UV Lamp Validation via a Bioassay Equals Reality

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During the 1980’s and early 90’s the majority of UV systems for disinfecting wastewater used the same lamps and ballasts. Manufacturers made the same low-pressure mercury lamp called a G64T5L and one company made the ballast. The only difference in the lamps was the end connector. The lamps were placed horizontally in the water with a center to center spacing of 6.03 to 7.62 cm. The majority of the systems that were sold had the wastewater flowing parallel to the lamps. A few manufacturers used the same lamps in a horizontal configuration but they used the same ballasts. Now almost every UV manufacturer has UV systems with their own patented or proprietary lamps and ballasts. These UV systems also come with various configurations of the lamps in the water. The outputs of these lamps are usually measured in still air at 20°C and as shown in Figure 1, this may not be indicative of their UV output inside a quartz sleeve under water at 5 to 20°C.

![Figure 1: Effect of water temperature on the UV output of a G64T5L lamp operating at 302 mAmps in a 24.5 mm OD quartz sleeve](image)

Even when a sensor under water measures the UV intensity it does not give any indication of how well the UV light is converted into actual germicidal power. At the present time there is no formula for comparing one UV system to another. The UV fluence (UV Dose) provided by a UV reactor can be calculated mathematically or by carrying out a test called a bioassay under controlled conditions with a microorganism which has a known response to UV light. Calculating the UV fluence mathematically has led to exaggerated claims about the performance of UV systems and this has resulted in failures in the field. Two of the major errors are a result of incomplete characterization of the reactor's distribution of residence times and the UV output of the lamps. Therefore, it is very difficult for a consultant or a potential owner to determine whether the claims of the UV manufacturer are true and if the UV equipment will perform once it is installed in a wastewater treatment plant. To alleviate this problem SUNTEC environmental based the development of their UV systems on the use of a bioassay.

The bioassay uses a microorganism with a known response to UV light to measure the germicidal power of a UV system. As the microorganisms pass through the UV system they are affected by all the parameters that determine the performance of the equipment and the UV fluence is measured. If the UV lamps are not performing according to the measurements in air or there is fluid which is short-circuiting through the array of UV lamps or if there is not adequate mixing perpendicular to the lamps, it will be reflected in a UV fluence that is less than what would be expected from the modeling. This will result in a lower flow per lamp to meet the disinfection requirements and higher power consumption per volume of water treated. A cultured microorganism such as the UV-resistant MS2 coliphage or one that is indigenous in the wastewater can be used for the bioassay. The organism is calibrated in the laboratory under exact conditions. The organisms are all subjected to the same UV fluence by being exposed to an exact amount of UV light in a perfectly mixed container. A calibrated curve for the total aerobic spore-formers in the wastewater that was used for these experiments is shown in Figure 2. These organisms are indigenous in all wastewater treatment plants and they can be used to measure the UV fluence of a UV system for ongoing or a single performance validation. Suntec environmental chose the total aerobic spore-formers as their test organism.

The LPX200 was developed with the following differences from the typical UV system where the water flows parallel to the horizontal low-pressure mercury lamps. The ballasts for the UV systems are usually placed in cabinets or above the waterline on the racks that hold the UV lamps. The LPX200 has patented submerged ballasts that are adjacent to each UV lamp and this results in optimal cooling of the ballasts. It eliminates the requirement for large cabinets with some form of cooling. A
A low-pressure lamp was developed that produces a higher UV output than the regular G64T5L (26.7 watts of UVC at a wavelength of 254 nm) thereby reducing the number of lamps. The center to center lamp spacing is 8.89 cm instead of 7.62 cm. This lamp, ballast and spacing combination had to be tested and compared to the typical UV system that made up the majority of sales in North America.

