Agreement Nos. HATS 02/2014 & HATS 03/2014

Study of Optimization of Dosage Control for Disinfection Facilities of HATS

and

Physical Scale Model Test for Chlorine Disinfection Facility of HATS

Executive Summary

The main objective of the studies is to unravel the causes of any inefficiencies of the Harbour Area Treatment Scheme (HATS) Advance Disinfection Facilities (ADF) system - in relation to both chlorine injection and mixing, and the chlorine consumption by various organic and inorganic substances in the sewage - and make recommendations to optimize the HATS ADF and Stage 2A disinfection operations.

Since March 2010 the Chemically Enhanced Primary Treatment (CEPT) effluent at the Stonecutters Island Sewage Treatment Works (SCISTW) had been disinfected by chlorination in the HATS ADF. The treated effluent from the sedimentation tanks entered a flow distribution chamber (FDC) via two inlet culverts. Sodium hypochlorite solution (10% w/w; relative density 1.2) was discharged into the CEPT effluent flow in the form of dense jets from two dosing units mounted in the FDC. The mixed flow passed over an inclined weir (1.8 m high) in the FDC and flowed into a twin box culvert that led to the downstream system. The average effluent flow was about 16 m^3/s; the chlorine dosing flow was 2-3 L/s. Full mixing of the chlorine solution with the effluent flow would result in a Total Residual Chlorine (TRC) concentration of around 20 mg/L for the maximum chlorine dosing flow. However, in view of the huge disparity of the effluent to dosing flows (a ratio of 5,000 to 10,000), a certain distance would be required before the chlorine jets can be sufficiently mixed over the channel cross-section. The 950 m long twin box culvert between Chamber 9 and Chamber 15 serves as a chlorine "contact tank" to provide sufficient contact time (10-20 minutes) for the bacterial kill. It was expected that most of the chlorine dosage would be used for inactivation of pathogens, and the *E. coli* concentration of the disinfected effluent would meet environmental regulations before discharge to the receiving water via a submarine outfall.

HATS Stage 2A has been commissioned in December 2015 with the current daily flow rate of about 1.9 million m^3/d, and the ultimate flow is 2.45 million m^3/d. The Final Disinfection Facilities (FDF) of HATS Stage 2A, based on the same design concept, has replaced the twin box culvert used in the ADF by the new effluent tunnel which could provide chlorine contact time of at least 30 minutes.

The works and model studies that have been conducted under the present studies included:

- Review of in-plant effluent quality data, sewage treatment and disinfection processes.
- A full scale experiment for half of the ADF dosing unit to study the jet discharges and relative dosing flows between the lower and upper pipes.

- Bench scale flume experiments in the chemical laboratory of SCISTW to obtain a preliminary understanding on the mixing and chemical reaction of chlorine with CEPT effluent using prototype chlorine dose.
- A special hydraulic model of the 1:2 FDC model, including the head tank and the upstream portion of the test flume (up to the weir) to develop the optimal design of the baffle configuration and to test the performance of the head tank.
- A 1:2 scale physical model built at the SCISTW site to study the chlorine demand in the FDC under Agreement No. HATS 03/2014.
- 1:20 physical model study for the flow distribution chamber for both HATS ADF and Stage 2A disinfection facility to examine the flow circulation and mass transport resulting from the different designs of the mixing chamber configurations.
- Field trial of reduced chlorine dosage based on the daily tidal form undertaken from December 2014 to February 2015 to assess the performance of this optimal chlorine dosing strategy.

In-plant and Laboratory Study of the Effluent Quality and Chlorine Demand

A review of the available in-plant effluent quality data as well as field and laboratory data has been conducted to study the correlation between the chlorine dosage level and key variables in the treatment processes. It is found that for the ADF system, the effluent *E. coli* level at Chamber 15 is very often well above 2,000,000 counts/100mL (over 73% of the samples) if the chlorine dosage is ≤ 8 mg/L. For chlorine dosage above 16 mg/L, more than 3-log kill is achieved in about 61% of the samples during the winter seasons. Also, it is noted that poorer disinfection efficiency (higher *E. coli* concentration at Chamber 15) is associated with higher temperature.

