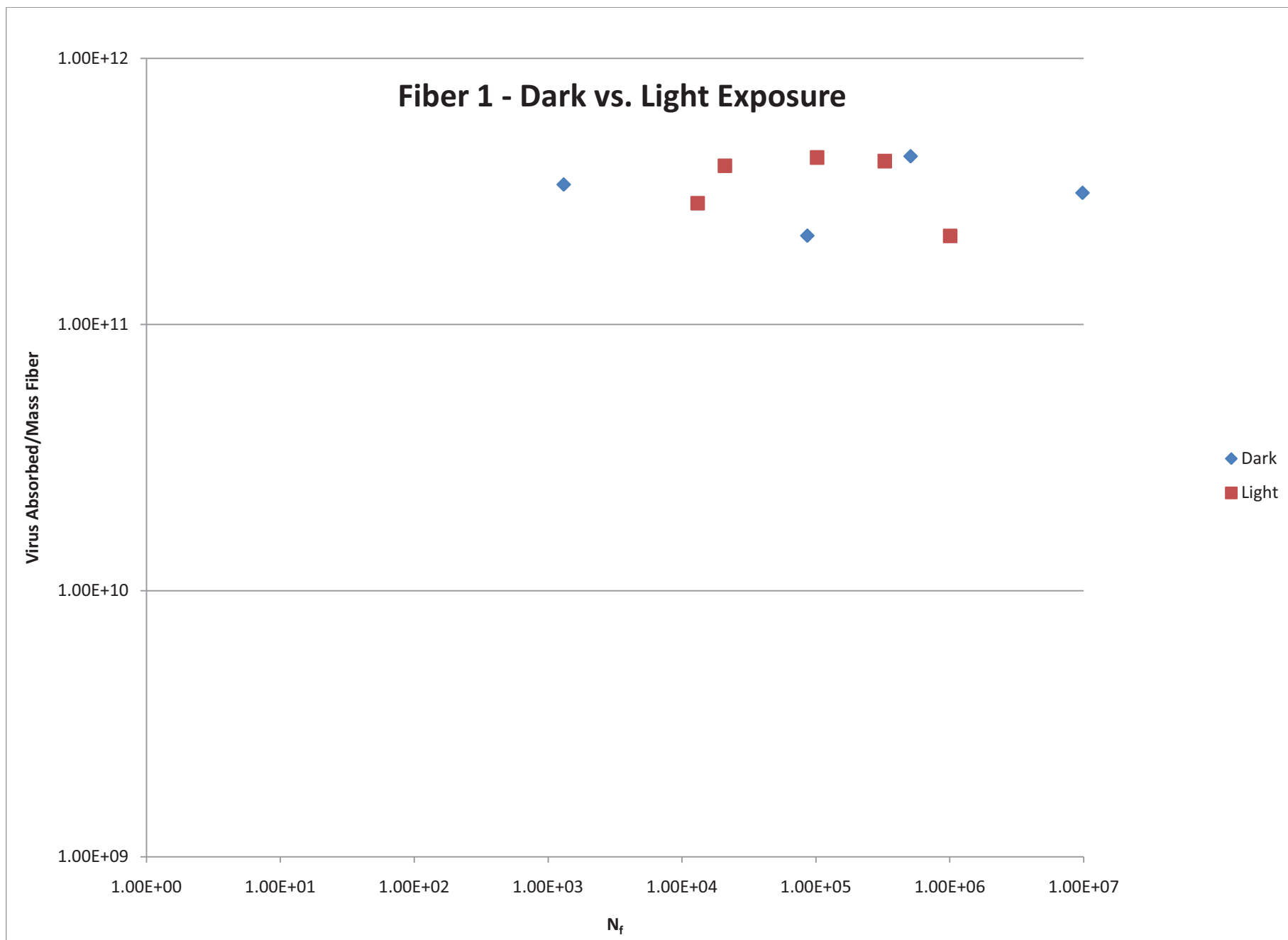
Date Various
Fiber 1
Experiment Ozonation morning of (1 hr)
 Transport time (2.5 min)
 Experiment entire in dark

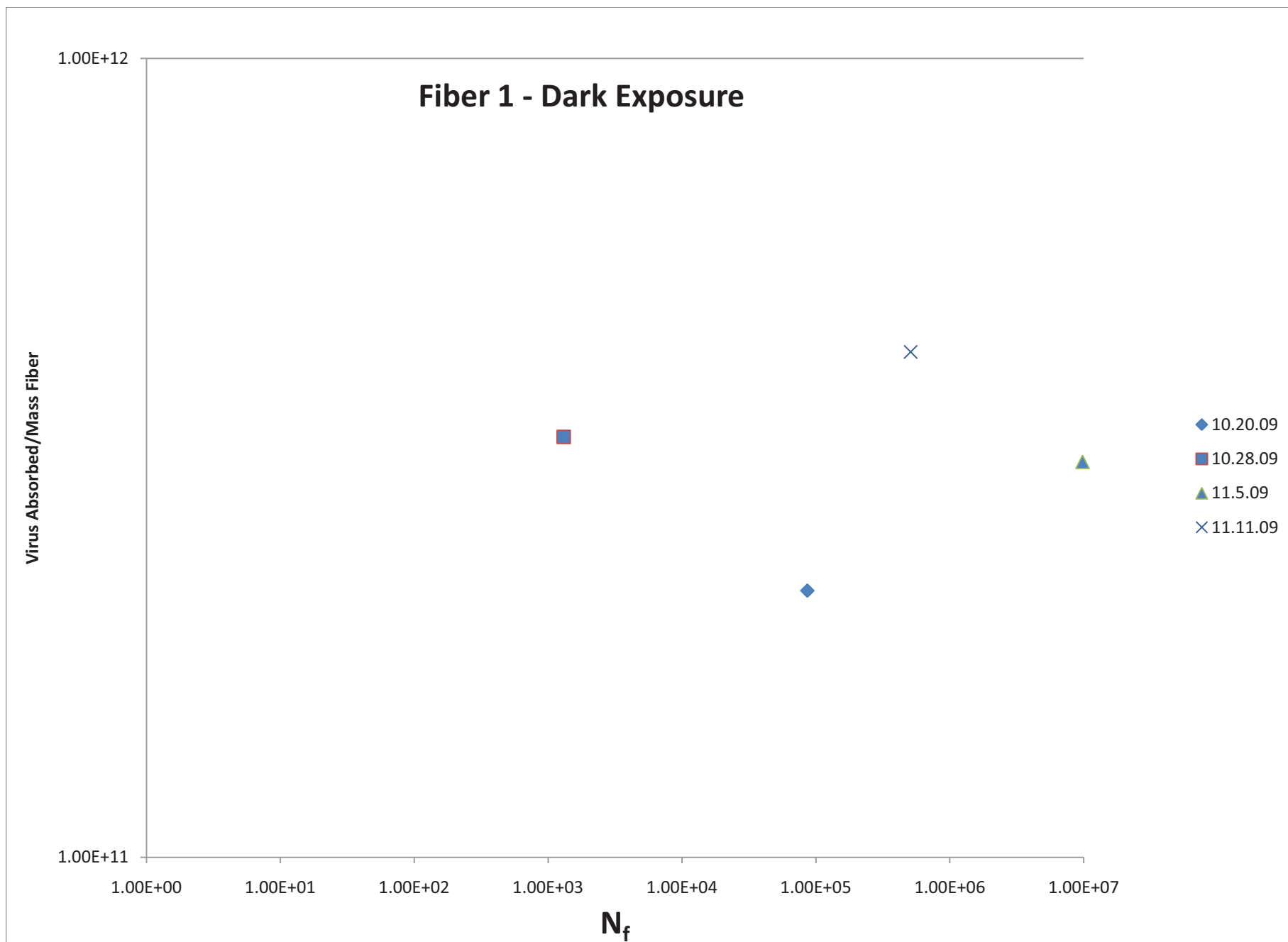
pH ~8.8-9
Temp 25 oC
Buffer 1mM CBS
Mass Cat Various grams
Volume 25 mL
Intensity ~450 W/m2
Filters > 400 nm, 10% Transmittance

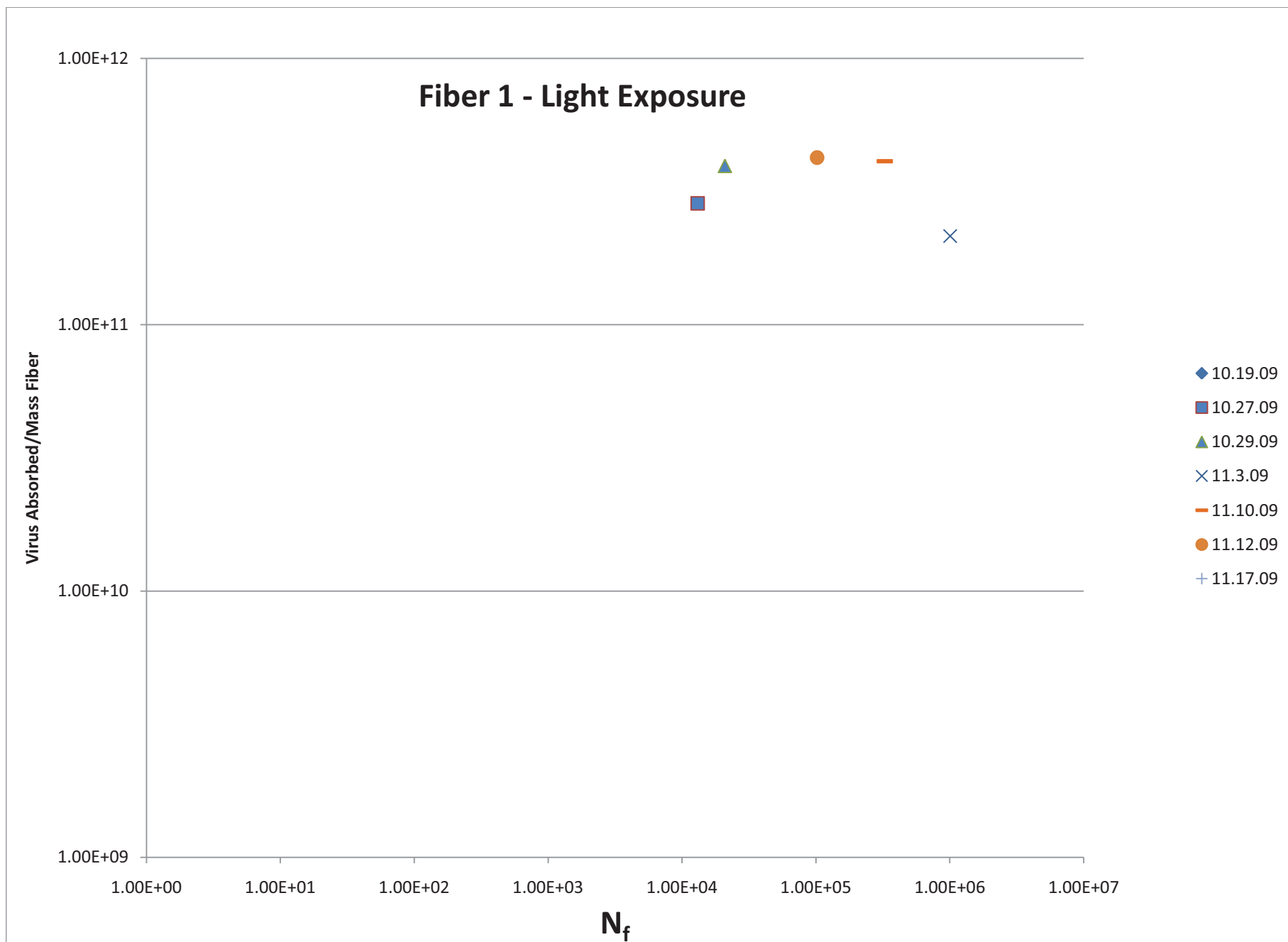
Volume Virus Stock Added 0.05 mL

Plaques per 0.85 ml at 10^X dilution									pfu/ml		
Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
1	0					tntc	tntc	268	28	358169934.6	1
2	60					tntc	114	11	0	14901960.78	0.041605839
3	120					117	6	0		1529411.765	0.004270073
4	180				330	34	3			444444.4444	0.001240876
5	240				42	9	3			54901.96078	0.000153285
6	300				66	3	0			86274.5098	0.000240876
1	0					tntc	tntc	tntc	40	522875817	1
2	60					140	10	1	0	1830065.359	0.0035
3	120					30	3	1	0	392156.8627	0.00075
4	180				52	5	0	1		67973.85621	0.00013
5	240				22	0	0	0		28758.16993	0.000055
6	300			33	1	0	0			1307.189542	0.0000025
1	0					tntc	tntc	tntc	53	692810457.5	1
2	60					tntc	tntc	287	38	435947712.4	0.629245283
3	120					tntc	tntc	176	9	230065359.5	0.332075472
4	180				tntc	tntc	tntc	103		134640522.9	0.194339623
5	240				tntc	tntc	tntc	61		79738562.09	0.11509434
6	300			tntc	tntc	tntc	tntc			0	0
1	0					tntc	tntc	239	26	326143790.8	1
2	60					tntc	tntc	99	21	201960784.3	0.619238477
3	120					tntc	tntc	56	7	73202614.38	0.224448898
4	180				tntc	tntc	tntc	41		53594771.24	0.164328657
5	240				tntc	tntc	185	43		40196078.43	0.123246493
6	300			tntc	tntc	tntc	75			9803921.569	0.03006012
1	0					tntc	tntc	287	36	422875817	1
2	60					tntc	tntc	75	7	98039215.69	0.231839258
3	120					tntc	172	15	2	21045751.63	0.049768161
4	180				tntc	tntc	35	4		4575163.399	0.010819165
5	240				tntc	133	18	0		2045751.634	0.004837713
6	300			tntc	tntc	39	4			509803.9216	0.001205564







