RD2079 Demonstration-scale trial of SANI process in Shatin Sewage Treatment Works

Executive Summary

Large-Scale Study on Realization and Application of SANI® Process in Sewage Treatment in Hong Kong

Prepared by

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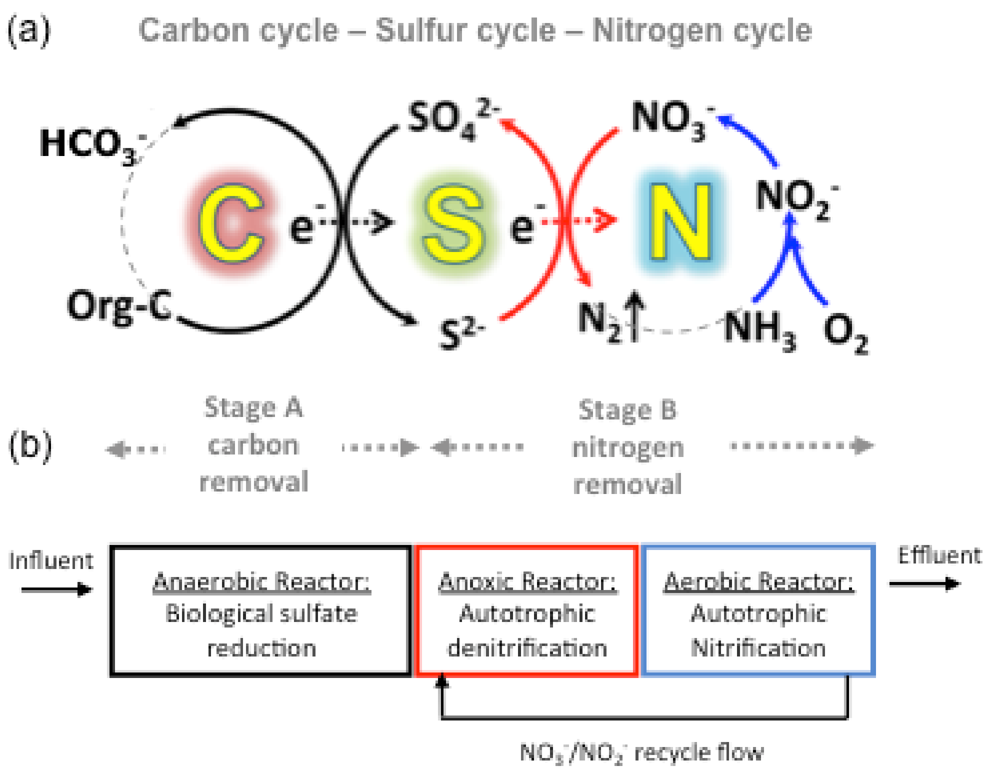
Introduction

Hong Kong has used seawater for toilet flushing (SWTF) since 1950s resulting in a considerable reduction in portable water demand. To extend and integrate the benefit of SWTF practice, the Hong Kong University of Science and Technology (HKUST) developed an innovative biological organic carbon and nitrogen removal process for treatment of saline sewage produced from SWTF, which is named "Sulfate Reduction, Autotrophic Denitrification and Nitrification Integrated process (SANI® process)", as depicted in Exhibit 1 below.

