UV DISINFECTION OF STORM WATER OVERFLOWS AND LOW UVT WASTEWATERS

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ABSTRACT

UV is commonly used for disinfecting many types of waters including treated wastewater, reclaimed wastewater for reuse, and drinking water. UV technology is also now being applied to low quality waters, such as primary treated wastewater and combined sewer overflows (CSO). Relative to traditional UV applications, disinfection of low quality water presents unique design challenges because of the higher concentration of solids and the darker water (high absorbance of UV). Through proper design and validation, UV has been proven effective and is installed at full-scale facilities. New research and carbon footprint analyses also illustrate that UV is a more sustainable approach to disinfection and has a smaller carbon footprint than either chemical disinfection or construction of storm water storage facilities.

Keywords: Ultraviolet, UV, disinfection, storm water, combined sewer overflow, CSO, low quality wastewater

INTRODUCTION

Ultraviolet (UV) is used for disinfecting many types of waters including low quality waters, such as primary treated wastewater and combined sewer overflows (CSO). Combined sewer systems are sewers that are designed to collect rainwater runoff and domestic wastewater in the same pipe. Most of the time, combined sewer systems transport all of their wastewater to a sewage treatment plant, where it is treated and then discharged to a water body. During periods of heavy rainfall or snowmelt, however, the wastewater volume in a combined sewer system can exceed the capacity of the municipal wastewater treatment plant. For this reason, combined sewer systems are designed to overflow occasionally and discharge excess wastewater directly to nearby streams, rivers, or other water bodies. These overflows, called combined sewer overflows (CSOs), contain not only storm water but also raw sanitary wastewater. CSOs may be thought of as a type of urban wet weather discharge. Since the untreated (or partially treated) effluent flows directly into the river or water bodies, the receiving body can be microbiologically disturbed for months before the river and marine ecosystems recover. For this reason, treatment of CSOs is becoming a regulatory requirement in many regions in order to protect receiving water bodies and the ecology within those areas.

Chlorine has traditionally been used to provide disinfection of CSOs due to its low cost. However, the growing awareness of the adverse environmental impacts associated with the byproducts of chlorination has led to increasingly restrictive chlorine residual requirements. A proven alternative disinfectant is the application of UV disinfection for storm-water overflows. UV has an advantage compared to chemical disinfectants because there are no health and safety concerns related to chemical storage and handling, it does not lead to environmentally harmful disinfection by-products (DBPs), and UV does not require the additional complexity and cost of subsequent chemical removal or treatment technologies (e.g., dechlorination, re-aeration) to ensure environmentally safe discharges. Although UV energy demands are typically higher than conventional UV applications, as a result of the lower UV transmittance of the water, the chlorine demands for chemical disinfection are also greater because of the higher levels of background organics. In many cases disinfection targets for these low water quality applications are not as stringent, so the design UV doses and overall energy consumption are not excessive. UV is a cost-effective technology for disinfecting low quality wastewaters, as long as the technical challenges imposed by them are met through proper design and testing of UV reactors for these applications.

Disinfection of storm water significantly reduces the release of pathogens into receiving waters. Indicator species are used to test for the presence of harmful pathogens in storm water discharges. Although these species are not normally harmful to humans, their presence in surface waters can indicate contamination from the fecal matter of warm-blooded animals, a source of pathogens. Various indicator species have been used to assess water quality degradation due to pathogens, including total coliform, fecal coliform, *Escherichia coli (E. coli)* and enterococci. In many parts of the United States, enterococci is commonly used in marine waters as an indicator in shellfish (a route of ingestion of pathogens to humans) harvesting waters and recreational waters.

The high flow rate and volume of storm water, combined with the inherently high suspended solids concentration, variable temperature, and disinfectant-resistant pathogens requires a disinfection technology with rapid oxidation and powerful pathogen-killing capabilities.

Traditional disinfectants, such as chlorine, have rapid oxidation capabilities and are relatively low cost, making

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them suitable and effective for storm waters. However, due to the high flow rates, volumes and chlorine demand of storm waters, effective treatment can require a lengthy contact time resulting in large equipment footprint and construction costs. In addition, the high chlorine doses applied can potentially result in a high chlorine residual and toxic DBPs in receiving waters.