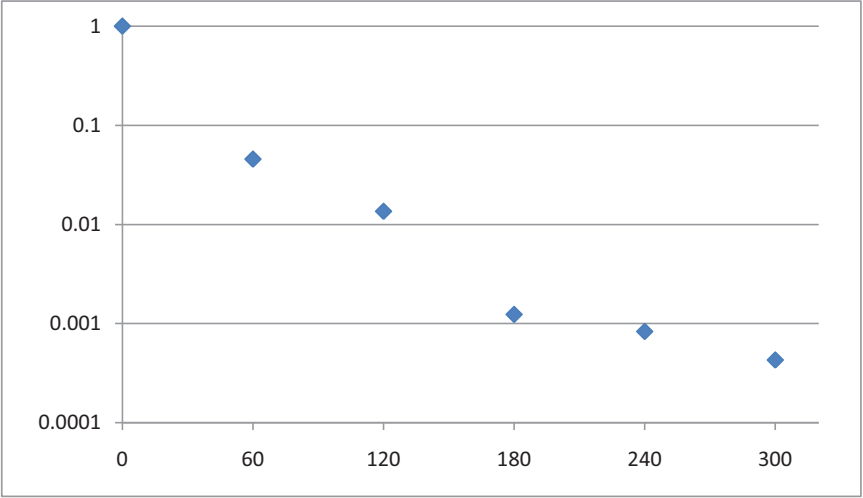


Date 10.22.09 Ozonation morning of experiment (1 hr)
Fiber 2 Transport time from ozonation to reactor (2.5 min)
Experiment 40 In light entire time

Plates counted at 21 hours

pH ~8.8 **Volume Virus Stock Added** 0.05 mL
Temp 25 oC
Buffer 1mM CBS
Mass Cat 0.0194 grams
Volume 25 mL
Intensity ~450 W/m2
Filters > 400 nm, 10% Transmittance

Plaques per 0.85 ml at 10^X dilution										pfu/ml	Time in	
Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀	Light (min)
1	0					tntc	tntc	tntc	42	549019608	1	0
2	60					tntc	193	19	3	25032680	0.045595	0
3	120					tntc	57	6	0	7450980.4	0.013571	0
4	180				tntc	52	6	0		679738.56	0.001238	0
5	240				tntc	35	2	0		457516.34	0.000833	0
6	300			tntc	181	18	0			235947.71	0.00043	0

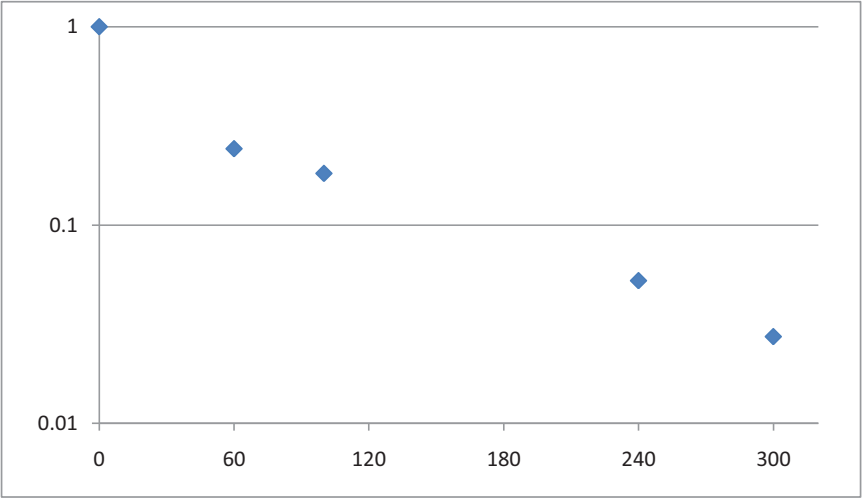


Date 10.23.09 Ozonation morning of experiment (1 hr)
Fiber 2 Transport time from ozonation to reactor (2.5 min)
Experiment 41 In dark entire time

Pipettor failed in middle of dilutions for sample 4
so numbers show more counts than had

pH ~8.8 **Volume Virus Stock Added** 0.05 mL
Temp 25 oC
Buffer 1mM CBS
Mass Cat 0.0194 grams
Volume 25 mL
Intensity ~450 W/m2
Filters > 400 nm, 10% Transmittance

		Plaques per 0.85 ml at 10^X dilution							pfu/ml		Time in	
Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀	Light (min)
dark	1	0				tntc	tntc	tntc	62	810457516	1	0
	2	60				tntc	tntc	151	15	196732026	0.242742	0
	3	100				tntc	tntc	76	15	147712418	0.182258	0
	4	160			tntc	tntc	tntc	139			0	0
	5	240			tntc	tntc	261	39		42549020	0.0525	0
	6	300		tntc	tntc	tntc	170			22222222	0.027419	0



Date8/31/2009

Fiber3

Experiment27

Ozonated Morning of experiment - fiber in light entire experiment

pH

Temp25

Buffer1mM CBS

Mass Cat0.0377

Volume25

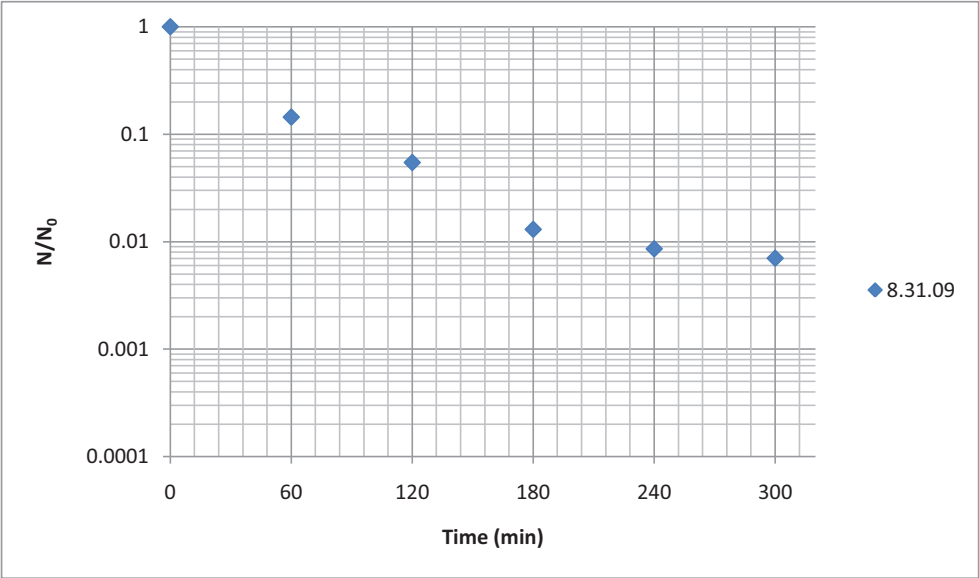
Intensity~450

Filters> 400 nm, 10% Transmittance

Volume Virus Stock Added

0.007 mL

Plaques per 0.85 ml at 10^X dilution										pfu/ml	
Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
1	0				tntc	108	6	1	0	1411764.7	1
2	60				156	16	2	0	0	203921.57	0.144444
3	120				59	4	1	0	0	77124.183	0.05463
4	180			141	14	2	0	0		18431.373	0.013056
5	240			93	4	0	0	0		12156.863	0.008611
6	300			76	2	0	0			9934.6405	0.007037

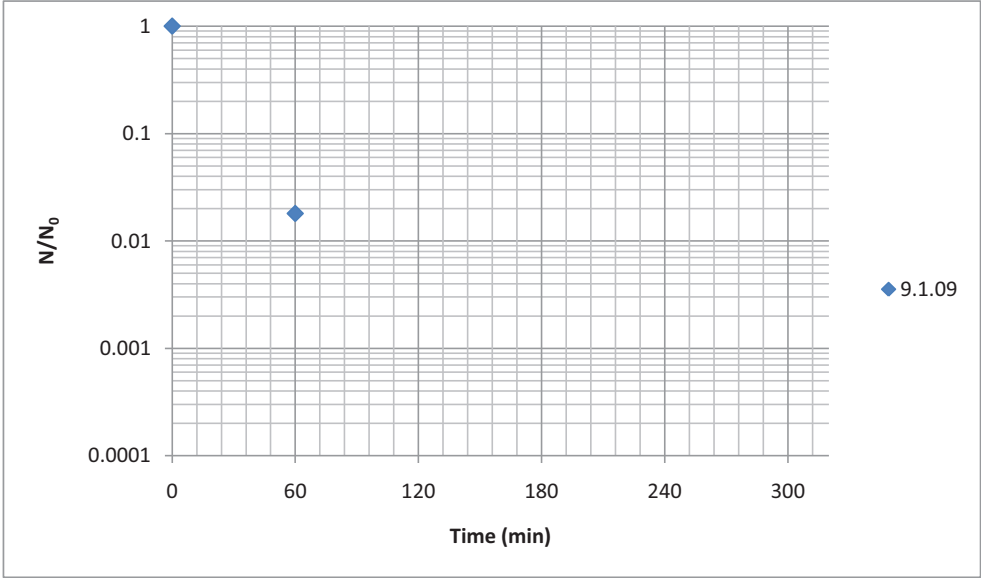


Date 9/1/2009 Ozonated Morning of experiment (ozonation done in "dark") - fiber in dark entire experiment
Fiber 3
Experiment 28

pH
Temp 25 oC
Buffer 1mM CBS
Mass Cat 0.0377 grams
Volume 25 mL
Intensity ~450 W/m2
Filters > 400 nm, 10% Transmittance

Volume Virus Stock Added 0.007 mL

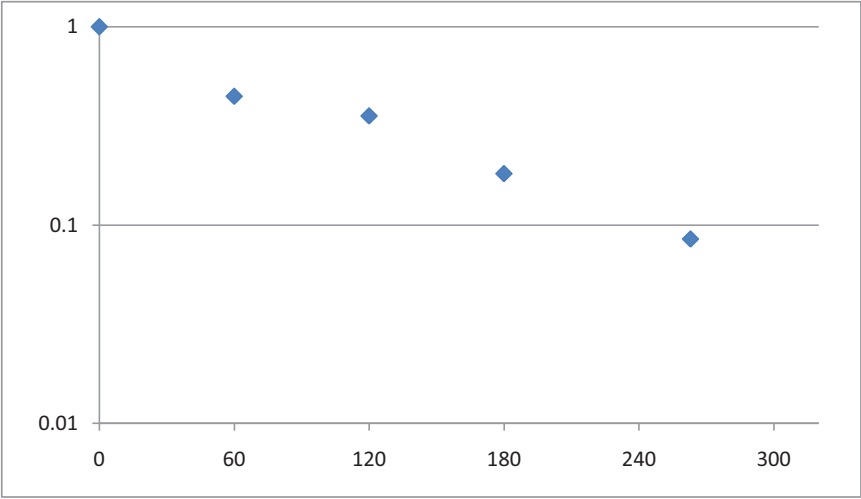
Plaques per 0.85 ml at 10^X dilution											pfu/ml	
	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
dark	1	0				tntc	89	7	0	0	1163398.7	1
	2	60				16	0	0	0	0	20915.033	0.017978
	3	120				0	0	0	0	0	0	0
	4	180			0	0	0	0	0		0	0
	5	240			0	0	0	0	0		0	0
	6	300			0	0	0	0			0	0



Date 11.19.09 Ozonation morning of experiment (1 hr)
Fiber 3 Transport time from ozonation to reactor (2.5 min)
Experiment 52 In light entire time

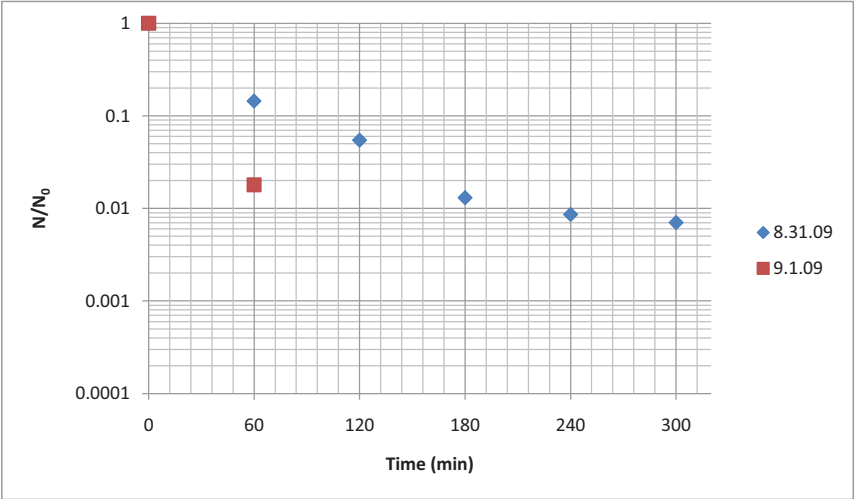
pH ~7.9 **Volume Virus Stock Added** 0.05 mL
Temp 25 oC
Buffer 1mM CBS
Mass Cat 0.0111 grams
Volume 25 mL
Intensity ~450 W/m2
Filters > 400 nm, 10% Transmittance

Plaques per 0.85 ml at 10^X dilution											pfu/ml	
	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
light	1	0					tntc	tntc	tntc	60	784313725	1
	2	60					tntc	tntc	225	31	349673203	0.445833
	3	120					tntc	tntc	196	23	278431373	0.355
	4	180				tntc	tntc	tntc	109		142483660	0.181667
	5	263				tntc	tntc	tntc	51		66666667	0.085
	6	300			tntc	tntc	tntc	tntc			#VALUE!	#VALUE!



Date	Various	Ozonation Morning of
Fiber	3	
Experiment		
pH		Volume Virus Stock Added
Temp	25	0.007 mL
Buffer	1mM CBS	oC
Mass Cat	0.0377	grams
Volume	25	mL
Intensity	~450	W/m2
Filters	> 400 nm, 10% Transmittance	

Plaques per 0.85 ml at 10^X dilution											pfu/ml	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
light	1	0				tntc	108	6	1	0	1411764.7	1
	2	60				156	16	2	0	0	203921.57	0.144444
	3	120				59	4	1	0	0	77124.183	0.05463
	4	180			141	14	2	0	0		18431.373	0.013056
	5	240			93	4	0	0	0		12156.863	0.008611
	6	300			76	2	0	0			9934.6405	0.007037
dark	1	0				tntc	89	7	0	0	1163398.7	1
	2	60				16	0	0	0	0	20915.033	0.017978
	3	120				0	0	0	0	0	0	0
	4	180			0	0	0	0	0		0	0
	5	240			0	0	0	0	0		0	0
	6	300			0	0	0	0			0	0



Appendix F

Regeneration Method: Ozone + Light with Dark/Light Methods

Fibers were ozonated for 1hr and the irradiated with visible light for 5 hr. The samples were stored overnight in darkness in CBS. The next day the virus was added and experiment proceeded in either dark/light. Experiments done to understand how capacity of material is formed.

