Chapter 8

Conclusions and recommendations for further work

8.1 Conclusions

Based on the numerical results of the CFD model and the experimental data from the operation of the three pilot-scale primary facultative ponds, the following conclusions can be drawn:

1. The source term functions that represent the *E. coli* removal, BOD_5 removal and the residence time distribution have been developed into a form consistent with a source term for the scalar transport equation in CFD using dimensional analysis to ensure correct dimensions and units. Numerical tests have demonstrated that the source term functions have been developed correctly and can be confidently used in simulating *E. coli* and BOD_5 removals and also the spatial residence time distribution in the CFD model of waste stabilization ponds with more complex flow patterns and operational conditions.

2. The numerical tests of CFD models have explicitly demonstrated the capacity of CFD to assess the effects of baffles on the treatment efficiency and hydraulic performance of waste stabilization ponds. The CFD model results have showed that the treatment performance of waste stabilization ponds could be improved significantly by installing 70% pond-width baffles along the longitudinal axis of the pond at a uniform separation distance.

3. The treatment performance of waste stabilization ponds with the 70% pond-width baffles could diminish in situations where the width of flow channel in baffle compartments is less than 30% of the baffle-opening. This condition initiates significant hydraulic short-circuiting due to the channelling flow pattern that links directly the inlet and outlet of the pond. This was shown clearly by the numerical results of the ten-baffle pond model with 70% pond-width baffles whose removal of *E. coli* was almost as poor as that of the two-baffle pond model.

4. The effective baffle length that could achieve maximum removal of *E. coli* in waste stabilization ponds is one that forms uniform width-flow channel in baffle compartments and at baffle openings. This baffle configuration creates a strong plug flow pattern. The numerical results of the ten-baffle pond model with 81.8% pond width baffles gave the lowest *E. coli* numbers of less than 0.001 per 100 ml among the conventional baffle configurations that were tested.

5. When short-baffles (10%, 15%, 20%, 25% and 30% pond-width) were fitted near the inlet and outlet, the 10% pond-width baffle is the most effective in improving the *E. coli* removal in waste stabilization pond model. The predicted effluent count (2.10×10^4 *E. coli* per 100 ml) was equivalent to that of the two-baffle pond model with 70% pond-width baffles. The short baffles can compete with conventional baffles when targeting a 3 - 4 log-unit removal of *E. coli*.

6. The CFD-based design of waste stabilization ponds shows that wind effects could affect the performance of waste stabilization ponds with large surface areas (˜ 20 ha). When the wind blows in the direction of the wastewater flow in the pond, the treatment performance of waste stabilization pond could be reduced due to the initiation of the hydraulic short-circuiting. However, the wind blowing against the direction of the wastewater flow could improve the treatment performance of waste stabilization ponds. The effects of waves on the pond surface were not simulated in the CFD model. However, the shear stress due to the wind velocity that was applied at the top surface of the pond model, could give a simple assessment of the induced waves.

7. Baffles can play a significant role in reducing the hydraulic short-circuiting associated with wind effects. The CFD model results of a 1-day anaerobic pond followed by a 4-day four-baffled facultative pond when incorporated with wind speed that blows against the wastewater flow in the pond could satisfy the requirements for unrestricted crop irrigation. Although such a pond series may appear ‘risky’ compared with conventional waste stabilization pond series (usually comprising at least three ponds) in satisfying these requirements for unrestricted irrigation, the excellent performance of the four-baffle pilot-scale primary facultative pond indicates

that this innovative pond series is able to minimize the land area requirements of waste stabilization ponds.

8. Thermo-stratification effects could be incorporated in the CFD model of waste stabilization by developing an empirical equation of the wastewater density function that depends on the temperature of the wastewater layers in the pond. Different wastewater densities along the pond depth could enable the precise prediction of the hydraulic flow pattern in the pond. In addition, the input design parameter of temperature profile in CFD could enable the accurate prediction of the first-order rate constants for the removal of *E. coli* and BOD for the individual wastewater layers in waste stabilization ponds that are thermally stratified.

9. The experimental data of the treatment performance of the four-baffle pilot-scale primary facultative pond, the two-baffle pilot-scale primary facultative pond and the unbaffled pilot-scale primary facultative pond confirm the CFD model results that the treatment performance of waste stabilization ponds is improved by installing the 70% pond-width baffles in the pond. The treatment performance of the baffled pilot-scale ponds at both 50% cumulative percentile and 95% cumulative percentile was generally higher than that of the unbaffled pilot-scale pond in removing *E. coli*, BOD_5, total nitrogen and ammonia.

