



Application of Ultraviolet Treatment for Paper Production - An Engineering Study

Klaus Dölle^{1*}, Neil Goodman¹ and William Lawrence¹

¹*Department of Paper and Bioprocess Engineering (PBE), College of Environmental Science and Forestry (ESF), State University of New York (SUNY), 1 Forestry Drive, Syracuse, NY 13210, USA.*

Authors' contributions

This work was carried out in collaboration among all authors. Author KD supervised the study, wrote the final draft and approved the final manuscript. Authors NG and WL managed the analyses of the study and wrote the first draft of the manuscript.

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ABSTRACT

Ultraviolet (UV) radiation systems are a common method of inactivating bacteria in municipal water treatment but has not been applied in a paper mill operations. Determining the feasibility of installing such a system is the purpose of this report. Directly treating a starch solution of sufficient concentration proved impossible as the transmittance required was far too low. Water used in the onsite water recycling facility's cooling towers had a transmittance over 90% and so was very treatable. Lab scale testing with a designed 15 liter laboratory benchtop ultraviolet treatment system showed that UV treatment can reduce the aerobic bacteria count by two fold for up to 24 hour of operation and significantly lower results for 48 and 72 hour of operation. Therefore, UV treatment can be considered a valuable process for the treatment of cooling tower water.

Keywords: *Water treatment; ultraviolet; cooling tower; heat exchanger; paper mill; process engineering.*

**Corresponding author: Email: kdoelle@esf.edu;*

1. INTRODUCTION

Ultraviolet light commonly referred to as “UV” is a subsection of the electromagnetic spectrum that exists between the wavelengths of 187-400 nm [1]. This range can be further broken down into subsections of UV light, each used in differing application depending on the wavelength. UV-V is a naturally existing wavelength (187 nm) of UV that does not often occur on earth as it is only present in the vacuum of space and is stopped by the upper atmosphere [1]. UV-A designates an portion of the UV spectrum that holds the highest wavelengths of light 315-400 nm and is most often used in blacklight applications as it presents the least amount of harm to living organisms [2]. UV-B populates the 290-315 nm range of light and is responsible for causing sunburn in humans [1]. UV-C dubbed short wave UV exists at a range of wavelengths existing between 220-290 nm and is often used for germicidal irradiation with the most optimum inactivation wavelength at 265 nm [2]. Industrial applications generally opt for mercury arc lamps which emit light at a close to optimal 253.7 nm [2,3].

UV light is also referred to as actinic waves or chemical waves, indicating that they are able to insight direct chemical alterations in molecules and living organisms [4]. A primary reason the UV light is preferred over other methods of sanitation is its lack of a tendency to leave behind so-called residuals, and otherwise provide an environmentally benign method of sanitation [5]. On the other hand, residuals can be helpful at times as they help prevent growth further along in the process. In addition, the necessity for high water clarity coupled with high capital and operating costs create barriers for installation in many situations [5].

UV-C has a large presence in wastewater treatment in present applications though it was not until 1916 that UV-C sanitation took hold in the United States [4]. Since then wastewater and drinking water, industrial and domestic, have been the primary applications of this technology [4,6]. Since then the use of the technology has spread to applications other than wastewater, including drinking water, and industrial housekeeping processes such as heat exchanger cleanliness [4,6]. Applications under development are for example the prevention of biofilm proliferation on surfaces and mold abatement at historic sites [7,8]. Within the context of paper mills, possible applications of

UV technology could be to sanitize starch slurries, circulating chiller water, and on site gray water treatment to control and minimize bacteria growth.

Starch is a commonly used additive in the paper industry, used to increase the internal strength of a sheet. Starch can be modified to have a net charge or be delivered in its native state. In a paper mill, starch is typically cooked before applied, in the wet-end such as the stock mixing chest, machine chest or approach flow system, known as mass sizing [9,10,11]. Other application includes surface sizing using a size press [12,13,14].

This study is looking to explore the potential of applying UV treatment for bacteria control at a paper mills dry starch system, were uncooked starch provides a ready food supply for bacteria as well as a paper mills chiller operation. For both systems, the use of biocide and sodium hypochlorite is necessary to control bacteria growth to ensure operational performance.

2. MATERIALS AND METHODS

This section describes the test methods, procedures, materials used for this study. Tests were run as duplicates according to the described procedures and testing methods.

