In the **Works**

Using simulation to model wastewater treatment plants effectively.

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In response to various European environmental legislative drivers — which include urban wastewater treatment, fresh-water quality standards for protection of fish and water framework directives — U.K. water companies have embarked on a new asset management plan. Part of this plan requires the treatment of significantly greater amounts of wastewater, either by building new treatment plants or by increasing flows through existing plants or works. At the same time, many sites face additional tighter constraints for effluent discharge. The majority of wastewater is treated in modern, large-capacity activated sludge process (ASP) plants. Water companies have been making increased use of analytical process modeling tools, such as computational fluid dynamics (CFD), to find capital cost savings, achieve performance improvements and improve energy savings for these plants.

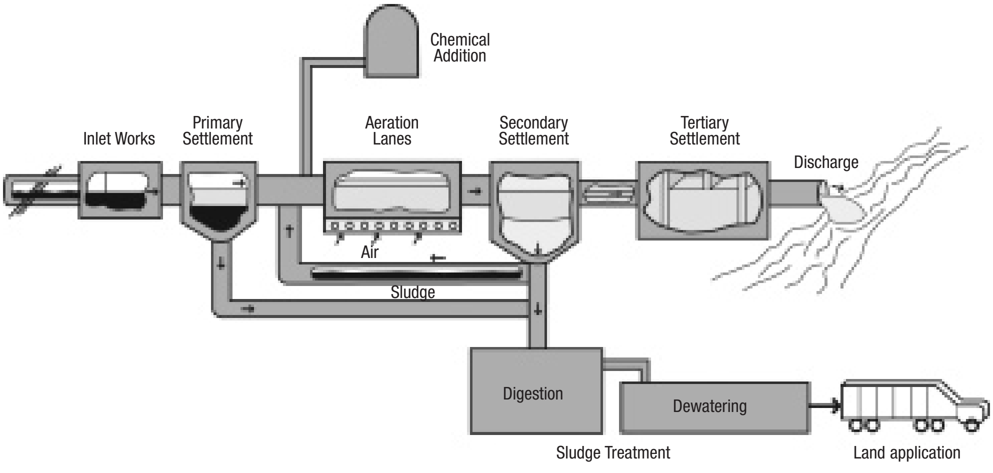
A modern wastewater ASP includes several operational stages that may be modeled with CFD. However, using CFD to investigate these unit operations successfully requires some process knowledge. This article illustrates a few of the processes and explains how they are best addressed with ANSYS CFX software and multiphase modeling techniques.

The basic sequence of operations at a wastewater treatment site with an ASP plant includes the following stages:

- Inlet works with de-gritting and flow balancing
- Primary settlement
- Activated sludge treatment in aeration lanes
- Secondary settlement
- Tertiary treatment

Inlet Works

In most U.K. works, the wastewater enters from an upstream combined sewer system. This wastewater is a mixture of rain water and sewage loaded with solid particles of irregular size, shape and density. A large inlet works removes gross solids and delivers equal flows and loads to the multiple lanes of an ASP; otherwise, the lanes may



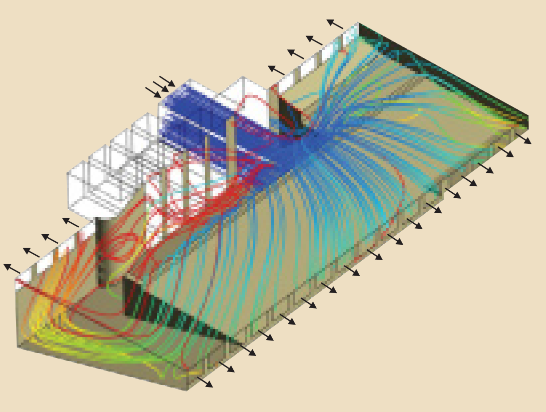
become overloaded or underloaded, and, subsequently, they will not work as well. CFD modeling of the inlet works can be used to determine the equality (or inequality) of the flow distribution among the lanes, as well as the trajectory and final resting place of solids that move independently of the bulk fluid. For example, a discrete particle tracking model may be used to determine the solids retention efficiency of grit traps and balancing tanks, whereas a continuum multiphase model may better show how solids move independently of the water down the different lanes of a distribution chamber.

Primary Settlement

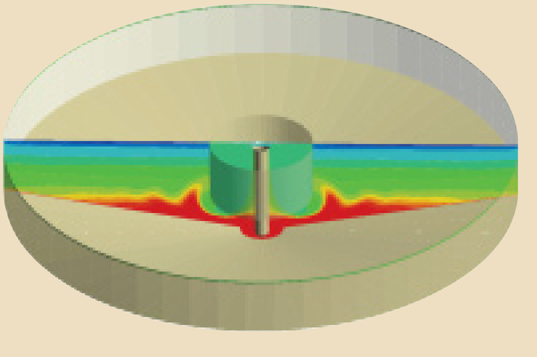
After removal of the larger solids in the inlet works, the wastewater passes into a primary separation zone. The primary tanks are often circular with a central influent, or riser pipe, at the center of the tank. Separation of solids occurs by settlement. The ability to retain solids depends on the balance between the radial up-flow velocity in the tank and the solids' settling velocity. In order to model settlement in a primary tank with CFD, a multiple drift flux model is used in which the influent solids particle size distribution is defined as a series of size groups (mass fractions). Each size group has a drift settling velocity pre-calculated from knowledge of the wet solids density. The total solids concentration thus is determined from the sum of the size groups progressing through the tank. This multiple drift flux modeling technique has been used to determine the optimum number of primary tanks and their required side wall depth for new build sites in the U.K., thus minimizing the land use requirement and reducing overall civil engineering costs.

