Clarifier Proce

Next-generation modeling tool helps you get the most from your clarifier

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sses Revealed

Clarifier performance depends on several interrelated factors. Hydrodynamics, settling properties, turbulence, flocculation, and solids rheology all have an impact, as do atmospheric conditions, tank geometry, internal features, and loading conditions. While the traditional clarifier design process does not account for all of these factors, computational fluid dynamics (CFD) can.

A computational fluid dynamics model can be used to optimize clarifier internal features such as the Stamford baffle shown in this 59.4-m-diameter (195-ft-diameter) secondary clarifier.

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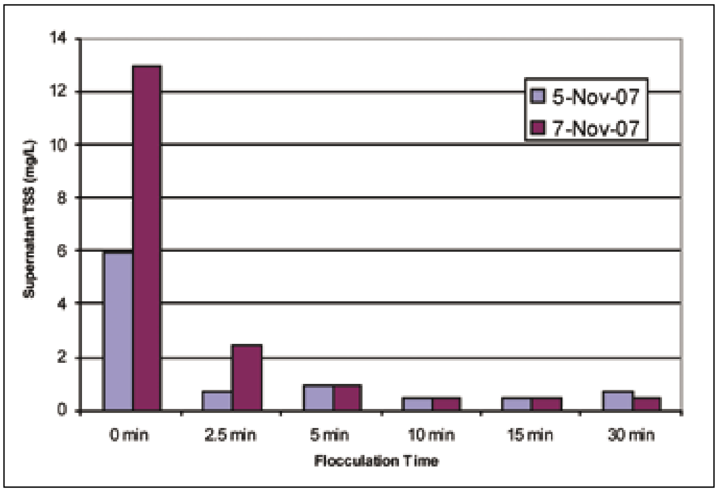
Figure 1. Flocculation Test



CFD is an advanced technique for clarifier design, troubleshooting, and optimization. It uses mathematical methods — and billions of calculations — to analyze systems that involve fluid motion, mass transfer, heat transfer, and associated phenomena, such as chemical and biological reactions. Today, it is one of the most advanced and accurate ways to simulate clarifier performance.

Stress testing data can be used in conjunction with CFD modeling to assess the real clarifier capacity under varying SVIs. Poor settling can severely compromise clarifier capacity and produce washout during peak flow conditions.

Clarifier Design and Optimization

CFD modeling is not new. In fact, researchers developed it more than 30 years ago to study settling tanks. Since then, knowledge of clarifier processes and computer processor speed both have advanced, making expanded applications of CFD more viable.

Traditionally, clarifiers have been designed based on empirical design guidelines or by applications of the solids flux theory, such as State Point Analysis. State Point Analysis is a box model approach that accounts for settling properties but not for major features, such as tank hydrodynamics, internal configuration, and density currents. State Point Analysis cannot predict the clarifier effluent suspended solids (ESS) or the position of the sludge blanket. CFD models, however, allow a much more accurate representation.

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2Dc Clarifier Model

One of a few CFD models now available for evaluating primary and secondary clarifiers is the 2Dc. This hydrodynamic model, developed at the University of New Orleans with funding from the U.S. Environmental Protection Agency, has two different versions, for circular and rectangular clarifiers. (The circular version includes a “swirl” component.) The beta version of the 2Dc model, released in 2005, has been applied to projects in Canada, the United States, Japan, Korea, and Australia.

The 2Dc research team wanted to address the deficiencies of previous CFD clarifier models and create a tool for wastewater engineers with relatively simple calibration and validation methods. The new model features discrete, zone, and compression settling; flocculation; non-Newtonian flow; floatable particles; and variable internal tank options, including skirts and baffles. Its capabilities are detailed in the sidebar on p. 57.

Stress Testing

Model calibration was performed using data gathered during recent stress testing of a secondary clarifier system. There are six circular 22.9-m-diameter (75-ft-diameter) center-feed clarifiers at this 28,387-m^3/d (7.5-mgd) facility. Clarifiers 1 and 2 are very shallow (side water depth of 2.7 m [9 ft]) and currently are decommissioned. Clarifiers 3 to 6 are 4 m (13 ft) deep with 4.9-m-diameter (16-ft-diameter) center wells. Clarifiers 3 and 4 have outboard launders, while clarifiers 5 and 6 have inboard launders and are equipped with McKinney-type peripheral baffles.