Like all disinfection technologies, UV disinfection technology design is a function of the water quality being treated. As a physical (vs. chemical) treatment, the relationships between UV disinfection and water quality are more easily defined and quantitated. It is therefore possible, once the relevant water quality parameters are defined for a storm-water event, to properly design the UV reactor to meet the pathogen disinfection requirements for future storm-water events.

THE PROPER DESIGN OF UV REACTORS FOR LOW WATER QUALITY WASTEWATERS

The objective for UV disinfection is to transfer UV energy into the water. Low quality wastewaters have low UV transmittance (UVT) (high absorbance), thus the UV reactor design challenge is a greater one, because a higher percentage of the UV is absorbed in a shorter distance – compared to secondary or tertiary wastewater.

The key to proper UV reactor design is to optimize the effective water layer between the UV lamps for the transmittance of the water in consideration. In low transmittance water, the effective water layers need to be smaller, which can be accomplished with more powerful lamps, a narrower spacing, or with hydraulic devices to induce streamlines and direct flow towards the lamps. Each of these options must be evaluated against its trade-offs. For instance, higher power lamps can have higher overall energy consumption at the cost of wider lamp spacing leading to a lower head loss reactor design. Alternately, with lower powered lamps, the required narrow lamp spacing and hydraulic devices can increase head loss. Higher head loss can result in water level increases in an open-channel UV reactor, which can lead to a large water layer above the top of lamps (short-circuiting), or leave a large section of downstream lamps exposed to air. These zones with large water layers or exposed lamps have little to no disinfection, and reactors with these hydraulic flaws will fail when challenged in full-scale operation.

Any fraction of the flow that receives less than optimal UV doses, whether due to short-circuiting or through exposed lamps, will limit the ultimate performance of the reactor. Trojan Technologies has overcome these constraints and limitations by using highly-sophisticated computational fluid dynamics (CFD) modeling coupled with accurate irradiance models to design UV reactors for storm-water applications. Using industry-standard bioassay protocols to test and validate reactor performance, UV reactors have been shown to be effective for these challenging low water quality applications.

Low quality wastewaters typically have high levels of suspended solids, and these particles can harbor microorganisms that are resistant to disinfectants. UV dose – response curves are generated in a laboratory using calibrated collimated-beam devices to quantify the relationship between applied UV dose and microorganism survival. Because of the large variability of water quality properties, extensive collimated beam UV dose – response

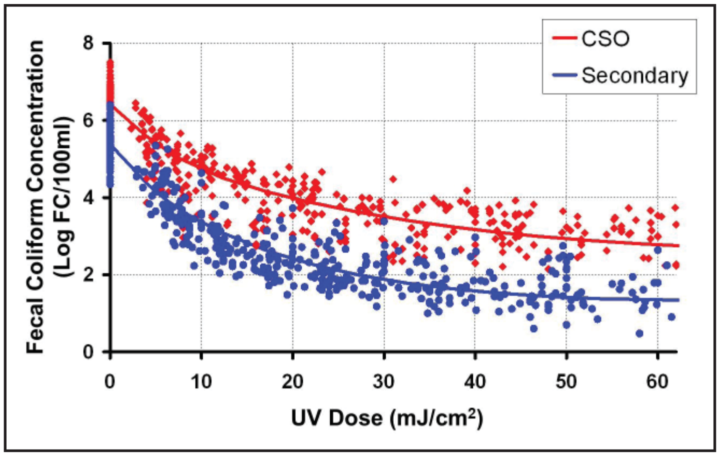

Figure 1: *Collimated beam UV dose-response curves for fecal coliforms comparing low quality (CSO) and high quality (secondary) wastewaters. These data show between-process differences, within-process variability, and the impact of difficult-to-disinfect solids.*

tests are required to properly characterize different waters. The UV dose – response curves for microorganisms in low quality wastewaters typically have two slopes, characterizing the easy-to-disinfect 'free-floating' microorganisms, and the more challenging particle-associated microorganisms (see **Figure 1**). Typical disinfection objectives for low-quality wastewater range from one to three log reductions of the target or indicator organism. In response, the design UV doses to meet these requirements do not need to be excessively high because the limits are typically reached by disinfecting the free-floating microorganisms.