2.1 Laboratory Benchtop Ultraviolet Treatment System

A Laboratory Benchtop Ultraviolet Treatment (LBUT) system was designed and installed according to Fig. 1. The LBUTS consisted of a 15 l wastewater reservoir, made from a 5 gal (18.92 l) pail (a). Liquid contained in the reservoir is pumped from the reservoir with small 50-Watt pond pump (b), which has a maximal flow rate of 330.0 gal/h (1249.2 l/min). Liquid flow through the pump was 5.0 l/min with the integrated pump control valve fully open. The liquid is supplied to the UV Clarifier (d) through a $\frac{3}{4}$ inch (19 mm) flexible Polyvinyl Chloride (PVC) hose (c). The UV lamp installed in the UV Clarifier is rated at 9W. Treated liquid from the UV clarifier is discharged back into the reservoir with a $\frac{3}{4}$ inch (19 mm) flexible Polyvinyl Chloride (PVC) hose (e). A pretest of the LBUT system function was done with tap water before the initial testing started. After the start-up phase, the reservoir was emptied and cleaned. The initial testing was done using 15 liters of mill water.

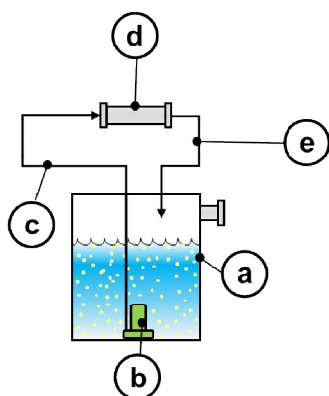


Fig. 1. Laboratory UV system

2.2 Absorbance and Transmittance

For the absorbance and transmittance analyzation, a Thermo Sceintific Genesis 10S UV-VIS was used. The wavelength was set to 254 nm and absorbance and transmission data obtained following the manufactures procedure.

2.3 Aerobic Bacteria Count

For the aerobic bacteria count (double evaluation) one Lambda Plus Micropipette (1 ml Capacity), one 600 ml and 50 ml Glass Beaker, two Sterile Pipette Tips VWR NA Catalog #: 83007-380, one 3M Petrifilm Spreader Part #:1223767436, and two 3M Petrifilm were used.

Deionized (DI) water was filled into the 600 ml glass beaker and the two 3M Petrifilm packs were prepared and set on the benchtop. The micropipette was set to 1000 μ L (1 mL), and the adjustment was in the locked. Position. Next 9 ml of DI water was pipetted into a clean 50 mL glass beaker. Following that, a new sterile pipette tip was used to pipette 1 ml of sample into the 9 ml sample which was then gently swirled. The upper film of the Petrifilm was rolled back and as before, a new sterile pipette tip was used to pipette 1 ml of diluted sample onto each 3M Petrifilm. The upper film was rolled back onto the drop making sure no air is entrapped. The 3M Spreader, ensuring that the ridged side is facing down, was placed on top of the film on the center of the sample as evenly as possible for 15 seconds. The spreader was lifted straight up without twisting, sliding, or otherwise disturbing the sample and set aside.

After approximately 60 sec. the sample was labeled (Sample ID, Date, and Time) and set

aside. The 50 mL beaker was washed, and the above procedure was repeated for the second 3M Petrifilm. Both 3M Petrifilms were placed in an oven at 37°C for 48 hours. After 48 hours, the number of colonies were accounted and recorded for in accordance with the 3M Petrifilm Interpretation Guide [15]. If the inoculated area be covered in a single mass of pink, or large area where individual colonies are indistinguishable from each other the sample was designated "Too Numerous To Count" (TNTC).

3. RESULTS AND DISCUSSION

Ultraviolet (UV) light can be considered a relatively inexpensive, effective, and environmentally sound method of bacteria control for a paper mills dry starch and chiller water supply systems to ensure best system operation performance without the use of biocide and/or sodium hypochlorite to ensure operational performance.

The application of UV treatment requires relatively specific operating conditions of the feed water supply into the UV system. Therefore, UV transmittance has an direct impact on the UV dosage delivery and cost of a system in regards to installation an operation [16,17]. In order to function as intended a UV transmittance of 50% is required as a minimum value for the operation of a small UV treatment system [18].

3.1 Dry Starch System

To assess a possible UV treatment application of the paper mills dry starch system which contains upto 1.695% starch (16.95 g/l) based on solids content a process water starch solution with different solids content needed to be prepared. The process water starch solutions had a solids content of 1.560% (15.60 g/l), 0.780% (7.80 g/l), 0.390% (3.90 g/l), 0.190% (1.95 g/l) and 0.098% (0.98 g/l). The transmittance and absorbance was measured with a Thermo Scientific Genesis 10S UV-VIS using 10 mm quartz cuvettes.