Fiber	Date	L/D	Notes
3	12.2.09	Dark	1-log removal
3	12.1.09/12.3.09		Samples taken to check for residual viruses off fiber
3	12.4.09	Light	Less than 1-log removal
4	12.10.09	Dark	Less than 1-log removal
4	12.11.09		Samples taken to check for residual viruses off fiber
4	12.12.09	Light	2-log removal
4	12.15.09	Dark	Less than 1-log removal
4	12.17.09	Light	Less than 1-log removal

*Done with Stock 2

Date12.2.09

Fiber3

Experiment54

Ozonation morning of day one of experiment (1 hr)

Transport time from ozonation to reactor (2.5 min)

In light for 5 hours during day one with no viruses added

Day two viruses were added in darkness

Experiment run in darkness entire time (5 hr)

Fiber and Reactor in darkness from light during day one to end of day 2

pH~7.9

Temp25

Buffer1mM CBS

Mass Cat0.0103

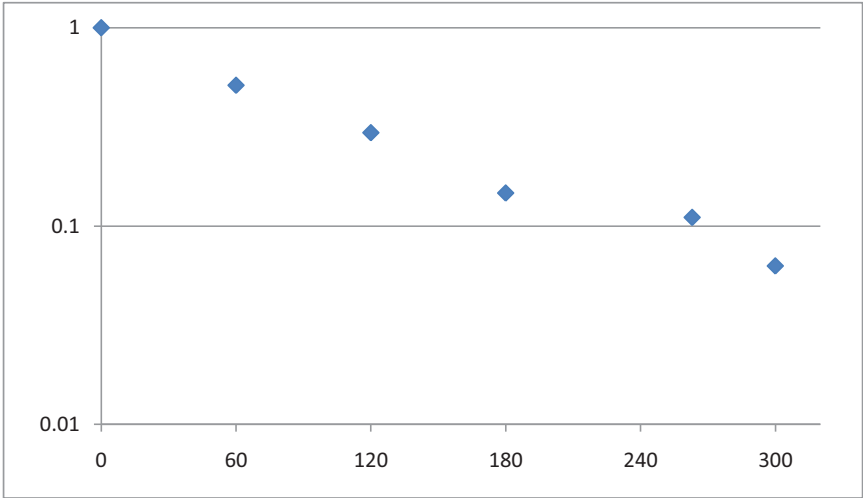
Volume25

Intensity~450

Filters> 400 nm, 10% Transmittance

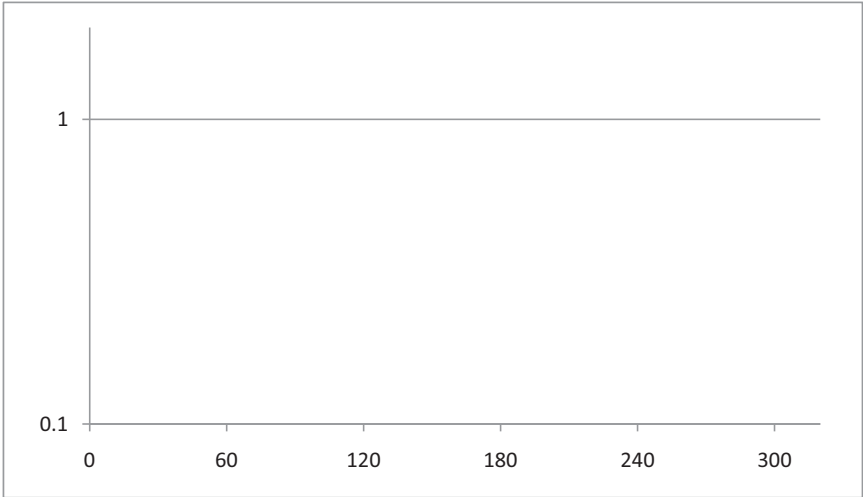
Volume Virus Stock Added0.05 mL

		Plaques per 0.85 ml at 10^X dilution									pfu/ml	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
dark	1	0					tntc	tntc	tntc	47	614379085	1
	2	60					tntc	tntc	242	24	315032680	0.512766
	3	120					tntc	tntc	128	15	181699346	0.295745
	4	180				tntc	tntc	tntc	69		90196078	0.146809
	5	263				tntc	tntc	tntc	52		67973856	0.110638
	6	300			tntc	tntc	tntc	296			38692810	0.062979



Date	12.1.09, 12.3.09	Ozonation morning of day one of experiment (1 hr)	Day two viruses were added in darkness
Fiber	3	Transport time from ozonation to reactor (2.5 min)	Experiment run in darkness entire time (5 hr)
Experiment	53,55	In light for 5 hours during day one with no viruses added	Fiber and Reactor in darkness from light during day one to end of day 2
		<i>*Incubated for 24 hours</i>	
pH	~7.9	Volume Virus Stock Added	0.05 mL
Temp	25		
Buffer	1mM CBS		
Mass Cat	0.0103	grams	
Volume	25	mL	
Intensity	~450	W/m2	
Filters	> 400 nm, 10% Transmittance		

Plaques per 0.85 ml at 10^X dilution											pfu/ml	
	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
12.1.09	1	0	0								0	#DIV/0!
	2	90	0								0	#DIV/0!
	3	195	0								0	#DIV/0!
	4	300	2								2.6143791	
12.3.09	1	0	tntc								#VALUE!	#VALUE!
	2	90	84								109.80392	#DIV/0!
	3	210	45								58.823529	#DIV/0!
	4	300	24								31.372549	



Date12.4.09

Fiber3

Experiment56

Ozonation morning of day one of experiment (1 hr)

Transport time from ozonation to reactor (2.5 min)

In light for 5 hours during day one with no viruses added

Day two viruses were added in light

Experiment run in light entire time (5 hr)

Fiber and Reactor in darkness from light during day one to end of day 2

pH~7.9

Temp25

Buffer1mM CBS

Mass Cat0.0103

Volume25

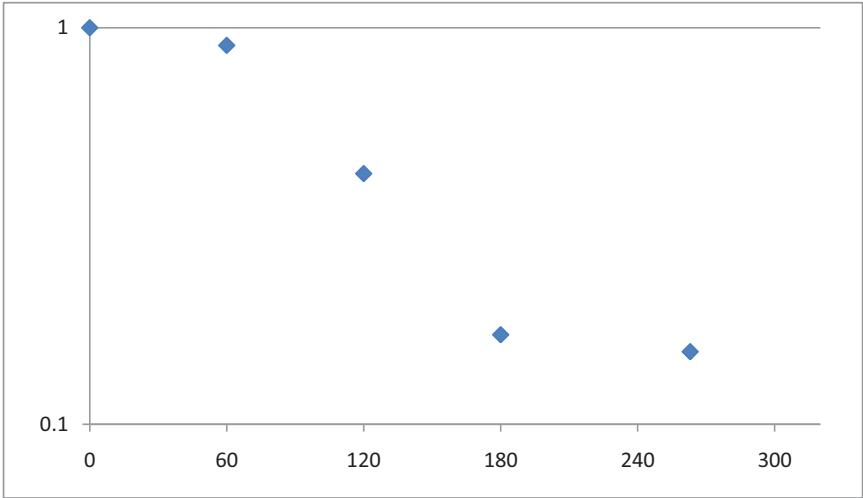
Intensity~450

Filters> 400 nm, 10% Transmittance

Volume Virus Stock Added

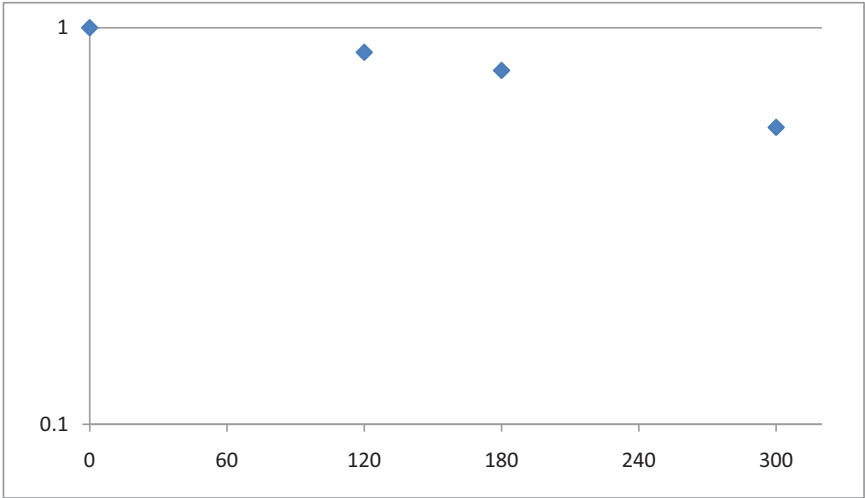
0.05 mL

Plaques per 0.85 ml at 10^X dilution											pfu/ml	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
light	1	0					tntc	tntc	326	38	496732026	1
	2	60					tntc	tntc	276	41	448366013	0.902632
	3	120					tntc	tntc	166	16	213071895	0.428947
	4	180				tntc	tntc	tntc	64		83660131	0.168421
	5	263				tntc	tntc	tntc	58		75816993	0.152632
	6	300			tntc	tntc	tntc	tntc			#VALUE!	#VALUE!



Date	12.10.09	Ozonation morning of day one of experiment (1 hr)	Day two viruses were added in darkness
Fiber	4	Transport time from ozonation to reactor (2.5 min)	Experiment run in darkness entire time (5 hr)
Experiment	57	In light for 5 hours during day one with no viruses added	Fiber and Reactor in darkness from light during day one to end of day 2
pH	~7.9	Volume Virus Stock Added	0.05 mL
Temp	25		
Buffer	1mM CBS		
Mass Cat	0.0238	grams	
Volume	25	mL	
Intensity	~450	W/m2	
Filters	> 400 nm, 10% Transmittance		

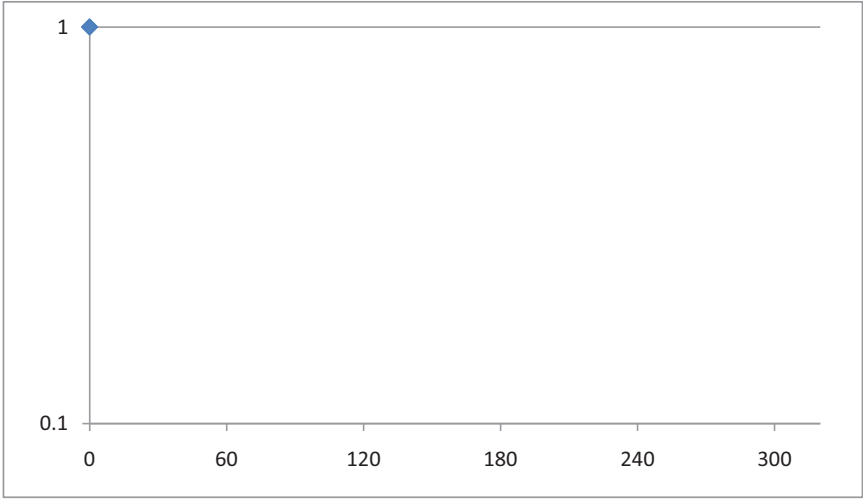
Dark or light	Sample	Time (min)	Plaques per 0.85 ml at 10^X dilution							pfu/ml		
			0	1	2	3	4	5	6	7	N	N/N ₀
dark	1	0					tntc	tntc	184	29	309803922	1
	2	60					tntc	tntc	192	39	380392157	1.227848
	3	120					tntc	tntc	201	21	268627451	0.867089
	4	180				tntc	tntc	tntc	185		241830065	0.780591
	5	263				tntc	tntc	tntc			0	0
	6	300			tntc	tntc	tntc	tntc	133		173856209	0.561181



Date	12.11.09	Ozonation morning of day one of experiment (1 hr)	Day two viruses were added in darkness
Fiber	4	Transport time from ozonation to reactor (2.5 min)	Experiment run in darkness entire time (5 hr)
Experiment	58	In light for 5 hours during day one with no viruses added	Fiber and Reactor in darkness from light during day one to end of day 2

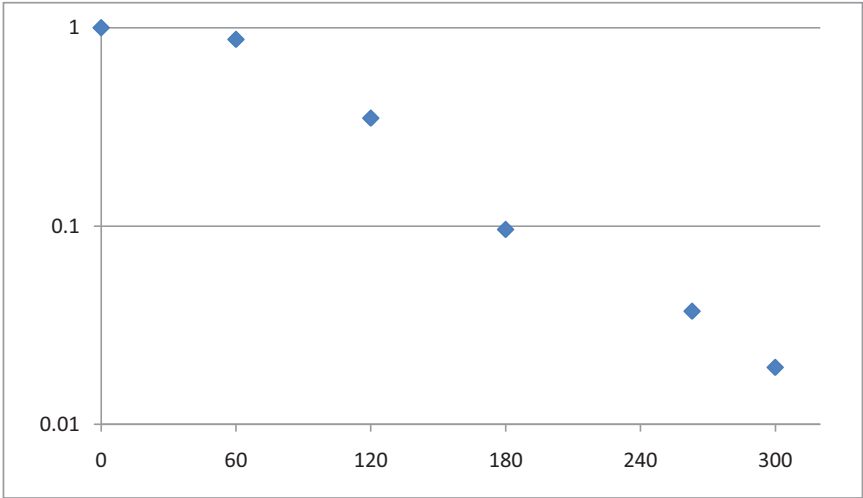
pH	~7.9	Volume Virus Stock Added	0.05 mL
Temp	25		
Buffer	1mM CBS		
Mass Cat	0.0228	grams	
Volume	25	mL	
Intensity	~450	W/m2	
Filters	> 400 nm, 10% Transmittance		

Plaques per 0.85 ml at 10^X dilution											pfu/ml	
	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
12.11.09	1	0	84								109.80392	1
	2	90	96								125.4902	1.142857
	3	195	133								173.85621	1.583333