EXHIBIT 1

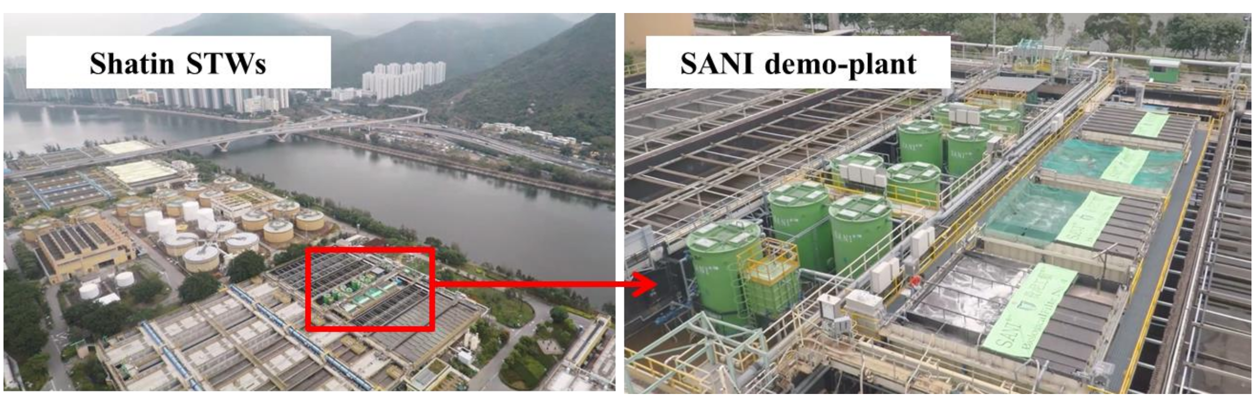


The SANI® process consists of two reactors: Sulfate Reducing Upflow Sludge Bed (SRUSB) reactor followed by a second Biofilm reactor with anoxic zone(s) and aerobic zone(s). The

SRUSB reactor is designed to make use of sulfate (originating from seawater) in the sewage for oxidation of organic carbon into carbon dioxide (dissoves as bicarbonate) and production of dissolved sulfide by sulfate reduction bacteria under anaerobic conditions. In the second Biofilm reactor, the anoxic zone(s) is designed for autotrophic denitrification of nitrate with dissolved sulfide produced in SRUSB reactor to produce harmless nitrogen gas through oxidation of sulfide back to sulfate ion and the aerobic zone(s) is to nitrify ammonia to nitrate, which is recirculated to the anoxic zone for denitrification. Since all three biochemical reactions involved in the SANI® process have very low sludge yield, the sludge production rate is much less than that produced by conventional secondary biological treatment. It effectively reduces the costs, energy and space for sludge handling and disposal.

With the support from the Innovation and Technology Fund and the Drainage Services Department (DSD), a 1,000 m^3/day SANI demo-plant study on saline sewage treatment on the application of SANI® process commenced on 18 March 2013 for a period of 2 years at Shatin Sewage Treatment Works (STSTWs) as depicted in Exhibit 2 below.

EXHIBIT 2



Objectives

The major objectives of this study are:

- To develop a set of full-scale SANI sewage treatment plant design criteria, in particular process design, reactor design and hydraulic flow conditions;
- To develop a mathematical SANI® process model for optimization of full-scale applications;
- To gain extensive operation know-how of the SANI® process and the sulfate-reducing bacteria (SRB) granular sludge reactor; and
- To demonstrate and confirm the plant performance, sludge reduction efficiency and saving on costs, space and energy.

Key Tasks and Programme

Since commencement in March 2013, the key tasks untaken in this study include:

- Pilot plant studies, comprising reactor design, site selection and investigation, environmental review, contract administration, procurement, construction, supervision, optimization studies, data analyses, and reporting; and
- Process wastewater quality monitoring including performance tests of process trains; compliance tests of discharge effluent quality. All sampling, preservation and testing of samples, shall be carried out in accordance with Standard Methods for Examination of Water and Wastewater published by American Public Health Association (Standard Methods) or other testing methods approved by the Engineer.

The key milestone events and dates are given in Exhibit 3 below.

EXHIBIT 3

	Tasks / Deliverables	Date
1	Project commencement	Mar 18, 2013
2	Design and tendering	Mar 18, 2013 – Dec 27 2013
3	Construction	Aug 1, 2013 – Jul 9, 2014
4	Plant comissioning, startup and optimization	Jul 17, 2014 – Nov 18, 2014
5	Steady-state operation (constant flow, 3 months)	Nov 19, 2014 – Feb 13, 2015
6	1st 4-days Intensive sampling & analysis	Feb 9, 2015 – Feb 13, 2015
7	Dynamic operation (diurnal flow, 1 month)	Feb 14, 2015 – Mar 13, 2015
8	2nd 4-days Intensive sampling & analysis	Mar 9 – Mar 13, 2015
9	3rd 4-days Intensive sampling & analysis (system demonstration)	Mar 13 – Mar 17, 2015
10	Completion of the project	Mar 17, 2015

