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DSD International Conference 2014

Pathogen Specific UV System Sizing for Wastewater and Reuse Disinfection – “Best Fit” Design Without the Pilot

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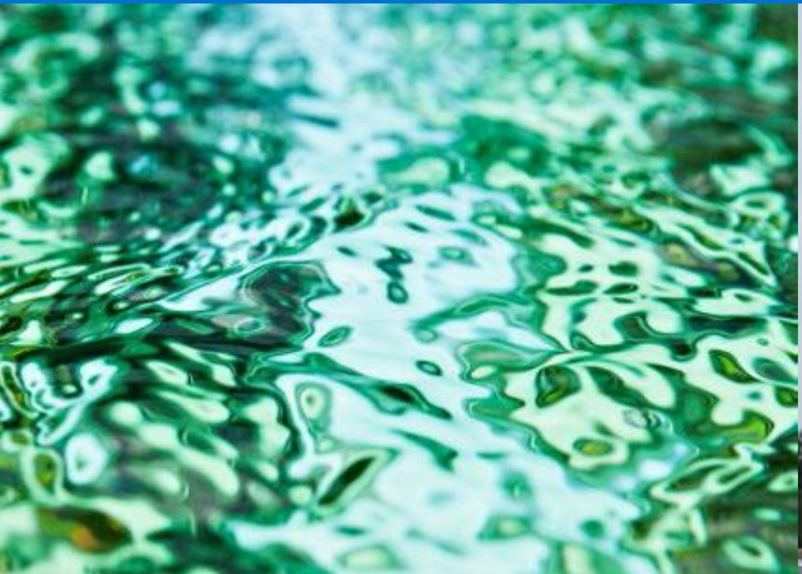


Outline

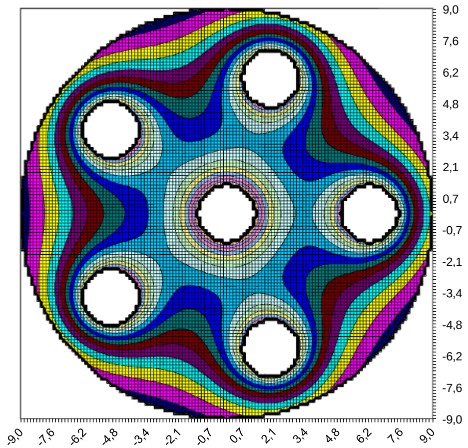
- Introduction
- Materials & Methods
- Results & Discussion
- Design Comparison
- Conclusions

Introduction – Traditional Design based on UV DIS

UV dose = Irradiation Time x UV intensity

Advantages

- Simple to apply
- Widely accepted
- Perceived easy comparison to competitive designs



Disadvantages

- Based on physical parameters of UV lamps and reactor geometry only
- Based on ideal conditions (hydraulics/ irradiation distribution)
- No consideration of shadowing effects of suspended solids
- Underestimation of the influence of fringe areas
- No consideration of water properties apart from UVT!
- **Connection to real disinfection performance only via link to empirical field data**

