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Developing an advanced reactor model for complex, non-ideal reactors

Prepared by

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A thesis submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, in fulfilment of the requirements for the degree of Doctor of Philosophy.

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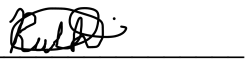
Declaration

I declare that this thesis is my own unaided work. It is being submitted for the degree of Doctor of Philosophy to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.



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Summary

Constructed wetlands are a low cost and low maintenance technology which can be used for treating wastewater of various types, and in a water scarce country, such as South Africa, have the potential to be used in a variety of contexts. However, to use this technology as an effective form of wastewater treatment, accurate modelling of both the kinetic and hydraulic behaviour is required. Work has been done to improve the kinetic modelling of constructed wetlands. Kinetic modelling techniques rely on reaction time, but reaction time is a function of the hydraulic behaviour of the system. If the reaction time is quantified incorrectly, a kinetic model will not produce accurate results, regardless of how detailed and comprehensive it may be. It cannot be said that reaction time relies only on the hydraulic behaviour of the system and the importance of mixing and local concentration must not be forgotten.Accordingly, this study investigated the development and use of two novel hydraulic modelling techniques for use in quantifying the flow behaviour of constructed wetlands. The aim was to combine the residence time distribution techniques with an existing biokinetic model. In this study, two techniques were developed which were based on limitations found in existing techniques, and hydraulic tracer studies were conducted to assess the applicability of the techniques for use in constructed wetlands.

The first technique was based on the method-of-moments technique, used in chemical engineering for reactor design, and in this technique, it was assumed that the flow through a system could be divided into sections. By determining the hydraulic parameters of each of the sections, the hydraulic behaviour could be investigated in more detail and the data obtained from the study could be used with an existing biokinetic model. Impulse-response tracer tests were conducted on two systems, vertical flow columns and a horizontal sub-surface flow constructed wetland. It was found that the data from these studies could be used in investigating the hydraulic behaviour of the system and could be combined with first-order rate kinetics.

The second technique aimed to address the environmental impact of tracer studies on water bodies. Tracer studies require the use of a conservative tracer, but the conservative nature of the tracer means that it persists in the environment long after the studies are complete. In this study the use of a non-conservative tracer was investigated. Step-change tracer studies were conducted on a horizontal sub-surface flow constructed wetland using a conservative tracer (uranine) and a non-conservative tracer (benzoate). The response curves of the two tracers were compared and the advective-dispersive solute transport equation, along with a non-linear least-

squares analysis, was used to determine the hydrodynamic dispersion, retardation factor and decay of each tracer. These transport parameters were used to determine if it was possible to relate the non-conservative tracer response curve with the conservative tracer response curve in such a way that the hydraulic parameters, which quantify flow behaviour, were the same. This technique was found to be most accurate for mean residence time.