Performance is the Key: How an Initial Failure Turned into Success

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Introduction
The cities of Maldonado and Punta del Este are located in southeast Uruguay in South America. These cities are home to the most exclusive beach resorts in the country and are among the most popular tourist destinations in South America.

In 2010, Obras Sanitarias del Estado (OSE), the Uruguayan water and sanitation company, secured a contract for the construction of a new sewage system intended to treat effluent from residents of Maldonado and Punta del Este. The construction and commissioning contract was given to Ciemsa, a Uruguayan company with more than 25 years of expertise in construction and operation of this kind of system. Completed in 2012, the system includes seven pump stations and an improved primary treatment plant, flocculation-sedimentation with aluminum sulfate – Al₂(SO₄)₃ – as the flocculating agent with an offshore outfall of 1,100 meters. The maximum capacity of the system is 4,960 cubic meters per hour (m³/h), and the median flow is 2,200 m³/h. The ultraviolet transmittance (UVT) of the influent to the systems is less than 40%, the total suspended solids level typically less than 30 mg/l. This low value was the design objective for treatment. To reach better values of UVT, we needed to use higher doses than designed [120mg/L of Al₂(SO₄)₃] with the risk of inhibition of the anaerobic sludge digestion.

This study examines two ultraviolet (UV) disinfection system designs and provides recommendations on optimizing system design for UV disinfection with low UVT influent. The study illustrates the importance of understanding influent parameters prior to the specification of a UV disinfection system in order to achieve optimum efficiency. Ultimately, an open channel UV disinfection system is found to be the optimum solution for UV disinfection with low UVT influent – delivering clean, safely treated wastewater of the highest standard using a minimum amount of energy.

Initial failure
Following commissioning of the UV disinfection system, the operators found that the technology originally selected did not perform in line with expectations of a 3 log (99.9%) reduction in fecal coliform numbers to less than 1,000 CFU/100 mL of fecal coliforms.

The original equipment selected was Xylem’s Wedeco TAK55 UV system with two banks in series of 11 modules and 18 lamps in each module. The project specification assumed that a single bank must be sufficient to disinfect a flow of 3,600 m³/h. At flow rates of 1,800 m³/h or less, however, the equipment did not achieve this objective. In its first year of operation, with medium flow of 1,300 m³/h (30% of the maximum capacity of the system), the equipment only achieved the expected 3 log reduction goal in 28% of tests. All of these values were tested with UVT and TSS values under specification.

To address this issue, more power was required to run the lamps, and spare banks were put into operation. Working in close collaboration, Ciemsa and Xylem made changes in the operational parameters of the UV system (power, number of lamps and banks, wiping frequency, etc.) with a view to increasing the log reduction. This led to the goals being met in 70% of cases. The best configuration for the Maldonado plant was two banks at 90% of power and four wipes per hour.

Possible reasons for underperformance in the original UV disinfection system selected
Confident that the system was properly installed, the system designers and operators together investigated all possible parameters and their impact on the system’s performance.

Water parameters
The design specification included the following parameters: (at maximum flow rate of 4,936 m³/h)
- UV transmittance ≥40%
- Total suspended solids ≤30 mg/L (average 10 mg/L)
- Particle size ≤30 µm
- Effluent temperature 5 to 30°C

While there were occasional samples showing a UVT of <40%, this alone would not explain the performance shortcomings of the UV system.

Maximum flow rate
The influent flow is measured by a Parshall flume and registered in a Supervisory Control and Data Acquisition (SCADA) system at one-minute intervals. The flow rate did not exceed the maximum capacity of the system. As the Wedeco TAK system’s flow meter showed similar values to that of the Parshall flume (five percent maximum deviation), the team concluded that the influent flow was not the issue.
Equipment
The investigation also focused on problems noted while the system was in operation, such as some lamps burning out before the end of their lifetime, and visible blackening of some bulbs. The impact of a single burned-out lamp on the UV disinfection results was examined.

Aging
The lamp parameters, including electrical and ambient parameters, were studied to establish why some lamps failed before the end of their expected lifetime.

Maintenance/fouling
The poor effluent quality proved to be a challenge for both channel and quartz sleeve cleanliness. While equipped with an automatic wiping system, the UV system still required additional maintenance (e.g. regular wiper ring replacement). Secondary effluents fouling factors >0.9 are commonly observed, but the fouling factor at this site was initially 0.5. With additional chemical cleaning with citric acid at 15%, the fouling factor reached 0.8. The operational parameters were corrected, and a more detailed investigation about the design of the technology was undertaken.

Lamp centerline
One of the parameters studied in more detail was the distance between the lamps (lamp centerline).

The installed Wedeco TAK55 has a lamp centerline of 120 mm, which results in a free distance of 7 centimeters (cm) between lamp sleeves, in both directions.

At a UVT of 40% (and sometimes lower), a 99.9% inactivation of fecal coliforms was not achievable consistently because of the irradiance and residence time distribution. The original sizing method based on point-source summation overestimated the effects of turbulence for complete mixing. With incomplete mixing, the wide lamp centerline prohibited the exposure of the bacteria to the UV dose relevant for a three log inactivation.