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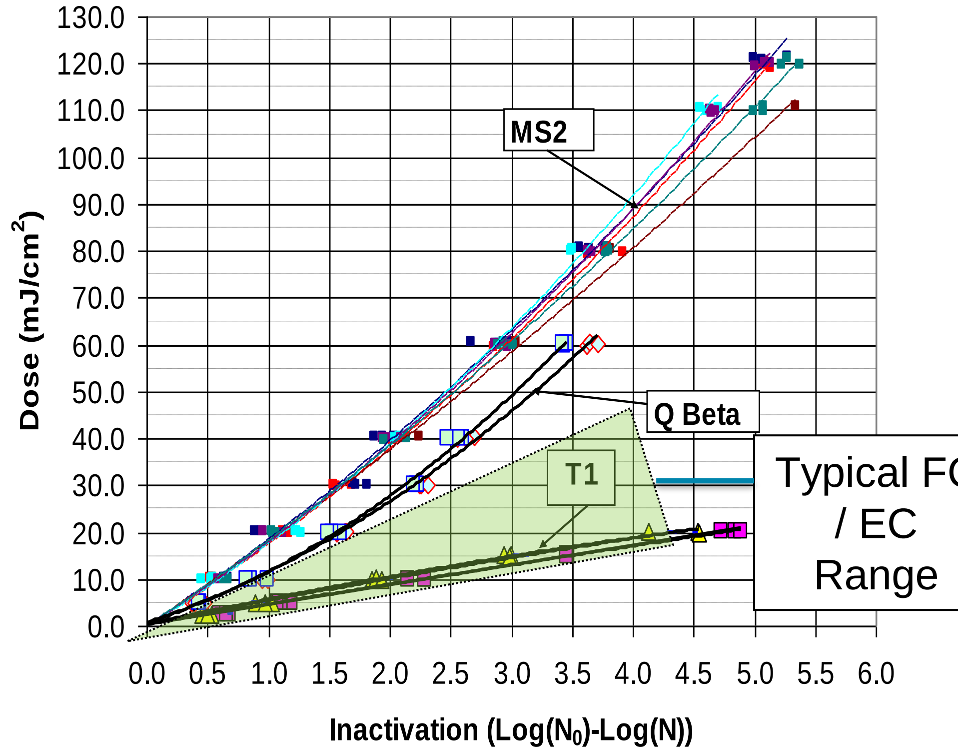
Introduction

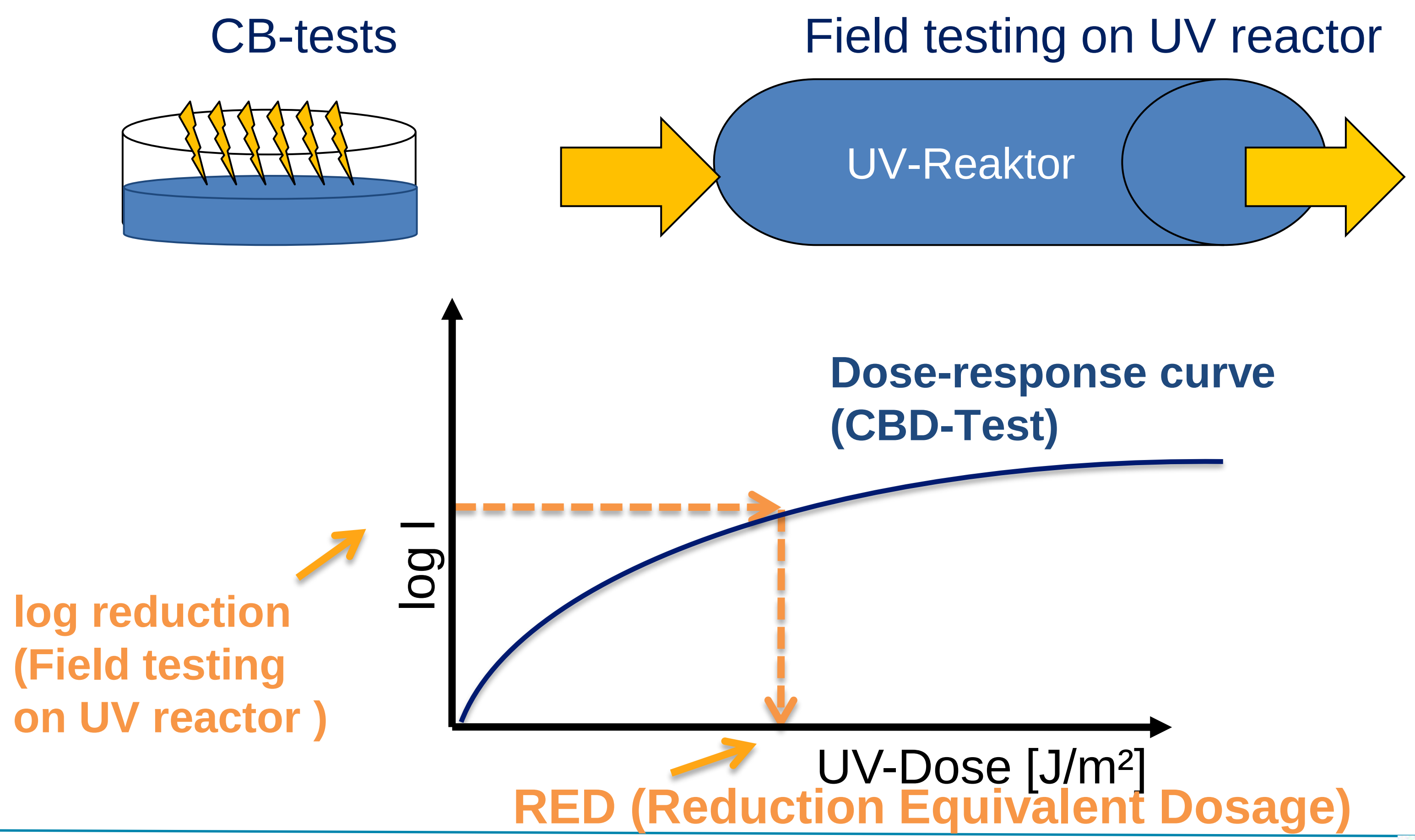
- Wastewater matrix has a known impact to UV disinfection performance
- Pathogens exhibit different UV sensitivities (D_L)
- Sensitivities for one specie may vary from site to site
- Sensitivities depend on targeted log inactivation
- **For proper disinfection prediction challenge and target organism should exhibit similar UV sensitivities!**



