"Solar Septic Tank": Evaluation of innovative decentralized treatment of black water in developing countries

Thammarat Koottatep[1], Stephanie Connelly[2,+], Tatchai Pussayanavin[1,3,*], Sopida Khamyai[1], Wattanapong Sangchun[1], William Sloan[2], Chongrak Polprasert[4]

[1] School of Environment, Resources and Development, Asian Institute of Technology, Thailand

[2] School of Engineering, University of Glasgow, United Kingdom

[3] Faculty of Science, Ramkhamhaeng University, Thailand

[4] Thammasat School of Engineering, Thammasat University, Thailand

* Corresponding author: poktatchai@gmail.com

+Joint first author

Abstract

An innovative decentralized wastewater treatment system, namely the "Solar Septic Tank (SST)", was constructed and tested at the household-scale in a community in central Thailand. This study aimed to investigate the long term performance of the SST in treating black water subject to year-round variation. Results of the three-year continuous operation and monitoring showed significant improvement in the SST effluent quality with the potential to minimize environmental problems and public health risks. The SST achieved significantly higher total chemical oxygen demand (TCOD), soluble chemical oxygen demand (SCOD), total biochemical oxygen demand (TBOD), soluble biochemical oxygen demand (SBOD), total kjeldahl nitrogen (TKN), total solid (TS) and total volatile solid (TVS) removal efficiencies than a conventional septic tank (CST). The average TBOD concentration of the SST effluent was 150±75 mg/L, meeting the Thai discharge standard (less than 200 mg/L of TBOD), while the average TBOD concentration of the CST was 240±140 mg/L, higher than the Thai discharge standard. The *E .coli* inactivation in the SST was 1-2 log reduction more than that in the CST. The removal efficiencies of TBOD and pathogens exhibited positive correlation with the ratios of the SST temperature.

Keywords: Solar Septic Tank; Reinvented Toilet Technology, WASH ; Blackwater treatment; Performance evaluation; Long-term study

Introduction

More than one billion people in developing countries still lack proper sanitation facilities and access to basic sanitation systems, resulting in more than a million deaths annually due to waterborne diseases (WHO, 2017). To achieve the United Nations Sustainable Development Goal 6 (SDG 6) requires urgent action to protect human health and ensure that all people enjoy prosperity by 2030. Water pollution related to sanitation, particularly in developing countries (or low-middle income countries), is a pressing issue directly affecting both public and environmental health (Ryals et al., 2019). A principal reason for this problem is the uncontrolled discharge of untreated wastewater. Domestic wastewater management in developing countries usually involves inadequate treatment facilities and lack of proper wastewater treatment system (Areias et al 2020,). Centralized wastewater treatment as being practiced in most developed countries is one of the solutions to treat those wastes, but, because of high investment cost and requirement of skilled operation, it seems to be inappropriate for low-middle income countries. Considering the case of Thailand, restricted local budgets or funding, coverage of wastewater treatment plants in many small and isolated villages is still inadequate. Moreover, in developing countries, large capital investment for sewer system and pumping costs is one of the barriers for construction of centralized wastewater management systems (Massoud et al., 2009). In this respect, even existing decentralized or on-site wastewater treatment technologies (such as conventional septic tanks (CST) or cesspools) are a better option for developing countries to treat wastewater close to the source. Although the CST does not require a huge budget for installation, it can not perform effectively to protect human health or environment (Polprasert et al. 1982).

Because of the low investment cost and less-complicated installation, since 1995, the government of Thailand has been promoting the application of CST or cesspools as a stand-alone wastewater treatment to treat black water or toilet wastewater for new housing or isolated residential/commercial establishments. However, a spatial survey by Koottatep et al. (2014) found the treatment efficiencies of the CST to be low (less than 60 % removal of organic matter) and the CST effluent still contained high concentrations of organic matter and pathogens (about more than 200 mg/L of TBOD and 10^6 no./mL of *E.coli*). The CST effluent has been identified as a major source of surface and ground water pollution in Thailand (Chaiwong et al. 2020). Since the CST can be influenced by high sludge accumulation and daily peak flow, direct discharge of effluent with high concentrations of solids, particulate organic matter and also pathogens to the surrounding environment is another potential problem (Gray, 2004; Sarathai et al. 2010). Thus, these issues require the Governments of Thailand and other developing countries to find appropriate solutions for wastewater treatment urgently. Up to the present, there are many reports of pollution and health problems caused by unsanitary managed technology (Heinss et al., 1999).