SANI-Demo-Plant

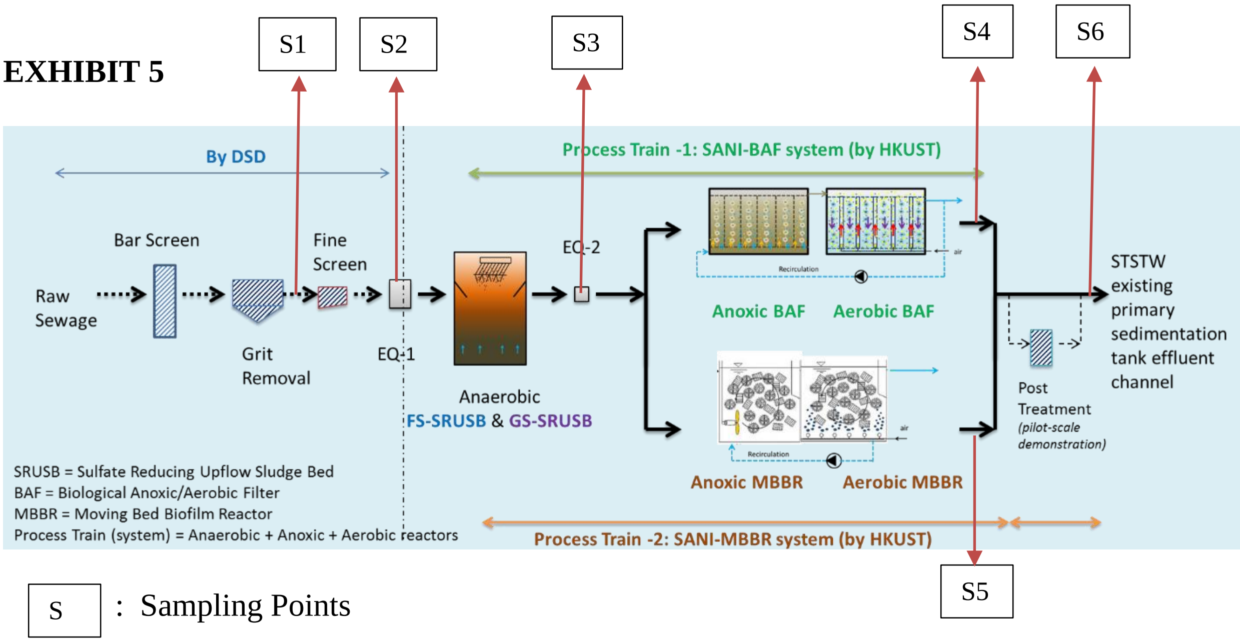
The SANI Demo-Plant was configured to combine different reactor designs as shown in Exhibit 4 to study their performance with a view to selecting the most suitable reactor / process train on the application of SANI® process. The process flow diagram was presented in Exhibit 5. The raw saline sewage at the inlet works of STSTW was preliminarily treated by 6 mm mechanical bar screens and grit removal chamber. The sewage was further passed through a Salsnes Filter with mesh size of 350 µm, which was installed and operated by DSD to remove around 30% of the suspended solids (SS). The screened sewage was then pumped to the SANI demo-plant for start-up, commissioning and operation. The process wastewater monitoring at 6 resprentative locations (namely S1-S6) were conducted to monitor the performance of the SANI Demo-Plant. The number of sampling points for monitoring depends on the type of process train adopted.

EXHIBIT 4

Stage	Biological Reactors / Process Trains	Reactor Size
Stage A **(Organic carbon removal)**	(1) Flocculent-sludge based SRUSB reactors (FS-SRUSB)	Diameter: 3.5 m Height: 5 m
	(2) Granular-sludge based SRUSB reactor (GS-SRUSB)	Diameter: 3.5 m Height: 5 m
Stage B **(Nitrogen removal)**	(3) Submerged Anoxic/aerobic Filter (SAF) reactors	8 m (W) x 7m (L) x 4 m (D)
	(4) Moving Bed Biofilm Reactor (MBBR)	8 m (W) x 7m (L) x 4 m (D)
Process Train	(1) SRUSB reactor + SAF reactor	
	(2a) SRUSB reactor + MBBR	
	(2b) SRUSB reactor + MBBR + Post Treatment[1]	

1. Post treatment is a pilot-scale tank to treat 25 m^3/d of MBBR effluent as a demonstration of final clarification and phosphorus removal.