A UV dose needs to be linked to a specific organism or UV sensitivity in order to determine the achievable log reduction!

Validation of UV reactor performance

Testing Results are Compared to Dose Response Curve to Calculate Reduction Equivalent Dose



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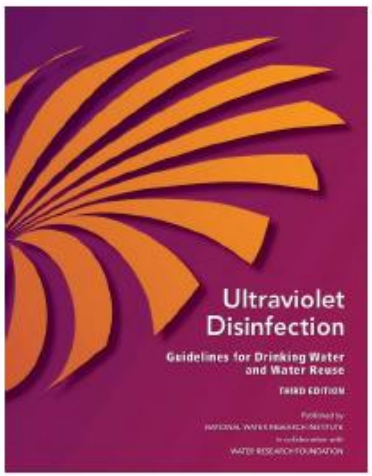
Materials & Methods

Validation of a Wedeco Duron open channel UV system with

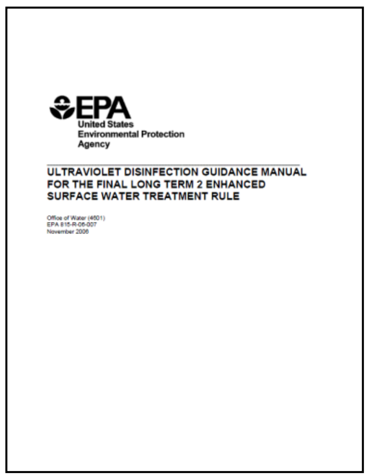
- 48 lamps installed in 4 banks
- Flow rates from < 500 m^3/h to >2,000 m^3/h
- UV transmittances from <30% to >70%
- 4 different surrogates
- Different quantities of banks in operation
- Sensor readings collected for every single point tested

Data Analysis

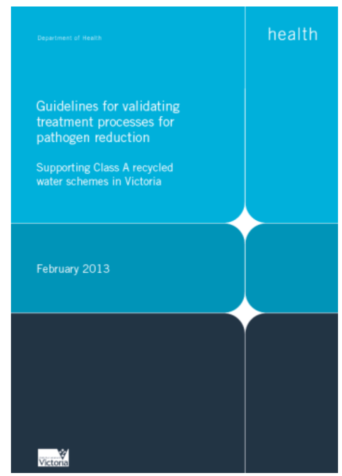
- By independent 3rd party Carollo Engineers
- In line with various validation and design guidelines



