Predicting the effect of mixing on oxygen transfer and nutrient removal in Activated Sludge Basins

Gregory Cartland Glover, Stephanie Vermande, Karim Essemiani** and Jens Meinhold*
Anjou Recherche – Veolia Water, France
**Veolia Water Technical Division, France*
***Corresponding Author Tel 00 33 1 34 93 31 55 Karim.essemiani@groupve.com*

Activated sludge basins (ASBs) are a key-step in the biological treatment of municipal wastewater. These processes are used to degrade biochemically reactive pollutants from water that is discharged to the natural environment. The bacteria found in the activated sludge consume and assimilate nutrients such as carbon, nitrogen and phosphorous under several environmental conditions. However, the design of ASBs is difficult due to many factors that include:

- the treatment aims (what pollutants need to be degraded),
- the influent wastewater composition (time and location dependent),
- the application of liquid agitation and aeration (brushes, disks, membrane aerators, impellers, turbines and venturi tube mixers),
- location and spatial requirements, (local weather, above or below ground, sparsely or densely populated regions),
- The daily treatment loading (few hundred litres to thousands of cubic metres).

Each one of these factors has an influence on the size, the form and the mode of operation (continuous or sequenced batch treatment) that is used in selecting and designing an ASB. The variation in some of the factors listed above can have a significant impact on the efficacy of the treatment process (i.e. diurnal or daily changes in the influent composition and flow rate, and the temperature can change the environmental conditions observed). Therefore, for the design of any ASB, the application of the appropriate agitation and aeration conditions is essential to provide optimal environmental conditions for the treatment of wastewater.

Therefore, a study that was co-funded by Anjou Recherche, the R&D arm of Veolia Water and the European Union was performed to develop a computational strategy for the modelling of ASBs. The particular interest of the study was to examination of the effect of the local hydrodynamics on the biochemical reactions observed in ASBs for both pilot and real scale processes. This therefore enabled us to gain further understanding of the hydrodynamic impact on the environmental conditions experienced by the bacteria.

A pilot-scale ASB (ps-ASB) was used to establish a database of hydrodynamic (circulation velocity and mean bubble sizes) and interphase mass transfer data under different operating conditions. The ps-ASB was then used to study the impact of the normal and abnormal operating conditions on the biochemical reaction phenomena by monitoring the change in concentration of key wastewater constituents (i.e. ammonia, organic carbon, nitrates, organic nitrogen and particulate matter).

The ps-ASB applied different environment conditions to the water being treated in a programmed sequence. The different conditions were affected by contacting the “mixed liquor” with air in the form of fine bubbles and applying a circulation velocity through the use of a marine type impeller. This condition enabled the aerobic oxidation of carbon to carbon dioxide and nitrogen in the form of ammonia to form nitrates. Therefore, a second condition was used to agitate the biomass in the mixed liquor to reduce the nitrogen content of the wastewater. Under these conditions a different type of biomass (anoxic bacteria) consumes the nitrate to reduce to nitrogen, which then evolves as a gas.

The operational data that was obtained (data points in Figure 1) was then used to create a hydrodynamic and biochemical reaction model of the ps-ASB. The first step was to model the biochemical reactions with the assumption of a perfectly mixed reactor by using the wastewater modelling tool, WEST® using the ASM1 protocol (Activated Sludge Model no. 1).

