

**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 (nOP) 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 nOP , 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 ($> 40,000 \mu\text{Ws cm}^{-2}$). 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 ($<10,000 \mu\text{Ws cm}^{-2}$) to fill the gap in the experimental data of Nguyen (1999).

The experimental trials were carried out using a commercially available, UV disinfection unit (LC5TM 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 $\mu\text{Ws cm}^{-2}$) 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 RoastTM instant coffee powder; 0.001 to 0.07 g L⁻¹), or by addition of suspended matter as diatomaceous earth (Celite 503TM; 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 503TM). 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

SUMMARY	iii
ACKNOWLEDGMENTS	v
CHAPTER 1: INTRODUCTION	1
1.1 Research Aims	3
1.2 Outline of thesis	3
CHAPTER 2: LITERATURE REVIEW	5
2.1 Introduction	5
2.2 UV disinfection design principles	6
2.2.1 Sources of UV radiation	6
2.2.2 Mechanism of UV induced damage	8
2.2.3 Cell repair to UV damage	10
2.2.4 UV disinfection of potable water and wastewater effluent	11
2.3 UV disinfection in combination with oxidants	13
2.4 Inactivation of pathogens by UV irradiation	15
2.5 Effect of some process factors on the efficacy of UV disinfection	19
2.5.1 Suspended solids	21
2.5.2 Intensity profile	24
2.5.2.1 Point-source summation	25
2.5.2.2 Bioassay determination	27
2.5.2.3 Chemical actinometry	27
2.5.3 Residence time distribution (RTD)	28
2.6 UV disinfection unit design	29
2.7 Economics of UV disinfection	31
2.8 Review of the main kinetic models for UV disinfection	34
2.9 Summary and concluding remarks	39
CHAPTER 3: EVALUATION OF FOUR ESTABLISHED MODEL FORMS FOR UV DISINFECTION KINETICS	40
3.1 Introduction	40
3.2 Experimental data of Nguyen (1999)	41
3.3 The model of Nguyen (1999)	42
3.4 Four selected model forms	42
3.5 Criteria for fit of an adequate model	44
3.6 Fitting of model forms	45
3.7 Results	46
3.8 Concluding remarks	58

CHAPTER 4: SYNTHESIS OF TWO NEW MODELS FOR UV DISINFECTION KINETICS	60
4.1 Introduction	60
4.2 UV data of Nelson (2000)	61
4.3 Fitting of new model forms	61
4.4 Exponentially Damped Polynomial	63
4.4.1 Modified Exponentially Damped Polynomial	63
4.4.2 Results and analyses	64
4.4.3 Summary	74
4.5 Weibull model	75
4.5.1 Results and analyses	76
4.5.2 Summary	87
4.6 Discussion	88
4.7 Concluding remarks	93
CHAPTER 5: EXPERIMENTAL STUDIES	94
5.1 Introduction	94
5.2 Commercial LC5 TM disinfection pilot apparatus	94
5.3 Experimental loop	95
5.4 Test micro-organism	100
5.5 UV shielding and UV absorbing agents	100
5.6 Experimental methodology	101
5.6.1 Cultivation and harvesting of the test micro-organism	101
5.6.2 UV exposure of the test micro-organism	102
5.6.3 Enumeration of viable cells	103
5.6.4 UV transmittance measurement	104
5.6.5 pH and temperature measurement	104
5.6.6 Dye studies (Methylene Blue)	104
5.7 A typical experiment	105
5.8 Concluding remarks	106
CHAPTER 6: RESULTS AND DISCUSSION	107
6.1 Introduction	107
6.2 Experimental data	107
6.2.1 Effect of initial concentration of viable bacteria (N_0)	114
6.2.2 Effect of agent concentration on transmission	116
6.2.3 Influence of pH and temperature	118
6.2.4 Dye studies	120
6.2.5 Assessment of pre-exposure to UV on resulting disinfection efficacy ¹²³	123
6.3 Validation of two new models for UV disinfection	125
6.3.1 Modified Exponentially Damped Polynomial	125
6.3.2 Weibull model	165
6.3.3 A comparison of the synthesised model forms	188
6.4 Some comparisons with the data of Nguyen (1999)	197
6.5 Concluding remarks	200
6.6 Shortcomings	201

CHAPTER 7: CONCLUSIONS	202
RECOMMENDATIONS FOR FURTHER STUDY	204
APPENDICES	206
Appendix A A definition of some important terms used in this study	206
Appendix B Refereed publications from this research	209
Appendix C Particle size analysis	210
Appendix D Test for cumulative damage	211
Appendix E Reynolds' number calculation	218
Appendix F Calculation of UV dose	220
Appendix G Microbiological data	221
Appendix H UV disinfection data of Nelson (2000)	228
Appendix I UV disinfection data of Nguyen (1999)	230
Appendix J Development of the EDP _m model form	234
Appendix K Fits of the EDP _m model to the disinfection data of Nelson (2000)	236
Appendix L Fits of the Weibull model to the disinfection data of Nelson (2000)	240
Appendix M Fits of the EDP _m model to the experimental disinfection data	244
Appendix N Fits of the Weibull model to the experimental disinfection data	256
Appendix O Experimental disinfection data	268
NOTATION	276
REFERENCES	279