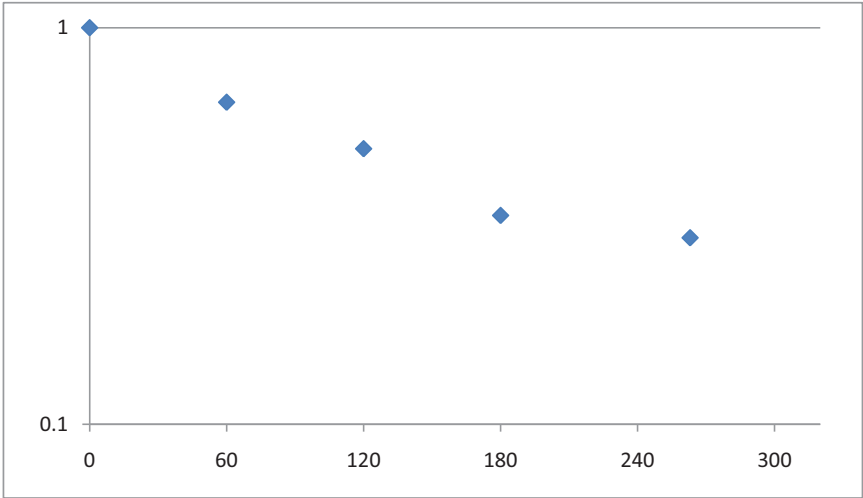
Date	12.12.09	Ozonation morning of day one of experiment (1 hr)	Day two viruses were added in light
Fiber	4	Transport time from ozonation to reactor (2.5 min)	Experiment run in light entire time (5 hr)
Experiment	59	In light for 5 hours during day one with no viruses added	Fiber and Reactor in darkness from light during day one to end of day 2
pH	~7.9	Volume Virus Stock Added	0.05 mL
Temp	25		
Buffer	1mM CBS		
Mass Cat	0.0228	grams	
Volume	25	mL	
Intensity	~450	W/m2	
Filters	> 400 nm, 10% Transmittance		

		Plaques per 0.85 ml at 10^X dilution									pfu/ml	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
light	1	0					tntc	tntc	327	32	418300654	1
	2	60					tntc	tntc	239	32	365359477	0.873438
	3	120					tntc	tntc	112	13	146405229	0.35
	4	180				tntc	tntc	275	34		40196078	0.096094
	5	263				tntc	tntc	119			15555556	0.037188
	6	300			tntc	tntc	tntc	62			8104575.2	0.019375



Date	12.15.09	Ozonation morning of day one of experiment (1 hr)	Day two viruses were added in dark
Fiber	4	Transport time from ozonation to reactor (2.5 min)	Experiment run in light entire time (5 hr)
Experiment	60	In light for 5 hours during day one with no viruses added	Fiber and Reactor in darkness from light during day one to end of day 2
pH	~7.9	Volume Virus Stock Added	0.05 mL
Temp	25		
Buffer	1mM CBS		
Mass Cat	0.0228	grams	
Volume	25	mL	
Intensity	~450	W/m2	
Filters	> 400 nm, 10% Transmittance		

Dark or light	Sample	Time (min)	Plaques per 0.85 ml at 10^X dilution							pfu/ml		
			0	1	2	3	4	5	6	7	N	N/N ₀
dark	1	0					tntc	tntc	tntc	44	575163399	1
	2	60					tntc	tntc	241	33	373202614	0.648864
	3	120					tntc	tntc	196	24	284967320	0.495455
	4	180				tntc	tntc	tntc	148		193464052	0.336364
	5	263				tntc	tntc	tntc	130		169934641	0.295455
	6	300			tntc	tntc	tntc	tntc			#VALUE!	#VALUE!



Date12.17.09

Fiber4

Experiment61

Ozonation morning of day one of experiment (1 hr)

Transport time from ozonation to reactor (2.5 min)

In light for 5 hours during day one with no viruses added

Day two viruses were added in light

Experiment run in light entire time (5 hr)

Fiber and Reactor in darkness from light during day one to end of day 2

pH~7.9

Temp25

Buffer1mM CBS

Mass Cat0.0226

Volume25

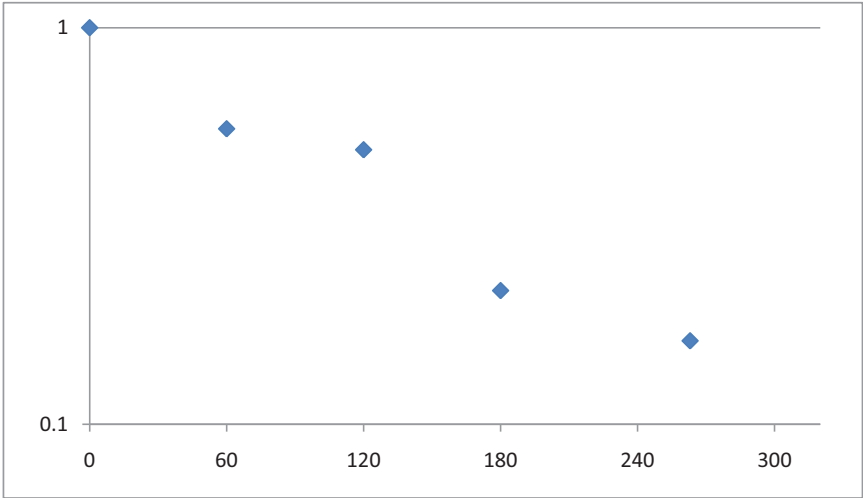
Intensity~450

Filters> 400 nm, 10% Transmittance

Volume Virus Stock Added0.05 mL

2,-7 - some spilled out of vial when going to waterbath

		Plaques per 0.85 ml at 10^X dilution									pfu/ml	
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
light	1	0					tntc	tntc	309	40	522875817	1
	2	60					tntc	tntc	195	25	290849673	0.55625
	3	120					tntc	tntc	197		257516340	0.4925
	4	180				tntc	tntc	tntc	87		113725490	0.2175
	5	263				tntc	tntc	tntc	65		84967320	0.1625
	6	300			tntc	tntc	tntc	325				0



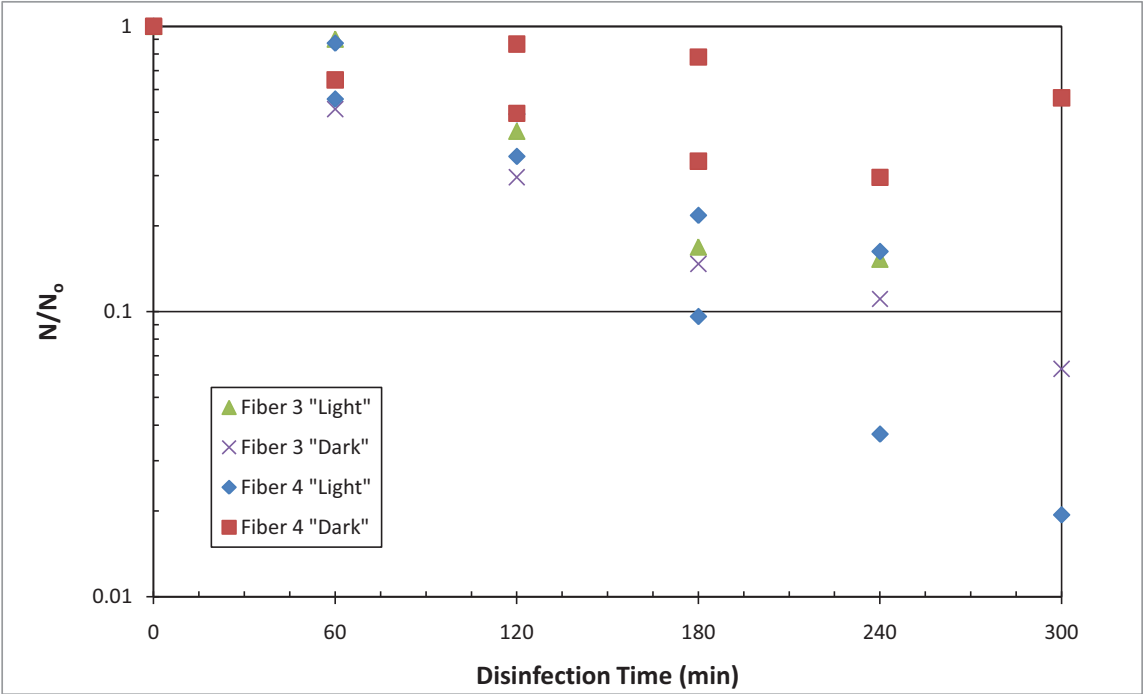
Date 12.2.09 - 12.17.09 Ozonation morning of day one of experiment (1 hr) Day two viruses were added in dark or light as noted
Fiber 3,4 Transport time from ozonation to reactor (2.5 min) Experiment run in light entire time (5 hr)
Experiment In light for 5 hours during day one with no viruses added Setup in darkness after light of day one to beginning of day 2

pH ~7.9
Temp 25 oC
Buffer 1mM CBS
Mass Cat Various grams
Volume 25 mL
Intensity ~450 W/m²
Filters > 400 nm, 10% Transmittance

Volume Virus Stock Added 0.05 mL

Dark or light	Sample	Time (h)	Plaques per 0.85 ml at 10 ⁴ X dilution						7	pfu/ml		1.31E+10
			0	1	2	3	4	5	6	N	N/N ₀	
dark	1	0					tntc	tntc	tntc	47	614379085	1
	2	60					tntc	tntc	242	24	315032680	0.512766
	3	120					tntc	tntc	128	15	181699346	0.295745
	4	180				tntc	tntc	tntc	69		90196078	0.146809
	5	240				tntc	tntc	tntc	52		67973856	0.110638
	6	300			tntc	tntc	tntc	296			38692810	0.062979
light	1	0					tntc	tntc	326	38	496732026	1
	2	60					tntc	tntc	276	41	448366013	0.902632
	3	120					tntc	tntc	166	16	213071895	0.428947
	4	180				tntc	tntc	tntc	64		83660131	0.168421
	5	240				tntc	tntc	tntc	58		75816993	0.152632
	6	300			tntc	tntc	tntc	tntc			#VALUE!	#VALUE!
dark	1	0					tntc	tntc	184	29	309803922	1
	2	60					tntc	tntc	192	39	380392157	1.227848
	3	120					tntc	tntc	201	21	268627451	0.867089
	4	180				tntc	tntc	tntc	185		241830065	0.780591
	5	240				tntc	tntc	tntc			0	0
	6	300			tntc	tntc	tntc	tntc	133		173856209	0.561181
light	1	0					tntc	tntc	327	32	418300654	1
	2	60					tntc	tntc	239	32	365359477	0.873438
	3	120					tntc	tntc	112	13	146405229	0.35
	4	180				tntc	tntc	275	34		40196078	0.096094
	5	240				tntc	tntc	119			15555556	0.037188
	6	300			tntc	tntc	tntc	62			8104575.2	0.019375
dark	1	0					tntc	tntc	tntc	44	575163399	1
	2	60					tntc	tntc	241	33	373202614	0.648864
	3	120					tntc	tntc	196	24	284967320	0.495455
	4	180				tntc	tntc	tntc	148		193464052	0.336364
	5	240				tntc	tntc	tntc	130		169934641	0.295455
	6	300			tntc	tntc	tntc	tntc			#VALUE!	#VALUE!

light	1	0			tntc	tntc	309	40	522875817	1
	2	60			tntc	tntc	195	25	290849673	0.55625
	3	120			tntc	tntc	197		257516340	0.4925
	4	180		tntc	tntc	tntc	87		113725490	0.2175
	5	240		tntc	tntc	tntc	65		84967320	0.1625
	6	300	tntc	tntc	tntc	tntc	325			0



Appendix G
Additional Analysis

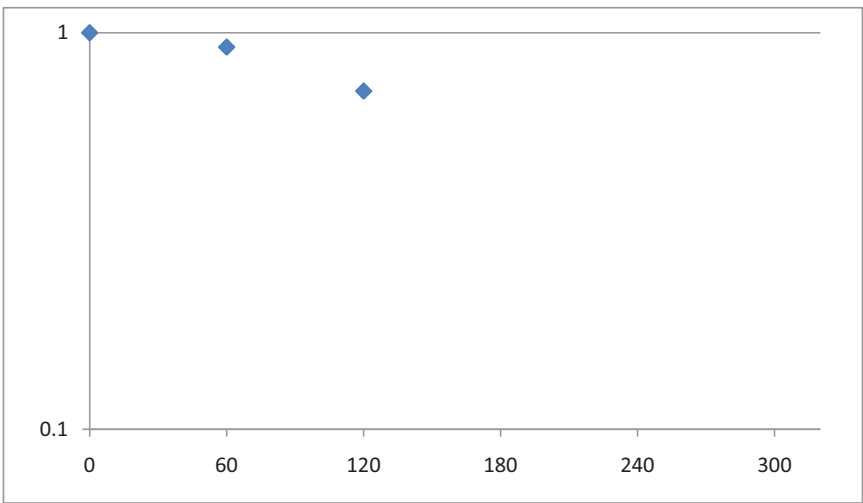
Various Graphs and Tables created to better understand data

Analysis	Notes
Concentration of Stock 2	
Additonal analysis table	Table containing information allowing calculation of normalized removal by mass
Basic information table	Table containing key information from each experiment to understand combinations and results
Different Regneration Technique Table	Table showing results from experiments using different regeneration methods with Fiber 3
Different Regneration Technique Chart	Chart showing from above table
Different Regneration Technique Chart	Same information but normalized by mass
Normalized Fiber Removal vs. Nf	
Normalized Fiber Removal vs. No	
Regeneration Comparison Normalized Removal vs. Nf	
Stock Comparison Normalized Removal vs. Nf	
Overnight Ozone Removal Capacity vs. Time	
Morning Ozone Removal Capacity vs. Time	
Stock Comparison Normalized Removal vs. No	
Low Removal (Normalized Removal vs. No)	

Date 1.19.10 Added .9 mL virus stock to (3) 1.5 mL centrifuge tubes. Did serial dilutions down to 10⁽⁻¹¹⁾
Fiber
Experiment Concentration of Stock

pH
Temp oC
Buffer 1mM CBS
Mass Cat
Volume 25 mL
Intensity ~450 W/m²
Filters > 400 nm, 10% Transmittance
Volume Virus Stock Added 0.9 mL

		Plaques per 0.85 ml at 10 ^X dilution										pfu/ml	
Dark or light	Sample	Time (min)	0	1	2	3	8	9	10	11		<i>N</i>	<i>N/N₀</i>
	1	0					tntc	181	22	1		2.35882E+11	1
	2	60					tntc	169	20	1		2.17059E+11	0.9202
light	3	120					tntc	146	14	2		1.68235E+11	0.713217