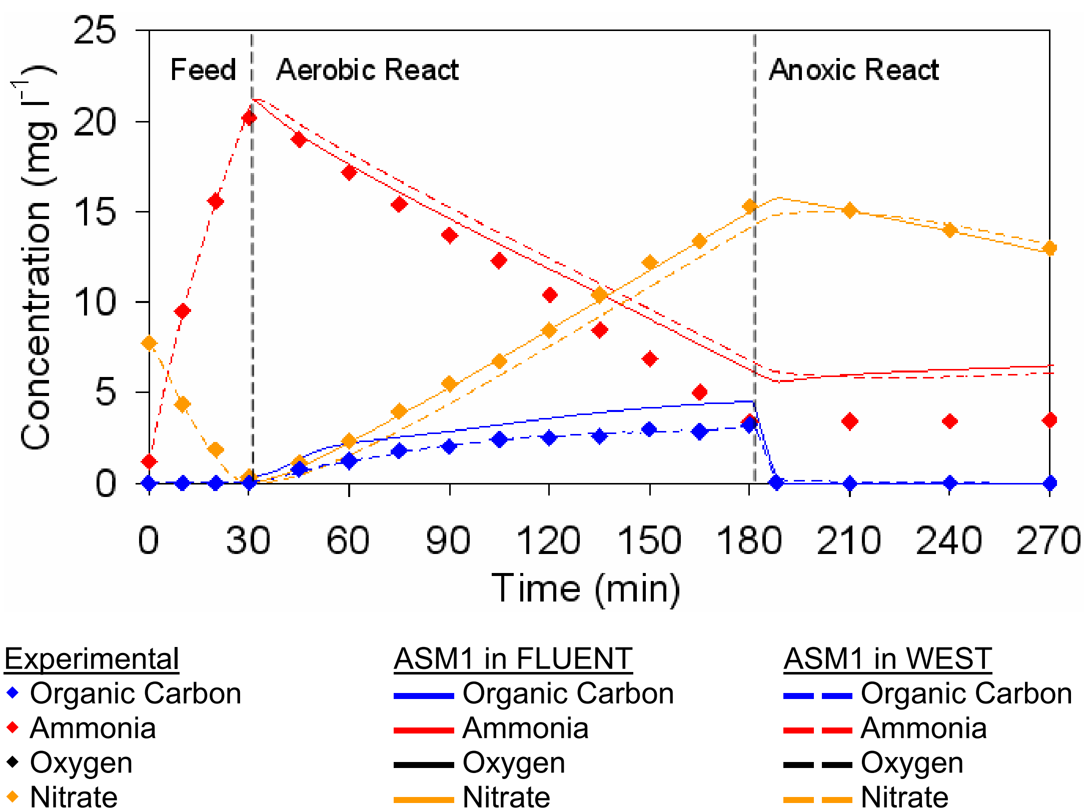
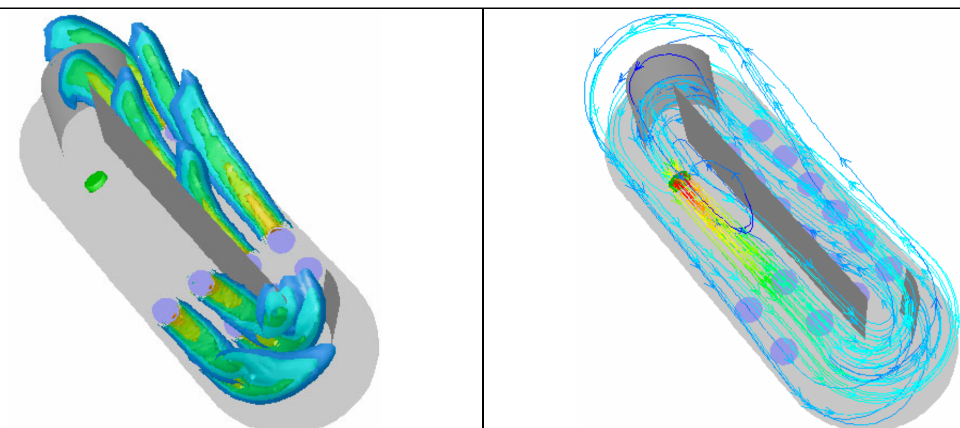


Figure 1. Profile plots of the reaction phenomena that occurred in the ps-ASB.