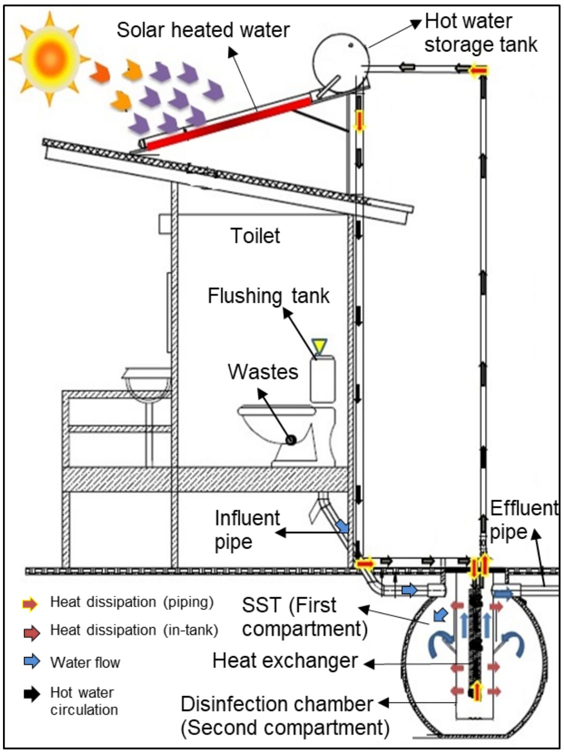
To address the global sanitation problems, the Bill & Melinda Gates Foundation has invested one hundred million US$ to reinvent toilet technologies. The Foundation's goals, since 2011, have focused on development of effective onsite sanitation technologies that poor people can access, and also to create a platform for global sustainability. From this perspective, alternative treatment systems such as the "Solar Septic Tank (SST)" could be one of the most effective solutions for developing countries (Pussayanavin et al., 2015; Connelly et al., 2019). The SST is a modified CST with a solar-heated water system to create higher temperature than ambient inside the septic tank. The enhancement of temperature promotes the biodegradation of organic matter and methane formation. Further, temperature also has a significant effect on the settleability and degradation of biological solids and pathogen inactivation (Polprasert et al. 2018; Keating et al. 2016; Connelly et al. 2017). SSTs have been applied for the treatment of black water (or toilet wastewater) because they are simple to install and do not require high skill to operate and maintain. At present, there is no scientific evidence to demonstrate the long-term performance of the SST. Thus, the goal of this study was to compare the long-term performance of the SST and CST systems (time-series study), and to determine the systems' capability to operate under variations in tropical temperatures and the change of seasons.

Methodology

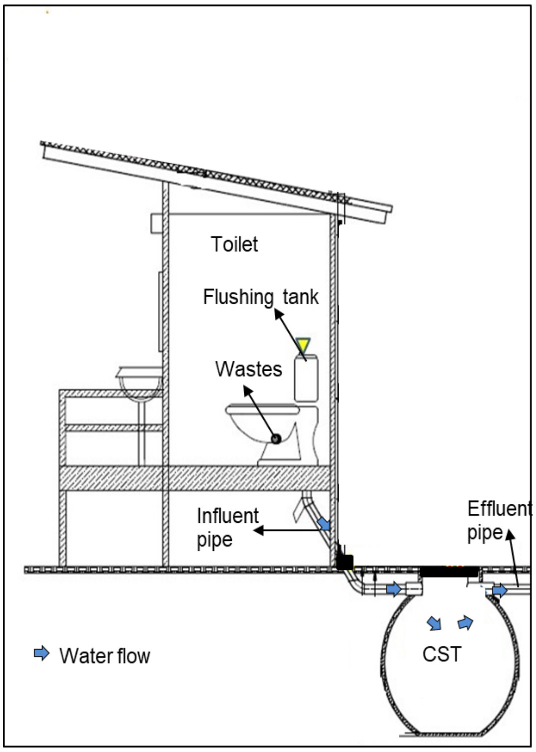
Prototypes description

Field testing of an SST and a CST unit was conducted at a housing community in central Thailand (Latitude:13.618795, Longitude:100.530521) (Fig.1e). The units were tested from 2015 to 2017 (the SST started in operation on May 2015 and the CST started in operation on August 2015) under actual conditions of fluctuating flowrates and climatic conditions (Fig.1 a and b). Each experimental unit directly received wastewater from a water-saving toilet with a 3-litre per flush (LPF) mechanism and served a family of 3 – 5 people. Fig.1 c and d show a photographic view and schematic sketch of the SST and CST. A magnetic counter (OMRON H7EC-N, Japan) was used to measure the number of uses per day, while the daily water usage of each unit was measured using an analogue flow meter (GMK, Asahi, Thailand). Ambient temperatures at the test-site were recorded hourly using temperature sensors (PT-100 type HDP/7, SWK Technology, Thailand) installed above ground. The in-tank temperature of the SST was also recorded hourly using a temperature sensor positioned in the centre of the tank.

(a) (b)


Solar heated water
Hot water storage tank
Toilet
Flushing tank
Wastes
Influent pipe
Effluent pipe
Heat dissipation (piping)
Heat dissipation (in-tank)
Water flow
Hot water circulation
SST (First compartment)
Heat exchanger
Disinfection chamber (Second compartment)

(c)


Toilet
Flushing tank
Wastes
Influent pipe
Effluent pipe
Water flow
CST

(d)


Housing community
Field testing site

(e)

Fig.1 Field testing of SST (a), Field testing of CST (b), Schematic configuration of SST (c), Schematic configuration of CST (d) and Testing site: housing community in central Thailand (e)

Both the SST and CST units were made of polyethylene (PE) polymer, each with a working volume of 1,000 L (with about 70% of effective volume) in a spherial shape, and received the black water (faeces, urine and anal cleansing water) whilst greywater was discharged separately. The SST unit consists of two compartments (Fig.1 a), while the CST has only one compartment (Fig.1 d). The first compartment of the SST was designed for solid settling and anaerobic digestion of collected solids (Fig.1c). The second compartment, defined as the disinfection chamber, was made of stainless steel (diameter 0.3 m and high 1.2 m) and functions as a polishing unit (Table 1). The disinfection chamber was designed to minimize the effect of short-circuiting from impulse flow and to maintain the temperature in the disinfection chamber more than 40 ^{o}C (during day time), which could simultaneously enhance inactivate pathogens in the effluent. Temperature difference in the first and second compartments was typically about 5 ^{o}C. Temperatures of the SST were increased by circulating hot water generated from a 6 m^2 solar water heating device through a heat exchanger copper spiral; the hot water was pumped through the heat exchange system at a rate of 5 L/min. A sensor in the hot water storage tank and an electric-circuit controller were used to control the flow circulation when the temperature of the hot water storage tank reached the target of 50 ^{o}C or more.