Experiment	MS2 Stock	Regeneration Technique	Experiment Exposure	Fiber	Mass (g)	V (mL) virus	N _o (pfu/mL)	N _i (pfu/mL)	Virus abs./mass fiber
1	1	Ozone - Overnight (CBS)	Combined	old	0.109	0.35	1.91E+08	1.31E+07	5.71E+08
2		Ozone - Overnight (CBS)	Combined		0.0977	0.25	1.93E+08	-----	#VALUE!
3		None (brand new fiber)	Combined		0.0566	0.125	-----	-----	#VALUE!
4		None	Combined		0.0558	0.125	6.14E+07	3.92E+07	4.98E+07
5		UV irradiation	Combined		0.0558	0.125	5.10E+07	1.70E+07	7.61E+07
6		Monochloramine	Combined		0.0558	0.125	4.44E+07	9.54E+06	7.82E+07
7		Monochloramine	Combined		0.0558	0.125	4.77E+07	1.14E+06	1.04E+08
8		Ozone - Overnight (air)	Combined	1	0.0897	0.007	7.19E+06	1.44E+03	5.61E+05
9		Ozone - Overnight (air) *7 days	Combined	3	0.0468	0.007	3.41E+06	3.05E+06	5.28E+04
10		Ozone - Overnight (air)	Combined	2	0.0377	0.007	5.88E+06	1.39E+05	1.07E+06
11		Ozone - Overnight (air)	Combined	3	0.0468	0.007	1.27E+07	9.41E+06	4.89E+05
12		Ozone - Overnight (air)	Combined	2	0.0377	0.007	1.32E+07	1.31E+06	2.21E+06
13		Ozone - Overnight (air)	Combined	1	0.0897	0.007	1.11E+07	-----	#VALUE!
14		Ozone - Overnight (air)	Combined	2	0.0377	0.007	2.33E+07	1.37E+06	4.07E+06
15		Ozone - Overnight (air)	Combined	3	0.0468	0.007	7.32E+06	-----	#VALUE!
16		Ozone - Overnight (air)	Combined	1	0.0897	0.007	4.84E+06	7.84E+03	3.77E+05
17		Ozone - Overnight (air)	Combined	3	0.0468	0.007	6.67E+06	2.40E+06	6.38E+05
18		Ozone - Overnight (air)	Combined	2	0.0377	0.007	6.67E+06	3.09E+05	1.18E+06
19		Ozone - Overnight (air)	Combined	1	0.0897	0.007	6.01E+06	3.79E+04	4.66E+05
20		Ozone - Overnight (air)	Combined	2	0.0377	0.007	3.35E+06	1.32E+06	3.76E+05
21		Ozone - Overnight (air)	Combined	3	0.0468	0.007	2.14E+06	7.45E+05	2.08E+05
22		Surfactant	Combined	3	0.0468	0.007	2.30E+06	1.19E+06	1.66E+05
23		Surfactant	Combined	3	0.0468	0.007	5.36E+06	3.95E+06	2.10E+05
24		Surfactant	Combined	3	0.0468	0.007	1.90E+06	9.80E+05	1.37E+05
25		Ozone - Same Day	Combined	4	0.04	0.007	7.84E+05	0.00E+00	1.37E+05
26		Ozone (Same Day) + Surfactant	Combined	3	0.0377	0.007	8.24E+05	3.29E+04	1.47E+05
27		Ozone - Same Day	Light	3	0.0377	0.007	1.41E+06	9.93E+03	2.60E+05
28		Ozone - Same Day	Dark	3	0.0377	0.007	1.16E+06	0.00E+00	2.16E+05
29		Ozone - Same Day	Combined	3	0.0377	0.007	1.45E+06	1.71E+04	2.66E+05
30		Ozone - Same Day	Combined	3	0.0377	0.007	2.62E+06	6.54E+03	4.85E+05
31		Ozone - Same Day	Combined	2	0.0205	0.007	2.65E+06	-----	#VALUE!
32		Ozone - Same Day	Combined	1	0.0474	0.007	1.57E+06	0.00E+00	2.32E+05
33		Ozone - Same Day	Combined	3	0.0215	0.007	1.86E+06	0.00E+00	6.06E+05
34		Ozone - Same Day	Combined	2	0.0205	0.007	1.62E+06	4.84E+05	3.88E+05
35		Ozone - Same Day	Combined	1	0.0474	0.007	1.18E+06	0.00E+00	1.74E+05
36		Ozone - Same Day	Combined	3	0.0215	0.007	5.82E+05	0.00E+00	1.89E+05
37		Ozone - Same Day	Combined	2	0.0205	0.007	---	3.27E+03	#VALUE!
38	2	Ozone - Same Day	Light	1	0.0415	0.05	4.44E+08	0.00E+00	5.35E+08
39		Ozone - Same Day	Dark	1	0.0415	0.05	3.58E+08	8.63E+04	4.31E+08
40		Ozone - Same Day	Light	2	0.0194	0.05	5.49E+08	2.36E+05	1.41E+09
41		Ozone - Same Day	Dark	2	0.0194	0.05	8.10E+08	2.22E+07	2.03E+09
42		Ozone - Same Day	Light	1	0.0389	0.05	4.44E+08	1.31E+04	5.71E+08
43		Ozone - Same Day	Dark	1	0.0389	0.05	5.23E+08	1.31E+03	6.72E+08
44		Ozone - Same Day	Light	1	0.0389	0.05	6.14E+08	2.09E+04	7.90E+08
45		Ozone - Same Day	Dark	1	0.0253	0.05	6.93E+08	----	#VALUE!
46		Ozone - Same Day	Light	1	0.0253	0.05	2.19E+08	1.01E+06	4.31E+08
47		Ozone - Same Day	Dark	1	0.0253	0.05	3.26E+08	9.80E+06	6.25E+08
48		Ozone - Same Day	Light	1	0.026	0.05	4.28E+08	3.27E+05	8.23E+08
49		Ozone - Same Day	Dark	1	0.0246	0.05	4.23E+08	5.10E+05	8.58E+08
50		Ozone - Same Day	Light	1	0.0244	0.05	4.14E+08	1.02E+05	8.49E+08
51		Ozone - Same Day	Light	1	0.0239	0.05	5.23E+08	4.97E+06	1.08E+09
52		Ozone - Same Day	Light	3	0.0111	0.05	7.84E+08	----	#VALUE!
53				3	0.0103	0.05	0.00E+00	2.61E+00	-1.27E+01
54		Ozone - Light	Dark	3	0.0103	0.05	6.14E+08	3.87E+07	2.79E+09
55				3	0.0103	0.05	----	3.14E+01	#VALUE!
56		Ozone - Light	Light	3	0.0103	0.05	4.97E+08	-----	#VALUE!
57		Ozone - Light	Dark	4	0.0238	0.05	3.10E+08	1.74E+08	2.86E+08
58				4	0.0228	0.05	1.10E+02	1.74E+02	-1.40E+02
59		Ozone - Light	Light	4	0.0228	0.05	4.18E+08	8.10E+06	9.00E+08
60		Ozone - Light	Dark	4	0.0228	0.05	5.75E+08	-----	#VALUE!
61		Ozone - Light	Light	4	0.0226	0.05	5.23E+08	-----	#VALUE!

Experiment	MS2 Stock	Date	Regeneration Technique	Experiment Exposure	Fiber	pH	No (pfu/mL)	Nf (pfu/mL)	Mass (g)	V (mL) of virus	V (mL)	log(No-Nf)/V/Mass of fiber	Virus absorbed/mass fiber	Log (Nf)	Log (No)
1		1/12/09	Ozone - Overnight (wet)	Combined	old		1.91E+08	1.31E+07	0.109	0.35	25	10.61	4.08E+10	7.12	8.28
2		1/19/09	Ozone - Overnight (wet)	Combined			1.93E+08		0.0977	0.25	25			#NUM!	8.29
3		1/23/09	None (brand new fiber)	Combined					0.0566	0.125	25			#NUM!	
4		1/29/09	None	Combined	new		6.14E+07	3.92E+07	0.0558	0.125	25	10.00	9.96E+09	7.59	7.79
5		2/5/09	UV irradiation	Combined			5.10E+07	1.70E+07	0.0558	0.125	25	10.18	1.52E+10	7.23	7.71
6		2/15/09	Monochloramine	Combined			4.44E+07	9.54E+06	0.0558	0.125	25	10.19	1.56E+10	6.98	7.65
7		2/20/09	Monochloramine	Combined			4.77E+07	1.14E+06	0.0558	0.125	25	10.32	2.09E+10	6.06	7.68
8		5/20/09	Ozone - Overnight (dry)	Combined	1		7.19E+06	1.44E+03	0.0897	0.007	25	9.30	2.00E+09	3.16	6.86
9		5/27/09	Ozone - Overnight (dry) *7 days	Combined	3		3.41E+06	3.05E+06	0.0468	0.007	25	8.28	1.89E+08	6.48	6.53
10		5/28/09	Ozone - Overnight (dry)	Combined	2		5.88E+06	1.39E+05	0.0377	0.007	25	9.58	3.81E+09	5.14	6.77
11		6/2/09	Ozone - Overnight (dry)	Combined	3		1.27E+07	9.41E+06	0.0468	0.007	25	9.24	1.75E+09	6.97	7.10
12		6/3/09	Ozone - Overnight (dry)	Combined	2		1.32E+07	1.31E+06	0.0377	0.007	25	9.90	7.89E+09	6.12	7.12
13		6/9/09	Ozone - Overnight (dry)	Combined	1		1.11E+07		0.0897	0.007	25			#NUM!	7.05
14		6/10/09	Ozone - Overnight (dry)	Combined	2		2.33E+07	1.37E+06	0.0377	0.007	25	10.16	1.45E+10	6.14	7.37
15		6/16/09	Ozone - Overnight (dry)	Combined	3		7.32E+06		0.0468	0.007	25			#NUM!	6.86
16		6/17/09	Ozone - Overnight (dry)	Combined	1		4.84E+06	7.84E+03	0.0897	0.007	25	9.13	1.35E+09	3.89	6.68
17		6/18/09	Ozone - Overnight (dry)	Combined	3		6.67E+06	2.40E+06	0.0468	0.007	25	9.36	2.28E+09	6.38	6.82
18		6/23/09	Ozone - Overnight (dry)	Combined	2		6.67E+06	3.09E+05	0.0377	0.007	25	9.62	4.22E+09	5.49	6.82
19	1	6/24/09	Ozone - Overnight (dry)	Combined	1		6.01E+06	3.79E+04	0.0897	0.007	25	9.22	1.67E+09	4.58	6.78
20		6/25/09	Ozone - Overnight (dry)	Combined	2		3.35E+06	1.32E+06	0.0377	0.007	25	9.13	1.34E+09	6.12	6.52
21		6/30/09	Ozone - Overnight (dry)	Combined	3		2.14E+06	7.45E+05	0.0468	0.007	25	8.87	7.44E+08	5.87	6.33
22		7/21/09	Surfactant	Combined	3		2.30E+06	1.19E+06	0.0468	0.007	25	8.77	5.94E+08	6.08	6.36
23		7/30/09	Surfactant	Combined	3		5.36E+06	3.95E+06	0.0468	0.007	25	8.88	7.51E+08	6.60	6.73
24		8/6/09	Surfactant	Combined	3		1.90E+06	9.80E+05	0.0468	0.007	25	8.69	4.89E+08	5.99	6.28
25		8/21/09	Ozone - Morning	Combined	4		7.84E+05	0.00E+00	0.04	0.007	25	8.69	4.90E+08	#NUM!	5.89
26		8/25/09	Ozone (Morning) + Surfactant	Combined	3		8.24E+05	3.29E+04	0.0377	0.007	25	8.72	5.24E+08	4.52	5.92
27		8/31/09	Ozone - Morning	Light	3		1.41E+06	9.93E+03	0.0377	0.007	25	8.97	9.30E+08	4.00	6.15
28		9/1/09	Ozone - Morning	Dark	3		1.16E+06	0.00E+00	0.0377	0.007	25	8.89	7.71E+08	#NUM!	6.07
29		9/3/09	Ozone - Morning	Combined	3		1.45E+06	1.71E+04	0.0377	0.007	25	8.98	9.51E+08	4.23	6.16
30		9/11/09	Ozone - Morning	Combined	3		2.62E+06	6.54E+03	0.0377	0.007	25	9.24	1.73E+09	3.82	6.42
31		9/21/09	Ozone - Morning	Combined	2		2.65E+06		0.0205	0.007	25			#NUM!	6.42
32		9/22/09	Ozone - Morning	Combined	1		1.57E+06	0.00E+00	0.0474	0.007	25	8.92	8.27E+08	#NUM!	6.20
33		9/23/09	Ozone - Morning	Combined	3		1.86E+06	0.00E+00	0.0215	0.007	25	9.34	2.17E+09	#NUM!	6.27
34		9/24/09	Ozone - Morning	Combined	2		1.62E+06	4.84E+05	0.0205	0.007	25	9.14	1.39E+09	5.68	6.21
35		9/29/09	Ozone - Morning	Combined	1		1.18E+06	0.00E+00	0.0474	0.007	25	8.79	6.21E+08	#NUM!	6.07
36		9/30/09	Ozone - Morning	Combined	3		5.82E+05	0.00E+00	0.0215	0.007	25	8.83	6.76E+08	#NUM!	5.76
37		10/1/09	Ozone - Morning	Combined	2			3.27E+03	0.0205	0.007	25		-3.99E+06	3.51	
38		10/19/09	Ozone - Morning	Light	1		4.44E+08	0.00E+00	0.0415	0.05	25	11.43	2.67E+11	#NUM!	8.65
39		10/20/09	Ozone - Morning	Dark	1		3.58E+08	8.63E+04	0.0415	0.05	25	11.33	2.16E+11	4.94	8.55
40		10/22/09	Ozone - Morning	Light	2		5.49E+08	2.36E+05	0.0194	0.05	25	11.85	7.07E+11	5.37	8.74
41		10/23/09	Ozone - Morning	Dark	2		8.10E+08	2.22E+07	0.0194	0.05	25	12.01	1.02E+12	7.35	8.91
42		10/27/09	Ozone - Morning	Light	1		4.44E+08	1.31E+04	0.0389	0.05	25	11.46	2.86E+11	4.12	8.65
43		10/28/09	Ozone - Morning	Dark	1		5.23E+08	1.31E+03	0.0389	0.05	25	11.53	3.36E+11	3.12	8.72
44		10/29/09	Ozone - Morning	Light	1		6.14E+08	2.09E+04	0.0389	0.05	25	11.60	3.95E+11	4.32	8.79
45		11/2/09	Ozone - Morning	Dark	1		6.93E+08		0.0253	0.05	25			#NUM!	8.84
46		11/3/09	Ozone - Morning	Light	1		2.19E+08	1.01E+06	0.0253	0.05	25	11.33	2.15E+11	6.00	8.34
47		11/5/09	Ozone - Morning	Dark	1		3.26E+08	9.80E+06	0.0253	0.05	25	11.49	3.13E+11	6.99	8.51
48		11/10/09	Ozone - Morning	Light	1		4.28E+08	3.27E+05	0.026	0.05	25	11.61	4.11E+11	5.51	8.63
49		11/11/09	Ozone - Morning	Dark	1		4.23E+08	5.10E+05	0.0246	0.05	25	11.63	4.29E+11	5.71	8.63
50	2	11/12/09	Ozone - Morning	Light	1		4.14E+08	1.02E+05	0.0244	0.05	25	11.63	4.24E+11	5.01	8.62
51		11/17/09	Ozone - Morning	Light	1		5.23E+08		0.0239	0.05	25	11.74	5.47E+11	#NUM!	8.72
52		11/19/09	Ozone - Morning	Light	3		7.84E+08		0.0111	0.05	25			#NUM!	8.89
53		12/1/09			3		0.00E+00	2.61E+00	0.0103	0.05	25		-6.35E+03	0.42	
54		12/2/09	Ozone - Light	Dark	3		6.14E+08	3.87E+07	0.0103	0.05	25	12.15	1.40E+12	7.59	8.79
55		12/3/09			3			3.14E+01	0.0103	0.05	25		-7.61E+04	1.50	
56		12/4/09	Ozone - Light	Light	3		4.97E+08		0.0103	0.05	25			#NUM!	8.70
57		12/10/09	Ozone - Light	Dark	4		3.10E+08	1.74E+08	0.0238	0.05	25	11.15	1.43E+11	8.24	8.49
58		12/11/09			4		1.10E+02	1.74E+02	0.0228	0.05	25		-7.02E+04	2.24	2.04
59		12/12/09	Ozone - Light	Light	4		4.18E+08	8.10E+06	0.0228	0.05	25	11.65	4.50E+11	6.91	8.62
60		12/15/09	Ozone - Light	Dark	4		5.75E+08		0.0228	0.05	25			#NUM!	8.76
61		12/17/09	Ozone - Light	Light	4		5.23E+08		0.0226	0.05	25			#NUM!	8.72

