New flocculation centre well design for circular final clarifiers at Tai Po Sewage Treatment Works

(Environmental Engineering)

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Abstract

In year 2012, the Drainage Services Department has adopted the new flocculation centre well (FCW) design for two circular final clarifiers at Tai Po Sewage Treatment Works. In the existing FCW design, the suspended solids and foam may accumulate and float inside the FCW under the condition of high sewage inlet flow rate and hence this may affect the suspended solids (SS) level in effluent. In this paper, with the assistance of the computational fluid dynamic (CFD) modelling, flow patterns and suspended solids distribution under the existing and new FCW design were simulated and analyzed in different aspects. The findings from the modelling were summarized for finalized the new FCW design. The subsequent testing of new design was carried out in December 2012 and January 2013 respectively. The data collected in the testing provided a complete picture of the effectiveness of the new FCW design such that the experience on design procedure and testing of new FCW design could be shared.

Secondary Treatment

Tai Po Sewage Treatment Works is a secondary sewage treatment works. Sewage arriving the inlet works is preliminarily treated by mechanical bar screens to remove solids. After screening, the screened sewage is then directed to detritors for removal of grits.

In primary sedimentation tanks, the settleable solids and scum in the preliminarily treated sewage are collected and removed as primary sludge by sludge scraping mechanisms. The settled sewage from the primary sedimentation tanks is then passed to the aeration tanks for biological treatment. At the aeration tanks, the modified Ludzack-Ettinger (MLE) activated sludge process was used.

The treated sewage then passes to final clarifiers which solid-liquid separation will take place. After final sedimentation, the treated sewage or effluent will be conveyed to a pumping station and pumped out through the effluent export tunnel. The flowchart of secondary sewage treatment process at Tai Po Sewage Treatment Works is shown in the Figure 1.

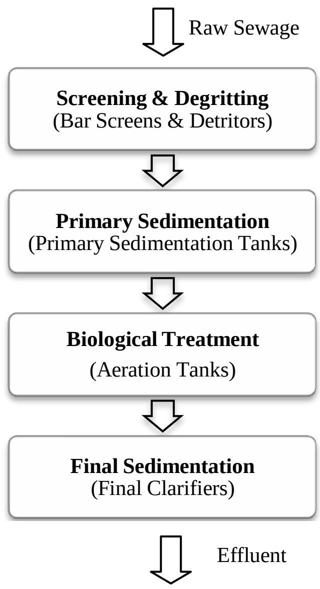


Figure 1 - Flowchart of secondary sewage treatment process at Tai Po Sewage Treatment Works.

Existing Final Clarifier

All the existing circular finial clarifiers in Hong Kong public sewage treatment works operated by the Drainage Services Department are adopted the central sewage inlet design. The general arrangement of this design at Tai Po Sewage Treatment Works is shown in the Figure 2 below.

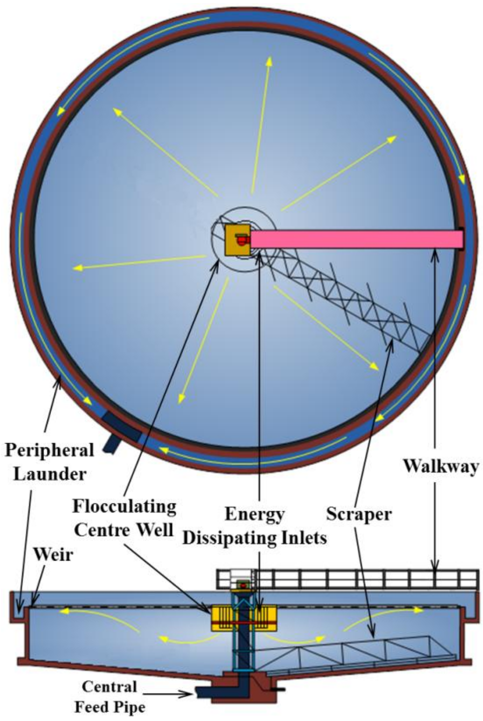


Figure 2 - Sewage flow direction and general arrangement of circular final clarifier for final sedimentation process.