EXHIBIT 5



Technical Performance and Findings

● Start-up / Commissioning of the Reactors

SRUSB reactors were seeded with anaerobic digester sludge while SAF and MBBR reactors were seeded with activated sludge. After sludge seeding, the SANI demo-plant was started-up with the fine screened sewage. The parameters, namely COD, SS, pH, alkalinity, ammonia, nitrate, sulfate, and sulfide concentrations in the influent and effluent of all reactors, and reactor biomass (MLSS and MLVSS) concentrations in the reactors were monitored weekly during the start-up period. Upon confirmation of satisfactory treatment of the sewage, the reactor loading was increased gradually based on a stepwise approach to the design flow rate of 1000 m^3/d in 4 months. The average operating sewage temperature was 29 ºC during the commissioning.

During the commissioning period, 4 SRUSB reactors were operated as the main reactors. The HRT of the SRUSB reactors were gradually reduced to 4.5 h while the OLR was gradually increased to 1.7 - 2 kg COD/m^3/d. The 4 SRUSB reactors were operated in the form of flocculent-sludge (FS). At the end of the commissioning period, the average organic carbon and TSS removal rate were 71 ± 11.5 % and 70 ± 13.6 %, respectively.

In respect of 2 types of Biofilm reactors, the performance of SAF reactor and MBBR were found to be different. For SAF reactor, it was operated smoothly for 1 month at about 200 m^3/d with HRT of 25 h and the effluent ammonia nitrogen level was below 2 mg N/L. Then the performance of the BAF reactor deteriorated afterwards, with a very high level of ammonia nitrogen in the effluent. As a result, the SAF reactor was not operated after 2 months.

On the contrary, the loading rate of MBBR was gradually be increased to 800 m^3/d with reduced HRT to 7 h. The MBBR's start-up was smooth and the effluent ammonia nitrogen level was below 2 mg N/L. As a result of the promising results of the MBBR, the process train was comprised of SRUSB reactor + MBBR, hereunder referred to "SRUSB-MBBR system",was selected for further tests on the application of the SANI® process. Due to limitation of pump and pipework capacities, the maximum loading rate to MBBR was 800 m^3/d and the maximum HRT of the MBBR under test is 6.72 h.

- **Steady-state and Diurnal Operation**

After the commissioning period, the SRUSB-MBBR system comprising of 4 SRUSB reactors (Total volume = 4 x 48 m^3 = 192 m^3) and 1 MBBR reactor (volume = 224 m^3) was operated under the constant flow of 800 m^3/d with a total HRT of 12.5 h during Nov 19, 2014 – Feb 13, 2015. The average sewage temperature was about 22 ^oC.

In order to investigate the effect of the diurnal variations of the flow and pollution loads, the SRUSB-MBBR system was operated in a dynamic diurnal flow rate of 21 – 37.5 m^3/h (equivalent to 500 – 900 m^3/d) with an overall HRT of 12.3 hr for 1 month. During this period, the SRUSB-MBBR system consisted of 3 SRUSB reactors (total volume = 3 x 48 m^3 = 144 m^3) and 1 MBBR (volume = 224 m^3) while the sampling frequency remained the same as the steady state operation. The average sewage temperature was about 22 ^oC.

As the effluent of the SRUSB-MBBR system had a moderate high TSS level, a post-treatment plant with a HRT of 1h was added at the end of SRUSB-MBBR system for demonstration purpose. A 4-day intensive sampling program with influent flow rate of 800 – 940 m^3/d, and a total HRT of 12.2 h (including the post-treatment unit) was conducted. The average effluent TCOD, BOD_5, TSS, TN, NH_4^+-N and NO_x-N levels were given in Exhibit 6 below and fully met the effluent discharge limits.