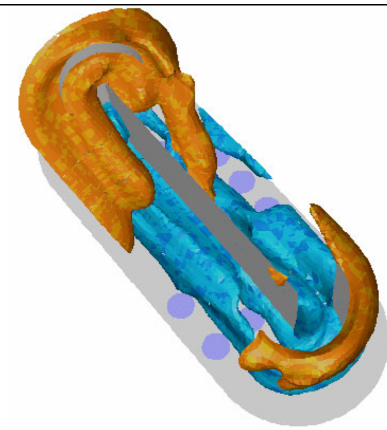
The mixed liquor composition, the calibrated kinetic and stoichiometric parameters derived (dashed lines in Figure 1) from this global model were then applied to a converged local hydrodynamic solution constructed in FLUENT. The Eulerian Multiphase model was employed with the dispersed phase the k-ε turbulence model to resolve the gas-liquid motion under steady flow conditions.

The application of the ASM1 protocol to FLUENT was validated through the analysis of the profiles obtained during the aerobic and anoxic react phases (thick lines in Figure 1). The rates under the different operating conditions were accurate to within 10 % of the experimentally measured reaction rates, where the accepted error was 10 to 15 %.

Figure 2 depicts the hydrodynamics (liquid velocity pathlines and volume fraction contours) of ps-ASB along with the distribution of dissolved oxygen after one hour of aeration. The difference between the cold and warm iso-surfaces is 0.4 mg l^{-1} over the range 2.9 to 3.4 mg^{-1}. Therefore, at this point the oxygen concentration gradient does not influence which biochemical reaction processes are predominant at this point in simulation. However, if a mean concentration of less than 0.5 mg l^{-1} had been observed different treatment regimes would be found in the reactor (i.e. informal aerobic and anoxic zones).



Gas fraction iso-surfaces	Path lines of liquid velocity



Iso-surfaces of high and low oxygen concentration

Figure 2 Hydrodynamic phenomena in ps-ASB

The aeration and agitation regimes applied to the ps-ASB in this study were considered to be perfectly mixed and are at a comparatively small scale for treatment processes. Thus, the effects observed with ps-ASB may be different from those of real scale Activated Sludge Basins (rs-ASBs) where volumes of up to 10000 m^3 are widely used. Therefore, the potential of the influence of the mixing regimes is much greater as perfectly mixed reactor or plug flow regimes are not guaranteed and is difficult to categorise. Thus, the incorrect operating conditions originating from the design specifications could apply mixing regimes that can hinder the process in meeting its treatment objectives.

For example two rs-ASBs with different geometries and hydrodynamic regimes were simulated (Figure 3). rs1-ASB is a carrousel type ASB, whereas rs2-ASB is a race-track type ASB. The information derived from these simulations (circulation velocity and oxygen mass transfer characteristics) indicated how well each ASB could meet its objectives.