Date 7/13/2009 Ran day after ozonation
 Fiber 3
 Experiment

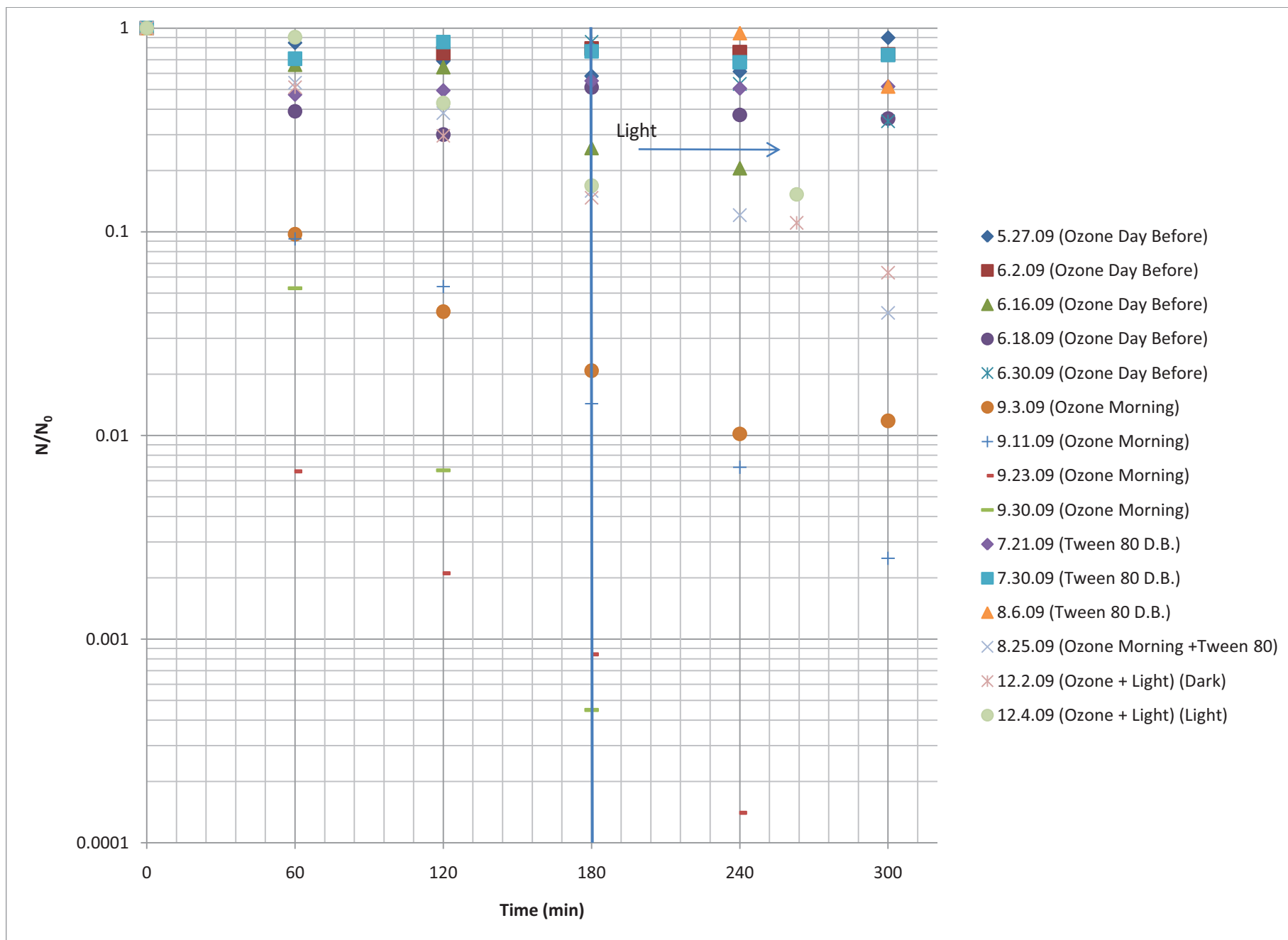
pH
 Temp 25 oC
 Buffer 1mM CBS
 Mass Cat 0.0468 grams
 Volume 25 mL
 Intensity ~450 W/m2
 Filters > 400 nm, 10% Transmittance

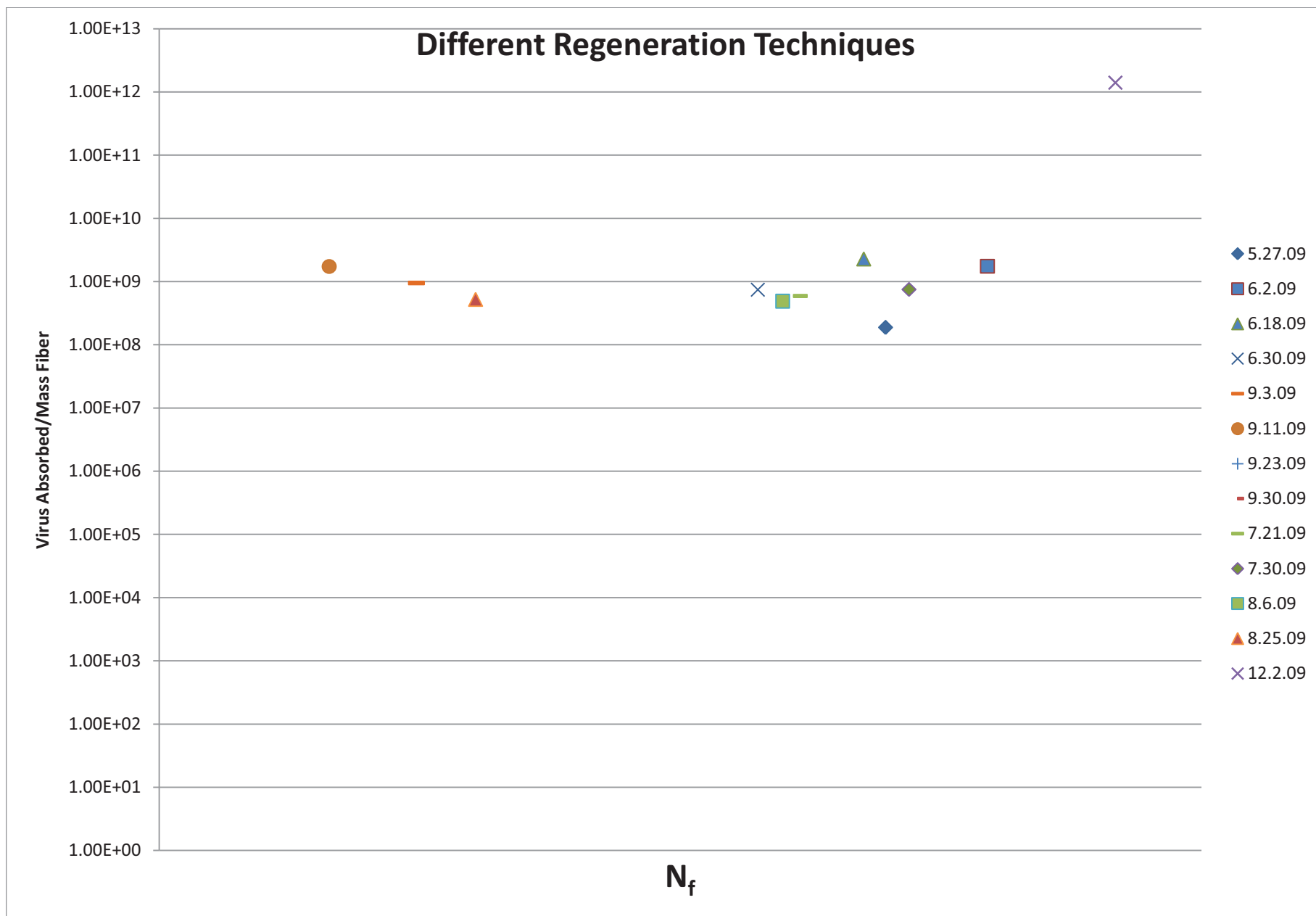
Volume Virus Stock Added 0.007 mL

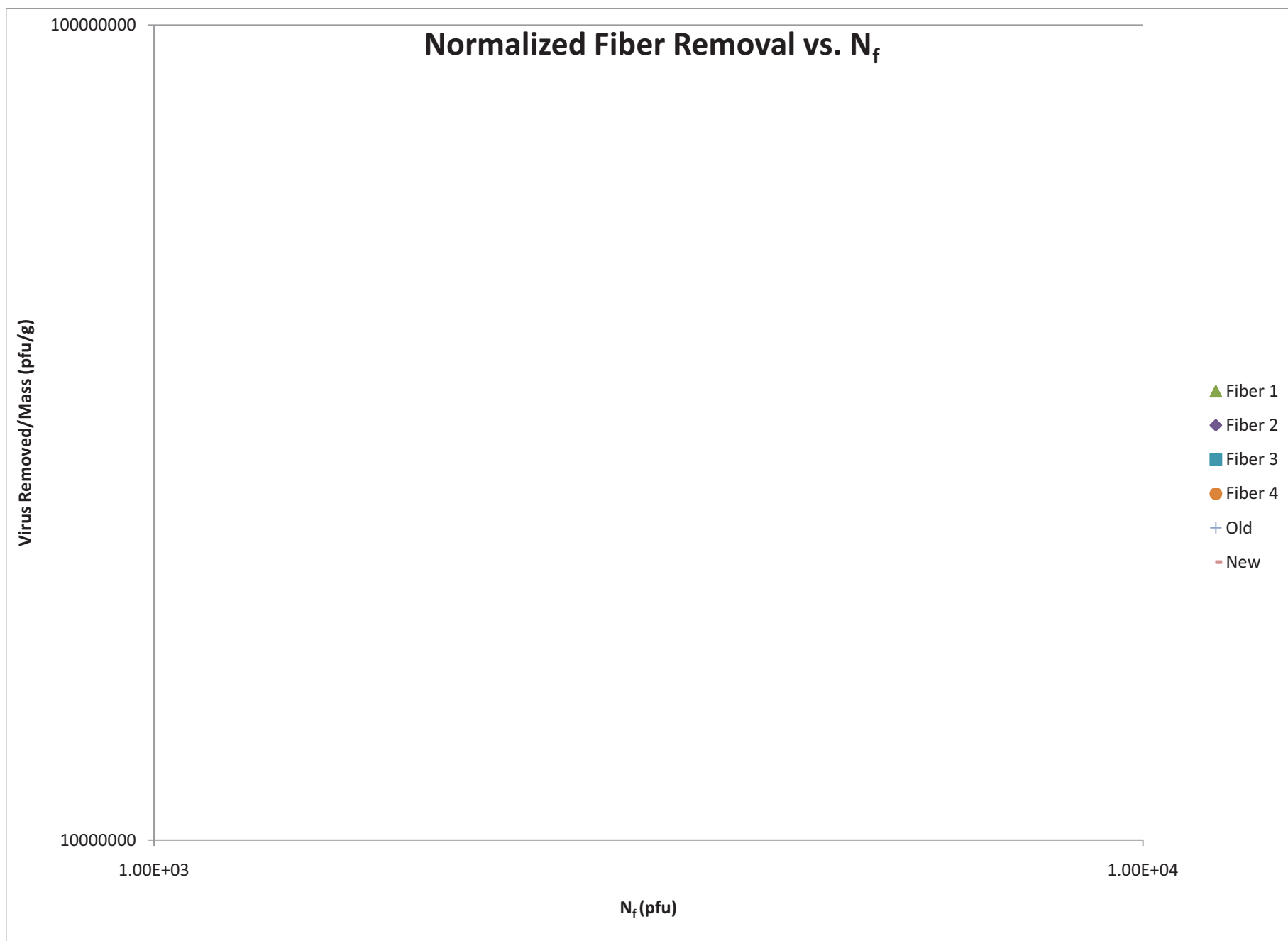
Plaques per 0.85 ml at 10^X dilution										pfu/ml		
Dark or light	Sample	Time (min)	0	1	2	3	4	5	6	7	N	N/N ₀
dark	1	0				tntc	231	29	4	1	3405228.76	1
	2	60				tntc	171	27	11	0	2882352.94	0.8464491
	3	120				tntc	180	18	2	1	2352941.18	0.6909789
light	4	180			tntc	tntc	133	17	2		1980392.16	0.5815739
	5	240			tntc	tntc	139	18	2		2084967.32	0.6122841
	6	300			tntc	tntc	167	30			3052287.58	0.8963532
dark	1	0				tntc	tntc	97	9	3	12679738.6	1
	2	60				tntc	tntc	98	11	1	12810457.5	1.0103093
	3	120				tntc	tntc	73	10	cont.	9542483.66	0.7525773
light	4	180			tntc	tntc	tntc	77	6	2	10065359.5	0.7938144
	5	240			tntc	tntc	tntc	74	7		9673202.61	0.7628866
	6	300			tntc	tntc	tntc	72			9411764.71	0.742268
dark	1	0				tntc	tntc	56	6	3	7320261.44	1
	2	60				tntc	tntc	37	12	9	4836601.31	0.6607143
	3	120				tntc	tntc	36	1	0	4705882.35	0.6428571
light	4	180			tntc	tntc	159	13	2		1888888.89	0.2580357
	5	240			tntc	tntc	100	13	8*		1503267.97	0.2053571
	6	300		tntc	tntc	tntc	cont.	cont.			#VALUE!	#VALUE!
dark	1	0				tntc	tntc	51	10	3	6666666.67	1
	2	60				tntc	218	18	6	0	2601307.19	0.3901961
	3	120				tntc	146	16	0	1	2000000	0.3
light	4	180			tntc	tntc	262	26	3		3411764.71	0.5117647
	5	240			tntc	tntc	192	19	4		2496732.03	0.3745098
	6	300			tntc	tntc	177	19			2398692.81	0.3598039
dark	1	0				tntc	127	20	3	0	2137254.9	1
	2	60				tntc	164	24	2	0	2640522.88	1.235474
	3	120				tntc	140	14	1	0	1830065.36	0.8562691
light	4	180			tntc	tntc	140	14	3		1830065.36	0.8562691
	5	240			tntc	tntc	87	9	0		1137254.9	0.5321101
	6	300			tntc	tntc	57	7			745098.039	0.3486239