Performance evaluation

Influent and effluent samples were collected bi-weekly during the first year and monthly during the second and third years to obtain key physical and chemical monitoring data of the system performance. The influent and effluent samples were collected in sealed buckets; for the influent samples, the inflow to the septic tanks was disconnected via a sampling valve for a period of 24 h. Physical and chemical (total chemical oxygen demand (TCOD), soluble chemical oxygen demand (SCOD), total biochemical oxygen demand (TBOD), soluble biochemical oxygen demand (SBOD), total kjeldahl nitrogen (TKN), total solid (TS) and total volatile solid (TVS)) and bacteriological parameters (*E.coli*) were analyzed according to the standard methods (APHA, 2017). Open source R software was used for statistical analyses and graphics of this study. Statistical difference (at a 95% confidential level) of the relationship between the treatment units and its efficiencies was done by analysis of the variance (ANOVA), and comparing the multiple means was assessed using poc-host test

(Tukey's Honest Significant Difference (HSD). The time-series plots were used in developing the local polynomial regression to build up a generalization of moving average (in line), a function that describes the deterministic part of the variation in the data . Treatment performance of the SST and CST was evaluated based on removal efficiency (RE) shown in Eq 1

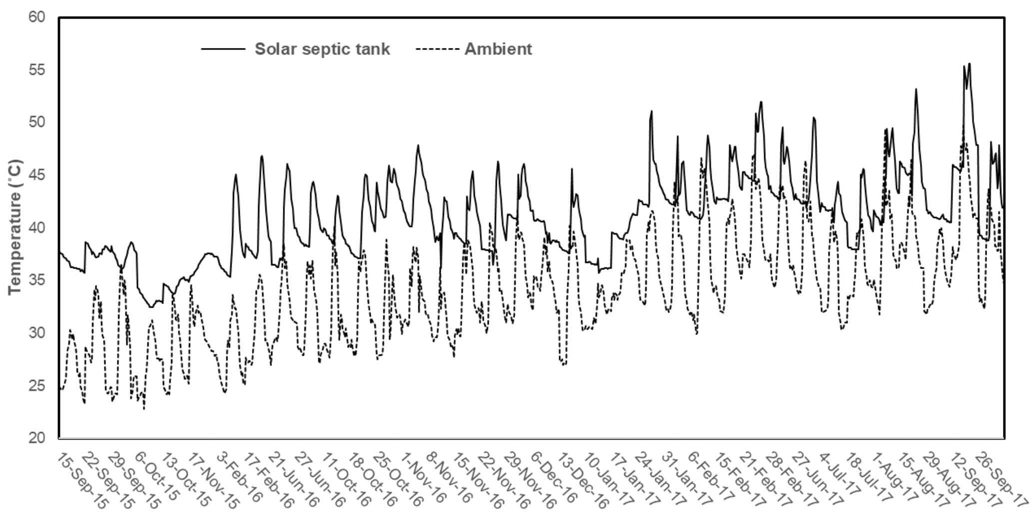
$$\text{Removal efficiency } (RE) = Si - Se\ Sex100 \qquad \text{Eq 1}$$

where; Si is concentration in influent (mg/L) and Se is concentration in effluent (mg/L).

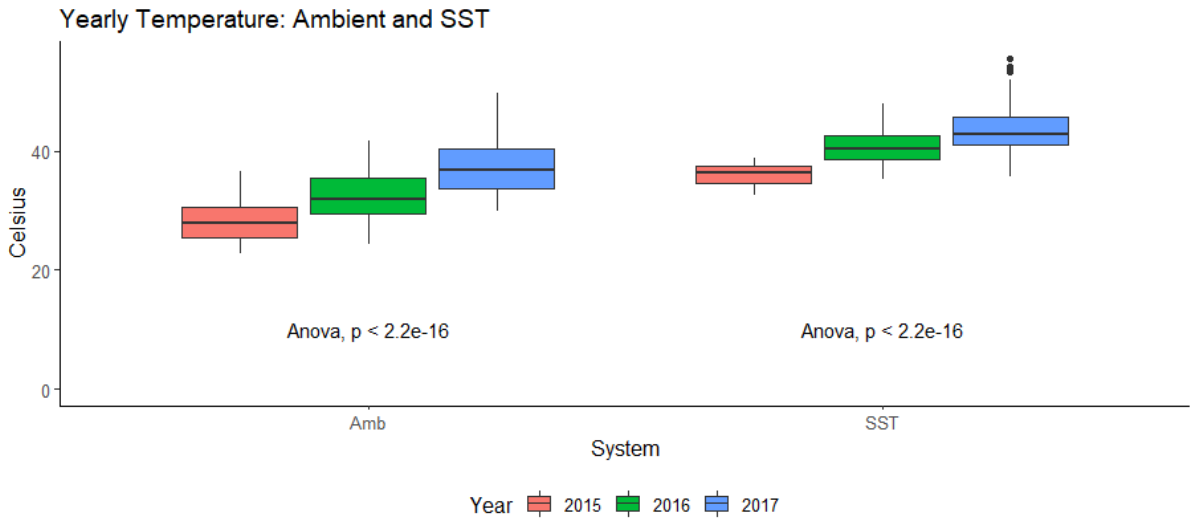
Results and discussion

System Operation: The climate in Thailand is considered to be in the "tropical range", the temperature at the daytime is grater than 36 ^{o} C, in the nighttime, the temperature is dropped to 31 ^{o}C. The average yearly ambient temperatures were found to have a steadily increasing trend during the operation period from 2015-2017, depending on the annual climatic conditions.

