**Advanced Dynamic Modelling of Wastewater Treatment Ponds**

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The public sanitation in Ecuador and Latin America still demands vast investments in research and development projects. More than 90% of the domestic discharges in Ecuador do not receive any treatment. The city of Cuenca (450,000 inhabitants) contributes with more than a half of the total wastewater treatment of the country. The waste stabilization pond (WSP) technology appears as a very convenient solution in tropical developing countries due to the high efficiency at low investment, operational and maintenance cost. Nevertheless, there is still room to improve the efficiency of these systems in terms of effluent quality and energy requirements.

In WSP systems, the use of mathematical models shows increasing popularity for the design of new systems and for improving the understanding of the complex biokinetic processes occurring inside. However, the complex bioprocesses and hydrodynamics of the WSPs make these systems very difficult to translate into accurate mathematical models. The use of Computational Fluid Dynamics (CFD) in WSPs is nowadays feasible. However, the computational load of these models is very high, especially for full scale systems that are large in nature. The incorporation of biokinetic models into the CFD codes is even more demanding and would be too slow to reach useful results for improved operation in a reasonable time frame. On the other hand, the poor modelling of hydrodynamics in simple models (e.g. by using tanks-in-series) is currently not done properly.

This thesis presents a hydrodynamic study of the full scale Ucubamba WSP system in Cuenca, Ecuador which consists of 3 different pond stages: aerated, facultative and maturation ponds. Each pond was modelled in CFD considering different challenges such as external momentum source by mechanical aerators, sludge deposition, severe short circuiting, etc. Based on CFD results, a methodology to create compartmental models is presented and the application of the concept is done in maturation pond which was modelled coupling a biokinetic model into the compartments.

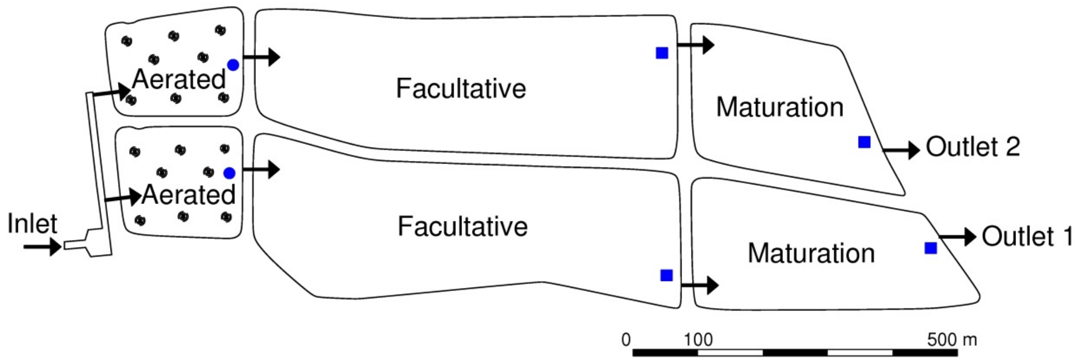


Fig.1 Ucubamba Waste Stabilization Pond System, Cuenca, Ecuador.

Initially, different 3D CFD models (one phase and multiphase) of a 3 ha Facultative Aerated Lagoon (FAL) were built. The thrust produced by the aerators was modelled by an external momentum source applied as velocity vectors into the pond fluid. The results of a single phase model were satisfactorily validated against experimental velocities and a residence time distribution RTD curve gathered from a tracer study. Subsequently, a scenario analysis assessing several aeration schemes with different numbers of aerators in operation were tested with respect to velocity profiles and residence time distribution (RTD) curves. This analysis showed that the aeration scheme with all 10 aerators switched on produces a similar hydraulic behaviour compared to using only 6 or 8 aerators. The current operational schemes comprises of switching off some aerators during the peak hours of the day and operating all 10 aerators during night. This current practice could be replaced by continuously operating 4 or 6 aerators without significantly affecting the overall mixing and saving significant costs. Furthermore, a continuous mixing regime minimises the sediment oxygen demand enhancing the oxygen levels.

The sludge deposition in the WSP system was studied in the Facultative ponds. Sludge accumulation patterns in WSPs are strongly influenced by the pond hydrodynamics. CFD modelling was applied to study the relation between velocity profiles and sludge deposition during 10 years of operation of the WSP system. One tracer experiment was performed and three sludge accumulation scenarios based on bathymetric surveys were simulated. A Residence Time Distribution (RTD) analysis illustrated the decrease of residence times due to sludge deposition. Sludge accumulation rates were calculated. The influence of flow pattern on the sludge deposition was studied, enabling better planning of future pond operation and desludging.

However, a further validation of the CFD model strategy is still needed. A more sophisticated model that accounts to sludge particles transport should be considered. The incorporation of dynamic wind profiles into the CFD model boundaries is highly recommended.