Activated Sludge Treatment in Aeration Lanes

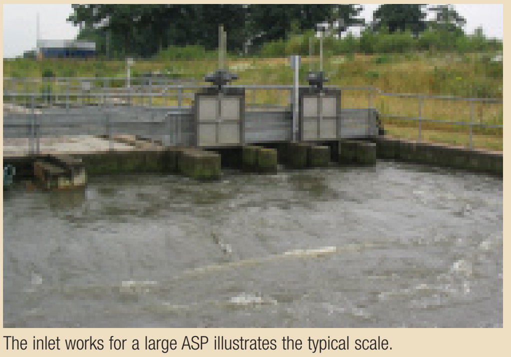
After primary separation, the wastewater stream passes into a series of aeration lanes in which bio-chemical reactions occur that convert the solid particulate waste into activated sludge. The sludge then can agglomerate (or flocculate) into large clusters of particles that can be more readily separated by sedimentation. The bio-chemical reaction rates depend on the levels of dissolved oxygen present within the wastewater. These levels can be modeled with multiphase CFD. A surface aerator, which draws liquid and solids from the lower region of the tank up through a draft tube and then sprays them back across the surface of the tank, influences the solids distributions within the tank and also introduces oxygen into the aeration lane. A study that varied the length of a draft tube diffuser was performed to investigate how the geometry affected the sludge bed



The interstage chamber was modeled with ANSYS CFX software. Streams from an inlet culvert demonstrate the typical flow patterns at the inlet distribution chamber. The streamlines are colored by time, with blue representing the initial time at 10 seconds.



A primary settling tank was modeled with multiple drift fluxes. This plot shows the stratified distribution of solids through a typical 30-m diameter tank.



The inlet works for a large ASP illustrates the typical scale.

Storm settling tank influent

entrainment. This research found that a longer draft tube should be used with the surface aerator under investigation. This change was shown to maximize the aeration and mixing capacity.

Secondary Settlement

After traveling through the aeration lane, the wastewater undergoes secondary treatment in a clarifier. The activated sludge settles out and the effluent passes over a v-notched side weir. The secondary clarifier may be modeled with an extended drift flux model incorporating both sludge settlement and rheology models defined as functions of local concentration. The results of simulation provide both the gradient of solids within the tank ranging from less than 5mg/l in the surface water to greater than 20,000 mg/l in the compressive zone near the bottom of the tank and a measure of the likely effluent solids concentration (solids going over an exit weir, typically in the range of 10 to 30 mg/l). This method has been used extensively to prove clarifier performance — as compared with idealized mass flux theory — and to optimize the position of retrofit baffles to allow a higher flow throughput for the same effluent solids concentration on existing units. MMI Engineering has used these techniques to design optimum clarifier influent arrangements that increase throughput and maintain the effluent solids at more than 40 sites.

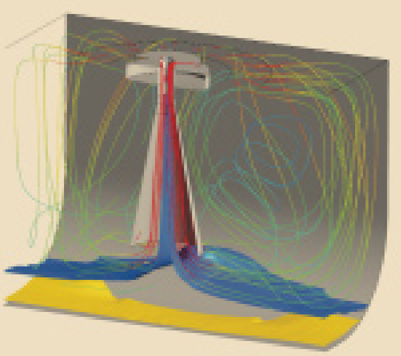
This article illustrates four examples of applying CFD to wastewater systems. Many other unit operations may be examined with similar models to those described here. The extension of aeration lane modeling to include microbial population balances and bio-kinetic reactions (the ASM1 model) currently is being investigated at MMI Engineering. ■

For further guidance on using CFD for wastewater modeling, consult the Aqua Enviro training course "Introduction to CFD Modeling for Water and Wastewater Treatment Plants" at www.aqua-enviro.net/calendar.asp.

References

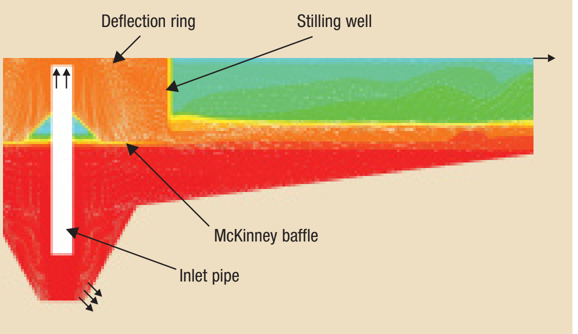
[1] Burt, D.; Ganeshalingam, J., "Design and Optimisation of Final Clarifier Performance with CFD Modelling," CIWEM/Aqua Enviro joint conference, Design and Operation of Activated Sludge Plants, April 19, 2005.

[2] Robinson C.; Wilson R.; and Hinsley S., "Calculating Primary Settling Tank Performance with Computational Fluid Dynamics," 4th Annual CIWEM Conference, Newcastle, U.K., September 12–14, 2006.



CFD was used to determine the influence of the draft tube depth on sludge bed entrainment for the surface aerator in the bio-reactor modeled here. Iso-surfaces of solids concentration are shown using blue at 3,000 mg/l and yellow at 20,000 mg/l. Streamlines identify flow patterns that pass up through the draft tube and are projected out, by way of the aerator, across the tank surface.

The surface aerator of this bio-reactor is used to resuspend the solids bed from within an aeration lane and to entrain air into the reactor.



These simulation results depict solids concentration for a radial cross section of a wastewater clarifier. Red indicates areas of higher concentration.

Activated sludge is settled out in this clarifier. Flow enters the tank from the top and flows radially outward.