ULTRAVIOLET DISINFECTION KINETICS FOR POTABLE WATER PRODUCTION

by

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SUMMARY

Irradiation with ultraviolet (UV) light is used for the disinfection of bacterial contaminants in the production of potable water, and in the treatment of selected wastewaters. However, efficacy of UV disinfection is limited by the combined effect of suspended solids concentration and UV absorbance. Limited published UV disinfection data are available that account for the combined effects of UV dose, suspended solids concentration and UV absorbance. This present lack of a rigorous quantitative understanding of the kinetics of UV disinfection limits process optimisation and wider application of UV treatment. The development and validation of an adequate model to describe UV disinfection kinetics presented in this thesis can therefore be justified by an increased confidence of reliability of design for UV disinfection.

Using the published data of Nguyen (1999), four established model forms were assessed to account for the combined effect of suspended solids and/or soluble UV absorbing compounds, and UV dose on the efficacy of disinfection. The four model forms were: a log-linear form, Davey Linear-Arrhenius (DL-A), Square-Root (or Ratkowsky-Belehradek) and a general n^{th} order Polynomial (*n*OP) form that was limited to a third order. Criteria for assessment of an adequate predictive model were established including: accuracy of predicted against observed values, *percent variance accounted for (%V)*, and; appraisal of residuals. The DL-A model was shown to best fit the data for UV disinfection of *Escherichia coli* (ATCC 25922); followed by the *n*OP, log-linear and Square-Root forms. However, the DL-A form must be used in conjunction with a first-order chemical reaction equation, and was shown to predict poorly at high experimental values of UV dose (> 40,000 μWs cm^{-2}). The DL-A model was not amenable to extrapolation beyond the observed UV dose range.

To overcome the shortcomings of the Davey Linear-Arrhenius model synthesis of two new, non-linear model forms was undertaken. The two models were a modified exponentially damped polynomial (EDP_m) and a form based on the Weibull probability distribution. The EDP_m model has three terms: a rate coefficient (k), a damping coefficient (λ), and; a breakpoint dose ($[dose]_B$). The rate coefficient governs the initial rate of disinfection prior to the onset of tailing, whilst the breakpoint is the UV dose that indicates the onset of tailing. The damping coefficient controls curvature in the survivor curve. The Weibull model has just two terms: a dimensionless scale parameter (β_0), and; a shape parameter (β_1). The scale parameter represents the level of disinfection in the tail of the survivor curve (as $\log_{10} N/N_0$), whilst the shape parameter governs the degree of curvature of the survivor data.

Each model was assessed against the independent and published UV disinfection data of Nelson (2000) for treatment of faecal coliforms in a range of waste stabilisation pond effluents. Both models were found to be well suited to account for tailing in these UV

disinfection data. Overall, the EDP_m model gave a better fit to the data than the Weibull model form.

To rigorously validate the suitability of the new EDP_m and Weibull models a series of experimental trials were designed and carried out in a small-scale pilot UV disinfection unit. These trials included data determined specifically at low values of UV dose (<10,000 μWs cm^{-2}) to fill the gap in the experimental data of Nguyen (1999).

The experimental trials were carried out using a commercially available, UV disinfection unit (LC5™ from Ultraviolet Technology of Australasia Pty Ltd). Purified water contaminated with *Escherichia coli* (ATCC 25922) with a range of feed water flow rates (1 to 4 L min^{-1}) was used. *E. coli* was selected because it is found in sewage, or water contaminated with faecal material, and is used as an indicator for the presence of enteric pathogens. *E. coli* should not be present in potable water. The hydrodynamics of water flow within the disinfection unit were established using digital video photography of dye trace studies with Methylene Blue. Nominal UV dose (2,700 to 44,200 μWs cm^{-2}) was controlled by manipulating the flow rate of feed water through the UV disinfection unit (i.e. residence time), or by varying the exposed length of the control volume of the disinfection unit. The transmittance of the feed water (at 254 nm) was adjusted by the addition of either a soluble UV absorbing agent (International Roast™ instant coffee powder; 0.001 to 0.07 g L^{-1}), or by addition of suspended matter as diatomaceous earth (Celite 503™; 0.1 to 0.7 g L^{-1}, with a median particle size of 23 μm).

The absorbing agent (instant coffee), when in a comparable concentration, was found to produce a greater reduction in water transmission than the suspended material (Celite 503™). It therefore contributed to a greater reduction in the initial rate of disinfection. Neither agent was found to produce a systematic reduction in the observed efficacy of disinfection however. Experimental results highlight that in the absence of soluble absorbing agents, or suspended solids, the initial rate of disinfection is higher when fewer viable bacteria are initially present.

Both the new EDP_m and Weibull forms gave a good fit to the experimental data. The EDP_m better fitted the data on the basis of residual sum-of-squares (0.03 to 2.13 for EDP_m *cf.* 0.16 to 4.37 for the Weibull form). These models are both of a form suitable for practical use in modelling UV disinfection data.

Results of this research highlight the impact of water quality, as influenced by the combined effect of UV dose, suspended solids concentration and UV absorbance, on small-scale UV disinfection for potable water production. Importantly, results show that the concentration of soluble UV absorbing agents and suspended solids are not in themselves sufficient criteria on which to base assessment of efficacy of UV disinfection.

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TABLE OF CONTENTS