State of the Art Clarifier Modeling Technology-Part II

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Abstract: As part of summary of the clarifier modeling chapter in Clarifier Design MOP FD-8, this paper illustrates modeling applications in several clarifier troubleshooting, retrofit and design evaluation projects. It emphasizes the practical application aspects of modeling. Included are results from model predictions for the clarifiers with and without modifications as well as field data measured before and after the field retrofit.

1 INTRODUCTION

1.1 Why a Numerical Model for Clarifiers

There is debate among design engineers and clarifier manufacturers on the performance (or efficiency) of several design alternatives developed for secondary clarifiers. For many years, a significant amount of field testing work has been conducted in order to evaluate and select design alternatives, which can be applied to build a secondary clarifier with a substantially higher performance and capacity. The field data provide us clarifier performance understanding in general as well as producing physical results. However, convincing conclusions may not be drawn only based on field tests and observational results due primarily to the following three reasons:

1. Many unavoidable *uncertainty factors* in the field tests, such as flow distribution and variations of process parameters, disturb a reliable evaluation of product alternatives.
2. *Insufficient information* obtained from the field tests prevents us from fully understanding the mechanism of the evaluated alternatives.
3. In a field test, it is very *difficult to isolate a single evaluation factor* from others to reveal its exact impact of the evaluated alternative.

Using a CFD model, clarifiers with two different design alternatives can be set exactly side by side under an identical operational condition.

The desired field testing data includes the 3D solids and flow fields within the tested clarifier at each different time steps in the operations under a diurnal flow condition and many variable process/bioreactor operational parameters. It is almost impossible to obtain an entire set of information needed to evaluate two different alternatives in a field test since a dramatic amount of performance data and operational conditions need to be monitored under a wide enough loading range.

So far, the most available field data which could be useful in explaining certain phenomenon under the given conditions still appear only piecemeal. For example, someone promotes a shallow flocculation well because he found it was doing well in a clarifier with massive sludge inventory due to longer sludge age in the process, while others are insisting that a deeper well is better based on their field experiences in a process with a lower MLSS.

The 3D Computational Fluid Dynamic (CFD) based clarifier/process modeling is an effective approach to simulate those pieces collected in different field tests and connect them together. The modeling practice is able to provide us a complete and objective picture describing both performance and application conditions for the evaluated alternatives.

1.2 Modeling Technology

Clarifier models can be generally divided into two classes, i.e. "Black Box" and "Glass Box" models based on their ability to represent the physical processes to describe the flow and solids fields within clarifiers.

1.2.1 "Black Box" Models

The first "black box" clarifier model was developed and published by Dobbins (1944). This type of models developed earlier have to adopt very rough approximations of clarifier hydraulic behavior, relying on over-simplifications or 'correction factors' and based mainly on solids flux equations.

The earlier clarifier models [Dobbins (1944) and Dick and Young (1972)] are considered to be black box models since the plug flow is a major assumption used in these models. Since true plug flow conditions are never achieved in any real clarifiers, the information provided by these models is limited if the models are used for clarifier design optimization or troubleshooting of existing system. The reliability of the model simulations is heavily dependent on the similarity between the calibration and the prediction scenarios. It is dubious to use these black box models to predict (or explain) the behavior of clarifiers with different configurations under the practical operating conditions.

1.2.2 "Glass Box" Models

During the last 25 years, the great advances in Computational Fluid Dynamics (CFD) and computer hardware have made it possible to base clarifier simulation upon the glass box models. The numerical solutions of the momentum and mass transport equations are able to give more complete multi-dimensional fields for the realistic flow and suspended solids in clarifiers. The research on clarifier modeling based on CFD principles was initiated by Larsen (1977). The clarifier models presented by Schamber and Larock (1981), Imam and McCorquodale (1983), Celik and Rodi (1985), Lyn and Zhang (1989), Adams and Rodi (1990), Gasonato and Gallerano (1990), and Szalai, Krebs and Rodi (1994) neglected density effects.

The density effects are included in the models of DeVantier and Larock (1987), Lyn, Stamou and Rodi (1992) and Larsen, et al (1977). The numerical difficulty encountered with strong density flows in clarifiers was overcome and the clarifier inlet “density water fall” and “the entrainment flow” into the flocculation well was captured by the modeling of Zhou and McCorquodale (1992a, b).

The ASCE Clarifier Research Technical Committee (CRTC) protocol field was applied in a performance evaluation of two circular secondary clarifiers located in the South Secondary Complex at MWRD's Center Treatment Plant, Denver Colorado (Wahlberg et al 1995). The protocol from this study provides a standard for field testing of clarifiers. The unsteady 2 and 3-D clarifier model (Zhou and McCorquodale, 1992) based on the Computational Fluid Dynamic theory was verified based on the field data gathered by Wahlberg (Vitasovic, Zhou and McCorquodale 1996).

In clarifier simulations the density impact is very strong in comparison with the weak flow convections. The commercial available CFD packages may not be readily applied in clarifier simulations until the numerical approach, which can effectively enhance the stability of numerical solutions, are developed and incorporated into the code.