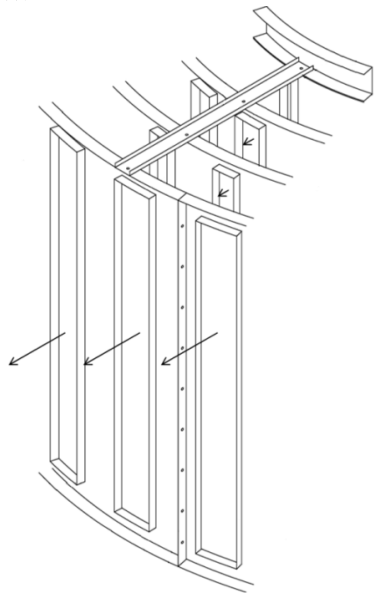
The treated sewage flows into the final clarifier through a central feed pipe, the energy of inlet sewage is first dissipated by the four layer energy dissipating inlets (EDIs), and then the sewage flows downward from the flocculation centre well (FCW). The bottom sewage current flows along the bottom of the final clarifier towards the end wall direction and then turns upward and over the weir and enters into the peripheral launder while the sludge is settled out at the bottom of the final clarifier and removed by scraper. [1]

Existing Flocculation Centre Well Design

In the existing FCW design, the four layers of energy dissipating inlets were separately installed inside the FCW. The general arrangement is shown in the Figure 3.

Figure 3 - General arrangement of existing flocculation centre well design (outside) and four layer of energy dissipating inlets at Tai Po Sewage Treatment Works.

The FCW and EDIs are designed to provide better hydraulics performance of flow into the final clarifiers and prevent short circuiting from happening at final clarifiers. In the daily operation, both FCW and EDIs can effectively control the inlet current where it is being developed at the final clarifier during the final sedimentation process. When the treated sewage passes through the EDIs and the subsequent FCW of final clarifier, the energy from the high turbulence flows from the inlet zone (central feed pipe) will be dissipated. The Figure 4 showed the flow direction of treated sewage across the four layers of EDIs before reaching the FCW.



Isometric View of Energy Dissipating Inlets

Figure 4 - Enlargement of four layers of energy dissipating inlets (EDIs) and sewage flow direction across them.

Foaming Problem

The existing EDIs and FCW design can dissipate the energy of inlet treated sewage from central feed pipe and separate the sludge from treated sewage very effectively. However, this design may cause foam accumulation problem in daily operation. According to operation experience and records, due to a major portion of kinetic energy of treated sewage from central feed pipe being dissipated by the four layers of energy dissipating inlet, the sewage then flow at very low velocity and hence the suspended solids and foam always accumulated and floated inside the energy dissipating inlets and flocculation centre well and this may affect the suspended solids (SS) level in effluent.

Figure 5 - Suspended solids and foam were accumulated and floated inside the energy dissipating inlets and flocculation centre well respectively.

In order to cope with this problem, a spray system was installed at the top of the FCW. By using the high pressure water sprays from the pump, foam was fluidized with sprays and forced below the surface.

Figure 6 - Foam was fluidized with sprays and forced below the surface.

New Flocculation Centre Well (FCW) Design

In order to improve the existing design, the study regarding of new FCW design was initiated in 2009. First of all, we make use of the existing FCW design at Tai Po Sewage Treatment Works to carry out the Computational Fluid Dynamics (CFD) modelling in order to determine the existing hydraulic enhancement features, sludge settling and flocculation characteristic. A number of similar studies [2] and [3] have been carried out before to investigate the sewage flow patterns and sludge distribution inside the final clarifiers.

CFD Modelling

Modification and optimization of new FCW design were obtained by using the CFD modelling. A 2-D CFD modelling namely High Accuracy Clarifier Model (HACM©) was used in this investigation. It can represent the physical sewage and solids movements of real sedimentation tanks and solve the differential equations of continuity, momentum, energy and mass transport. This CFD modelling was validated by application to over 30 primary and final clarifiers at different treatment plants.

During the design process, four conditions of FCW design were taken into consideration and CFD modelling was used for simulation. The table below is a summary of the four cases.

	Design	EDI	FCW Diameter	FCW Depth
Case 1	Existing	×	8.8 m	2.6 m
Case 2	New	×	5 m	2.6 m
Case 3	New	×	5 m	3.8 m
Case 4	New	✓	5 m	2.6 m

Table 1 - The summary table of four cases simulated by CFD modelling.

In order to obtain more accurate data from the CFD modelling, the calibration of modelling is necessary. During calibration stage, the adjustable parameters were adjusted until the calculated and predicted suspended solids distribution and concentration were matched with the actual measurement. The similar approach was successfully implemented by Dahl et al. [4]. The calibration parameter values are shown as follow.