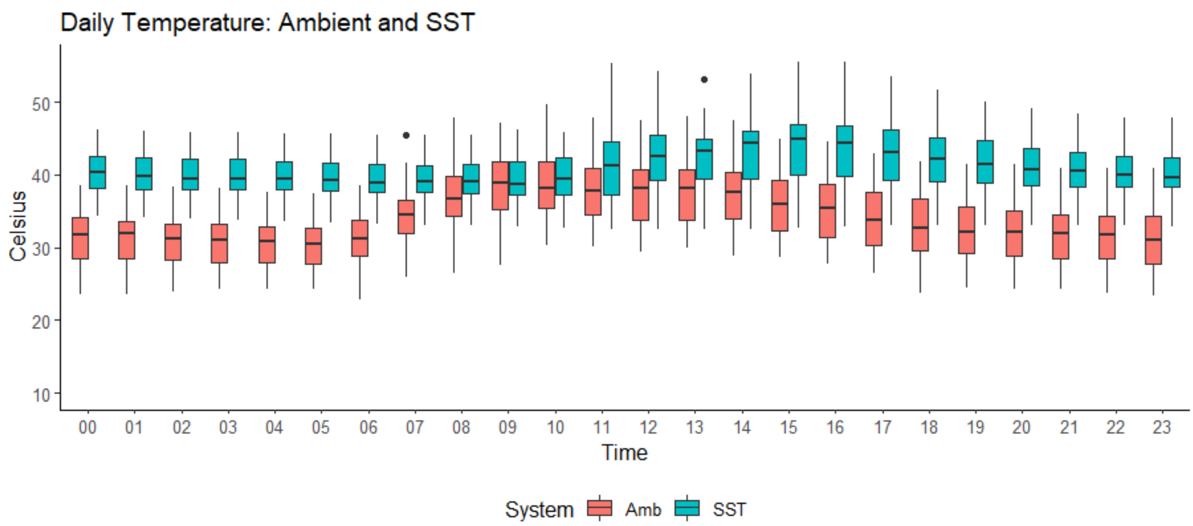
The temperature profile of the SST over the course of the experiment is presented in Fig.2, and the calculated mean in-tank temperature over the course of the study was 41 ± 4.0 ^{o}C which was satisfactory for the thermophilic condition. It is obvious from Fig.2 that the average SST temperature was between 41.5 ± 4.5 in the daytime and 40.3 ± 3.1 in the nighttime. The performance of the solar system was effective in daytime and sufficient to maintain temperature in the nighttime (Fig 2 a). The difference in daytime and nighttime temperatures of the SST was between 1-2 ^{o}C, which should not have much effects on the microbial actives inside the tank.



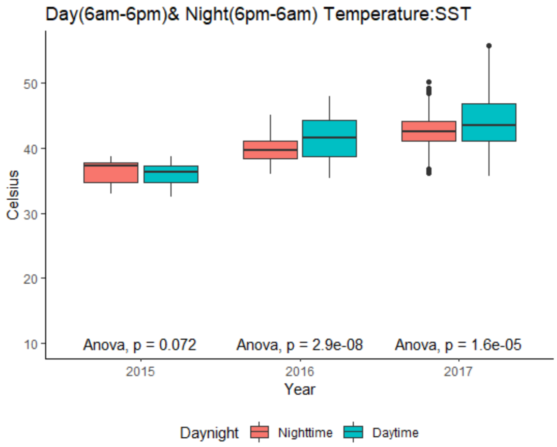
(a) In-tank temperature of SST and ambient temperature (Time series)