2 Clarifier Retrofit with Better Cost-Effectiveness

2.1 Field Observation of Existing Clarifier Performance

As shown in Figure 1[1], the effluent from rectangular secondary clarifiers at Worthing WWTP, UK, contained high effluent SS concentrations when the contractor was transferring the plant to the project owner in this design-build project.

The problem not only prevented the plant from satisfying the discharge standard but also significantly increased the cost of the planned downstream UV disinfection tanks. For a secondary treatment system, a high effluent turbidity in the secondary clarifier effluent

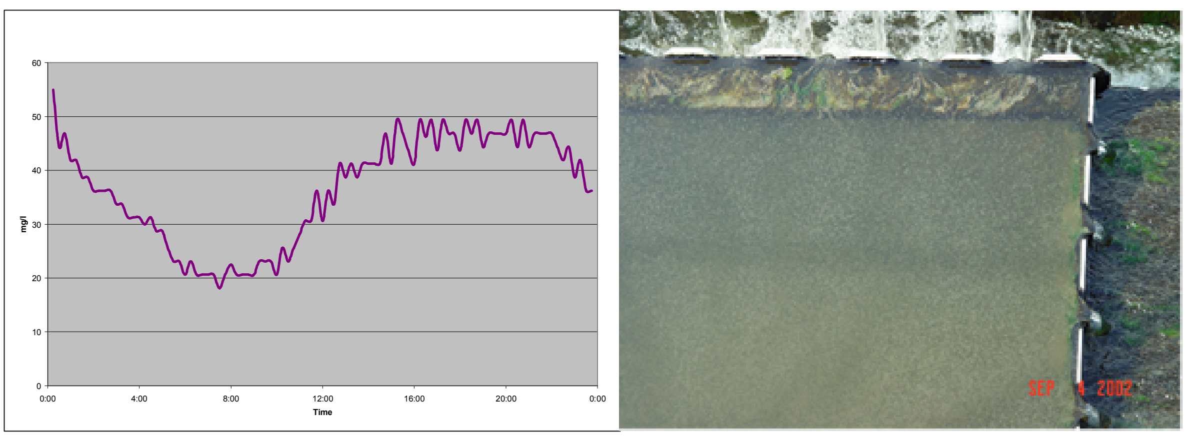


Figure 1 Impact of diurnal flow variations on clarifier effluent SS

may require construction of effluent filters between the clarifiers and the UV disinfection

[1] All graphs in this paper are best viewed on computer screen at 1.5X magnification

tanks in order to reduce the size of the UV disinfection tanks and lower the overall construction and maintenance cost.

Figure 1 shows a typical monitoring profile of clarifier effluent SS in 24 hours, which was provided by the project owner (Southern Water, 2002). In the figure, the clarifier effluent quality is with respect to the system operation time. The field data show the very clear impact of clarifier flow variations on the effluent SS concentration. The effluent SS trend indicates that the clarifier effluent SS was between 20 to 30 mg/L during the daily low flow period and 40 to 50 mg/L during the daily high flow period.

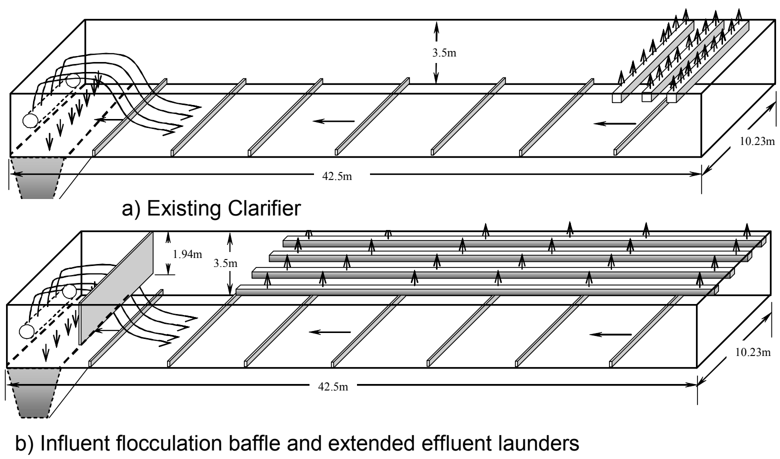


Figure 2 Clarifiers with and with on baffle and launder Modifications

It had been found in most of the current process/clarifier operations that the light flocculant solids were consistently blowing out in substantial amounts around the existing launder system - even during the daily low flow period as shown in Figure 1. There were no obvious flocculant solids observed on the rest of clarifier surface area except in the area around the existing effluent launders, which are located at the very downstream end of the clarifier and cover only approximately 1/10 of the total clarifier surface area as shown on Figure 2(a).

During site visits, the following major features of hydraulic performance have been observed in the existing clarifiers:

1. There is strong impingement between the clarifier water surface water and upward influent jet flows, which are created at the upstream end of the clarifiers by directing MLSS through influent diffusers consisting of four nozzles aimed toward the water surface.
2. After the impingement with the water surface, the clarifier influent dives toward the clarifier floor within a distance ranging from 2 to 3 meters away the influent wall due to the strong density current formed.
3. The density interface between clarifier influent jets and ambient clean water in the surface layers can be visually observed, although massive scum behind the scum baffle often covers it.
4. The direction of the surface flow is driven more or less by the wind within a very shallow surface layer of a few inches as well as scum floating on the water surface. Therefore, it often changes due to variations of the wind direction.