NWRI guidelines 2012



UV Disinfection Guidance Manual 2006



Guideline for Class A, recycled water 2013, Victoria, AUS

Uniform protocol for wastewater 2011, IUVA

Data Analysis

Determination of the Reduction Equivalent Dose (RED)

RED calculated by comparing…

- the level of inactivation for each test condition
- to the dose response curve generated from the Collimated Beam

RED is specific to…

- the specific challenge microorganism
- the specific test conditions flow, UVT, intensity/ power, rows

$$RED = 10^{A} \times UVA^{B \times UVA} \times \left(\frac{S/S_0}{Q \times D_L} \right)^{C + D \times UVA + E \times UVA^2} \times Modules^{F + G \times UVA + H \times UVA^2} \times D_L$$

RED	- Reduction Equivalent Dose
UVA	- UV absorbance
D_L	- UV sensitivity
S/S_0	- Relative UV intensity
Q	- Flow rate
A-H	- Coefficients

Data Analysis

Adjust for Uncertainty to Calculate the Validated Dose

- Divide the RED by a Validation Factor
- Quantitatively accounts for…
    - experimental uncertainties
    - difference in UV sensitivity of challenge and target organism

$$D_{val} = RED / VF$$

$$VF = B_{RED} \times \left(1 + U_{val} / 100\right)$$

D_{val} – Validated Dose

RED - Reduction Equivalent Dose

VF – Validation Factor

B_{RED} – RED Bias Factor

U_{val} – Uncertainty of validation

RED bias factor (B_{RED})

- Needs to be applied whenever UV sensitivities of challenge organisms are higher than the one of the target pathogen
- Defined by the UVDGM as

  …"a correction factor that accounts for the difference between the UV sensitivity of the target pathogen and the UV sensitivity of the challenge microorganism"

- Reason: real world vessels having less than perfect dose distributions

Figure D.1. UV Dose Distributions of Ideal, Realistic, and Worst-case UV Reactors

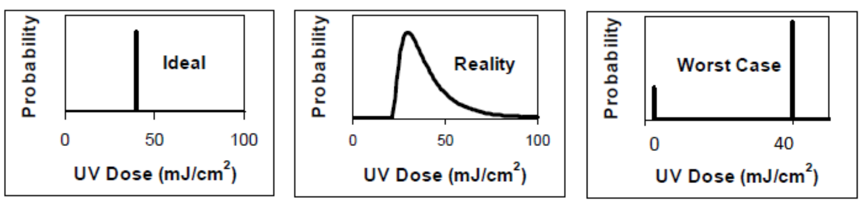


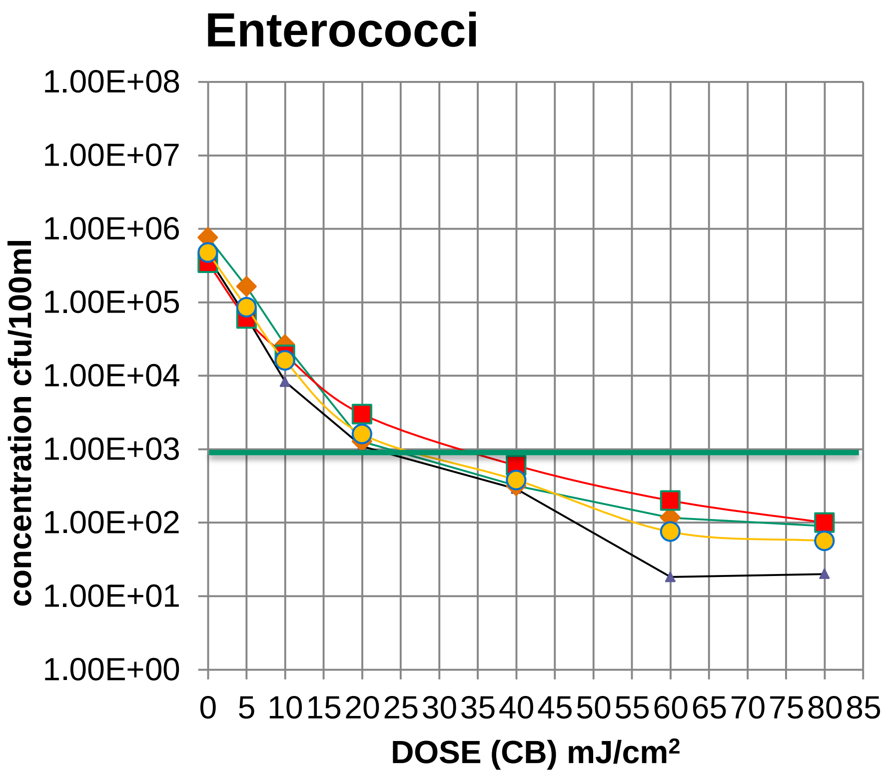
Table G.3. RED Bias Values for 3.0-log *Cryptosporidium* Inactivation Credit as a Function of UVT and UV Challenge Microorganism Sensitivity