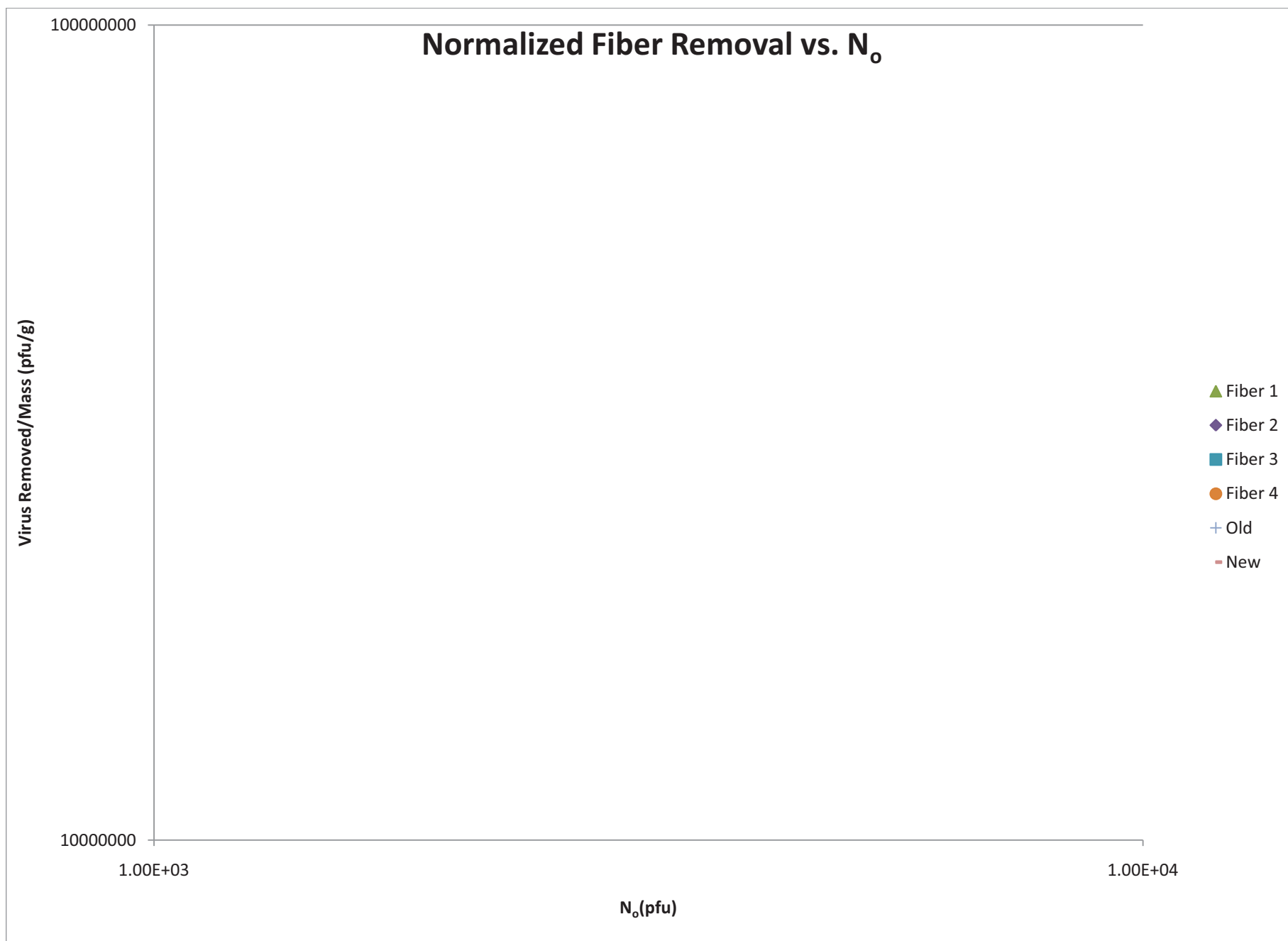
	1	0		tntc	111	5	0	0	1450980.39	1
dark	2	60		108	4	0	0	0	141176.471	0.0972973
	3	120		45	7	0	0	0	58823.5294	0.0405405
	4	180	212	25	2	0	0		30196.0784	0.0208108
light	5	240	113	10	2	0	0		14771.2418	0.0101802
	6	300	131	4	1	0			17124.183	0.0118018
	1	0		tntc	201	20	4		2620915.03	1
dark	2	60		180	19	2	0		241830.065	0.0922693
	3	120		108	9	1	0		141176.471	0.0538653
	4	180	275	30	4	0	0		37581.6993	0.0143392
light	5	240	140	14	1	0			18300.6536	0.0069825
	6	300	tntc 50	6	1	0			6535.94771	0.0024938
	1	0		tntc	155	13	0		1862745.1	1
dark	2	60		9	1	0	0		12418.3007	0.0066667
	3	120		3	2	0	0		3921.56863	0.0021053
	4	180	4	2	0	0			1568.62745	0.0008421
light	5	240	2	0	0	0			261.437908	0.0001404
	6	300	0	0	0	0			0	0
	1	0		tntc	49	4	1		581699.346	1
dark	2	60		17	3	1	0		30718.9542	0.052809
	3	120		3	0	1	0		3921.56863	0.0067416
	4	180	4	0	0	0			261.437908	0.0004494
light	5	240	0	0	0	0			0	0
	6	300	0	0	0	1			0	0
	1	0		tntc	202	15	5	0	2300653.59	1
dark	2	60		tntc	83	14	0	0	1084967.32	0.4715909
	3	120		tntc	87	12	1	0	1137254.9	0.4943182
	4	180	tntc	tntc	97	8	1		1267973.86	0.5511364
light	5	240	tntc	tntc	89	14	0		1163398.69	0.5056818
	6	300	tntc	tntc	91	10			1189542.48	0.5170455
	1	0		tntc	tntc	41	4	1	5359477.12	1
dark	2	60		tntc	341	29	1	0	3790849.67	0.7073171
	3	120		tntc	329	35	4	1	4575163.4	0.8536585
	4	180	tntc	tntc	290	34	3		4117647.06	0.7682927
light	5	240	tntc	tntc	277	28	8		3640522.88	0.6792683
	6	300	tntc	tntc	265	34			3954248.37	0.7378049
	1	0		tntc	145	12	3	0	1895424.84	1
dark	2	60		tntc	168	22	4	0	2535947.71	1.337931
	3	120		tntc	155	24	4	0	2581699.35	1.362069
	4	180	tntc	tntc	165	16	2		2124183.01	1.1206897
light	5	240	tntc	tntc	137	9	-		1790849.67	0.9448276
	6	300	tntc	tntc	75	7			980392.157	0.5172414
	1	0		tntc	63	8	3	0	823529.412	1
dark	2	60		tntc	34	2	0	0	444444.444	0.5396825

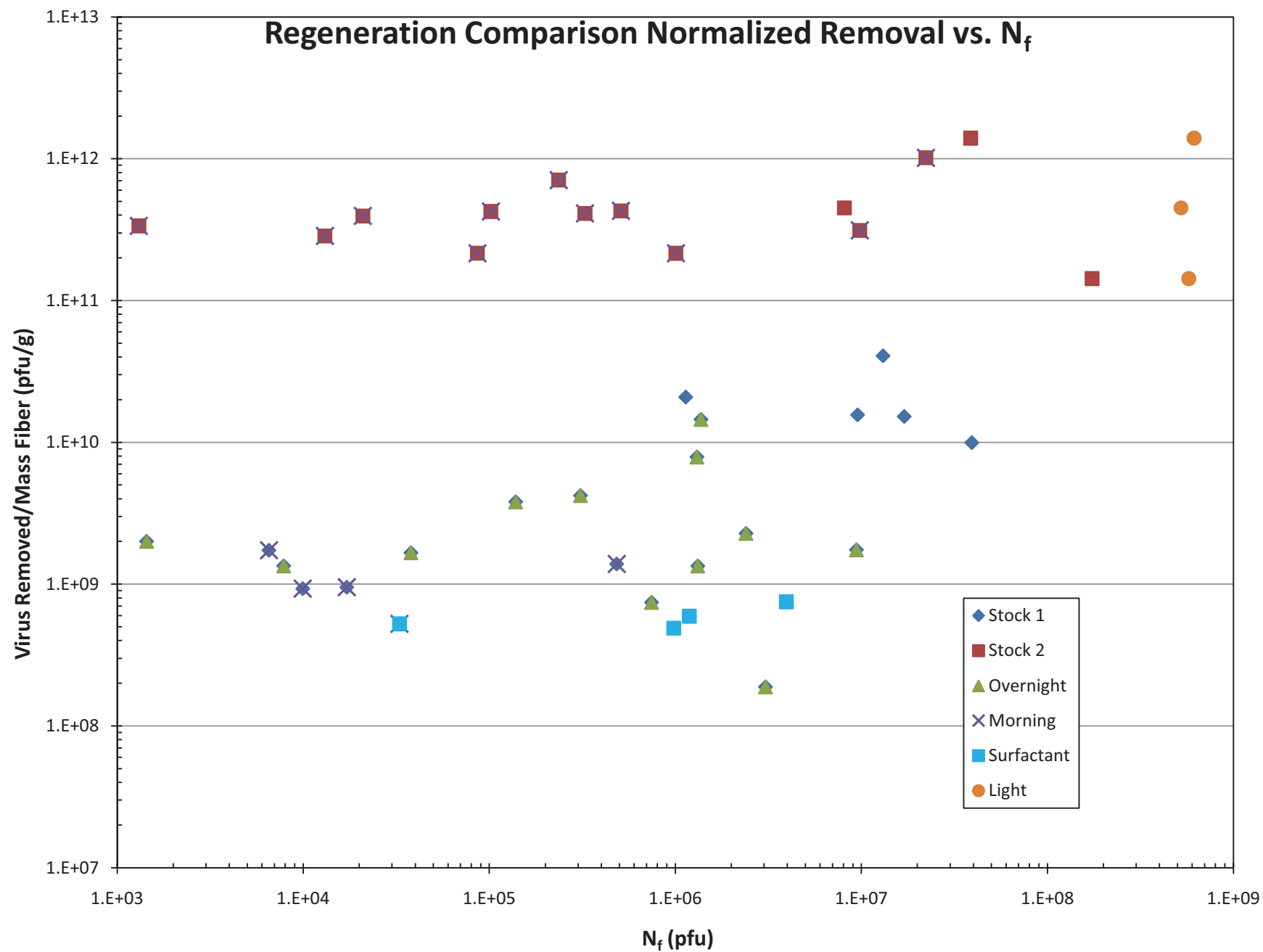
light	3	120		192	29	1	0	0	315032.68	<u>0.3825397</u>
	4	180	tntc	100	10	1	0		130718.954	<u>0.1587302</u>
	5	240	tntc	76	9	0	0		99346.4052	<u>0.1206349</u>
	6	300	254	25	3	0			32941.1765	<u>0.04</u>
dark	1	0			tntc	tntc	tntc	47	614379085	<u>1</u>
	2	60			tntc	tntc	tntc	242	315032680	<u>0.512766</u>
	3	120			tntc	tntc	tntc	128	181699346	<u>0.2957447</u>
	4	180		tntc	tntc	tntc	tntc	69	90196078.4	<u>0.1468085</u>
	5	263		tntc	tntc	tntc	tntc	52	67973856.2	<u>0.1106383</u>
	6	300	tntc	tntc	tntc	296			38692810.5	<u>0.0629787</u>
light	1	0			tntc	tntc	326	38	496732026	<u>1</u>
	2	60			tntc	tntc	276	41	448366013	<u>0.9026316</u>
	3	120			tntc	tntc	166	16	213071895	<u>0.4289474</u>
	4	180		tntc	tntc	tntc	64		83660130.7	<u>0.1684211</u>
	5	263		tntc	tntc	tntc	58		75816993.5	<u>0.1526316</u>
	6	300	tntc	tntc	tntc	tntc			#VALUE!	<u>#VALUE!</u>