However, the clear and consistent reverse current towards clarifier upstream end was observed in layers a few inches below the surface.

Massive amounts of light flocculant solids are consistently blowing out around the existing launder system - even during the daily low flow period.

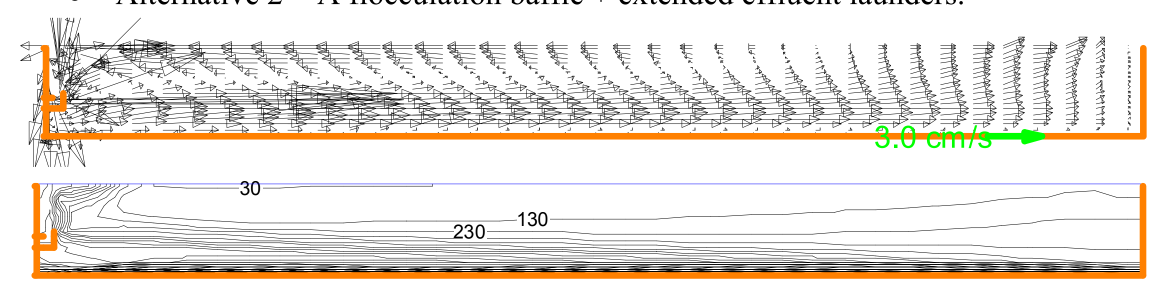
2.2 3D Modeling Results

The 3D CFD based clarifier modeling technology was used to explore an optimized modification package in order to enhance the performance of the existing secondary treatment system by improving clarifier hydraulic behavior and solids flocculation within clarifiers while satisfying the requirement of a low construction cost.

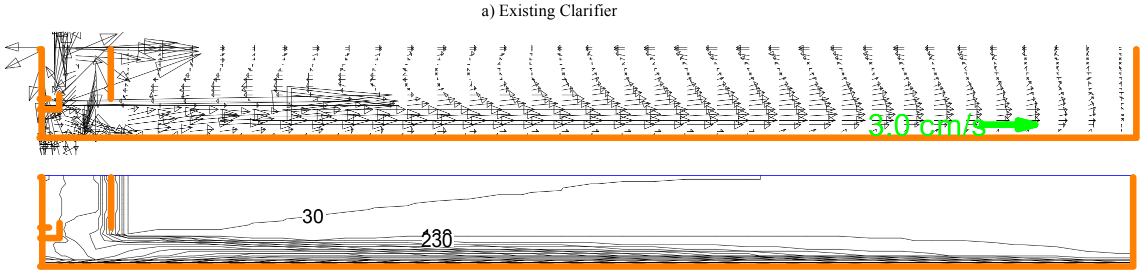
Existing Clarifier Configurations: As shown in Figures 2(a) and 2(b) the length of the existing clarifier = 42.5 m, the tank width = 10.25 m, the average water depth at the tank midstream part = 3.5 m. The surface area of each tank is 435.6 m2. Each tank's influent flow is introduced through an influent diffuser with four inlet nozzles aimed toward the surface. In each tank there are 3 effluent launders, which go along the lateral direction and are distributed in a range of 4 meters from the downstream wall. The multiple scrapers driven by chain move toward the tank upstream hopper to collect the settled sludge into the sludge hoppers located at the front end of tank.

The modeling scenarios for the modified system include two major alternatives:

- Alternative 1 = a flocculation baffle with optimized depth and location
- Alternative 2 = A flocculation baffle + extended effluent launders.



a) Existing Clarifier



b) Optimized Clarifier

Figure 3 Hydraulic behavior and performance in clarifiers with and without retrofit

The two scenarios cases developed in the study not only provide the contractor (and project owner) a solution with the best effectiveness but also let them have a choice requiring a very limited cost while providing reasonable performance enhancement.

Figures 3(a) and 3(b)[1]present the comparison of velocity fields between the existing clarifier and the clarifier with Alternative 1 to give insight into the significant enhancement of clarifier performance due to the modifications. The flow pattern is presented in a vertical section near the center axis for the clarifier SOR of 1.5 m3/m2/h and MLSS of 2300 mg/L.

As shown in Figure 3(a), the predicted hydraulic regime typically consists of the upward inlet jet, the influent density waterfall, a bottom density current and a strong surface reverse flow in the absence of proper baffling. For a case with a thick sludge blanket (not shown), the simulated velocity field showed that the bottom density current deflects upward while near the tank bottom a strong reverse sludge flow appears. According to both the field observations and the modeling of the existing process, each of the following reasons (or combination of them) may cause the clarification problems, i.e. the flocculant solids blowing out:

1. The location of the existing launders (distributed in a range of 4 meters at the very downstream end of the clarifier) cause very strong upward currents, which could be one of the major reasons that the flocculant solids were blowing out around the effluent area (see Figure 2).