Cryptosporidium log inactivation credit		3.0						
Required UV dose (mJ/cm²)		12						
Cryptosporidium UV sensitivity (mJ/cm²/log I)		4.0						
UVT (%)		≥ 98	≥ 95	≥ 90	≥ 85	≥ 80	≥ 75	≥ 65
Challenge UV sensitivity (mJ/cm²/log I)		RED Bias						
Lower	Upper							
0	≤ 2	1.00	1.00	1.00	1.00	1.00	1.00	1.00
> 2	≤ 4	1.00	1.00	1.00	1.00	1.00	1.00	1.00
> 4	≤ 6	1.05	1.10	1.15	1.17	1.19	1.21	1.23
> 6	≤ 8	1.09	1.18	1.27	1.32	1.36	1.40	1.45
> 8	≤ 10	1.12	1.23	1.38	1.47	1.52	1.58	1.66
> 10	≤ 12	1.14	1.27	1.47	1.59	1.68	1.75	1.86
> 12	≤ 14	1.16	1.31	1.55	1.71	1.82	1.92	2.06
> 14	≤ 16	1.17	1.33	1.62	1.82	1.96	2.08	2.26
> 16	≤ 18	1.18	1.36	1.68	1.92	2.09	2.24	2.45
> 18	≤ 20	1.19	1.38	1.73	2.01	2.22	2.39	2.65
> 20	≤ 22	1.20	1.39	1.78	2.10	2.34	2.54	2.84
> 22	≤ 24	1.21	1.41	1.82	2.18	2.45	2.69	3.03
> 24	≤ 26	1.22	1.42	1.85	2.25	2.56	2.83	3.21

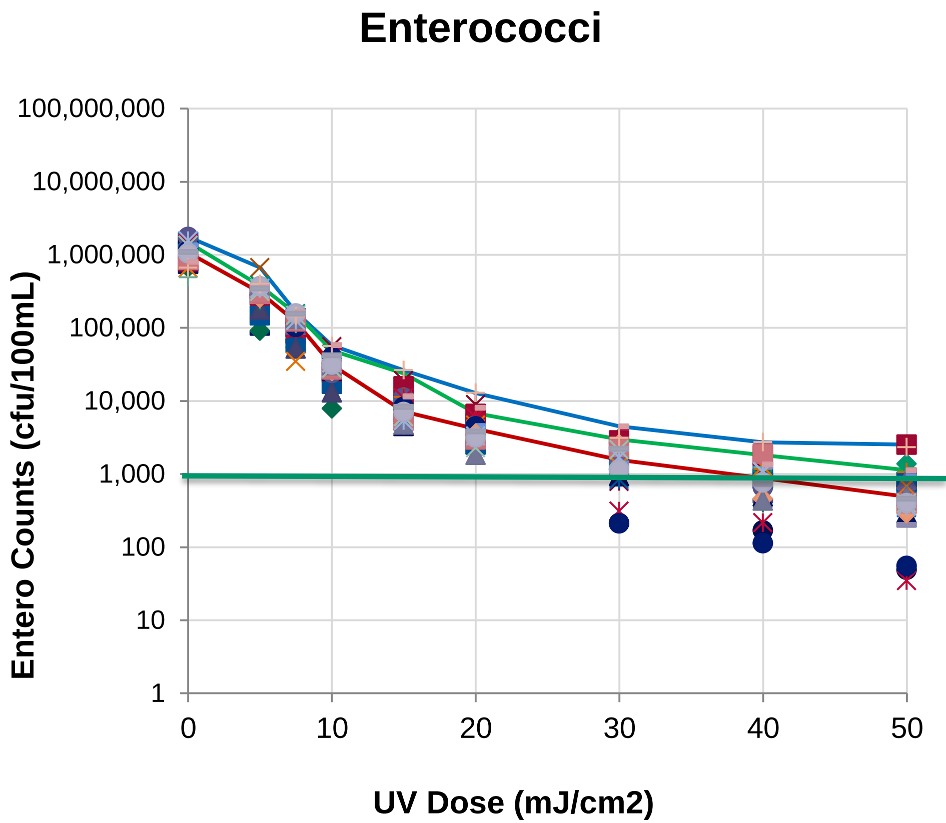
- **If UV sensitivities bracket the target organism's than B_{RED} =1**

