Analyzing wet weather flow management using state of the art tools

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ABSTRACT

Optimal secondary clarifier performance is crucial to meet treatment requirements, especially when treating peak wet weather flows (PWWFs), to prevent high effluent suspended solids (ESS) concentrations and elevated sludge blankets. A state-of-the-art computational fluid dynamic (CFD) model was successfully used as a design and diagnostic tool to optimize performance for municipal wastewater treatment plants subject to significant PWWFs. Two case studies are presented. For Case Study 1, the model was used to determine the number of secondary clarifiers that will be necessary to treat future PWWF conditions for a plant under design. For Case Study 2, the model was used to identify modifications that are currently being made to increase the clarifier capacity for handling PWWF.

Key words | computational fluid dynamic, flocculation, peak wet weather flow, secondary clarifier, sludge blanket

BACKGROUND

Peak wet weather flows (PWWFs) can present a substantial challenge for wastewater treatment plants. PWWFs can result in collection system overflows, hydraulic failures within the plant, and/or process failures in any number of process units at the plant. The capacity of an activated sludge process depends in large part on the performance of the secondary clarifier, and the critical design condition for municipal wastewater treatment plants is usually under PWWF conditions. PWWFs can cause secondary clarifier process failure resulting in elevated effluent suspended solids (ESS) concentrations potentially leading to permit violations.

Secondary clarifier performance is a function of several variables including: mixed liquor settling and compacting properties, mixed liquor suspended solids (MLSS) concentration, temperature, inlet design, surface overflow rate (SOR), solids loading rate (SLR), tank geometry, sidewater depth, weir placement, and return activated sludge (RAS) flow rate. The mixed liquor properties that are important for secondary clarifier performance are sludge settleability and flocculation characteristics. Secondary clarifier ESS concentrations can be reduced with a properly designed flocculator center well (Parker et al. 1971; Parker 1983).

There are several models that can be applied to predict secondary clarifier performance ranging from simple to complex and from steady-state to dynamic. One-dimensional models such as a state point analysis can be used as a first step to determine if a clarifier is overloaded. However, one-dimensional, steady state models such as a state point analysis do not account for the hydrodynamics of the secondary clarifier nor do they account for the flocculent nature of mixed liquors. As a result, they cannot be used to predict ESS concentrations and may overstate the ability of the clarifier to thicken solids. Computational fluid dynamic (CFD) models can be applied to secondary clarifiers to simulate fluid hydrodynamics. McCorquodale et al. (2005) described a two-dimensional CFD model for secondary clarifiers that accounts for axi-symmetric hydrodynamics (including swirl components), sludge settling, turbulence, sludge rheology, flocculation and floc break-up, clarifier geometry, and varying hydraulic and solids loads. Discrete particle settling,
Flocculation-induced settling, hindered settling, and compression settling also are described. The model is the most advanced clarifier CFD model available in the wastewater industry at this time.

For existing plants, mixed liquor settling and compression characteristics were determined by performing batch settling tests using settling columns equipped with a slow-speed to minimize wall effects following the WERF/CRTC protocol (Wahlberg 2004). Mixed liquor flocculation parameters were determined following the protocol described by Wahlberg et al. (1994). Discrete settling fractions were determined as described by McCorquodale et al. (2005).

The CFD model has been used to analyze a growing number of plants. Two case studies are drawn from that set.

**RESULTS AND DISCUSSION**

**Case study 1 (plant 1)**

For Case Study 1, the model was used to determine the number of secondary clarifiers necessary to treat PWWF for a future new wastewater treatment plant. The heavy rainfalls and high flows experienced in early January 2005 were higher than had previously been used in the planning of Plant 1. This precipitated a reassessment of secondary clarifier design requirements during PWWF events, so that more accurate predictions could be made. The January 2005 storm event was used to forecast PWWF conditions for the year 2020. Flows will be divided between Plant 1 and an existing facility. Table 1 summarizes some of the features of the secondary clarifiers designed for Plant 1. Because Plant 1 was under design and not in operation, it was not possible to obtain sludge settling and flocculating characteristics. Typical values were assumed to be representative for the mixed liquor.