On stress-testing day, Clarifier 3 was taken out of service at 9 a.m., Clarifier 6 was taken out of service at 2:20 p.m., and flow was redirected to the remaining units. Clarifiers 3 and 6 were put back in service at about 5:30 p.m. after high blankets developed in clarifiers 4 and 5. The mixed liquor suspended solids (MLSS) for the duration of the stress testing was approximately 3200 mg/L. The simulated surface overflow rates (SORs) varied between 0.21 and 1.36 m/h.

Settling and Flocculation Properties

The zone settling and compression rate of the

Settling Properties Used for Clarifier Evaluation (Case History A)

Description	SVI (mL/g)	Vo (ft/h)	K (L/g)
Field sampling day (good settling properties)	110	31.1	0.406
Historical — 95th percentile (poor settling properties)	145	28.1	0.540

SVI = Sludge Volume Index.

solids are simulated in the 2Dc model using the Vesilind (exponential) equation. The two kinetic parameters of this equation, Vo and K, are determined in the field using batch column settling tests. In order to obtain the settling velocity as a function of solids concentration, the batch settling tests were conducted using different concentrations. The individual settling velocities are measured following the procedure described in Standard Method 2710 E for the evaluation of the zone settling rate. The batch settling tests were performed using a 1.5-m-tall (5-ft-tall), 152-mm-diameter (6-in.-diameter) settling column provided with a stirring mechanism to minimize the wall effect.

The resulting Vo and K values were 9.0 m/h and 0.539 L/g, respectively. These values are indicative of a poor settling sludge with poor compressibility that may strongly limit the clarifier capacity.

The following differential equation is used in the 2Dc model to account for the shear-induced flocculation:

$$\frac{dn}{dt} = K_B \cdot X \cdot G^2 - K_A \cdot X \cdot n \cdot G \qquad (1)$$

where

X is the MLSS concentration (g/L),

G is the root-mean-square velocity gradient (s-1) $= \sqrt{\frac{P}{V\mu}}$ = dissipation rate obtained from the power input to the jar test,

K_A is a floc aggregation coefficient (L/g),

K_B is a floc breakup rate coefficient (s), and

n is the primary particle concentration (g/L).

The flocculation constants K_A and K_B are obtained using a simple batch flocculation test. A six-paddle stirrer was used to flocculate the activated sludge samples, assigning different flocculation times to each sample and measuring the supernatant suspended solids (see Figure 1, p. 54).

Model Calibration Results

Using the geometry, loading, operational, and solids properties data obtained during the stress testing and additional field sampling period, the 2Dc model was calibrated. Three major comparisons were used to ensure proper calibration: the ESS from the clarifiers, the sludge blanket heights, and the returned activated sludge suspended solids (RAS SS) concentration.

The maximum observed and predicted ESS and the RAS SS concentration during the stress-testing period were in good agreement, as were the observed and predicted sludge blanket heights. The ability of the model to reproduce observed ESS, RAS SS, and sludge blanket depth values indicates that it is well calibrated and can be used as a numerical tool for determining clarifier performance and predicting thickening and clarification failures.

A settling column was used to determine settling properties.

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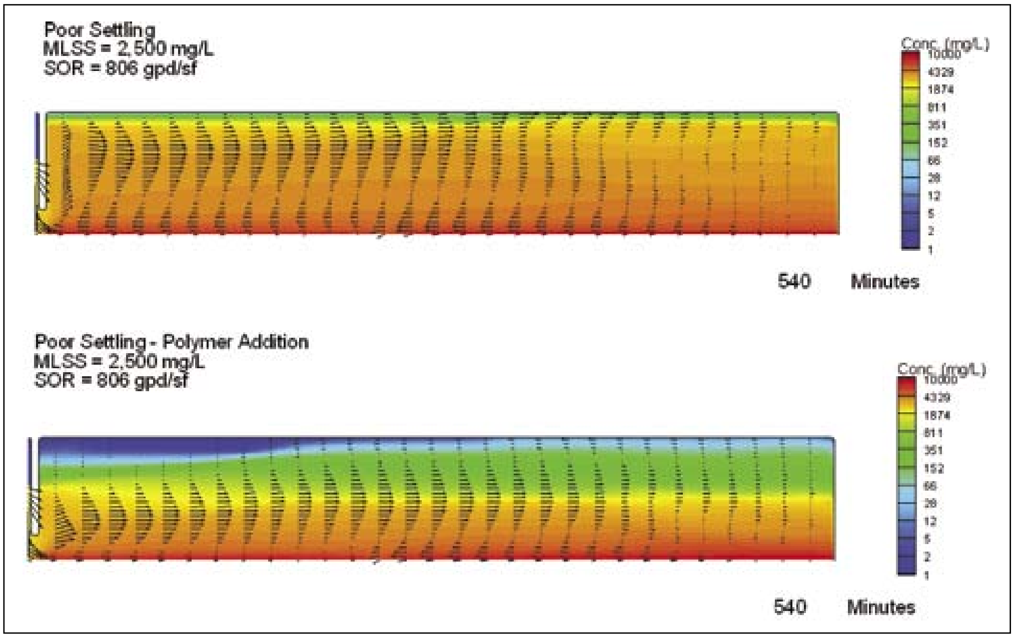
Figure 2. Effect of Polymer Addition on Clarifier Performance (Facility C)