In typical applications requiring the disinfection of stormwaters, the CSO or primary wastewaters are characterized by high flows, low UV transmittance and high total suspended solids. UV disinfection technology testing is typically carried out at lower flow rates because of logistical limitations, and scale-up becomes a necessary task. In testing, the UVT is manually lowered using industry-accepted UVT modifiers. Water quality and suspended solids are determined by frequent collimated-beam sampling and testing. Over the years, UV dose response data has been collected that spans a wide range of water qualities and sources, as well as thousands of locations around the globe. This database contains UV dose response data for multiple types of upstream treatment processes including: conventional activated sludge, fixed film processes, membranes, media filtration, stormwaters, primary/chemically enhanced primary treatment and combined sewer overflow (CSO). Storm waters have high suspended solids, and the effectiveness of any UV design dose depends on the disinfectability of the water and in turn on the properties of the suspended solids in the wastewater. The relationships between total suspended solids (TSS) and UVT can be derived from this database and used for sizing.

As an example, from Trojan's database, the typical water quality during a stormwater event can be:

- 200 mg/L TSS (peak value, first flush), 90 mg/L TSS (extended storm value)
- UVT varies during the storm between <20% during first flush to >65% near end of storm when water is mostly rainwater.

This representative data, combined with water quality from sampling events, provides the Owner and Design Engineer with a high level of confidence that the UV system design will consistently meet the discharge requirements set out for the application in a cost-effective manner.

UV EQUIPMENT DESIGN AND KEY CONSIDERATIONS FOR OPERATION IN LOW UVT WATER

UV disinfection technology has been used successfully in low UVT applications through proper UV reactor design and validation. The TrojanUV4000Plus™ reactor has been tested, installed and is operating in a number of low UVT applications and has several design features that enable cost-effective disinfection for challenging waters.

UV Energy Source: Effluent flows by gravity through a fully submerged, tubular reactor, where it is exposed to high levels of UV generated by medium pressure (MP) high intensity lamps. The innovative, contoured reactor walls ensure stringent control of the water layer around the lamps for consistent disinfection regardless of flow rate or water level. UV modules house the lamps, quartz sleeves and cleaning system and pivot into the reactor opening at upstream and downstream ends. Lamps are placed in a staggered array, spaced evenly apart and optimized to balance the tradeoffs between head loss generated and mixing induced. After extensive CFD modeling and field testing, vortex mixers (shown in **Figure 2**) were successfully incorporated into the module design to optimize performance at lower UVTs. The vortex mixers are mounted on the quartz sleeves, and increase flow turbulence and mixing around the lamps (**Figures 3 and 4**).

Monitoring: An important consideration in the operation of a low UVT system is the ability to respond to varying water quality conditions. Over the course of a storm, the water quality can vary significantly, and the UV system must respond accordingly to ensure full treatment performance and to optimize power and lamp use. Key monitoring equipment includes UV intensity sensors to measure lamp output, flow meters and on-line UVT monitoring to track water quality throughout the storm event. As operating conditions and water quality fluctuate, the UV system controller (PLC) automatically and continuously calculates operational power settings required to achieve the UV lamp output necessary to ensure adequate disinfection. The Power Distribution Center (PDC) houses the high-efficiency, variable output ballasts which deliver the power to the lamps. A typical schematic of a UV4000 System used for storm water treatment is shown in **Figure 5**.

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Figure 2. *Vortex mixers mounted on quartz sleeves housing medium pressure UV lamps provide additional mixing and direct the low UVT water toward the high intensity light source.*

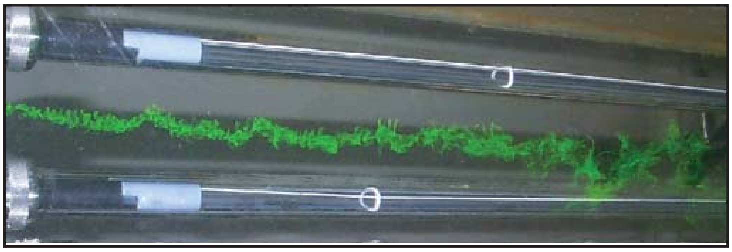

Figure 3. *Dye tests illustrate potential paths of short-circuiting where water does not reach the UV lamps, resulting in poor performance and potential reactor failure.*