EXHIBIT 6

Parameters	SRUSB+MBBR +Post Treatment	Effluent Discharge Standard		
		95 Percentile	Annual Average	Upper Limit

TCOD (mg COD/L)	62 ± 43.5	-	-	-
BOD_5 (mg BOD/L)	5.6 ± 1.8	20	-	40
TSS (mg SS/L)	18.9 ± 1.6	30	-	60
TN (mg N/L)	8.9 ± 1.95	-	20	35
NH_4^+-N (mg N/L)	0.43 ± 0.39	-	5	10
NO_x-N (mg N/L)	7.53 ± 1.65	-	-	-

- **Sludge Production**

During the operation period from 17 July 2014 to 17 March 2015, no de-sludging operation was carried out while the sludge content in the SRUSB-MBBR system remained stable. The secondary sludge generated daily was equal to that of sludge discharged to the effluent. As a result, the average TSS level in the SRUSB-MBBR system effluent was 65 mg/L, and the secondary sludge production rate was estimated to be around 2.17 ton sludge cake (at 30% solid content) per 10,000 m^3 sewage treated (65 g /m^3 / 30% x 10,000 m^3 = 2.17 tonnes).

- **Development of Granular Sludge**

The organic carbon removal performance by Granular Sludge (GS) is better than Flocculent Sludge (FS) in SRUSB reactor. In this pilot trial, a GS-SRUSB reactor was designed to develop granules under anaerobic conditions. The GS-SRUSB reactor was seeded with pre-cultured FS from FS-SRUSB reactor. However, due to the late start-up of this reactor and the slow growth of the anaerobic bacteria, the acclimation and granulation process of the GS-SRUSB reactor has not been completed yet. Nevertheless, clear indication of granulation process, including an increase in size, the sludge particular size distribution, and decrease in the SVI_5/SVI_{30} ratio from 2.2 to 1.5 were observed after 2 months of GS development, and the microgranules under the microscope were found.

- **Steady State Modeling**

The steady state mathematical model was developed for the design and operation of the full scale SANI® process. Based on the mass balance and steady state modeling, the biomass growth in SRUSB-MBBR system is 0.05 g VSS/g COD (theoretical value), while the biomass growth in a conventional activated sludge process is about 0.29 g VSS/g COD (theoretical value). This leads to about 83% ([1-(0.05 g VSS/g COD)/(0.29 g VSS/g COD)] x 100%) reduction in biomass production as compared with conventional activated sludge process and about 70 ± 5% ([1- (65 mg $TSS_{\text{SANI-bioreactor effluent}}$/L – 20 mg $TSS_{\text{final effluent}}$/L)/ (150~200 mg $TSS_{\text{CAS-bioreactor effluent}}$/L – 20 mg $TSS_{\text{final effluent}}$/L))*100%) reduction of total sludge in the bioreactors. Through the steady state model simulation, COD removal capacity of SRUSB is found to be the critical factor governing the sludge reduction and full scale SANI® process application.

Conclusion

After optimization and improvement on operation and maintenance of the process train comprising of SRUSB+MBBR+Post Treatment Plant, the HRT was reduced from 31 h to 11.2~12.5 h and the system performance fully met the effluent discharge limits. No de-sludge operation was carried out during the pilot test. The SRUSB-MBBR system has a very low sludge production rate (2.17 tons of sludge cake/10,000 m^3 sewage), in term of bioreactor. The bioreactor sludge reduction was estimated to be 60 - 70% . Taking the benefits of the significant sludge reduction, the full scale SRUSB-MBBR system was estimated to save about 10 - 20 % of energy, space and capital cost as compared with convential secondary biological treatment system.

Recommendations

Based on the optimization experience gained from this Pilot tests, the following recommendations are proposed for future development on the application of SANI® process:-

- The design data for FS-SRUSB reactor size (sewage temperature = 22 ^{o}C): (i) HRT of 3 – 4 h; and (ii) up-flow velocity of 1.3 - 1.7 m/h.
- The design data for MBBR (sewage temperature = 22 ^{o}C): (i) nitrification rate - 1.0 g NH_4-N/m^2/d ; (ii) denitrification rate - 1.2 g NO_x-N/m^2/d; and (iii) recycle ratio – 3 to 4.
- The SRUSB-MBBR system should be equipped with automatic control equipment and on-line monitors to optimize the operation and reduce the energy consumption.
- The HRT and operating energy of the SRUSB-MBBR system could be improved further by optimizing the reactor and system design.
- Further development of granules under anaerobic conditions.