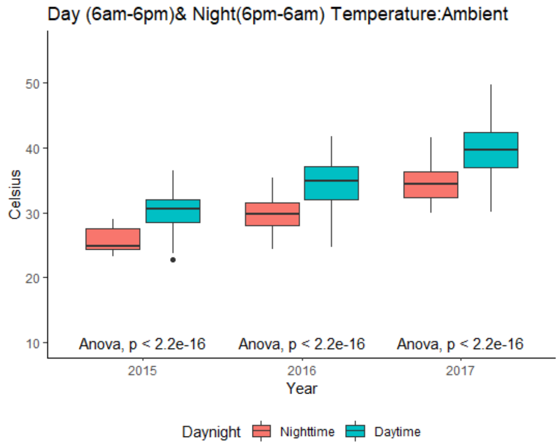
(b) Average yearly temperature



(c) Daily temperature profile



(d) Yealy daytime (6am - 6pm) and nighttime (6pm-6am) temperature:SST



(e) Yealy daytime (6am - 6pm) and nighttime (6pm-6am) temperature:Amb

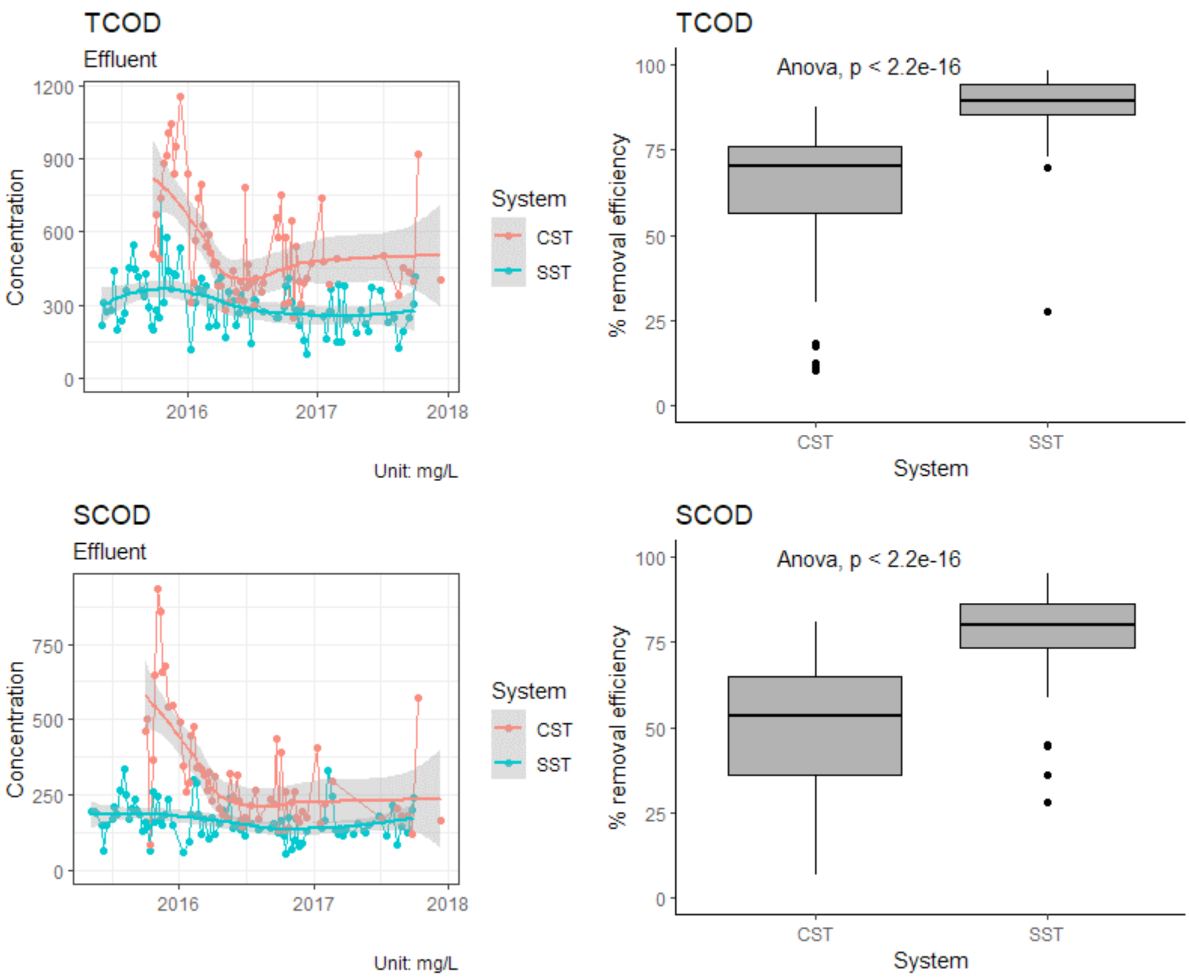
Fig.2 Temperatures of SST and ambient (Amb)

Operation of the SST and CST units was commenced in 2015 by feeding the blackwater without additional inoculation i.e. the systems were seeded from the microbes present in the blackwater entering the system only. The average values of wastewater flow and number of users were found in the same magnitude of about 98.8-110.0 L/d and 17-23 persons, respectively.

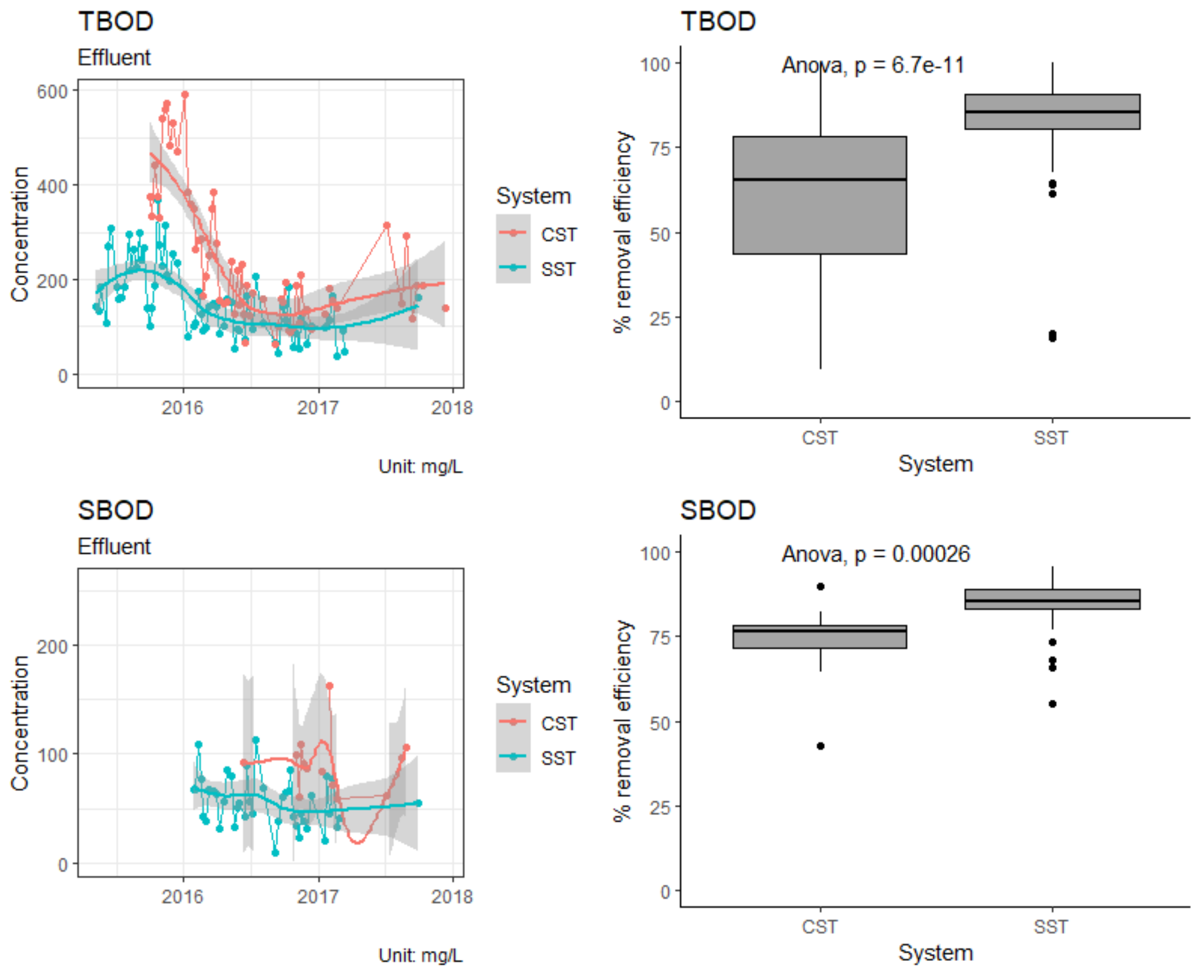
The influent TCOD, SCOD, TBOD, SBOD, TKN, TS, TVS and *E.coli* concentrations of the CST unit were 1,618±810 mg/L, 494±182 mg/L, 643±289 mg/L, 74±139, 295±95, 1,556±646, 943±471 mg/L and 9.7 x 10^8 MPN/100mL of *E.coli*, respectively. Similar trend was noticed for influent concentrations of the SST units which were 3,834±2,828 mg/L of TCOD, 879±495 mg/L of SCOD, 1,131±725 mg/L of TBOD and 399±183 mg/L of SBOD, 463±218 mg/L of TKN, 3,046±1,659 mg/L of TS, 2,351±1,450 mg/L of TVS and 1.1 x 10^8 MPN/100mL of *E.coli*. The influent black water quality (Table 1) was within the range of "high strength" wastewater. In general, there was high variation of pollutant concentrations in the black water , depending on the user behavior and characteristic of feces, urine and toilet paper.