MLSS = mixed liquor suspended solids.
SOR = surface overflow rate.

At 5 p.m. on stress-testing day, both clarifiers 4 and 5 showed high blankets and good ESS. However, the ESS of Clarifier 5 was slightly lower than that of Clarifier 4, probably due to the beneficial effect of the peripheral baffle.

Application of CFD Models

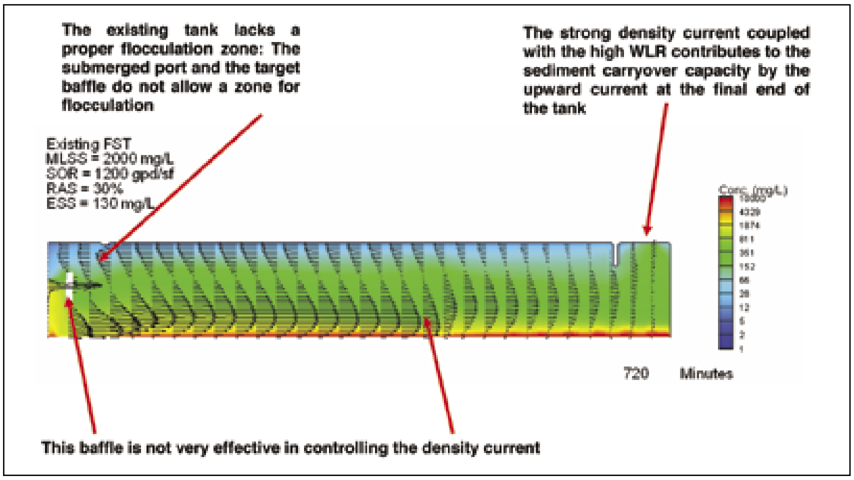
CFD models can be used to identify improvements to existing clarifier infrastructure that increase clarifier performance and capacity. A calibrated CFD model can serve to test design concepts and considerations, resulting in an optimized design from both a process and cost-effectiveness perspective. The modeling also can determine design and operational deficiencies not identified by traditional clarifier evaluation methods and allows development of site-specific wet weather and sludge-bulking strategies.

Predicting Clarifier Performance

Perhaps the most important factor affecting secondary clarifier capacity is solids settleability. The most common test used for evaluating this is the Sludge Volume Index (SVI) test. As pointed out by many researchers, SVI is an unreliable measurement that is affected, among other things, by the solids concentration and the device used for measuring the settled volume.

Most wastewater treatment plants only use SVI as a representation of solids settleability, and its correlation to the model settling parameters (Vo and K) is needed to assess clarifier capacity under different settling conditions. The following CFD modeling application to a 56,775-m^3/d (15-mgd) facility illustrates this procedure.

Figure 3. Existing Final Settling Tanks Suspended Solids Contours (Facility D)


The existing tank lacks a proper flocculation zone: The submerged port and the target baffle do not allow a zone for flocculation

The strong density current coupled with the high WLR contributes to the sediment carryover capacity by the upward current at the final end of the tank