Effluent Flow Rate	: 114.0 L/s
Surface Overflow Rate	: 0.6 m^3/h
Return Flow	: 100 %
MLSS	: 2,780 mg/L
Measured Suspended Solids	: 17.5 mg/L

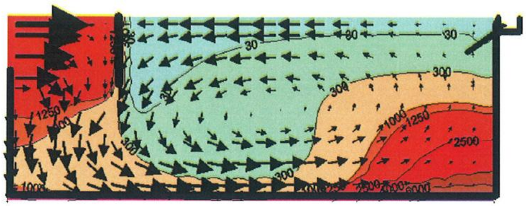
Predicted Suspended Solids	: 18 mg/L
Predicted Return Concentration	: 5,100 mg/L
Settling Parameters	
SVI	: 55 – 65 mg/L
SSVI	: 52 mg/L

In the following CFD analysis and figures, the results are based on the calibration parameters above. The size of the arrow and its direction in the figures indicates the velocity at the point corresponding to the tail of the arrow. In addition, coloring and iso-concentration lines indicate the suspended solids concentration and distribution.

The EDIs were left out of the calibration modelling because the high velocities exiting the ports in the central feed pipe are baffled with the gates of EDIs. A 2-D CFD modelling is very difficult to model EDIs without very many approximations. In this connection, the model is calibrated using the settling velocity equation by adjusting the settling parameters in the Takács equation [5]. The effect of EDIs is minimal since it doesn't affect the flow regime in the settling zone where the parameters are important.

Case 1 – Existing FCW with 8.8 m Diameter

The CFD modelling analysis result for flow pattern and suspended solids distribution under the existing FCW design of final clarifier at Tai Po Sewage Treatment Works is shown in the figure 7 below. In the figure, indicated that there is a bottom current downstream of the FCW, this bottom current flows along the bottom of the final clarifier to the end wall and then turns upward and overflow the weir to the peripheral launder.

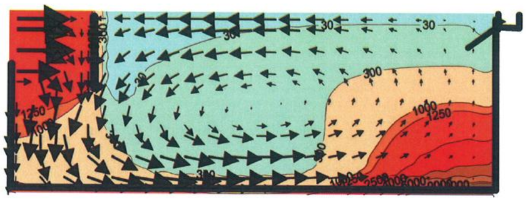


Effluent Flow Rate = 114 L/s Return Flow Rate = 114 L/s
Influent Flow Rate = 228 L/s
Effluent Concentration = 18 mg/L
Return Sludge Concentration = 5,100 mg/L

Figure 7 - Flow pattern and suspended solids distribution under existing FCW design.

Case 2 – New FCW Design with 5 m Diameter

In this case, the effect of installing a smaller FCW was investigated by the calibrated modelling. Instead of modelling by the flocculation and breakup equations, the G value distribution was used to determine the size of FCW. The smaller FCW with 5 m diameter and a depth of 2.6 m were used in the CFD modelling. As G value is the input to the flocculation model, it is an indirect way to look at the flocculation. Analysis results indicated that the smaller FCW would not change performance. The suspended solids of effluent would slightly increase from 18 mg/L to 18.5 mg/L only. This also proves that the FCW design with larger surface area or diameter does not provide any significant improvement over smaller FCW.

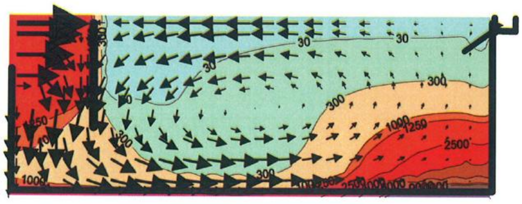


Effluent Flow Rate = 114 L/s Return Flow Rate = 114 L/s
Influent Flow Rate = 228 L/s
Effluent Concentration = 18.5 mg/L
Return Sludge Concentration = 5,111 mg/L

Figure 8 - Flow pattern and suspended solids distribution under smaller FCW design.

Case 3 – New FCW Design with 3.8 m in Depth

In this case, the effect of installing a deeper FCW was investigated by the calibrated modelling. The deeper FCW with 5 m diameter and depth of 3.8 m was used in the CFD modelling. Analysis results indicated that the deeper FCW would decrease the effluent suspended solids level. The suspended solids of effluent were lowered from 18.5 mg/L to 14.5 mg/L.