10. Facultative conditions developed in the two-baffle pilot-scale pond and four-baffle pilot-scale pond during the operation of the pond covering both winter and summer seasons. The concentration of the dissolved oxygen and pH in the baffled pilot-scale ponds compared well with those of the unbaffled pilot-scale pond. The experimental data showed that BOD overloading was not created in the baffled pilot-scale ponds at a BOD loading of 80 kg per ha per day as recommended by Mara (1987). Designers and plant operators can indeed use confidently Mara’s (1987) equation to determine the optimum BOD loading when designing baffled primary facultative ponds.

11. Thermo-stratification and isothermal conditions developed in the pilot-scale primary facultative pond during summer and winter seasons respectively. The

experimental data showed that there was insignificant difference of the treatment performance of the pilot-scale primary facultative ponds when isothermal and thermo-stratification conditions developed in the pond. The variation of the wastewater density during thermo-stratification condition was small, so much so that the wastewater layers were not prevented from mixing. It appears that the use of the long retention time (30 days) reduced the hydraulic short-circuiting associated with thermo-stratification effects.

12. The experimental data of the tracer experiment showed that there was an improvement in the hydraulic performance of the baffled pilot-scale ponds compared to that of the unbaffled pilot-scale pond. Although the increase of the average hydraulic retention time in the four-baffle pilot-scale pond and two-baffle pilot-scale pond was marginally higher than that of the unbaffled pilot-scale pond, the results of the hydraulic performance indicate that the hydraulic short-circuiting was reduced when the 70% pond-width baffles were installed in the pilot-scale pond. The CFD simulation of the tracer experiment agreed satisfactorily with the tracer experiment despite the unsteady state influent flow, temperature difference and wind velocities that were observed in the pilot-scale pond but were not included in the CFD.

13. The precise simulations of *E. coli* and BOD_5 removals in the CFD model of the pilot-scale pond showed that CFD is satisfactory in predicting the treatment performance of unbaffled and baffled waste stabilization ponds. The significance of these CFD model results is that regulators and designers can use CFD confidently both as a reactor model and as a hydraulic tool to assessing realistically the treatment efficiency of waste stabilization ponds that are fitted with baffles of various configurations.

8.2 Recommendations for further work

In light of the experimental data from the three pilot-scale ponds and the numerical results of the CFD modelling, further work is needed as follows:

1. Shorter hydraulic retention times in the range of 10- 20 days should be employed to investigate the effects of thermo-stratification and the 70% pond-width baffles on the treatment efficiency and hydraulic performance of the studied pilot-scale ponds.

2. Investigation of BOD overloading in secondary facultative ponds with 6-8 baffles of length 70% pond-width should be carried out to determine the number of baffles that could be installed in a secondary facultative pond.

3. The numerical results of the CFD model of the ten-baffle pond with 70- 82% pond-width baffles show that the high performance of baffled waste stabilization ponds is not *always* the case as previously reported if the design of baffle configuration is unsatisfactory. The investigation should test the removal of pollutants in waste stabilization ponds with constant width of flow channel in baffle compartments and at baffle openings. The research should also investigate the performance of baffled waste stabilization ponds with width of flow channel in baffle compartments that is less than that of the baffle opening. These tests should be carried out in maturation ponds as the risk of BOD overloading is unlikely to occur.

4. The effects of wind speed and its prevailing direction should be investigated to assess the treatment efficiency of full-scale waste stabilization ponds with emphasis on the geometric design of the pond, positions of inlet and outlet structures, BOD loading, the amount of sludge in the pond as most publications do not indicate these parameters when reporting the effects of wind on pond performance. CFD modelling with simulated wind effects should be carried out to predict the performance of such full-scale waste stabilization ponds.

5. CFD models of nutrients removal in waste stabilization ponds should be investigated out to assess the removal of the total nitrogen and ammonia in waste stabilization ponds. The sub-models should take into account various processes such as sedimentation, vaporisation, denitrification, algae uptake etc that are responsible for the removal of these nutrients in waste stabilization ponds.

6. A series of baffled primary facultative pond (with 2- 4 baffles) and baffled maturation pond(s) (2- 4 baffles) should be investigated to assess the pond effluent quality in satisfying the requirement of the unrestricted crop irrigation. CFD modelling should be carried out to predict the treatment performance of such waste stabilization ponds series as this could provide useful data regarding the design of efficient baffled waste stabilization ponds.