AN INVESTIGATION INTO MATHEMATICAL MODELLING OF INTEGRATED BIOSYSTEMS FOR OPERATIONAL CONTROL AND MANAGEMENT

By

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ABSTRACT

The South Australian Research & Development Institute (SARDI) and the Environmental Biotechnology Cooperative Research Centre (EBCRC) undertook a project *"Commercial Scale Integrated Biosystems for Organic Waste and Wastewater Treatment for the Livestock and Food Processing Industries"*, for which this research forms a part. The Integrated Biosystems (IBS) project laboratory was set up at the Roseworthy campus of The University of Adelaide, South Australia. The major objective of this project was to develop an Integrated Biosystems (IBS) on a commercial scale for the treatment of wastewater by applying the stages of anaerobic digestion and bioconversion stages involving algae, zooplankton and fish. The IBS developed could be used in both rural and urban settings for efficient waste disposal and generation of energy in the process. The overall aim of this research was to develop a mathematical model of an IBS for operational control and management.

The objectives of this research were to:

1. Develop a mathematical model for the anaerobic digestion system.
2. Use an existing model to simulate the aquaculture stages of the IBS and to test its suitability for a commercial scale IBS for effective control and management.
3. Conduct a sensitivity analysis on the parameters of the aquaculture model.
4. Develop an automatic calibration program to validate the aquaculture model with real time field data.

The major contribution from this research was to elucidate the key parameters required to simulate the integrated IBS model. The data was collected through a series of rigorous experimentation for both the anaerobic digestion and aquaculture modules of the IBS. The data obtained was used to parameterise a coupled anaerobic digestion-hydrodynamic ecological

model. The resulting model adequately simulated key processes within the IBS, which was further improved with a novel auto calibration algorithm.

The primary contribution of this work has been to develop an automatic parameter calibration for the aquaculture component of the model. Parameter calibration in aquaculture models has been time consuming as it is basically a "trial and error" procedure. This thesis presents a significant contribution in this area.

A literature review conducted on the models developed for the IBS and automatic calibration revealed certain gaps in the previous research conducted, which formed a basis for further work in this PhD study. A significant proportion of research time was invested in set up, installation and commissioning of the pilot plant two-stage anaerobic digestion system and the Integrated Aquaculture (mesocosm) facility. This was done to understand the mechanism of the IBS. Both the systems were run for a period of 12 months for data collection. During this time, operational glitches and troubleshooting provided the researcher an opportunity to implement engineering skills in the IBS context and understand the behaviour of this complex system. Batch scale experiments were conducted in the laboratory for data collection to develop a model for the anaerobic digestion system using microbial kinetics. The aquaculture model DYRESM CAEDYM was used to simulate the aquaculture stages of the IBS. The model source code was altered to run the model for the IBS set up. Real time field data could not be obtained as the commercial scale IBS was not constructed due to administrative hurdles which were beyond the researcher's control. A sensitivity analysis was conducted on selected parameters of the model to determine the behaviour of model outputs on controlled changes to those parameters. Finally an automatic model calibration and validation program was written in FORTRAN 90 to automatically validate the model with field data as opposed to the conventional methods of manual parameter validation. Pseudo field data was used for demonstration purposes.

The primary contributions from this research have been to assess the suitability of DYRESM CAEDYM as the modelling software for the commercial scale IBS, run a sensitivity analysis on selected parameters of the model and execute an automatic model calibration and validation program.

The phytoplankton ponds had a domination of cyanobacteria growth for the maximum part of the year, due to thermal stratification in the summer months, which otherwise would not happen in an IBS with proper control and management. There was negligible zooplankton and fish growth due to diminished chlorophyte concentrations.

Results from similar IBS studies in India and France were used to compare results with the proposed commercial IBS. The comparative IBS examples sourced from sites in India and France show that IBS has been successfully implemented in different parts of the world comprising tools for better control and management of ponds. The use of mixing (agitation) and aeration assist in mixing the ponds and the effluent uniformly which minimises stratification in ponds and thus reduces the growth of cyanobacteria, and in turn improves the growth of phytoplankton, zooplankton and fish. The model DYRESM CAEDYM could incorporate the use of mixers and aeration in the IBS ponds to overcome the problems of algal crashes in summer.

The sensitivity analysis conducted on the parameters of the model show that the model results for phytoplankton growth is highly sensitive to those parameters that directly affect the growth rates e.g. maximum phytoplankton growth rate, phytoplankton respiration coefficient and phytoplankton temperature multiplier. The automated calibration routine incorporated a novel methodology to calibrate and validate DYRESM CAEDYM automatically without having to manually adjust parameters. This procedure is a significant improvement over the conventional methodology of validating the model by “trial and error” which was time consuming and to a certain extent inaccurate. The simulations ran successfully to validate the model parameters with the pseudo field data. This calibration program could

be also used to validate other outputs from the model and is a significant contribution in this research.

The parameters which can be controlled for managing the commercial scale IBS in an effective way would be parameters related to inflow and outflow volumes and flow rates of effluent, retention time of the effluent, nutrient loads, rates of mixing and aeration within the ponds and control of biomass conversion for primary, secondary and tertiary productions. These management strategies could also be used to operate an IBS with a variety of different effluents to its maximum capacity and construct an IBS with better module design.

The use of automated calibration of parameters has high applicability in the development of mathematical models for managing the performance of wastewater recycling technology, which is in high demand in the modern world in order to reduce the dependence on limited water resources. The calibration routine developed in this PhD study has demonstrated that for a complex aquaculture model like DYRESM CAEDYM where manually validating the parameters is a tedious task, automatic calibration routine using GLUE methodology is an effective way to validate the model which minimises the risks of computational errors.

STATEMENT OF ORIGINALITY

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

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KHALID SHAMIM

Dated: ……

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