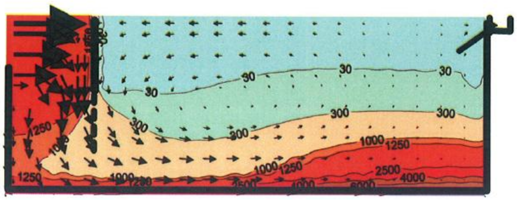


Effluent Flow Rate = 114 L/s Return Flow Rate = 114 L/s
Influent Flow Rate = 228 L/s
Effluent Concentration = 14.5 mg/L
Return Sludge Concentration = 5,198 mg/L

Figure 9 - Flow pattern and suspended solids distribution under deeper FCW design.

Case 4 – New FCW & EDI Design with 5 m Diameter and 2.6 m in Depth

In this case, the effect of installing a smaller and deeper FCW, equipped with Flocculating and Energy Dissipating Baffles (FEDB) were investigated by the calibrated modelling. The FEDB (1.58 m in depth) would be attached to the FCW, giving the FCW an overall dimension of 5 m diameter and depth of 4.18 m (2.6 m + 1.58 m) and these were used in the CFD modelling. The FEDB are perforated to allow liquor flowing through the perforation. Analysis results indicated that the 5 m diameter FCW with FEDB would decrease the effluent suspended solids level significantly. The suspended solids of effluent were lowered from 18.5 mg/L to 9 mg/L. This is mainly due to the FEDB reducing the strength of the bottom density currents leading to less uplifting of solids inside the setting zone.



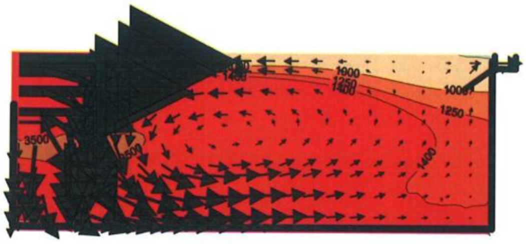
Effluent Flow Rate = 114 L/s Return Flow Rate = 114 L/s
Influent Flow Rate = 228 L/s
Effluent Concentration = 9 mg/L
Return Sludge Concentration = 5,220 mg/L

Figure 10 - Flow pattern and suspended solids distribution under new FCW design with FEDB.

Taking into consideration the four cases above, the flocculation centre well (FCW) with 5 m diameter and 2.6 m in depth equipped with Flocculating and Energy Dissipating Baffles (FEDB) was adopted as the new FCW design in view of the optimization of the sludge clarification performance.

Maximum Capacity of New FCW Design

The capacity of the final clarifier under the new FCW design with FEDB was investigated by the calibrated modelling. According to the capacity simulation result, the final clarifier installed with the new FCW design could handle effluent flows of up to 320 L/s. However, at this effluent flow rate, the blanket levels may be very close to the water surface of the clarifier. Therefore, the maximum capacity of final clarifier under the new FCW design was set to under 320 L/s.



Effluent Flow Rate = 320 L/s Return Flow Rate = 320 L/s
Influent Flow Rate = 640 L/s
Effluent Concentration = 34 mg/L
Return Sludge Concentration = 4,988 mg/L

Figure 11 - Flow pattern and suspended solids distribution under FCW design with FEDB.

Existing FCW Design and New FCW Design

In the existing design, the four layers of energy dissipating inlets were separately installed inside the FCW. However, in the new design, the EDIs were attached under the FCW, namely the Flocculating and Energy Dissipating Baffles (FEDB). The outlooks of existing and new FCW design are shown in the Figure 12 and Figure 13 respectively.

Figure 12 - Existing FCW design of Final Clarifier No. 2 at Tai Po Sewage Treatment Works.

Figure 13 - New FCW design with FEBD of Final Clarifier No. 12 at Tai Po Sewage Treatment Works.

Comparing to the existing FCW design of the final clarifier, the treated sewage in the new design flowing from the central feed pipe first flows to the FCW and then to the FEDB. The strength of sewage and bottom density was reduced a lot by the FEDB. As a result, there were mostly bottom density currents, leading to less uplifting of solids at the setting zone and finally removed by scraper.