Absorbance and transmittance data of the starch slurry in Fig. 2 show that even at the lowest starch concentration of 0.98g/l (0.098%), a transmittance of 49.77% could be achieved. In order to transmit UV light through a starch slurry, an enormous reduction in starch concentrations will be required to achieve a minimum 50% transmittance [18]. Therefore, UV treatment will not be a possible process solution due to the innumerable and likely impossible changes

required to make this occur due to increased water volume handling and process changes required for the paper manufacturing process.

3.2 Ciller System Water Supply

A laboratory bench test was conducted using the designed LBUT system for the evaluation of the incoming chiller system water supply. The LBUT system reservoir was filled with 15 liters of the incoming chiller system process water. The system was run as described in section 2.1 for 72 hours with the UV lamp off. Then the LBUT system was cleaned before the reservoir was filled again with 15 l incoming chiller system process water for the 72 hours run with the UV lamp on. For each run every 24 hours samples were taken and an aerobic bacteria count was initiated using 3M Petrifilm as described in section 2.3.

UV transmittance and absorbance of the incoming chiller system water was tested with a Thermo Scientific Genesis 10S UV-VIS at 254 nm using 10 mm quartz cuvettes. The average absorbance of the incoming water was found to be 0.035 at 254 nm standard deviation 0.034. The transmittance of the water was found to be 94.39% with a standard deviation of 2.75%.

It was found that UV treatment does, in fact, negatively impact the growth of bacteria as seen in Figs. 3 and 4.

Fig. 3 shows the results of the UV LBUT system with the UV light turned off. As shown from the beginning of the trial the aerobic bacteria colony count became TNTC after 48 hours, indicated by the solid pink mass taking up the entirety of the inoculated area of the 3M Petrifilm.

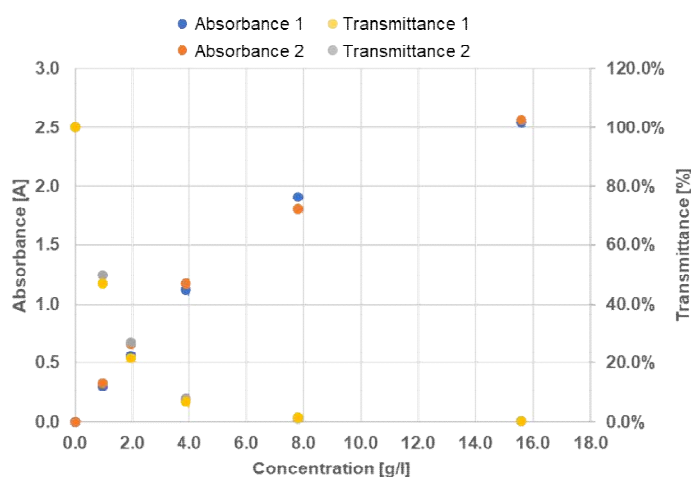


Fig. 2. Absorbance/transmittance of starch slurry at 254 nm

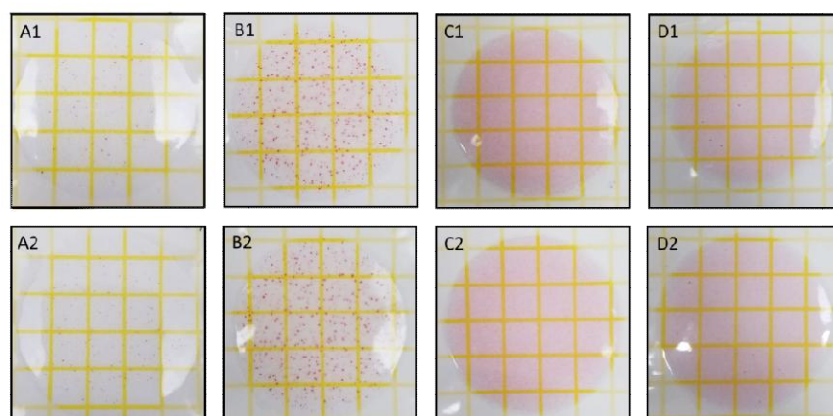


Fig. 3. Visual comparison bacteria growth A1 & A2) 0-hours, B1 & B2) 24-hours, C1 & C2) 48-hours, and D1 & D2) 72-hours with no UV light off