2. The strong upward flow is not only related to the small cross section area the effluent flow passes through but also to the rebound effect between the clarifier bottom density current and the downstream wall. The “rebound” phenomenon has been observed and reported by many operators as well as field investigators, especially in circular clarifiers with small amounts of sludge inventory. A reasonable amount of sludge inventory can help dissipate the kinetic energy of the bottom density current, which is often described by some operators as “sludge blanket filtering”.

3. The relatively shallow water depth (3.5 m) in the existing clarifiers provide less separation between the high concentration layers and the surface effluent than that of clarifiers with a deeper water depth. Therefore, the effluent quality might be more sensitive to the launder arrangement in a shallow clarifier than that in a deeper clarifier.

4. In the existing operation, the bottom density current must be fairly strong due to the lack of proper baffling and the shortage of sludge inventory in the tank.

It can be observed that in clarifiers with both retrofit packages 1 and 2, the clarifier-settling zone is effectively isolated from the influent zone as well as the surface influent momentum due to the application of the optimized flocculation baffle [see Figure 3(b) for

1 All graphs in this paper are best viewed on computer screen at 1.5X magnification

package 1]. In the settling zone, the strong surface reverse flow, which occurs in the existing tank, has been almost eliminated due to the flocculation baffle. The extended launder gives a much lower intensity of the upward velocities caused by the effluent flow withdrawal.

Figure 3(a) also visually illustrates that the level of solids contour line of 130 mg/L is very close to the downstream effluent area in the existing clarifier in the simulation with an ultimate SOR of 1.5 (m3/m2/h) combined with a MLSS of 2300 mg/L although the sludge blanket is lower than 20% of water depth. In the clarifier with the full retrofit package [Figure 3(b)], the contour line of 130 is very close to tank bottom.

2.3 Field Data after Cost-Effective Retrofit

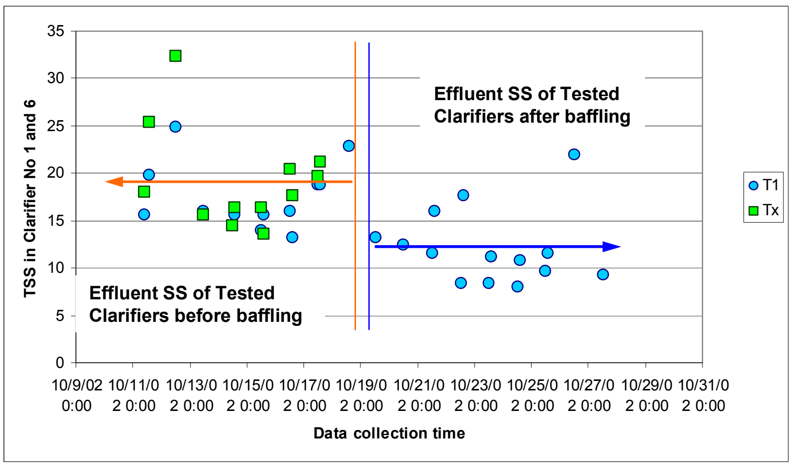


Figure 4 Field data of ESS before and after inlet baffle installation (South Water, UK, 2002)

The full clarifier retrofit package includes baffle and effluent launder modifications and has a high construction cost. The cost of the sole baffle retrofit is much lower than that required by the launder retrofit. Therefore, the prototype retrofit was divided into two stages based upon the cost-effectiveness analysis of 3D modeling.

Figure 4 shows the clarifier effluent SS right before and after the flocculation baffle installation in the field clarifiers. The field measurement was accomplished by South Water, UK (2002). The field data indicate that the sole baffle retrofit is able to provide more than 30% clarification enhancement. The field data after the retrofit verified that the baffle retrofit (having a very low cost and a short construction period) is able to make the clarifier performance achieve the effluent standard. The entire treatment plant was smoothly transferred from the contractor to the project owner in this Design-Build project.

3 Optimization of Center Feed Clarifiers

3.1 Existing Clarifier Performance

As shown in Figure 5, the existing secondary clarifiers at Western Treatment Plant, Melbourne, often experience very high effluent TSS due to the impact of a massive sludge inventory. In the overloaded clarifiers, the effluent TSS (and BOD) is extremely sensitive to any minor variations in plant flow. This is because the top of sludge blanket is close to the surface and can easily be carried over the effluent weirs. The overloaded conditions can often cause a large unexpected loss of bio-solids from the secondary treatment process.

Figure 5 Overloaded clarifier operations

The flow capacity for the four existing clarifiers studied ranges from 115 to 145 ML/day due to variations of the process parameters (sSVI and MLSS). The clarifiers are unable to achieve their expected design flow of 190 ML/day due primarily to the thickening limitation of clarifiers.

The performance and capacity of a center feed clarifier is very sensitive to the strength of the influent jets into the clarifiers. A traditional center feed clarifier naturally generates a strong influent jet due to its small center feed area. Thus, it often brings significant turbulence into the settling compartment, especially under high flow conditions.

3.2 Performance of Clarifiers with an Optimized Influent Structure

To enhance the hydraulic efficiency and capacity of the center feed clarifiers, the key is to develop a new center feed structure, which could be used to effectively reduce the strength of the center influent jet under high-flow conditions. To produce satisfactory hydraulic behavior, one of the necessary design conditions is that the cumulative space of the inlet slots must be big enough. However, this condition alone is not sufficient to guarantee a low momentum entry into the clarifiers.