14-Day Testing Period of New FCW Design

In order to compare the performance of existing and new FCW design for final clarifier. The 14-day comparative tests involving otherwise identical unmodified final clarifiers [6] were held in December 2012 and January 2013 at Tai Po Sewage Treatment Works respectively. An on-site laboratory was set up and equipped with the calibrated sampling apparatus to perform the bi-hourly sampling during the testing period. In

14-day testing period, 376 bi-hourly samples from on-site laboratory and 14 daily samples from The Hong Kong Laboratory Accreditation Scheme (HKOLAS) laboratory were taken.

Foam Accumulation

The 14-day testing period was divided into 2 sessions, dated 20 to 26 December 2012 and 4 to 10 January 2013 respectively. The reason for selecting two periods is due to the fact that foam is always forming at the low temperature condition according to past operation experience. Making reference to the Hong Kong Observatory records, the lowest temperature in two periods are 10.1˚C (24 December 2012) and 11.3˚C (4 January 2013) respectively. Referring to the site observation on these two days, no foam was found at the final clarifier with new FCW design, while some foam was still accumulated inside the EDIs and FCW under the existing design of final clarifier.

Figure 14 - No foam was observed at the final clarifier with new FCW design (24 December 2012).

Comparison on Suspend Solids Level

During the 14-day testing period, besides the new FCW design, the data from existing FCW design of final clarifier were also be collected. Figure 15 and Figure 16 show the effluent suspended solids level between the existing and new FCW design of final clarifier at the same instant flow rate measured by the on-site laboratory in 14 days testing period.

In the two figures, the suspended solids in effluent under the new FCW design was slightly lower than the existing FCW design at the same instant flow rate most of time during the 14-day testing period in December 2012 and January 2013.

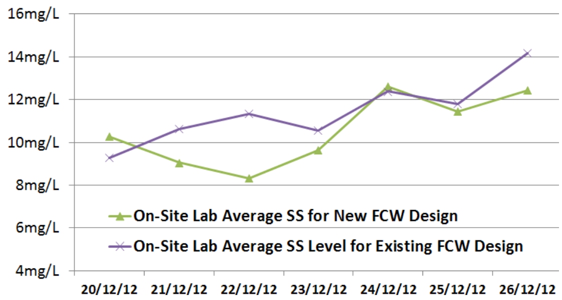


Figure 15 - The comparison of effluent suspended solids level between the existing and new FCW design of final clarifier at the same instant flow rate in December 2012.

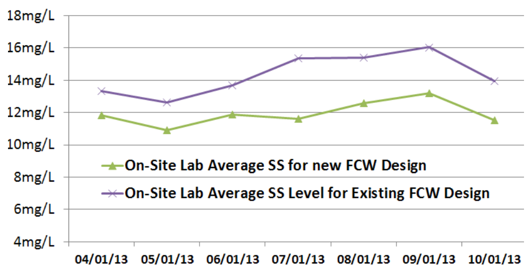


Figure 16 - The comparison of effluent suspended solids level between the existing and new FCW design of final clarifier at the same instant flow rate in January 2013.

Verification of the Improved Design

According to 188 bi-hourly sample results of suspended solids in effluent under the new FCW design from the on-site laboratory, 66 samples (35%) had effluent suspended solids level below 10 mg/L and about half of the samples are below 11 mg/L at the design treated sewage inlet flow rate. The results are summarized in the Table 2.

Effluent Suspended Solids	No. of Sample	Percentage
Less than 10 mg/L	66	35%
10 mg/L - 11 mg/L	25	13%
11 mg/L - 12 mg/L	20	11%
12 mg/L - 13 mg/L	23	12%
13 mg/L - 14 mg/L	9	5%
14 mg/L - 15 mg/L	15	8%
Larger than 15 mg/L	30	16%
Total	**188**	**100%**

Table 2 - Level of suspended solids in effluent under the new FCW design measured by on-site laboratory.

Furthermore, the 14 daily samples results of suspended solids in effluent under the new FCW design from HKOLAS laboratory showed very similar result compare with the on-site laboratory. Over 50% of the daily results obtained had suspended solids level in effluent below 11 mg/L. The mean and standard deviation of effluent suspended level in these 14 samples are 10.4 mg/L and 2.35 mg/L respectively.