The operating conditions of the SST and CST from the field data are as shown in the Supplementary material Table 1:

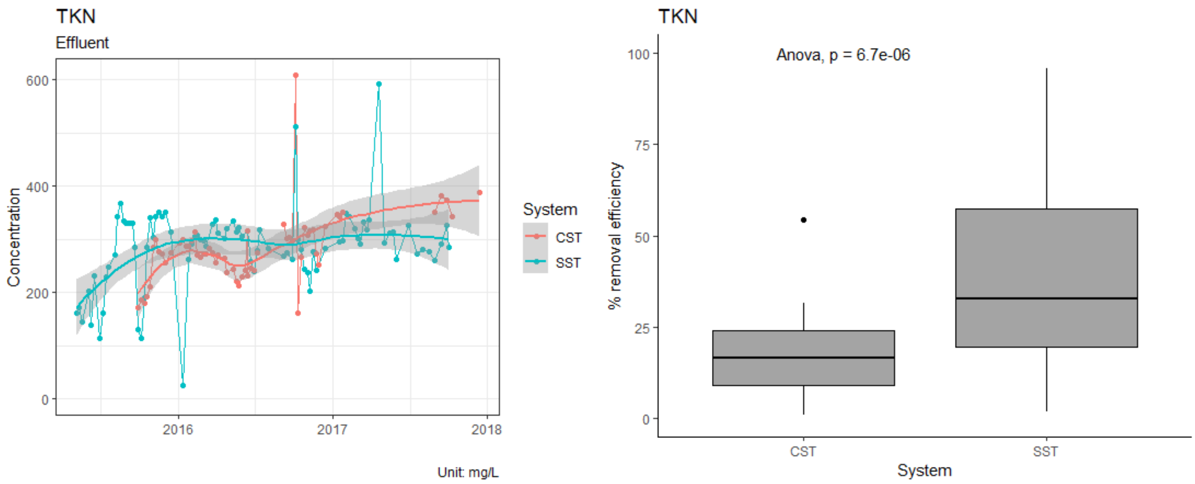
System Performance: Effluent concentrations of TCOD, SCOD, TBOD and SBOD in the SST were consistently lower than that of the CST, particularly during the first four months of operation indicating that heating the system enabled considerably more effective treatment during start-up of new SST unit than that of the new CST systems. The removal efficiencies of TCOD and TBOD (Fig. 3 (a) and (b)) of the SST and the CST units improved over time and increased to above 80% after 180 days of operation. In addition to promoting pathogen inactivation and minimizing short-circuiting, the disinfection chamber installed in the SST was hypothesized to serve as a polishing unit, contributing to the removal of residual pollutants. Indeed, it was observed that during the three years of continuous operation, the SST unit yielded significantly better performance (anova, $p<0.05$) for each of the parameters monitored (Fig.3). The SST performed with average treatment efficiencies of 88±9% for TCOD removal and 83±13% for TBOD removal, more effective than the treatment performance of the CST unit which were 61±24% and 58±28%, respectively, resulting in the effluent TCOD and TBOD concentration of 534±216 mg/L and 240±140 mg/L, respectively (Fig.3). These data demonstrate that the performance of the SST for TCOD, SCOD, TBOD and SBOD removal was typically 20-30% ($p<0.05$) better than that of the CST, and, that the removal efficiencies were generally more stable over time. The greater variability in removal efficiency and discharge quality in the CST was probably affected by the hydraulic and impulse loads, and that operation in the absence of heating resulted in lower amount of active biomass responsible for the biodegradation of organic matter. In spite of fluctuation in the operating temperatures (Fig.2), the effluent characteristics from the SST (mean ± standard deviation of 310±115 mg/L of TCOD, 160±60 mg/L of SCOD, 150±75 mg/L of TBOD and 60±20 mg/L of SBOD) were relatively stable (Fig.3 (a) and (b)), and, importantly, frequently satisfy the discharge standards of Thailand (MNRE 2010). It is noted, however, that the effluent TBOD concentrations during the monsoon season or cloudy conditions were occasionally above the discharge standards even for the SST.