![Graph of the average fluence (mJ/cm²) within the wastewater versus the Log of NNO, of the total aerobic sporeformers](image)

SUNTEC Environmental and GAP Environmental Services Inc. of Toronto and London, Ontario, Canada, respectively, conducted an assay and related testing on a LPX200 ultraviolet disinfection system from SUNTEC Environmental and a Standard low-pressure UV System using G64T5L lamps which were operated at 525 mA. These are both open channel UV systems where the water flows parallel to the lamps.

The LPX200 consisted of a 6-lamp battery assembled in a 3 x 2 array with centerline spacing of 8.89 cm. The lamps had an arc length of 162.6 cm and were configured horizontally and parallel to the direction of flow. The quartz sleeves had an OD of 23 mm and an ID of 20 mm. The LPX200 UV system was tested beside a Standard low-pressure UV System. The equipment consisted of a 6-lamp battery assembled in a 3 x 2 array with a centerline spacing of 7.62 cm. The lamps had an arc length of 147.3 cm and were configured horizontally and parallel to the direction of flow. The quartz sleeves had an OD of 23 mm and an ID of 20 mm. The lamps were conventional low-pressure lamps that produce 26.7 Watts of UV light at a wavelength of 254 nm in air. The electronic ballasts operated the UV lamps at a current of 525 mA for 100 percent lamp output. The experimental setup is shown in Figure 3.

The bioassays were conducted with undisinfected final effluent from a secondary activated sludge wastewater treatment plant. The UV transmittance of the wastewater was allowed to vary naturally at wavelength of 254 nm. The average UV transmission was 59 percent and the total suspended solids were less than 5 mg/L. These variables were taken into account by being able to compare the LPX200 to the Standard low-pressure UV System at the same time. The UV output of the lamps of the LPX200 was adjusted to 100 percent for the first tests and then to 60 percent to simulate a lower power setting with the variable output ballasts. The LPX200 was tested with flow rates of approximately 681, 757, 946, 1136, 1325, 1514, 1703, and 1893 liters per minute. The Standard low-pressure UV system was tested with flow rates of approximately 416, 568, 757, 946, 1136, 1325, and 1514, liters per minute. The results of the testing are shown in Figure 4.

![Layout of the UV systems at the wastewater treatment plant. The LPX200 is UV unit B and the Standard Low-pressure UV unit is A.](image)

The average UV fluence is equal to the retention time multiplied by the UV intensity. From the bioassay the average UV fluence is known. From tracer studies the average retention time can be calculated. Therefore, the average intensity can be calculated over the range of flows that were tested. This average intensity will be influenced by the hydraulics of the UV system, the UV output of the lamps, and their configuration in the wastewater. The average UV intensity will allow the calculation of the usable UV light produced by the lamps and the configuration of the UV system. Various germicidal wattages of the LPX200 lamp were put into TULIP, the point source summation portion of the UVDIS 3.1 program (HydroQual Inc., Mahwah, NJ, USA), until it predicted the average UV intensity. The average UV intensity for flows from 100 to 300 L/min per minute per lamp was 9.3 mW/cm². With the addition of 10 percent for the losses through the quartz sleeves, this corresponds to an average lamp power of 63 Watts over the flow range that was tested for the LPX200.

On an equal flow per lamp basis the increase in the UV fluence by the LPX200 is 2.2 times that of the Standard low-pressure UV system. If the UV output of the lamps of the LPX 200 were to be measured in air it would show a higher UV output, but the 63 Watts that have been demonstrated here is the working portion of the entire germicidal output at a wavelength of 254 nm.

In conclusion, mathematical models and measurements of the UV output of lamps in air are important tools for the designing
and understanding of a UV reactor, but they must be confirmed by experiments that measure the actual disinfection performance of the UV equipment. Validating the efficiency of a UV system and the output of the lamps by a bioassay provides the reality that will give the consultant or potential owner confidence that the UV system will perform as specified.

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**Figure 4:** The effect of flow rate on the UV fluence of the LPX200 and the Standard Low-pressure UV System.