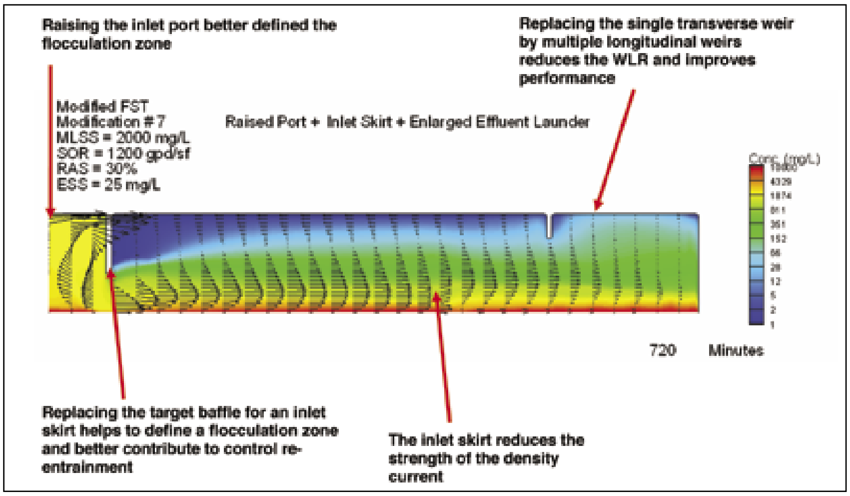
This baffle is not very effective in controlling the density current

FST = final settling tank.
MLSS = mixed liquor suspended solids.
SOR = surface overflow rate.
RAS = return activated sludge.
ESS = effluent suspended solids.
WLR = weir loading rate.

At Facility A, there are three secondary circular center-feed clarifiers, 38.1 m (125 ft) in diameter and with a 4.4-m (14.5-ft) side water depth. All clarifiers are provided with sloped bottom, inboard launder, spiral scrapers, a 4.9-m-diameter (16-ft-diameter), 0.9-m-deep (3-ft-deep) energy-dissipating inlet, a 9.4-m-diameter (31-ft-diameter), 2.0-m-deep (6.5-ft-deep) center well, and a Stamford-type peripheral baffle. The solids-settling properties, including the Vesilind parameters and the SVI, were measured at the field and are reported in the table on p. 55.

The settling properties measured during the field visit are representative of the plant's historical average solids-settling conditions. Clarifier capacity could be assessed using these properties; however, 50% of the time,

Figure 4. Retrofitted Final Settling Tanks Suspended Solids Contours (Facility D)



FST = final settling tank.
MLSS = mixed liquor suspended solids.
SOR = surface overflow rate.
RAS = return activated sludge.
ESS = effluent suspended solids.
WLR = weir loading rate.

the plant experiences poorer settling, and there is a process risk in using such properties. Risk can be substantially minimized by evaluating clarifier capacity under more critical settling conditions. In this particular case, the 95th percentile of the SVI was selected to represent poor settling. Since the Vo and K for the 95th percentile SVI differ from the values measured during the field visit, it is necessary to correlate the two different measurements. Several researches have published a different relationship between these parameters, and it is the designer's task to find the correlation that best fits the data set.

Modeling results indicated that Facility A's clarifier performance strongly depends on the settling properties and is severely compromised when the settling properties are poor. The model suggests that peak flow can be sustained only for 9 hours, after which time a significant loss of solids occurs through the effluent weirs. The model indicates this failure occurs due to thickening limitations. Total RAS flows of 0.66 m^3/s (15 mgd, 50%) and 0.88 m^3/s (20 mgd, 66%) were evaluated and proved ineffective in controlling the rise of the blanket. Additional clarifier area or the implementation of a wet weather strategy is needed to prevent clarifier failure under these conditions.

Validating Wet Weather Strategies

Wet weather events usually pose additional challenges to the unit treatment processes. Successful post-storm treatment depends on a plant's ability to retain the solids inventory and maintain an active biomass. These factors, in turn, depend on secondary clarifier performance. If poor settling conditions occur simultaneously with peak flows, the performance of any secondary clarifier can be severely compromised.

The 2Dc model was used to evaluate wet weather strategies in two scenarios. In Facility B, a calibrated CFD model was used to evaluate the effect that step feed and nonstep feed modes can have on clarifier performance. A calibrated model was used to predict the MLSS concentration under both scenarios for the case of a storm event in which the clarifier SOR rises from 0.54 to 1.38 m/h in about 24 hours and the peak flow is sustained for other 24 hours. The analysis was conducted for two existing 39.6-m-diameter (130-ft-diameter), 3.7-m (12-ft) side-water-depth secondary clarifiers.