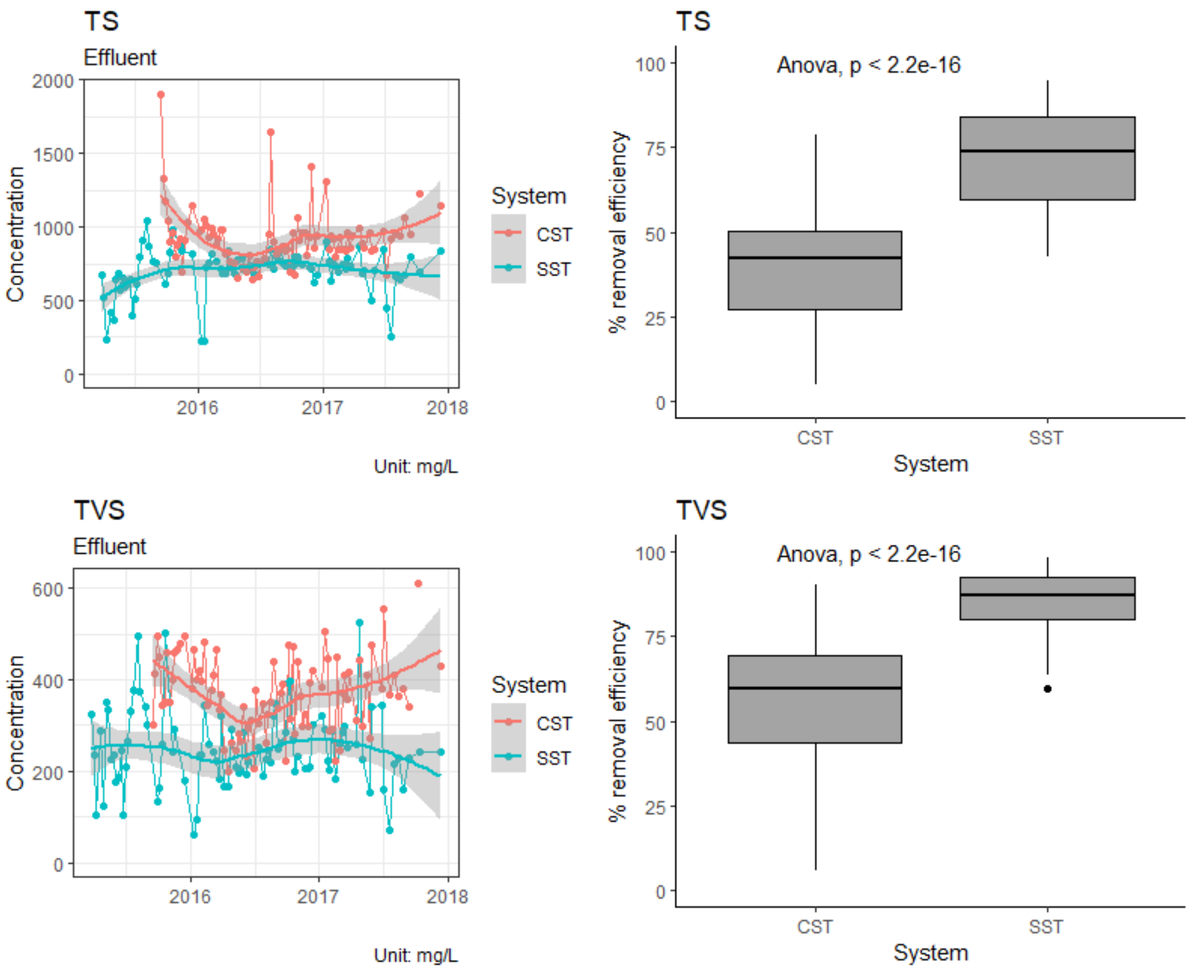
(a)


TBOD
Effluent
Concentration
600
400
200
0
2016
2017
2018
Unit: mg/L
System
CST
SST
TBOD
Anova, p = 6.7e-11
% removal efficiency
100
75
50
25
0
CST
SST
System
SBOD
Effluent
Concentration
200
100
0
2016
2017
2018
Unit: mg/L
System
CST
SST
SBOD
Anova, p = 0.00026
% removal efficiency
100
75
50
25
0
CST
SST
System