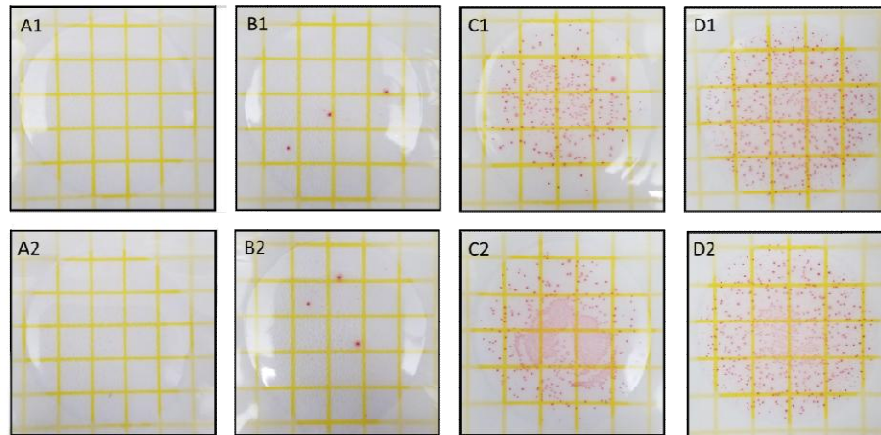


Fig. 4. Visual comparison bacteria growth A1 & A2) 0-hours, B1 & B2) 24-hours, C1 & C2) 48-hours, and D1 & D2) 72-hours with UV light on

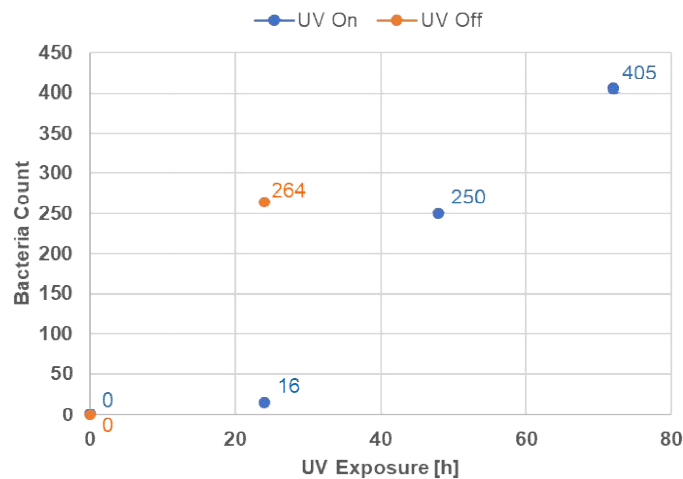


Fig. 5. Bacteria count for in incoming mill water with UV on and UV off

Fig. 4 shows the results of the UV LBUT system with the UV light turned on. For the inoculated area of each of the UV light on samples the aerobic bacteria count was readable through the duration of the 72-hour trial.

The numerical representation of the 3M Petrifilm aerobic bacteria count is shown in Fig. 5 based on the 3M Petrifilm Interpretation Guide [15]. Both conditions started at the same level of bacterial contamination (essentially 0) using incoming chiller system water. After 24 hours UV LBUT system with the UV light turned off had an aerobic bacteria count of 264 compared to 16 with the UV light turned on. After 48 hours and 72 hours, the anaerobic bacteria count was TNTC for the UV LBUT system with the UV light turned off. The UV LBUT system with the UV

light turned on showed an aerobic bacteria count of 250 and 405 for 48 hours and 72-hours respectively. UV treatment can increase the LBUT system performance two fold by half or significantly lower anaerobic bacteria count at 24, 48 and 72-hour operation.

4. CONCLUSION

Ultraviolet (UV) light can be considered a relatively inexpensive, effective, and environmentally sound method of bacteria control for a paper mills dry starch and chiller water supply systems.

UV Transmittance (UVT) has a direct impact on the UV dosage delivery and cost of a system in regards to installation an operation cost.

Absorbance and transmittance data of the investigated starch slurry from 1.695% to 0.098% showed the highest transmittance of 49.77% at a concentration of 0.098%, eliminating UV treatment for starch-water slurry applications, due to the innumerable and likely impossible changes required to make this occur in regards to increased water volume handling and process changes required for the paper manufacturing process.

On the other hand, using a laboratory benchtop ultraviolet treatment system for the evaluation of the chiller water supply system showed a reduction in the numerical aerobic bacteria count using 3M Petrifilm of up to two fold for up to 24 hour of operation and significantly lower results for 48 and 72 hour of operation. Therefore, UV treatment can be considered a valuable process for the treatment of cooling tower water, even without any pretreatment on incoming mill water.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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