On-site monitoring of TRC and sulfide at various locations in SCISTW is conducted from May to July 2014 to examine the chlorine demand and sulfide generation in the CEPT treatment processes. In general, most chlorine demand comes from the substances present in the original sewage; during treatment processing, the demand is NOT increased; instead, it is somewhat reduced due to the removal of suspended solids from sewage. When the influent is pumped into the plant, it already contains a high level of chlorine demand from about 8 to 11 mg/L, while the observed chlorine demands in the CEPT effluent are found to range approximately from 5 to 9 mg/L. Also, the sulfide level in sewage does not increase during the treatment processing. The observed sulfide levels are in general less than 0.3 mg/L and those for the CEPT effluent are below 0.1 mg/L. In view of the low sulfide levels measured in the CEPT effluent, chlorine demand by sulfide is judged insignificant.

In-situ TRC measurements and beaker tests in May-June 2014 are carried out to determine the chlorine demands in the CEPT effluent. The monitoring results show that there are significant differences of TRC between samples well mixed with chlorine and those sampled at Chamber 15. The field observations suggest that most of the chlorine consumption and disinfection has already taken place before Chamber 9, and the twin box culverts do not seem to play a critical role as “contact tanks” in the disinfection process. A series of beaker tests are conducted to study the induced chlorine demands in response to the dosed chlorine concentration and it is found that the higher the chlorine concentration, the greater the chlorine demand.

1:2 Scale Physical Model Tests

The model is constructed inside the SCISTW, on the roof top above and between the sedimentation tanks No. 32 & 34. The 1:2 physical model simulates a 1/16 width slice of the FDC flow; the width of the model test section is 0.22 m. For a maximum chlorine dosing flow of 3.0 L/s at 10% concentration (w/w), and a flow ratio of 5.657, the corresponding dosing flow in the model would be about 0.033 L/s. In practice, the experiments are carried out around a dosing flow rate of 20 mL/s. Under a design model effluent discharge flow of 0.1 m^3/s, the chlorine dosage is then about 20 mg/L which is approximately equal to the dosage used in the prototype. In essence the model is an analog of an idealized "slice" of the FDC with a length of 5 m (i.e. to the center of the inclined weir).

The model consists of an inflow head tank, a flume test section, and a collection chamber with two outflow tanks. The main body of the model is fabricated from stainless steel and aluminum, with 17 mm thick double-layer glass panels for flow visualization and observation on both sides of the flume. In steady operation a maximum CEPT effluent flow of 100 L/s is drawn from sedimentation tank no. 32 into the inlet tank equipped with diffuser manifolds and an inlet baffle for uniform flow distribution. The free surface CEPT effluent flow then enters the 0.22 m wide flume via a smooth rounded entrance. A chlorine dosing device is located 0.88 m downstream of the entrance. The chlorine dosing unit has one upper and one lower port, with diameter of 5mm and 2.5mm respectively. The two dense jets issuing from the ports are discharged into the ambient effluent flow. The turbulent jet mixing between the high concentration chlorine solution and the crossflow results in rapid dilution; chlorine is also consumed by chemical reaction among the constituents of the dosing solution and the effluent.

The partially chlorinated CEPT effluent then flows over a 0.9 m high weir plate installed at a distance of L_w = 2.5m from the dosing unit. The chlorinated CEPT effluent flow flows over the weir like a free overfall plunging into the downstream pool. The flow depth downstream of the weir plate can be controlled by two side weirs in the collection chamber. The CEPT effluent flow is returned to the sedimentation tank no. 32 through the two outlet tanks.

Model experiments with CEPT effluent centered around four key sets of nominal conditions based on the effluent flow, chlorine dosage flow and the source chlorine concentration. For each nominal experimental condition, a full set of measurements of the TRC and bacteria concentration profile, and other water quality parameters at key locations in the FDC is made. Due to the limited size of the chlorine storage tank, a daily supply of around 500 L of sodium hypochlorite solution would allow only a few profiles to be measured. A complete set of measurements for an "experiment" hence requires several days to complete - often interrupted by adverse weather conditions (e.g. heavy rainfall).