Design UV dose
At the time the TAK system was designed for this site, the common design approach for open channel UV systems was based on a calculated dose. The tender called for a UV design dose >30 mJ/cm² under the described operational parameters. Using the results of the UVCalc®1 software, it was calculated that for a flow-rate of 400 m³/h in an 18-lamp module at a UVT = 40% the delivered UV dose would be about 38 mJ/cm². However, as seen in Fig. 1 below, the fluence rate distribution in the module is very inhomogeneous under such a low UVT. Some parts of the flow only receive a UV dose of 20 mJ/cm² causing the lower than expected biological performance.

That’s why UV system validation testing has gained increased importance – even for wastewater UV system designs over the course of the last several years. If a UV system has undergone such testing, then performance can be better predicted for the set of tested conditions. If the validated conditions include comparable low-water qualities, then this would

![Photo 1. Internal view of the TAK55](image)

**Figure 1.** Fluence rate distribution in the central plane for the Xylem Wedeco TAK55 UV system. X is along the length of the module, and Y is along the width.
even apply for such low-water qualities as encountered at this site.

**Design revision based on validated UV dose**

Having established a clear understanding of the parameters of the system, the Xylem team was able to recommend a “best fit” solution, which would ensure optimum efficiency and reliability. Xylem’s Wedeco Duron UV system consists of 216 UV lamps in one channel (18 modules with 12 lamps each, installed in six banks). Xylem’s application engineers worked closely with the system operators to deliver the alternative UV solution in a timely manner, with minimal disruption to operations.

The Wedeco Duron UV system (new to the market in 2012) with the 600 W UV lamps was installed inclined at 45 degrees. The system also has the following:

- Staggered lamp arrangement for high-disinfection performance.
- Fast and easy lamp change with UV modules remaining in the channel.
- Reduced channel depth for lower construction costs.
- All electrical connections are out of the water.

The Wedeco Duron UV system has been validated according to the US Environmental Protection Agency (EPA) UV Disinfection Guidance Manual (UVDGM); the National Water Research Institute (NWRI) 2012 Guidelines for Drinking Water and Water Reuse; and the International UV Association (IUVA) uniform protocol for wastewater UV validation applications. Being validated down to the conditions encountered at this site, the Duron system’s design was based on a bioassay.

Figure 2 explains the difference in the critical particle path for the lamp arrangement of the Duron system compared to a horizontal lamp system, such as the TAK55 system.

While – assuming zero mixing effects – the particle in the very center of four lamps of a horizontal lamp system will only receive a minimum UV dose (and at low UVTs this could in effect be zero), whereas the staggered array of the Duron system forces the particle to high zones of irradiance (and hence UV dose).

This is further highlighted in the visual display of CFD simulations shown in Figure 3.

The Wedeco Duron system has passed the commissioning phase successfully, and it is meeting the design objectives and outperforming the TAK55 system under similar conditions.

The disinfection achieved was in the range of four log inactivation (three log inactivation is the design objective), as shown in Figure 4. Because of the poor quality of the water, a high fouling potential still is observed.

In order to avoid increased operational attendance, Xylem is testing a special non-chemical wiper ring design for such challenging effluents.
The photos below show the current Duron installation at Maldonado.

**Figure 4.** Disinfection of fecal coliforms. The blue dots represent influent values, and the red dots represent effluent values.

### Recommendations for specification of low UVT disinfection by ultraviolet

Based on these studies, recommendations can be made about the specification, operation and maintenance of UV equipment when it is used in wastewater treatment plants with influents of low UV transmittance.

1. UV system designs for low-quality effluents based on a calculated UV dose approach (PSS) may lead to overestimation of UV system performance. Therefore, UV system design should be based on validated UV systems.
2. The selected system should be proven independently to deliver the required UV dose – especially at low UVT rates.
3. If the effluent exhibits a high fouling potential (e.g., due to high iron or manganese levels), a site-specific fouling factor should be established. One cannot simply use a fouling factor from a different quality effluent irrespective of cleaning system. The fouling factor in this situation was 0.85. A lamp aging factor set at 0.9 or less is acceptable for the design calculations if one does not have on-site studies.
4. In operation, the power and lamp intensities must be controlled daily to monitor and control fouling.
5. The lamp aging factor must be controlled and the lamps replaced when lamps reach aging factor values lower than calculated values – all the lamps in one bank (or row) must be in operation.
6. The equipment must have mechanical or chemical wiping.
7. Every six months, all the equipment must be cleaned outside the channel with proper equipment and products.

### Conclusions

All influent parameters must be thoroughly investigated before the specification of a UV disinfection system to ensure the optimum efficiency of the system.

Technology suppliers should engage in their own ongoing studies of these parameters to inform equipment design.

The system operator and maintenance provider also must have an in-depth knowledge of the technology. The new specifications and guidance for design (UVDGM) must be used when the predesign and specifications are being drafted. Finally, regular testing should be undertaken during the first month after commissioning of the system to ensure optimum performance of the UV disinfection system and process is achieved. At the Maldonado plant, scientists are continuing to study and increase the efficiency of the UV system.

### References