Importance of site specific UV sensitivities

- Site specific conditions impact the UV sensitivity.



Required Dose: 24 mJ/cm²



Required Dose: 40 mJ/cm²

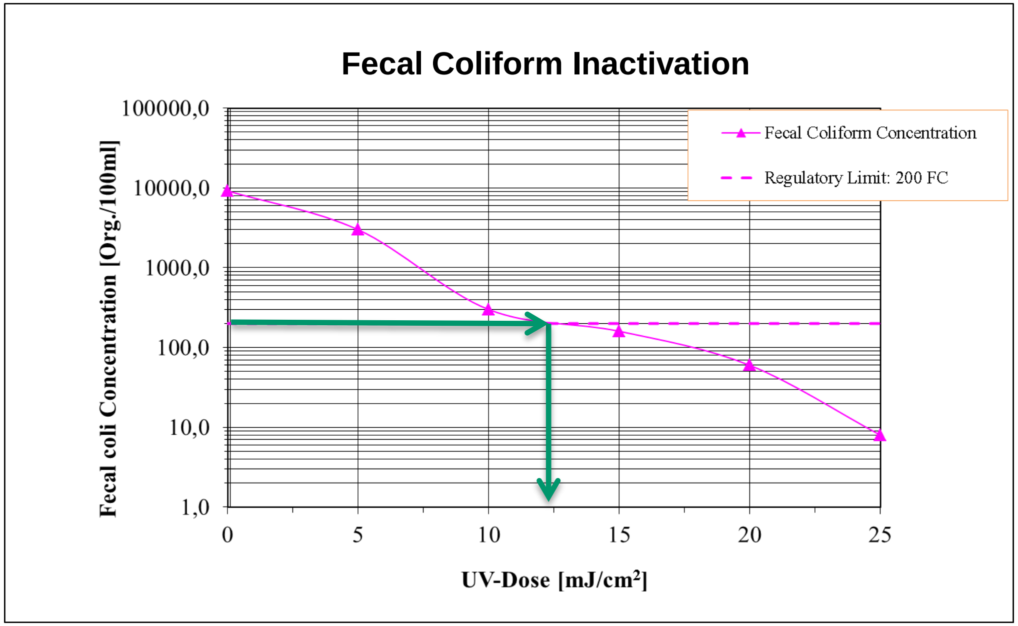
Can be determined by site specific CBTs!