Three scenarios were investigated for Plant 1: six new secondary clarifiers, five new secondary clarifiers or four new secondary clarifiers, each having a peak hour wet weather surface overflow rate (SOR) of 3.6 m/h. These conditions were evaluated to determine if cost savings could be realized, reducing the number of planned secondary clarifiers. For the two cases with less than six clarifiers, some blending of primary effluent with secondary effluent would be involved during the design peak storm event. The peak SOR value was applied based on previous experience with similar secondary clarifier designs (Parker et al. 1996). Figure 1 shows the flow patterns that will occur under each of the three scenarios. Comparing the three scenarios, it can be seen that with the case of six secondary clarifiers, the peak SOR of 3.6 m/h is reached for one hour during the storm event. For five secondary clarifiers, the peak SOR is reached (or nearly so) for 12 hours of the 24-hour period, and for four clarifiers, the peak SOR is reached for 13 hours of the 24-hour period. The latter two scenarios obviously represent a much more critical loading condition for the secondary clarifiers.

**Model results for plant 1**

The simulations made for PWWF conditions for the three clarifier design conditions examined are presented in Figure 2. The extended duration of peak SOR values for the case of four and five secondary clarifiers exacerbates the impact on ESS, causing the composite for the day to rise from 29 to 44 mg/L for...
five clarifiers and to 51 mg/L for four clarifiers. The fact that the ESS drops only when the SOR drops indicates that the clarifiers are not at equilibrium with the higher loadings during the event. The greater disruption caused by the extended high SORs for the four and five clarifier scenarios indicates that the clarifiers are almost in failure.

Conclusions for plant 1

Designing less than six secondary clarifiers while sustaining a peak SOR of 3.6 m/h, represents a non-conservative design approach. The modeling results indicate that with the six clarifiers, this additional stress from the new design storm (January 2005) can be handled because of the peak overflow rate occurs for only a short duration. However, if the number of clarifiers were reduced to five or four, the peak SOR (or nearly the peak SOR) would be extended to at least 12 hours of the peak day flow event, not the one hour that occurs with six clarifiers. In establishing the peak hour SOR at 3.6 m/h for the 6-clarifier case originally, it had been the assumption that this was not a sustained condition and occurred in only one hour during the storm event. Model results show that extending this stress condition further deteriorates performance to the extent that the clarifiers are close to failure. Given the potential inaccuracy in the assumptions about sludge quality input to the model, designing for four or five secondary clarifiers for Plant 1 was considered not to be conservative and the design proceeded with six secondary clarifiers.

Case Study 1 shows that while an aggressive SOR had been initially chosen (3.6 m/h) to save space and conserve cost based upon past experience, the CFD model was able to provide valuable additional information about how long such peak SOR values can be sustained. It showed that a design optimum already had been found based on experience and avoided adoption of higher risk alternatives.

Case study 2 (plant 2)

Plant 2 is an existing facility that has two circular, 16.7 m diameter secondary clarifiers. Existing clarifier details are shown in Table 2. The secondary clarifiers are equipped with suction mechanisms for the removal of the thickened sludge at the bottom of the units. These units have the distinction of not being equipped with a properly sized flocculation center wells or energy dissipating inlets.

There was a concern about clarifier capacity in this plant, as the clarifiers consistently had high blanket levels when state point analysis showed that the clarifiers were underloaded. To avoid derating the clarifiers, a special study was conducted to determine the cause of the high blankets as well as to determine the most suitable means for correction.

Plant 2 calibration

For Case Study 2, the model was used to optimize the existing secondary clarifiers to sustain acceptable performance during the PWWF condition. Field analyses were performed to collect sludge settling characteristics to perform a model calibration.