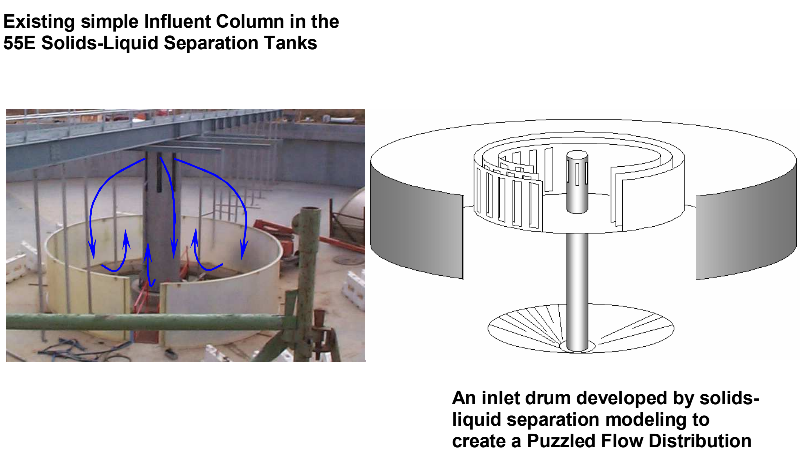


Figure 6 Existing and Modified Central Inlet Structure

Using the traditional influent structure (as shown in Figures 6), the jet of clarifier influent through a few influent slots is very strong due to the very small cross sectional area of the slots. However, if the cross sectional area of the inlet slots is simply enlarged, flow short-circuiting (or unevenly distributed flow) may occur among the slots.

An optimized design of clarifier inlet structure should simultaneously satisfy both the principles, i.e. a large slot space and a uniform flow distribution among the slots. An innovative "Multilayer Puzzled Inlet Slots" (MPIS) was used as an effective solution against the problem of strong center influent jets. As shown in Figures 6 and 7, the MPIS consists of multiple perforated columns and a circular bottom, which partially seals the bottom of the drum. There are many vertical slots on the walls of the columns. The layout of the slots between any two perforated columns must be staggered to create a puzzled flow path and flow impingement on the baffles.

Figure 7 Prototype of Modified Central Inlet Structure

The 3D clarifier modeling technology was used to evaluate the retrofit alternative. Comparing the modeling results presented in Figure 8, substantially improved clarifier

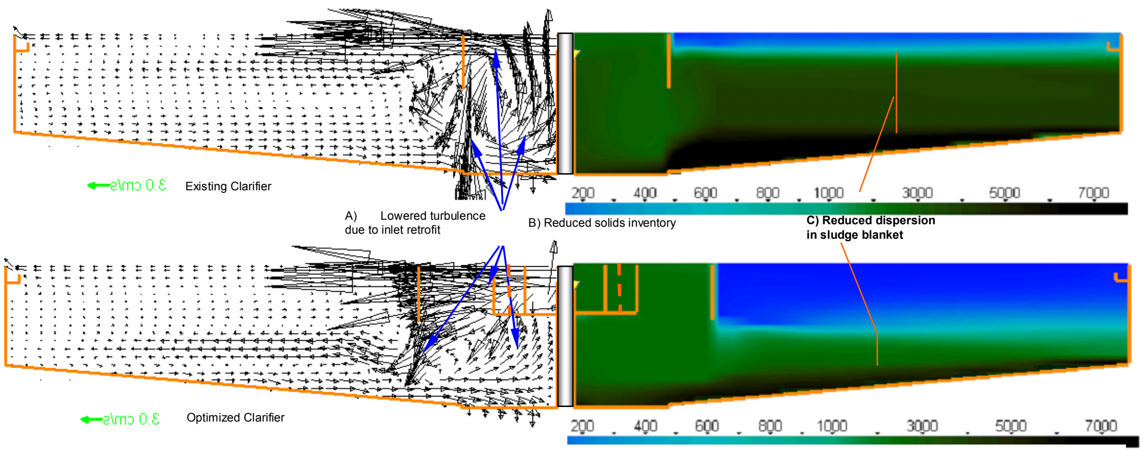


Figure 8 Performance before and after central inlet retrofit

hydraulic behavior as well as enhanced performance can be observed in the following aspects:

1. The very strong influent jet due to the small influent slots impinges with the perforated baffles one after another. The velocities of the influent jets have been reduced to less than 3 cm/sec before and after the last perforated baffle as shown in Figure 8. The resistance created by multiple perforated baffles forces the influent jet to be sufficiently distributed along the vertical and tangential directions before the jet enters the flocculation well.

2. The downward current due to the deflection of the influent jet on the flocculation well has been significantly reduced since the momentum of the influent jet is effectively dissipated by applying multiple perforated baffles.

3. The pinched flow underneath the lip of the baffle (flocculation well) has been eliminated and the level of density forward current is much closer to the clarifier's bottom due to the sufficiently controlled sludge inventory in the clarifier.