“Best fit” design

- Collimated beam test allows to determine the log inactivation of a *site specific* microbial surrogate within the *site specific* water quality

Example:
Required UV Dose: 12.5 mJ/cm²
Log reduction: 1.7
Corresponding D_L: 7.4 mJ/cm²/log

D_L: Entry value to validation formula



Design comparison D_L vs. MS-2 approach

Disinfection Target	216 cfu/100ml
FC Inlet	100,000 cfu/100ml
Log reduction	2.67
D_L	4 mJ/cm²/log
Required dose	10.7 mJ/cm²
RED bias @ 65% UVT for MS-2 (D_L =18-20 mJ/cm²/log)	2.65

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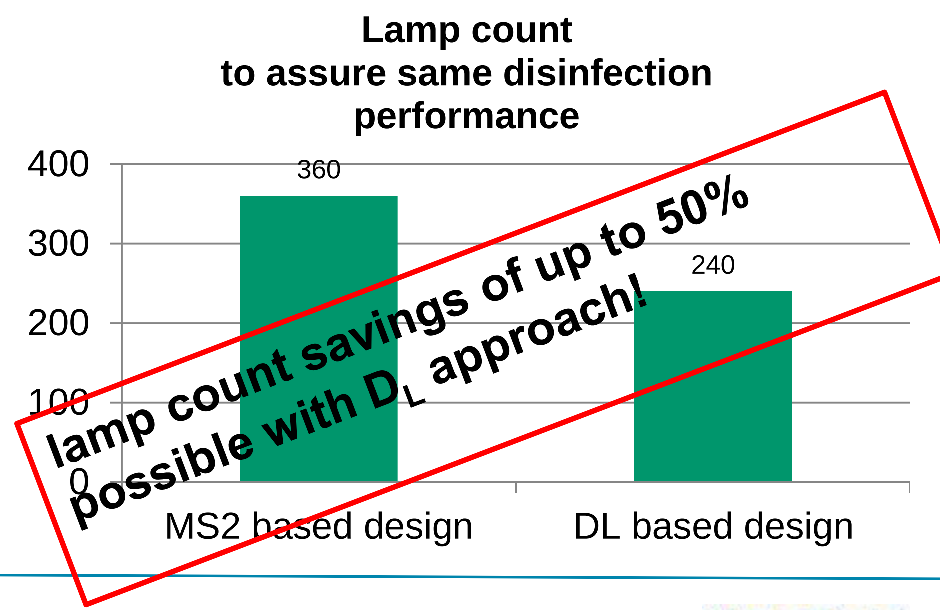
Required dose

- Based on D_L approach: 10.7 mJ/cm²
- Based on MS-2: 28.4 mJ/cm²
  (2.65 x 10.7)



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UV System Control

OptiDose Control

➢ Assure that disinfection performance is met

"In order to assure performance of the UV system the same UV amount needs to be delivered into the water at the same operating conditions (UVT, flow) as during the validation testing"

How to achieve this?

- Control the UV system based on UV intensity readings
- Consider real life aging and fouling of lamps

➢ Operate the system economically

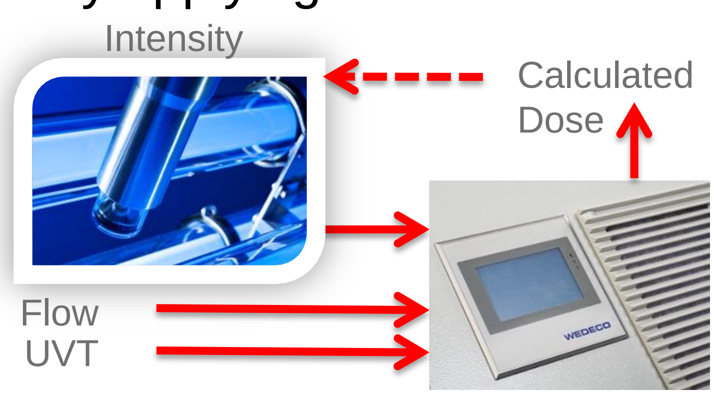
Control Philosophy

An “accurate” design requires an “accurate” control

- Consider real life aging & fouling via online UV intensity readings
- Collect UV intensity (S) readings during validation for every single test condition
- Monitor actual UV absorbance of the water via online UV transmittance readings
- Consider the actual flow rate (per channel)
- Apply high quality UV sensors (e.g. meeting ÖNORM standard)
- Control the system based on these signals by applying the validation formula