At the time of field data collection, the clarifiers were operated at an SOR of 1 m/h and a solids loading rate (SLR) of 3.3 kg/m²h. A solids flux analysis (state point analysis) was performed using the field collected settling characteristics. As before, the state point analysis showed that the

Table 2 | Select features of the existing secondary clarifiers at plant 2

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clarifier diameter</td>
<td>16.7 m</td>
</tr>
<tr>
<td>Depth of outer wall</td>
<td>3.6 m</td>
</tr>
<tr>
<td>Bottom slope</td>
<td>Flat</td>
</tr>
<tr>
<td>Peripheral baffle</td>
<td>No</td>
</tr>
<tr>
<td>Sludge removal</td>
<td>Suction</td>
</tr>
<tr>
<td>Launder type</td>
<td>Outboard</td>
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</tbody>
</table>
clarifiers should be under loaded from a thickening point of view and should not develop a blanket. However, during the field analysis, the sludge blankets in the secondary clarifiers were approximately 1 m deep despite the fact that the units were under loaded.

The model was used to determine the cause of the sludge blanket during under loaded conditions. As seen in this Figure 3, the model was predicting high sludge blankets similar to those observed during the field test. Special sampling was performed and showed that the elevated
blanket levels were not due to seal failure in the sludge collection mechanism. Using the model, the high sludge blankets were determined to be due to hydrodynamic problems within the clarifiers. The velocities coming out of the inlet pipe are too high, creating a lifting effect of the blanket at the bottom of the clarifier. The model-predicted ESS concentration was 45 mg/L.

Secondary clarifier optimization for plant 2

The model was used to evaluate modifications to the existing secondary clarifiers that could be implemented to reduce the sludge blanket height to reasonable levels which would eliminate the need to construct additional clarifiers. Two different scenarios were evaluated: (1) adding a 6 m diameter, 2.1 m deep flocculator center well and (2) adding a 6 m diameter, 2.1 m deep flocculator center well plus an inboard launder at 25 percent of the clarifier diameter. Figure 4 shows the model results for each alternative evaluated. Both alternatives would reduce the SBD to approximately 0.3 m improving the performance of the existing unit configuration and regaining the clarifier capacity. In addition, the ESS concentration was improved from 45 mg/L (during the calibration run) to 15 mg/L for scenario 1 and 14 mg/L for scenario 2. From the two scenarios evaluated, scenario 1 was used to determine the capacity of the secondary clarifiers at Plant 2. Scenario 1 was recommended and implemented because the necessary modifications were less expensive than those necessary for scenario 2.

Case Study 2 showed the power of the CFD model to solve the mystery of high sludge blankets when state point analysis failed to identify a cause. The combination of our experience with successful modifications in other plants, with the use of the CFD tool allowed a solution that could be designed without having to go through an expensive pilot test of the modification. Finally, identification of the problem and the recovery of the capacity of these clarifiers allowed the utility to avoid the construction of an additional clarifier at the cost of 750,000 USD.

CONCLUSIONS

Combined with our past experience on successful secondary clarifier modifications, the CFD model was found to be an effective tool to determine: 1) capacity of existing clarifiers, 2) performance limitations of clarifiers, 3) effects of clarifier modifications that can potentially improve performance and increase their capacity, and 4) design considerations for new clarifiers. The model has been successfully used on a number of projects where PWWF are an issue. Two were chosen as case examples. For Plant 1, the model was used to determine the number of secondary clarifiers necessary for a new plant as part of a design study. The model results showed that six secondary clarifiers will be necessary to meet future PWWF conditions. The model was used to determine the cause of elevated sludge blankets occurring during seemingly under loaded conditions for Plant 2. The model showed that sludge blankets were a result of hydrodynamic conditions in the secondary clarifier causing a lifting effect of the blanket due to insufficient energy dissipation in the inlet. The model was used to optimize the secondary clarifier design by installing a flocculator centerwell to promote energy dissipation and flocculation. As a result, the need to add additional secondary clarification capacity to compensate for the high blankets was eliminated.

REFERENCES