4. Because the significantly slowed influent jet generates a much weaker shear influence on the ambient flow, the significant reverse flow underneath the surface influent jet predicted in the clarifiers has been almost eliminated.

5. The dispersed sludge blanket has been significantly lowered due primarily to the substantially reduced turbulence in the clarifiers equipped with a MPIS (See Figure 8)

The existing clarifiers have flow capacities of approximately 1500 (m3/h) under the normal process condition, which is most of the year. The optimized clarifiers can achieve a flow capacity of around 2000 (m3/h), which is 30% higher than that of the existing clarifiers.

4 Troubleshooting of Clarifiers

4.1 Performance of Existing Clarifiers

The Passaic Valley Sewerage Commission Wastewater Treatment Plant (PVSC), in Newark, New Jersey is one of the largest secondary WWTPs (400 MGD) in the United States (see Figure 10). The clarifier effluent SS and BOD in Figure 9 shows the field data collected in these unusual, large (100*36*4 m^3) rectangular clarifiers equipped with multiple circular collector mechanisms. Before clarifier retrofit, about 50% of the time the ESS concentration was higher than 40 mg/L in first five months in 1994; this was due to the poor tank hydraulic efficiency - even in the operations with relatively low sludge blanket levels (below than 35% of the water depth).

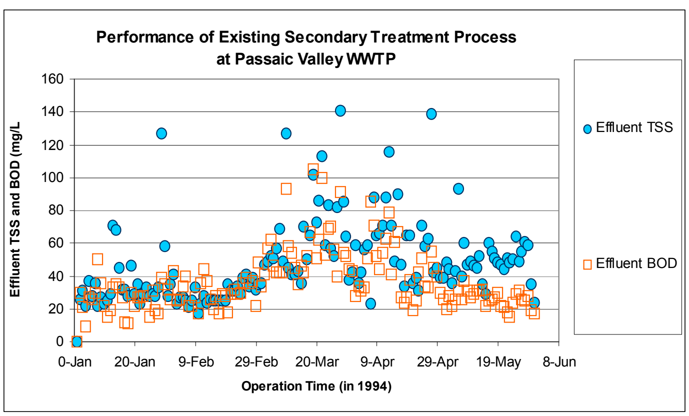


Figure 9 Daily average effluent quality of existing secondary treatment process at PVSC in 1994

Albertson (1995) used field data collected during the previous 5 years to analyze the clarifier behavior and to enhance the performance of these secondary clarifiers. Also, an extensive dye test was completed by Crosby in 1988. Several tank modifications (including flocculation baffle, energy dissipation baffles, perforated baffles and relocated effluent launders) were recommend based on their field investigations. However, it is

Figure 10 Existing clarifiers

possible that some tank configuration changes may have given no substantial positive effect (or even adverse impact) on tank performance. The engineers were wondering if the undesirable tank performance could be exaggerated under certain operational conditions. The 3D clarifier model was applied to evaluate the proposed design modifications of the PVSC secondary clarifiers.

The relationship between effluent concentration and sludge blanket in the PVSC tanks is presented in Figure 11. Both model predictions and field data show that the hydraulic behavior in the existing tank can be divided into two stages. At stage 1 while the sludge blanket level is below 40% of the water depth, the slow increase in effluent concentration with an increase sludge blanket indicates that the tank performance is primarily controlled by tank hydraulic efficiency. At stage 2 the sludge blanket is in range of 45% to 65% of the water depth. The steep trend of the profile suggests that the tank performance be controlled by sludge blanket.

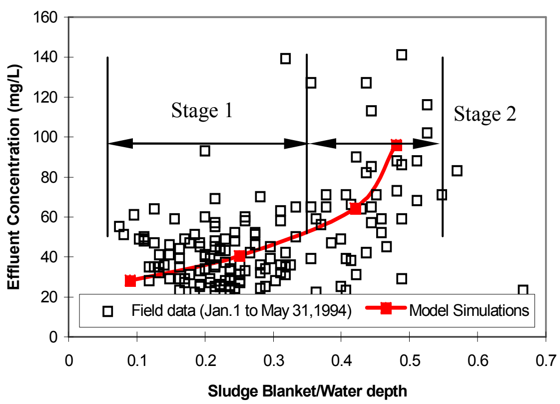


Figure 11 Impact of sludge blanket on ESS

4.2 3D Modeling Results

Total of the six alternatives tested by 3D modeling are presented in Table 1.

The relationship between the effluent SS and the hydraulic loading is summarised in Table 1 for the existing clarifier and ones with three different modification combinations. The predicted ESS in Table 1 and Figure 12 indicates that the average ESS can be significantly reduced by improving the tank hydraulic efficiency. The comparison of model predictions with the subsequent field data indicates that the significantly improvement of clarifier performance was obtained by using the minor modifications based on the 3-D computer modeling.