Effluent Suspended Solids	No. of Sample	Percentage
Less than 10 mg/L	4	29%
10 mg/L - 11 mg/L	4	29%
11 mg/L - 12 mg/L	3	21%
12 mg/L - 13 mg/L	2	14%
13 mg/L - 14 mg/L	1	7%
Total	**14**	**100%**

Table 3 - Level of suspended solids in effluent under the new FCW design measured by HKOLAS laboratory.

The suspended solids level from on-site and HKOLAS laboratories are both about 10 mg/L which is matched with the predicted result (9 mg/L) from the CFD modelling under the new design. It verified that the results from CFD modelling in simulating the suspended solids level at the new FCW design of final clarifier are satisfactory.

Finally, we have compared the performance of existing and new FCW design at the same instant flow rate measured by on-site laboratory during the 14-day testing period. 188 samples were taken from existing and new FCW respectively, and it was found that the effluent suspended solids levels under the new FCW design are relative lower than the existing design.

Effluent Suspended Solids	Existing FCW Design	New FCW Design
Less than 10 mg/L	21%	35%
10 mg/L - 11 mg/L	13%	13%
11 mg/L - 12 mg/L	9%	11%
12 mg/L - 13 mg/L	13%	12%
13 mg/L - 14 mg/L	9%	5%
14 mg/L - 15 mg/L	11%	8%
Larger than 15 mg/L	26%	16%
Total	**100% 188 Samples**	**100% 188 Samples**

Table 4 - Distribution of suspended solids in effluent under the existing and new FCW design at same instant flow rate measured by on-site laboratory.

Parallel Comparison

Hany and Alex [7] have stated that it is better to conduct a parallel comparison between modified and unmodified clarifiers as it is the most accurate technique for verification of effect of modifications. Therefore, beside the comparison on level of suspended solids mentioned above, a set of parallel test data during the 14-day testing period are shown in the table below for comparison.

	Modified Final Clarifier	Unmodified Final Clarifier
Effluent Flow Rate	184.5 L/s	114 L/s
Surface Overflow Rate	0.5 m/h	0.6 m/h
RAS Flowrate	155 L/s	114 L/s
Influent Flowrate	339.5 L/s	288 L/s
Effluent TSS	11 mg/L	18 mg/L
RAS Concentration	5,235 mg/L	5,100mg/L
Feed ML Concentration	2,610 mg/L	2,780mg/L
SVI	178 mg/L	65 mg/L
SSVI	97 mL/g	52 mL/g

Table 5 - Parallel test data showing the comparison between modified and unmodified final clarifiers.

Conclusions

In this paper, I carefully examined the measured data collected from the final clarifiers with the existing and new flocculation centre well design. The suspended solids in effluent between the existing and new FCW design was mainly studied using a rigorous analysis method and the following conclusions were made.

The new flocculation centre well design for circular final clarifiers at Tai Po Sewage Treatment Works had reduced the frequency of suspended solids and foam accumulation at energy dissipating inlets. During the 14-day testing records and observations, it was proved that under the same sewage instant flow rate, a small amount of suspend solids and no foam were found at the final clarifier installed with the new flocculation centre well design, however at the same time, obvious suspended solids and foam floated inside the energy dissipating inlets under the existing flocculation centre well design. In addition, the performance in suspended solids settling is relative better under the new FCW design during the 14-day testing period.

According to the 376 bi-hourly sample results from on-site laboratory and 14 daily sample results from HKOLAS laboratory, it was found that the treated sewage and sludge are separated effectively at different flow rates in the final sedimentation process under the new flocculation centre well design.

The new flocculation centre well design with 5 m diameter and 2.6 m in depth equipped with Flocculating and Energy Dissipating Baffles (FEDB) mentioned in Case 4 above can eliminate the problem of formation and accumulation of foam and in addition, it can provide lower effluent suspended solids level in daily operation compared with existing FCW design at different flow rate. Therefore, this new design is effective for circular final clarifiers in the final sedimentation process.

The CFD modelling used in this investigation has a subroutine that applies the flocculation breakup and aggregation equations. If these equations had been incorporated into the CFD modelling on both existing and new final clarifiers with the smaller FCW radius, the results would have been very close because the G value is used to size the FCW which is like using the flocculation breakup and aggregation equations.

On the basis of this test and findings, four more existing final clarifiers at Tai Po Sewage Treatment Works will be modified to conform to the new design. The modification works would be commenced in September 2013 and the four modified final clarifiers would be put into operation in March 2014.

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