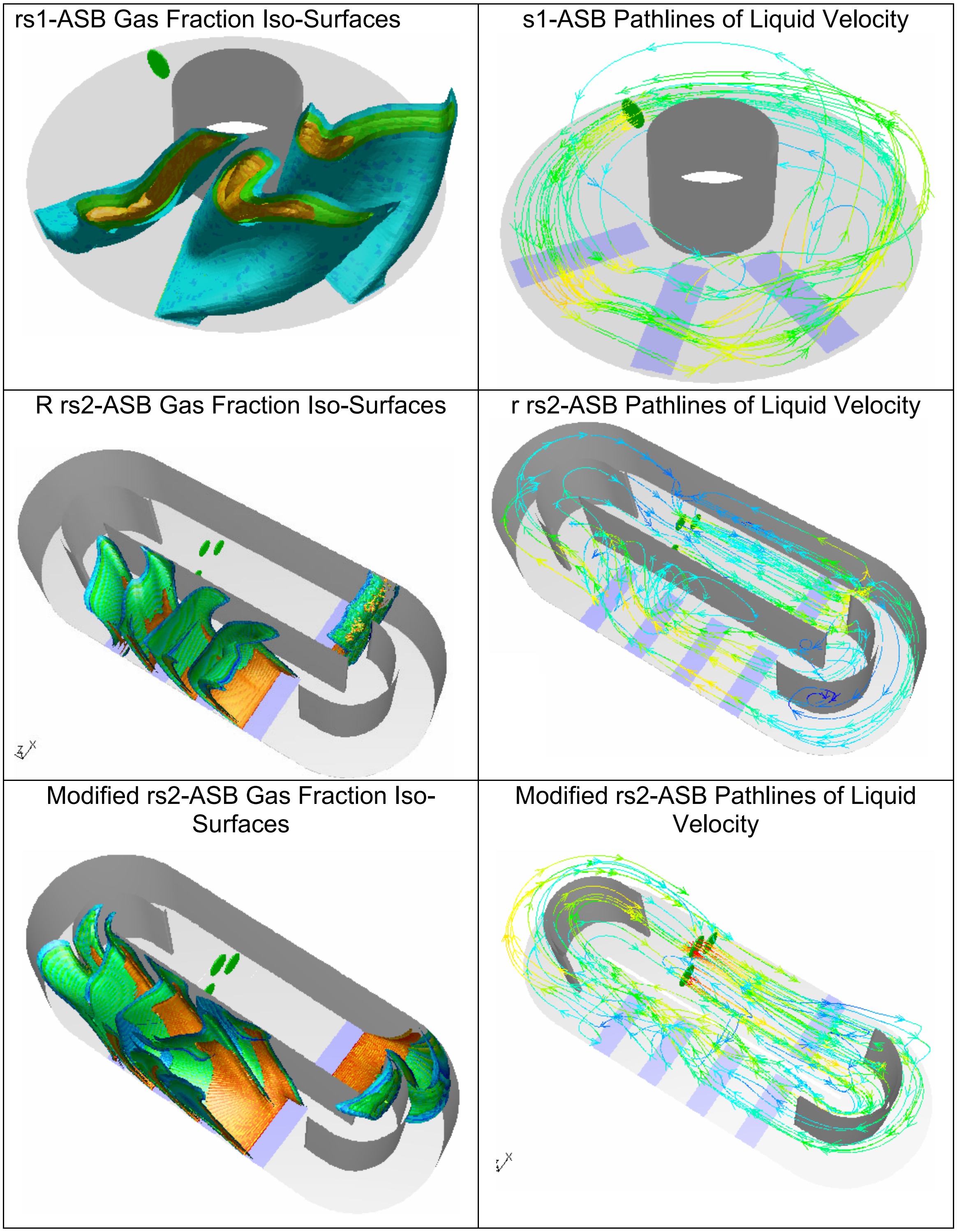


Figure 3. Hydrodynamic studies of rs1-ASB and rs2-ASB

The simulation of rs2-ASB implies that the process was not operating under optimal conditions with low horizontal liquid velocities and large recirculations or short-circuits upstream of the bubble plumes. Examining Figure 3 it is possible to see that the poor circulation velocity was caused by the disruption of the liquid circulation by the bubble plumes. Poor liquid circulation reduces the oxygen mass transfer rates and the dispersion of oxygen about the ASB. Therefore, the ability of the biomass in the basin to aerobically treat the wastewater could be limited by the operating conditions applied for the case of rs2-ASB.

Further simulations were performed to improve the aeration strategy by analysing the effect that different aerator and agitator configurations had on these two design parameters. The different configurations examined the position of the aerators and the agitators plus the agitation rate and size of the impellers to improve the mass transfer characteristics of rs2-ASB. The hydrodynamics of the modified rs2-ASB (Figure 3) show improved liquid circulation with less disruption of the flow by the bubble plumes that resulted in a 250 % increase of the circulation velocity.

Thus, the computational strategies developed during the course of this study have enabled Anjou Recherche and Veolia Water to obtain a numerical tool that can aide decisions made in selecting aeration and agitation configurations Activated Sludge Basins. Further studies are currently being performed that examine the response of the biochemical reaction models to the different operating conditions applied to rs2-ASB.

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