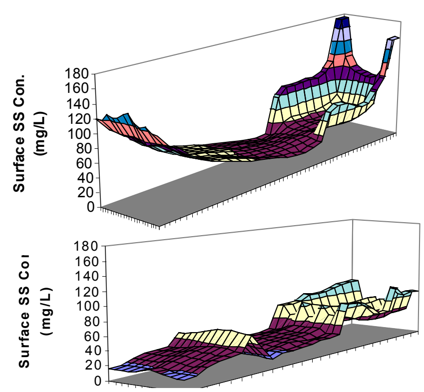


Figure 12 Surface SS before and after retrofit

4.3 Comparison of model predictions with field data before and after clarifier retrofit

Table 2 shows a comparison between the model predictions and field data before and after prototype clarifier modifications. The model

Table 1 Summary of 3D modeling results

	Qo = 244 MGD MLSS=2800mg/L RAS flow = 50%	Qo = 314 MGD MLSS=2800mg/L RAS flow = 46%	Qo= 420 MGD MLSS=2800mg/L RAS flow = 35%	Qo = 420 MGD MLSS=3100mg/L RAS flow = 35%
	Predicted Average Effluent Concentration (mg)			
Existing Tank	**28.3**	**40.5**	**64.5**	**95.6**
Modification 1, 2, 3	**13.4**	**18.5**	**33.8**	**79.6**
Modification 1,4,5	**13.8**	**18.2**	**37.0**	**160.7**
Modification 1, 2, 3, 6	**10.7**	**15.1**	**27.1**	**60.0**

Modification 1 = Inlet flocculation baffle, the distance from tank influent to the baffle = 6.6 m (21.6 ft) and the baffle depth = 2.4 m (the space under the baffle lip = 41% of the flow cross section area)
Modification 2 = A perforated baffle between bay A and B with slot space of 52% of flow cross section area
Modification 3 = A perforated baffle between bay B and C with slot space of 65% of flow cross section area
Modification 4 = A conventional baffle between bay A and B with baffle depth of 1.73 m below the surface (the space under the baffle lip = 58% of the flow cross section area).
Modification 5 = A conventional baffle between bay B and C with baffle depth of 1.39 m below the surface (the space under the baffle lip = 66% of the flow cross section area).
Modification 6 = Removing existing surrounding effluent launders and adding 4 new launders in the bay C. All effluent launders are aligned with the tank longitudinal direction. The launders extend from the end wall to the perforated baffle between B and C. The total length of launders = 960 ft [8x120] which is 33.3% longer than that of the existing launders.

SSVI = 85 for all of simulations

Table 2 Comparison of model predictions with field data before and after clarifier retrofit

	Operation Conditions		**Effluent TSS (mg/L) and Improvement**		
	Ave. MLSS (mg/L)	**Ave. Flow (mgd)**	**No Modifications**	**Baffle Modification**	**Baffle & Launder Modifications**
Field Data March~April, 94	2600	41.6	54.0	N/A	N/A
Model Predictions Jan. 1996	2800	41.7	41.0	18.5 (+54.9%)	15.1 (+63.2%)
Field Data March~April, 97	2407~2408	46.2~46.5	N/A	11.0 (+79.6%)	12.0 (+77.8%)

All field data used in this Table was offered by Hazen and Sawyer and Passaic Valley Sewerage Commission Wastewater Treatment Plant (S. Lipke, M. DeNicola and P. Sauer, in 1995 and 1997).
Model Predictions was accomplished by S. Zhou et al during 1995 to 1996)

predictions reported in 1996, which indicated that the clarifier effluent quality could be enhanced more than 60% by using recommended packages, were verified by the field measurement in 1997 in the clarifiers with modifications. The verification of 3-d clarifier model by using data before and after modifications illustrates that the 3D clarifier model is a very useful tool to optimize clarifier design and enhance clarifier performance by simulating tank internal hydraulics behavior and sludge blanket movement.

There are ten clarifiers in the PVSC plant. The retrofit for the first two clarifiers was accomplished in early 1997 and the last two clarifiers were modified in 2003 since a significant amount of construction is required for the retrofit in the large clarifiers.

5 Evaluations of Clarifier Design Alternatives

The 3D clarifier model can be used for design evaluations to select clarifier equipment, which fits the specified process better. For example, bigger clarifier storage may reduce the cost of sludge collection facility. An optimized sludge removal mechanism could significantly reduce the possibility of under flow short-circuiting (or watery sludge) due to insufficient sludge transport ability. In a process with longer sludge age for nitrogen removal, an optimized sludge transfer facility could also achieve a rapid sludge removal and a more concentrated sludge blanket, thus quickly returning the biomass into clarifiers for a more stable process operation.

The efficiency of sludge collection/withdrawal facilities is also dependent on clarifier