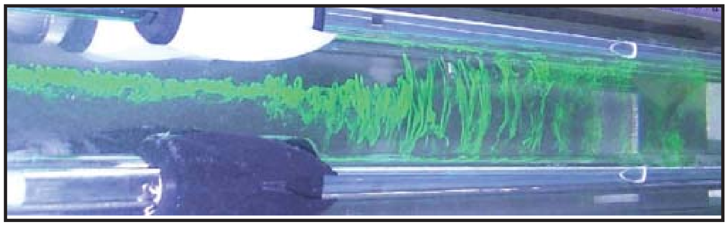

Figure 4. *With vortex mixers, additional turbulence is induced, ensuring that particles and microorganisms reach the UV lamps for reliable disinfection.*

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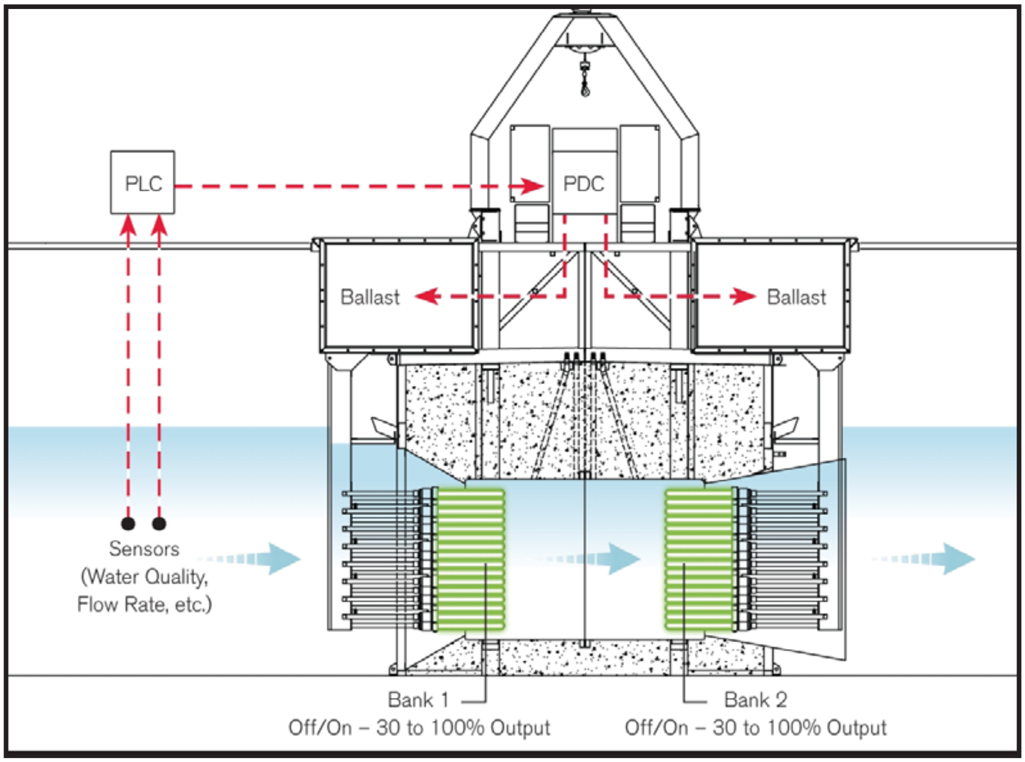

Figure 5. *Typical Schematic of UV4000 System for Storm Water Treatment*

Maintenance: Another design challenge equally critical to ensure proper performance and long-term operation is to consider the quartz sleeve fouling rates and extent, as well as the solution for foulant removal. If not fully addressed, there is a performance risk (UV is unable to reach the water) and a maintenance risk (Operators will spend excessive time cleaning the UV system).

Because the low UVT, higher solids and in some cases, the type of coagulants used, the rate and degree of fouling on the quartz sleeves can be accelerated in low UVT applications. Fouling must be removed from the quartz sleeves to maximize the UV transfer to the water. Options for fouling removal include manual cleaning, semi-automatic or automatic cleaning mechanisms.

Regardless of type, it is critical that both mechanical (wipe-action) and chemical (dissolve-action) are provided to fully remove organic and inorganic fouling. Selected commercially-available UV systems today offer automatic systems that provide both mechanical and chemical cleaning methods to completely remove fouling, optimize UV delivery and reduce operator maintenance.