The advancement of experimental and computational resources has facilitated the use of computational fluid dynamics (CFD) models as a predictive tool for mixing behaviour in full-scale waste stabilization pond systems. However, in view of combining hydraulic behaviour with a biokinetic process model, the computational load is still too high for practical use. Based on a validated CFD model with tracer experiments, a compartmental model (CM) was development to a simpler description of the hydraulics of the full-scale maturation pond (7 ha). 3D CFD models were validated with experimental data from pulse tracer experiments, showing a sufficient agreement. Based on the CFD model results, a number of compartments were selected considering the turbulence characteristics of the flow, the residence time distribution (RTD) curves and the dominant velocity component at different pond locations. The arrangement of compartments based on the introduction of recirculation flow rate between adjacent compartments, which in turn is dependent on the turbulence diffusion coefficient, is illustrated. Simulated RTDs from a systemic tanks-in-series (TIS) model and the developed CM were compared. The TIS was unable to capture the measured RTD, whereas the CM predicted convincingly the peaks and lags of the tracer experiment using only a minimal fraction of the computational demand of the CFD model. Finally, a biokinetic model was coupled to both approaches demonstrating the impact an insufficient hydraulic model can have on the outcome of a modelling exercise. TIS and CM showed drastic differences in the output loads implying that the CM approach is to be used when modelling the biological performance of the full-scale system.

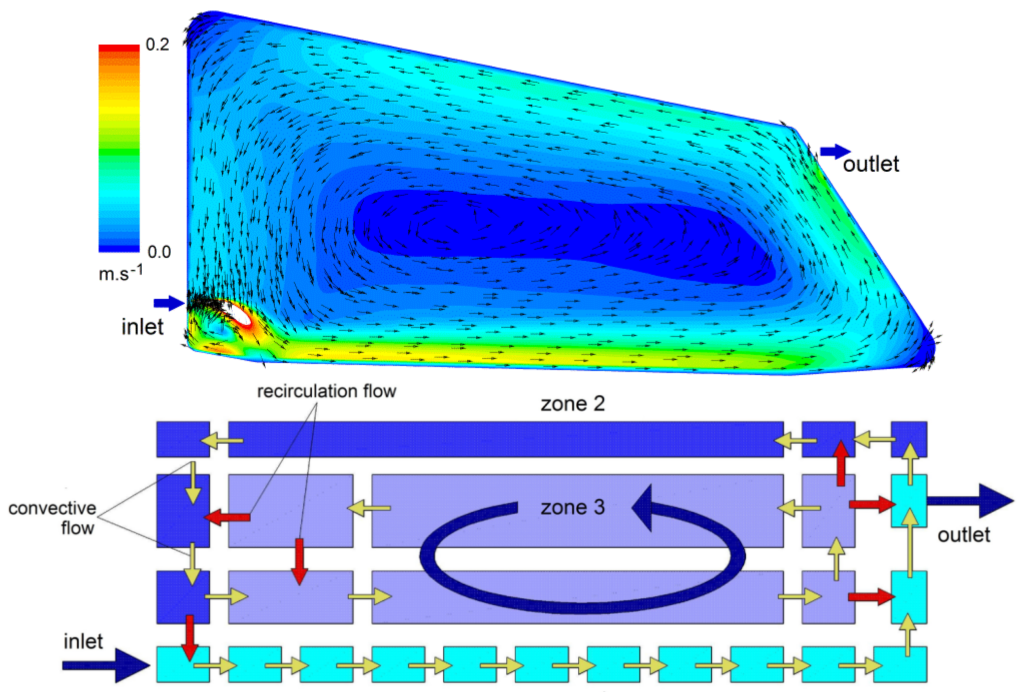


Fig.2 CFD velocity contours and compartemental model configuration

Finally, a coupled hydrodynamic-biokinetic models is presented. The ALEX model (Alex et al., 2009) and the SAH model (Sah et al., 2010) were integrated into two combined rigorous hydraulic-biokinetic models of the full scale maturation pond 1. The compartmental model (CM) approach for modelling the pond's hydrodynamics is used as platform to incorporate the two different full biokinetic models. Dynamic influent profiles were created using data gathered at the Ucubamba WSP. Both models were assessed in terms of total COD, COD fractions and biomass outputs, showing similarities in the effluent COD. However, the biomass concentrations were predicted dissimilar in both biokinetic models, suggesting that default parameters or processes included in the model need reconsideration. The behaviour of the models was compared against a simple tank-in-series model (TIS). The TIS model was not able to capture the hydrodynamics of the system compared to the CM which performed better.

The main conclusions of the work, i.e. the compartmental model methodology for modelling the hydraulics in large pond systems, the CFD applications to different pond stages, etc. are listed together to further research perspectives in this field. It is proposed among others, new rigorous CFD models to validate the approaches used in this study and to assess different baffling scenarios to improve the hydraulics in facultative and maturation ponds; a proper assessment of the oxygen levels and the characterization of the biomass in aerated ponds; a further effort in build-up influent data which account to the daily variability observed in the phototrophic biomass activity and finally a development of new biokinetic models which properly account for the carbonaceous system and the nitrogen-related processes in algae biomass systems.