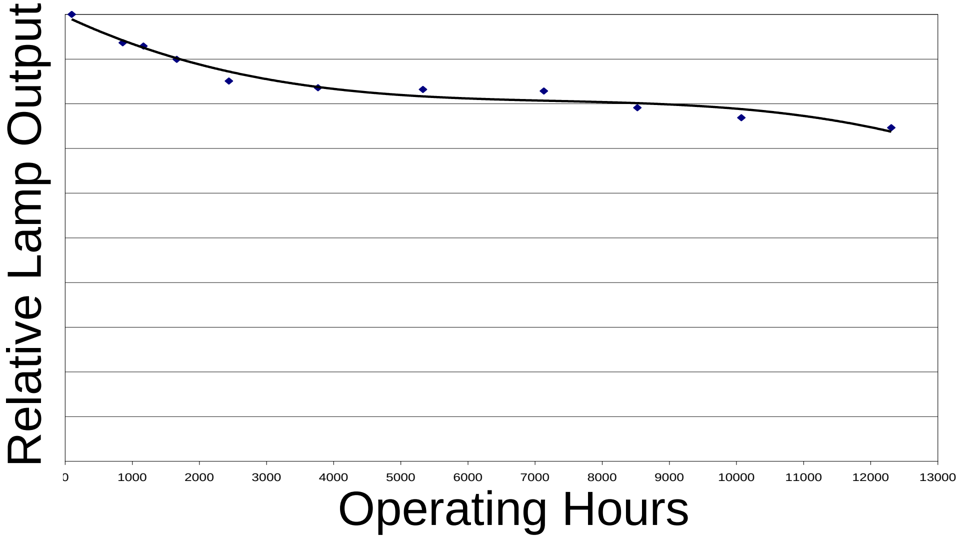
$$RED = 10^{A} \times UVA^{B \times UVA} \times \left(\frac{S/S_0}{Q \times D_L} \right)^{C+D \times UVA + E \times UVA^2} \times Modules^{F+G \times UVA + H \times UVA^2} \times D_L$$

- Assure that $S_{validation} < S_{operation}$



Aging & Fouling Factors

- Directly influence the design!
- Inappropriate factors applicable without sensor based design!
- Assure that realistic factors are specified!



Ageing is non linear

- 2-5% output fluctuation
- Aging in the field can be accelerated by adverse operating conditions (Excessive cycling, Overheating)

Fouling

- Site-specific
- Depending on constituents such as Iron, Manganese, Hardness

Conclusions

- Different pathogens respond differently to UV light
- Different wastewater sources and treatment schemes influence the pathogen's UV dose response (sensitivity)
- Calculated UV Dose values give no valid indication on the achievable UV disinfection performance
- Performance related UV Dose values need to be linked to a specific organism / or UV sensitivity and need to be derived by validation testing
- With the DL approach it is possible to design site and pathogen specific and thus can replace pilot testing
- Sensor based control (e.g. OptiDose) is the only currently available approach to reliably & efficiently operate a UV system

Conclusions

How to design a UV wastewater system most efficiently?

- Site specific - based on the D_L approach

- Assess site specific UV sensitivity of target pathogen via CBD testing
- Determine RED requirement based on the determined sensitivity (D_L) and disinfection target
- Specify the required RED and the corresponding D_L
- Assure that validation envelope includes design parameters
- Assure conservative RED bias factors are considered in case validation of a UV system has not been conducted with multiple surrogates bracketing the determined D_L

Conclusions

How to control a UV wastewater system most efficiently?

- **An “accurate” design requires an “accurate” control**
- Based on UV validation formula under consideration of
  - Online UV sensor data
  - Online UV transmittance data

- Dim the lamps according to the real life requirements
- Apply automatic on/ off switching of banks/ channels upon the requirements
- Assure that UV sensor data has been collected during validation testing over the full range of validated conditions

Acknowledgements

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Further questions:

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