INDEPENDENT BIOASSAY VALIDATION

In April 2010, bioassay validation testing was performed on the TrojanUV4000Plus™ disinfection system equipped with vortex mixers. The bioassay testing was conducted by adding non-pathogenic indicator viruses, (MS2 and T1UV bacteriophages) to the influent water. A UVT modifier (SuperhumeTM) was used to adjust the UVT of the water to desired low levels, thereby representing low UVT wastewaters and CSO applications. Samples were collected from the influent and effluent of the UV reactor to determine reactor disinfection efficiency over a range of flows, UVTs, and lamp power settings. Analyses were performed on the data generated to determine reduction equivalent doses (RED) as a function of flow, water quality (UVT), lamp power setting, and microbe sensitivity. All sampling and data analyses were witnessed by an independent third party to validate the results

The completed validation report presents the validation data for the range of UVT tested (10 to 70%). The delivered UV dose is shown along with the relationship to flow rate for the range of water quality tested. The completed validation report and data contained therein can then be utilized to verify system sizing for low UVT wastewaters, thus providing confidence that disinfection levels will be achieved.

FULL-SCALE APPLICATIONS OF UV FOR STORMWATER TREATMENT

It is estimated that over one billion gallons per day (44 million m^3/s) of storm water and/or very low quality wastewater (low UVT) is currently being treated with UV disinfection with installations in North America, Europe, Australia and Asia. Prior to selecting UV technology, several of these municipalities underwent a comprehensive bench scale and/or full scale field testing project to confirm UV's effectiveness on their challenging effluent.

One particular municipality who evaluated, tested and installed UV for their CSO treatment is the Cog Moors Wastewater Treatment Works (WwTW) facility located near Cardiff, UK in the Barry catchment (southwestern UK region). The region in South Wales served by the Cog Moors WwTW includes three popular bathing water beaches. To protect public health, the Environment Agency Wales introduced stringent consents and storm-water spill limits of only three per bathing season, posing a compliance challenge for the Cog Moors WwTW. The plant is equipped with an activated sludge process for secondary treatment and utilizes storm tanks to capture and store the storm flows. The facility evaluated several options that would enable compliance with the Bathing Water Directives (including the limit on spill events per season). Options included: (1) provision of additional 25,000 m^3 storm-water storage capacity and (2) UV disinfection of 2,380 L/s (54 MGD) storm flow with UVT down to 30%. Three key evaluations led to the selection of UV disinfection technology. First, a cost analysis, for CAPEX and OPEX provision of additional storm storage capacity was 2.3 times more costly than installation and intermittent operation of UV disinfection based on a 20-year Net Present Value comparison (Imtech Process, Ltd). Secondly, the carbon footprint was evaluated for both options. It was concluded that UV treatment generated approximately one tenth the amount of greenhouse gas emissions. The largest contributing factor for the storm-water storage option was the embodied emissions of greenhouse gas due to the use of concrete for construction of the storm-water tanks.

In comparison, UV had a smaller footprint, used a fraction of the concrete and power consumption was intermittent (during storm events only) making the UV option even more attractive in the sustainability evaluation. Lastly, a pilot study was conducted to confirm the effectiveness of UV disinfection for the Cog Moors CSO effluent – being the first UV plant in the UK designed to treat storm-water flows. Since commissioning in 2009, the UV plant has operated successfully. Effluent quality monitoring has shown the plant meets the required bacteriological reductions, ensuring that local beaches were safe for the community.

SUMMARY

To ensure reliable disinfection performance in low UVT applications, it is critical that the equipment manufacturer has knowledge and understanding in the following:

- Water quality or comparable water quality (i.e. from a historical database) whether it be primary effluent or CSOs
- Proper UV reactor design including the science of UV disinfection as it relates to overcoming the challenges of delivering UV energy to the pathogens of concern.
- Successful history of UV installations for storm-water disinfection

The equipment selected should be from a reputable manufacturer with good scientific understanding and a demonstrated history of applying UV for low quality wastewaters. The design trade-offs, in terms of head loss and power consumption, are a function of UV lamp intensity, lamp spacing and mixing and must be evaluated. Finally, the selected UV-reactor configuration must have been verified through field-testing and independent bioassay validation to guarantee performance at a full-scale level.