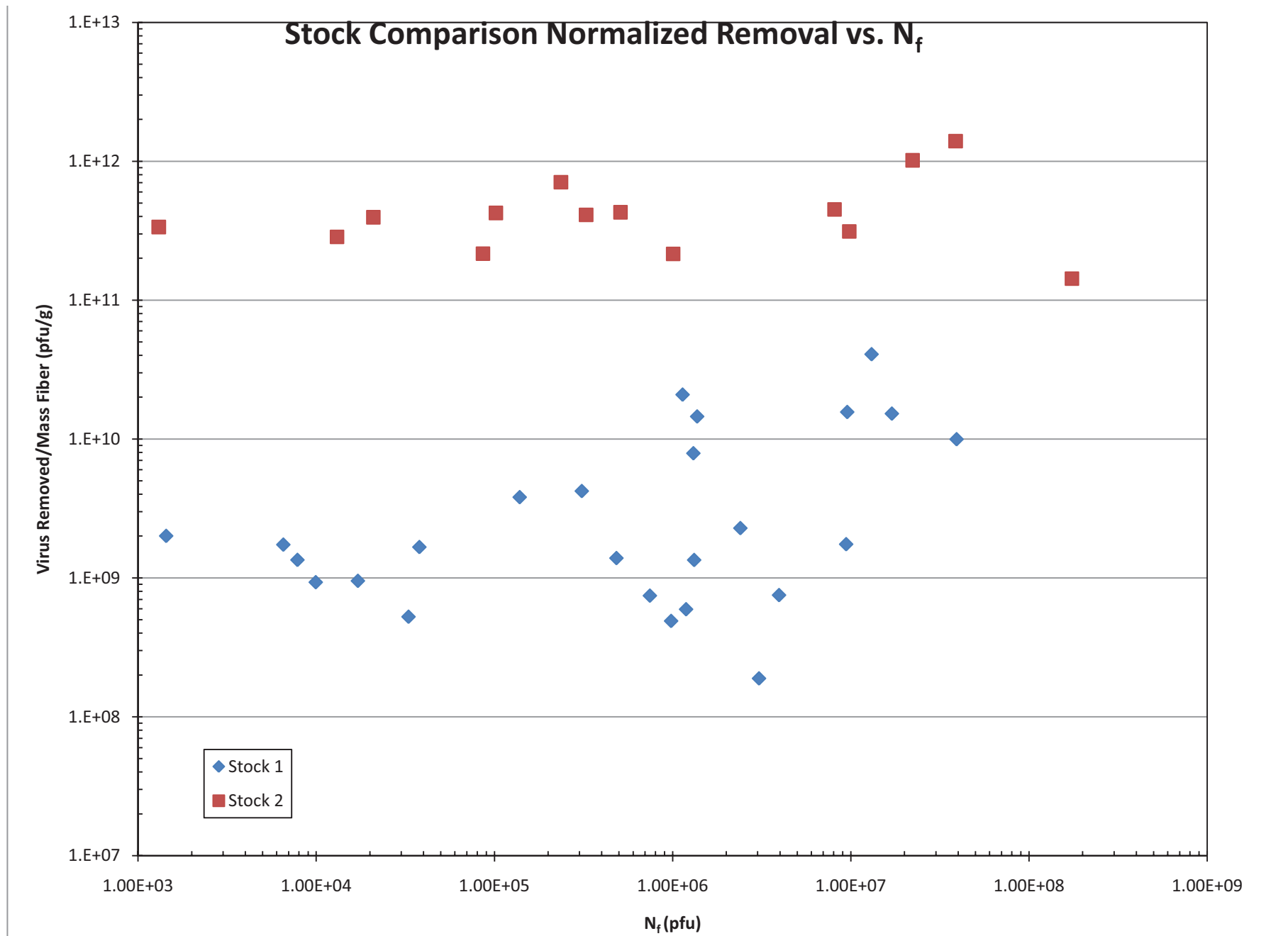


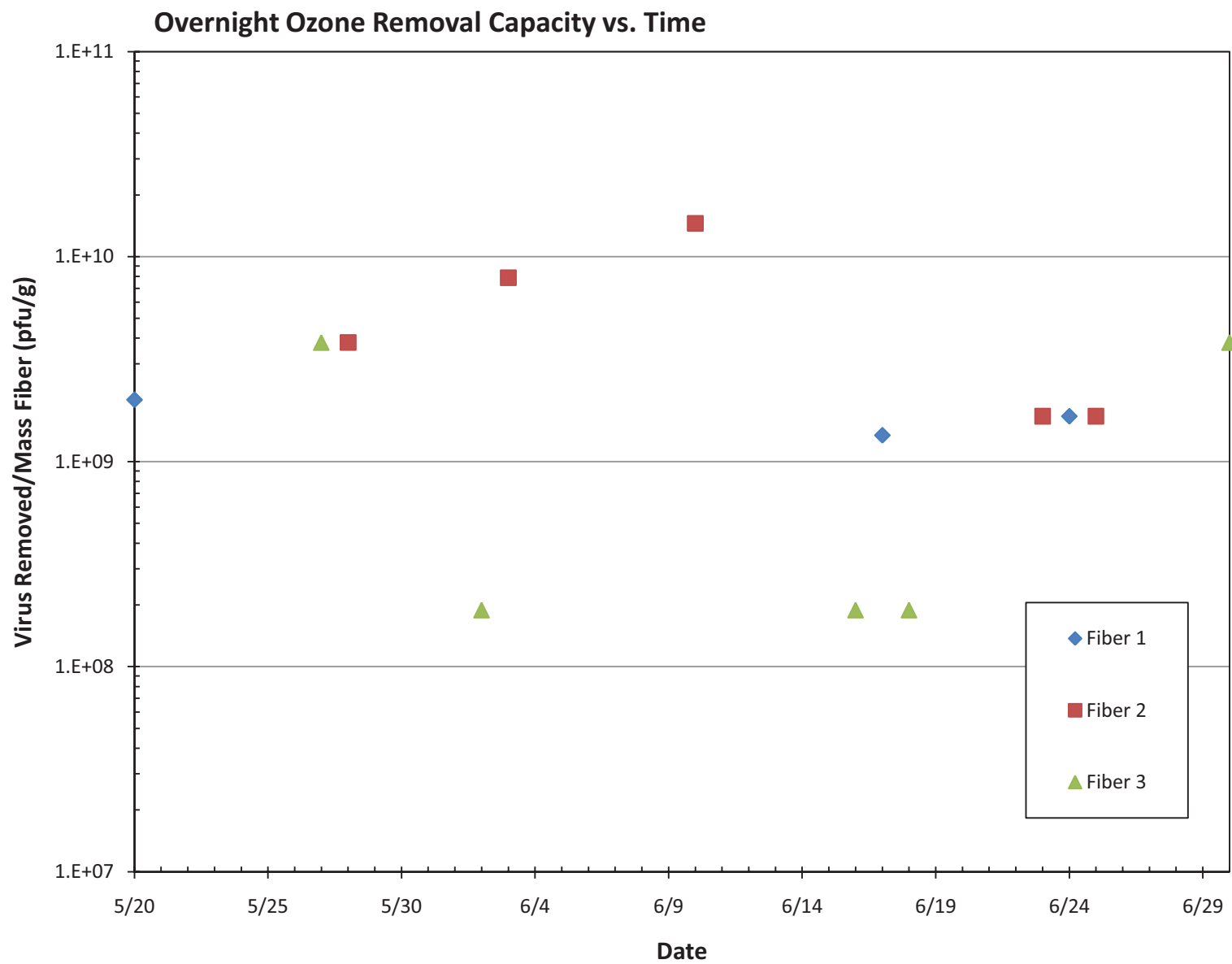


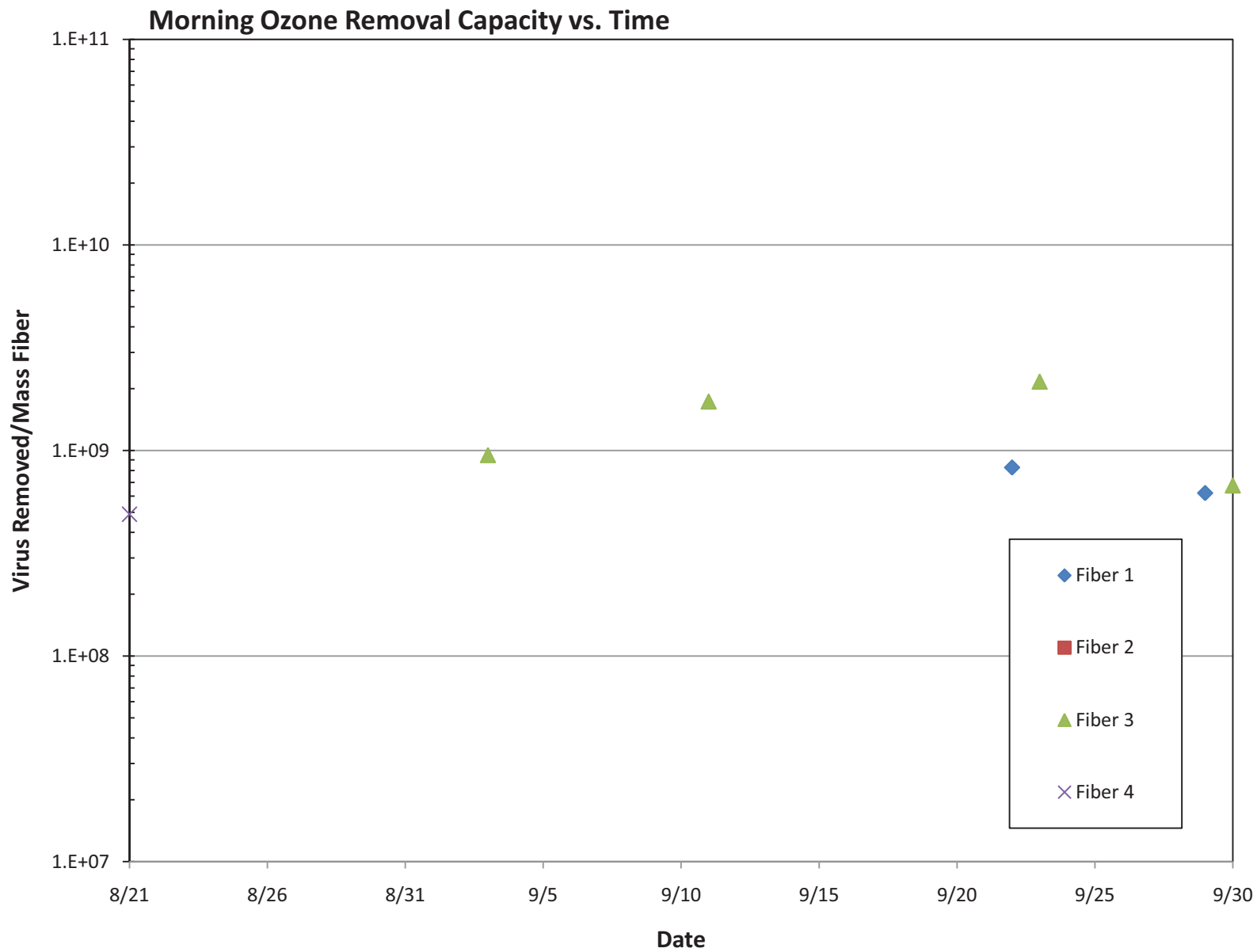




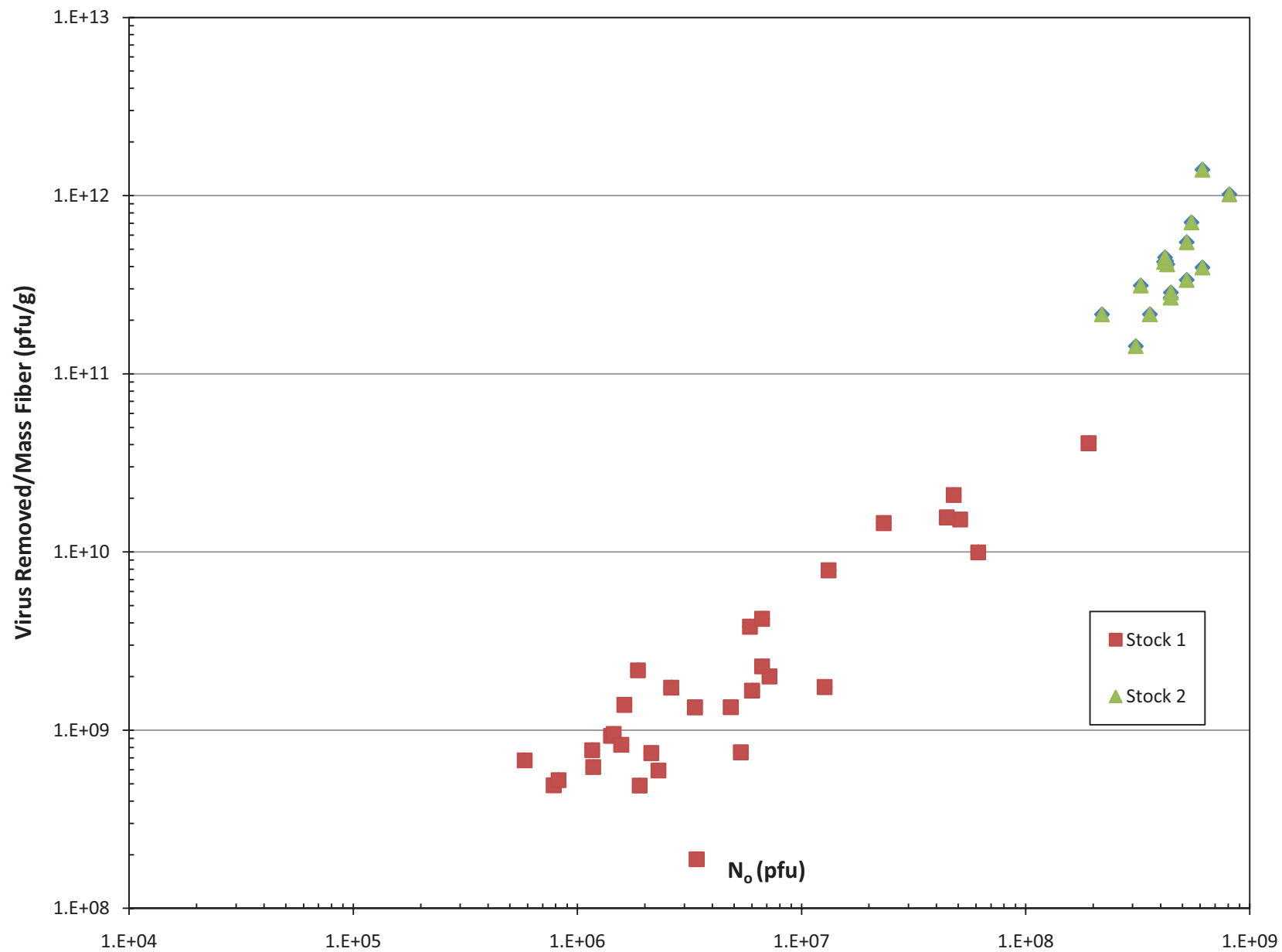








Stock Comparison Normalized Removal vs. N_o



Low Removal (Normalized Removal vs. N_o)