Modeling results demonstrated that the use of step feed considerably decreases the solids loading in the secondary clarifier, resulting in a lower ESS during the storm event. Without step

2Dc Model Capabilities

Simulation Capabilities of General Model

- Inlet, settling, and outlet zones
- Steady and unsteady conditions for mass and hydraulic loadings
- Dynamic inventory of the sludge blanket
- Flocculation inside the tanks
- Temperature variations and heat exchange
- Density currents

Additional Capabilities for Circular Clarifiers

- Modeling of center-feed and peripheral-feed clarifiers
- Modeling of inlet deflectors
- Simulation of center-well, canopy, midtank (Crosby) baffle and peripheral (Stamford) baffle, positive or negative slope, inboard or outboard launder, and simple inlet arrangements
- Simulation of solids removal systems (hopper or suction), constant or proportional recirculation flow rate, and rake or spiral scraper simulation

Additional Capabilities for Rectangular Clarifiers

- Modeling of solids or porous inlet walls
- Modeling of different types of skits, positive or negative slope, inboard or outboard launder, and simple inlet arrangements
- Modeling of perforated baffles
- Simulation of solids removal systems, constant or proportional recirculation flow rate, and scraper simulation
- Simulation of floatable and nonsettling particles

Model Calibration and Verification Data

In general, the data needed for calibration and validation of the computational fluid dynamics model include the following:

- Solids-settling properties (zone, discrete, and compression rates)
- Flocculation parameters
- Mixed liquor suspended solids
- Effluent flow rate
- Secondary clarifier effluent suspended solids concentration
- Return activated sludge suspended solids concentration
- Return activated sludge flow rate
- Sludge blanket depth

feed, the maximum ESS is about 162 mg/L, while step feed is able to reduce ESS to about 55 mg/L. The use of step feed also significantly reduces the solids loading rate to the clarifiers, resulting in lower sludge blanket depth and better clarifier performance.

One other strategy is polymer addition. Polymers enhance clarifier performance by improving flocculation and the compressibility of the solids. Figure 2 (p. 56) shows CFD modeling results, with and without polymer addition, for a rectangular secondary clarifier under poor settling conditions (Facility C). The results demonstrate that adding polymers will improve the compressibility of the solids, preventing washout and considerably improving effluent quality.

Improving Performance

Generally, adding flocculating center wells to circular secondary clarifiers significantly benefits tank performance and capacity by providing an area where, at relative high-suspended-solids concentrations, dispersed particles can be incorporated into settleable flocs. The center well also improves tank hydrodynamics by reducing the entrainment of clarified liquid into the inlet zone, therefore reducing the strength of the density current and end-wall upflow. These two principles should similarly be applicable to rectangular secondary clarifiers.

Rectangular tanks are commonly designed with target baffles to help distribute the incoming momentum, but these baffles sometimes are located too close to the inlet, making them less effective for promoting flocculation or controlling re-entrainment. In Facility D, a calibrated CFD model was applied to improve the performance of 61.0 m (200 ft) long × 20.7 m (68 ft) wide × 3.7 m (12 ft) deep rectangular secondary clarifiers. The clarifiers have a transversal launder located 2.3 m (7.5 ft) from the end wall.

The modeling results indicated that clarifier performance is satisfactory at design mixed liquor concentrations of 1200 mg/L, but is compromised as the mixed liquor concentration approaches 2000 mg/L when the surface overflow rate approaches 2.04 m/h. The poor performance is due to poor flocculation and hydrodynamic limitations. As illustrated in Figure 3 (p. 56), the existing final settling tanks exhibit a strong density current, which, coupled with a high weir loading rate, limits their capacity to treat peak flows. The existing tanks also lack a proper flocculation zone.

To improve performance, different modifications were configured and evaluated. The results show that the definition of a flocculation zone, by replacing the target baffle with an inlet skirt, had a major benefit on the tank performance (see Figure 4, p. 57). The inlet skirt also improves the hydrodynamic of the tank by reducing the re-entrainment of clarified liquid into the inlet zone and reducing the strength of the density current. Replacing the single transverse launder by multiple longitudinal launders reduces the weir loading rate and improves performance. For the evaluated modifications, the best result was obtained by a combination of inlet skirt, raised ports and extended longitudinal launders.

Ensuring Success

CFD models are a powerful tool for clarifier design and optimization. As with any model, CFD must be used cautiously and with a good understanding of the processes and factors that affect, in this case, clarifier performance. Model calibration is an important step to enhance model accuracy and the user's credibility in the model output.

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More Information Online

For more data on the model calibration and clarifier performance discussed in this article, see this month's "Features" at www.wef.org/magazine.

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