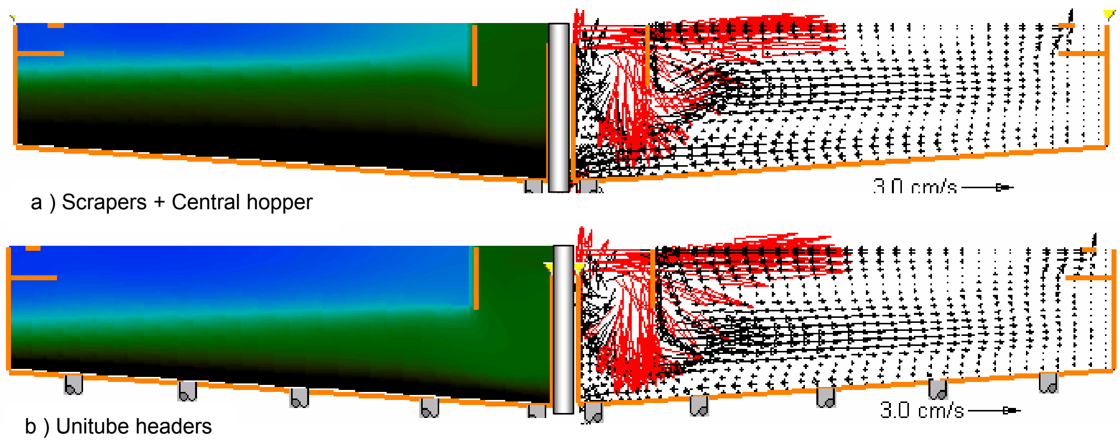


Figure 13 Impact of sludge withdrawal facilities on sludge blanket

floor slopes. For a specified clarifier configuration and the process conditions, an optimized sludge withdrawal facility could be obtained by comparing sludge compression/withdrawal efficiencies between different alternatives.

5.1 Scrapers and Center Sludge Withdrawal Hopper

As shown in Figure 13(a) the model prediction uncovers the mechanism of sludge compression/withdrawal process for the clarifiers equipped with sludge collection scrapers combined with a center sludge withdrawal hopper. The sludge withdrawal efficiency is proportional to the sludge inventory in clarifiers. The design alternative provides a better sludge withdrawal efficiency when the clarifier operations hold enough amount of sludge inventory. It shows a relatively weak ability to control solids inventory rising up during a flow increase period because of its poor efficiency at the operation stages with a lower solids inventory.

5.2 Sludge Blanket Stratifications

Figure 13 shows the model predicted sludge reverse flow toward to the center hopper. It explains that the sludge transfer in this case is primarily dependent on the bottom slope and the sludge inventory. For the given bottom slope of 1/12, the strongest sludge reverse flow appears when the clarifier operation accumulates the highest solids inventory.

As shown in Figure 13, the sludge blanket can be divided into two layers, i.e. a highly concentrated layer and a dispersed sludge layer in which the sludge has a solids concentration less than the influent MLSS. The sludge concentration often exceeds 10,000 mg/L near the bottom of concentrated sludge layers. The model revealed sludge blanket stratification can be confirmed by the field measurement data presented in Figures 14. As shown in the figure, depth of the dispersed sludge layer is significant because of the peak flow conditions during the field test. The well concentrated sludge layer has a thickness of approximately 3 feet.

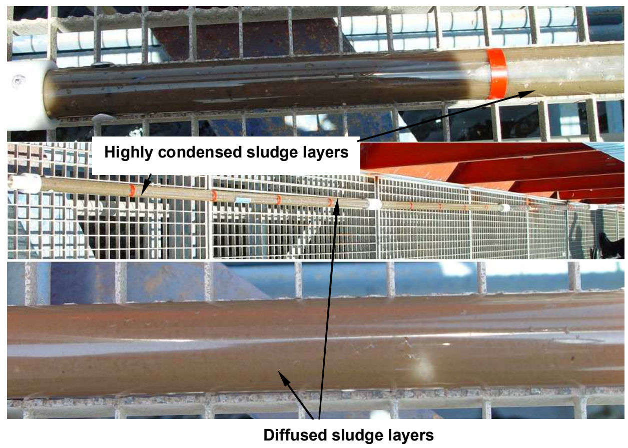


Figure 14 Sludge blanket stratifications

5.3 Rotational Unitube Headers

There is another sludge collection facility commonly used in recent years[2]. In principle, the tested rotational unitube headers collect and withdraw sludge along the entire clarifier diameter thus they could avoid sludge dilution in the operations with less sludge inventory.

Using the rotational unitube headers the concentrated sludge layers in Figures 13 are substantially lowered in comparison with that in clarifiers equipped with scrappers and a center hopper. The tested rotational unitube header was able to quickly return solids inventory back into the bioreactors since the unitube header design with evenly space orifices significantly lowers the dilution risk within the sludge compression layers. The detailed modeling results conclude that the application of rotational unitube headers in secondary clarifiers is an effective approach in terms of controlling the concentrated sludge blanket layers.

Using the rotational unitube header the dispersed sludge layers in Figure 13(b) is similar to that in the clarifiers equipped with the first alternative presented in Figure 13(a). The direct impact of the tested rotational unitube header on the dispersed sludge layers, in which the sludge concentration is less than the influent MLSS, is limited. The modeling

[2] as exemplified by USFilter's Tow-Bro® collectors

results illustrate not only a fast sludge compression and withdrawal process but also a consistent higher sludge draw-off concentration in the clarifiers using tested rotational unitube header. The simulation results can be confirmed by many field tests conducted by the vendor in recent years.

6 Conclusions

As the examples illustrated here, a well developed clarifier modeling technology is a powerful tool to help process design engineers and clarifier manufacturers in following aspects:

1. Troubleshoot existing clarifiers and related process operations
2. Evaluated clarifier design under the specified process conditions
3. Develop reliable retrofit alternatives with the best cost-effectiveness

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