In each experiment, TRC profiles are measured in situ at different cross sections. In selected experiments, *E.coli* and enterococci concentrations are measured at upstream of the dosing unit (composite sample), above the weir (15 points), downstream of the weir (composite 236 sample) and the outlet tank of the model (grab sample) respectively. Water quality parameter analysis are carried out also for the experiments with bacterial measurement.

Besides using the 10% sodium hypochlorite (NaOCl) solution, extensive experiments with different source concentrations (5%, 2.5% and 1.25% NaOCl) are conducted to study the feasibility of pre-diluting the 10% hypochlorite solution. Also, a series of beaker tests have been performed to study the chlorine demand when CEPT effluent is used to dilute the 10% NaOCl solution.

Dosage Reduction Based on Daily Tidal Conditions

The daily water quality of Tsuen Wan beaches in Hong Kong is highly dependent on the tidal conditions. To better utilize the natural assimilative capacity, a dosing optimization strategy based on a daily tidal form factor has been developed and tested. For the days with diurnal tides ($F_d > 1$), whole day reduction of chlorine dosage (below the standard dosage). For the days with mixed tides (F_d is between 0.5 and 1.0), a 6-hour period reduction starting 6.5 hours before the Lower Low Water (LLW); and for days with semi-diurnal tides ($F_d < 0.5$), no dosage reduction. Field surveys and 3D hydrodynamic models have been employed to study the effectiveness of the chlorine dosage reduction. Both the field observations and model predictions confirm that with carefully planned dosage reduction, the water quality at the Tsuen Wan bathing beaches would still meet the Water Quality Objectives. Savings of 30-40% of volume of chemicals (about 40-50 m^3/d) with respect to the averaged non-bathing season dosage of 12 mg/L could be achieved.

The 3D flow model is not needed for the implementation of the proposed dosing optimization strategy. `The preparation of the dosing plan only requires the daily tidal form factor and the time of LLW which can be computed using the well-established tidal constituents (harmonics) in Victoria Harbour.

Main Findings & Recommendations

The main findings and recoomendations arised from the two studies include:

1. Jet mixing of the sodium hypochlorite solution with the CEPT effluent co-flow achieves a rapid dilution in the order of 1,000-2,000 in the FDC. This high dilution however falls short of the value required to achieve full mixing (i.e. a dilution of 5,000-10,000). Approximately 60-80% of the effluent flow over the FDC weir is chlorinated.

2. Approximately 70-80% of the chlorine mass flux is consumed within a very short distance (0.5-1 m, or a matter of several seconds) from the chlorine dosing unit, well upstream of the weir. Only a small fraction of the expected average concentration can be measured in the effluent outflow from the FDC.

3. No settling and accumulation of sodium hypochlorite solution or organic solids in the FDC has been observed in the model.

4. There is a direct local correlation between TRC and *E. coli*. Overall there is a one-log *E. coli* kill above the weir, within a short travel time of about 7-10s from the chlorine injection. After immediate chlorine demand is satisfied, the residual (> 1.5 mg/L) can effectively disinfect the effluent by 2-log kill within contact time of about 5 minutes.

5. The chlorine demand appears to be accompanied by a decrease in ammonia nitrogen of around 4 mg/L.

6. By pre-diluting of 10% NaOCl dosing solution to 2.5%, it is found that it is possible to reduce the chlorine demand by 10-20%.

7. The use of alternative mixing devices cannot provide sufficient rapid mixing capacity required to compensate for the almost instantaneous chemical reactions between the high concentration NaOCl dosing solution and chlorine-demanding substances in the sewage.

8. From the experiments, it is found that with TRC concentration of ~1.0 mg/L at the outflow from the FDC, a 2 log10 *E. coli* kill can be achieved with a contact time of 5 minutes, so it should be aimed to maintain a TRC level around 1.0 - 1.5 mg/L at the downstream end of the FDC before entering into the drop shaft.

9. The initial beaker tests suggest that it is feasible to pre-dilute the 10% NaOCl solution with CEPT effluent instead of tap water.

10. To better utilize the natural assimilative capacity, a dosing optimization strategy based on a daily tidal form factor has been developed and tested.