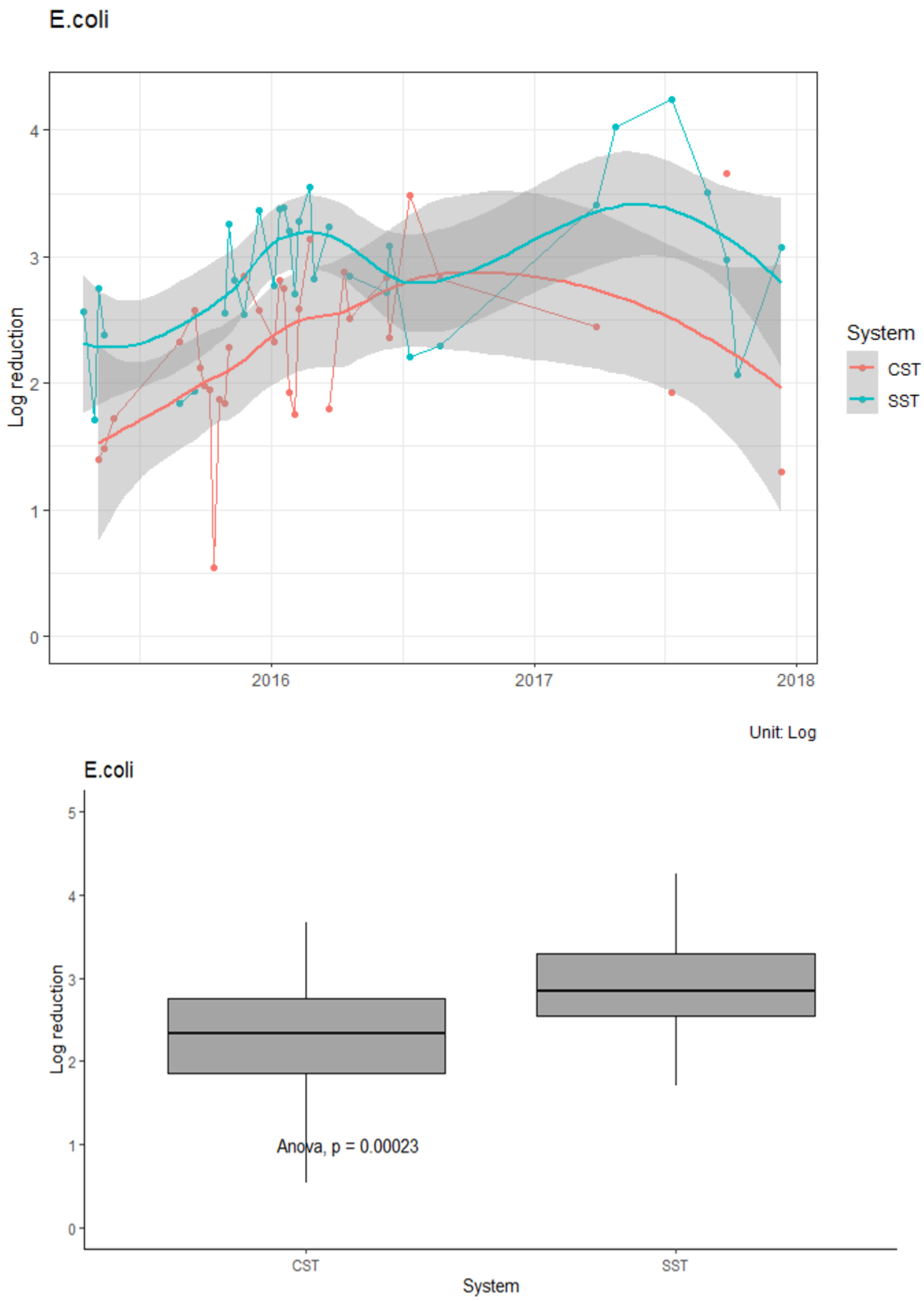
(b)


TKN
Effluent
Concentration
600
400
200
0
2016
2017
2018
Unit: mg/L
System
CST
SST
TKN
Anova, p = 6.7e-06
% removal efficiency
100
75
50
25
0
CST
SST
System

(c)


TS
Effluent
Concentration
2000
1500
1000
500
0
2016
2017
2018
System
CST
SST
Unit: mg/L
TS
Anova, p < 2.2e-16
% removal efficiency
100
75
50
25
0
CST
SST
System
TVS
Effluent
Concentration
600
400
200
0
2016
2017
2018
System
CST
SST
Unit: mg/L
TVS
Anova, p < 2.2e-16
% removal efficiency
100
75
50
25
0
CST
SST
System

(d)



(e)

Fig.3 Treatment performance of SST and CST: (a) COD (b) BOD, (c) TKN, (d) TS and TVS and (e) *E. coli*

Whilst mean removal rates were significantly higher in the SST than the CST, the mean effluent TKN concentrations of the CST and SST (Fig.3 (c)) were observed to be in the same magnitude of about 100-400,mg/L, respectively. The mean TS and TVS removal efficiencies of the SST were 71 % and 85%, respectively, significantly higher ($p<0.05$) than those of the CST which were 32 % and 52 %, respectively. Thus the CST was found to be less effective in solids sedimentation than the SST. It could be hypothesized that higher temperatures in the SST reduced the liquid density and viscosity, resulting in better sedimentation of the influent TS and TVS.

The heated chamber in the SST targets coliform reduction by partial pasteurization, resulting in the SST more 1-2 log of *E. coli* inactivation than in the CST (Fig.3). The statistical test revealed that the *E. coli* inactivations differ significantly between the SST and CST ($p<0.05$). It was observed, howevwer, that the *E. coli* inactivation in both the SST and CST units was influenced by the drop in temperature or daily temperature variation during the monsoon season.

Fig.4 compares the treatment performance of the SST and CST during two different seasons, i.e. hot (November to April) and monsoon (May to October). TukeyHSD analysis was performed for each performance parameter to determine the statistical significance of seasonal difference in performance of each system during each season at 95% confidence interval using R program. Whilst seasonal effects were observed in each system, the analysis demonstrates that in each season (SST:CST in monsoon season and SST:CST in hot season), the SST performed significantly better than the CST for most of the parameters (except: TCOD was found be insignificant ($p > 0.05$) between the SST and CST). The results presented in Fig.5 show a clear evidence that the treatment efficiencies of SCOD, TBOD, SBOD, TKN, TS and TVS of the SST were higher than those of the CST and significantly different in the hot and monsoon seasons.

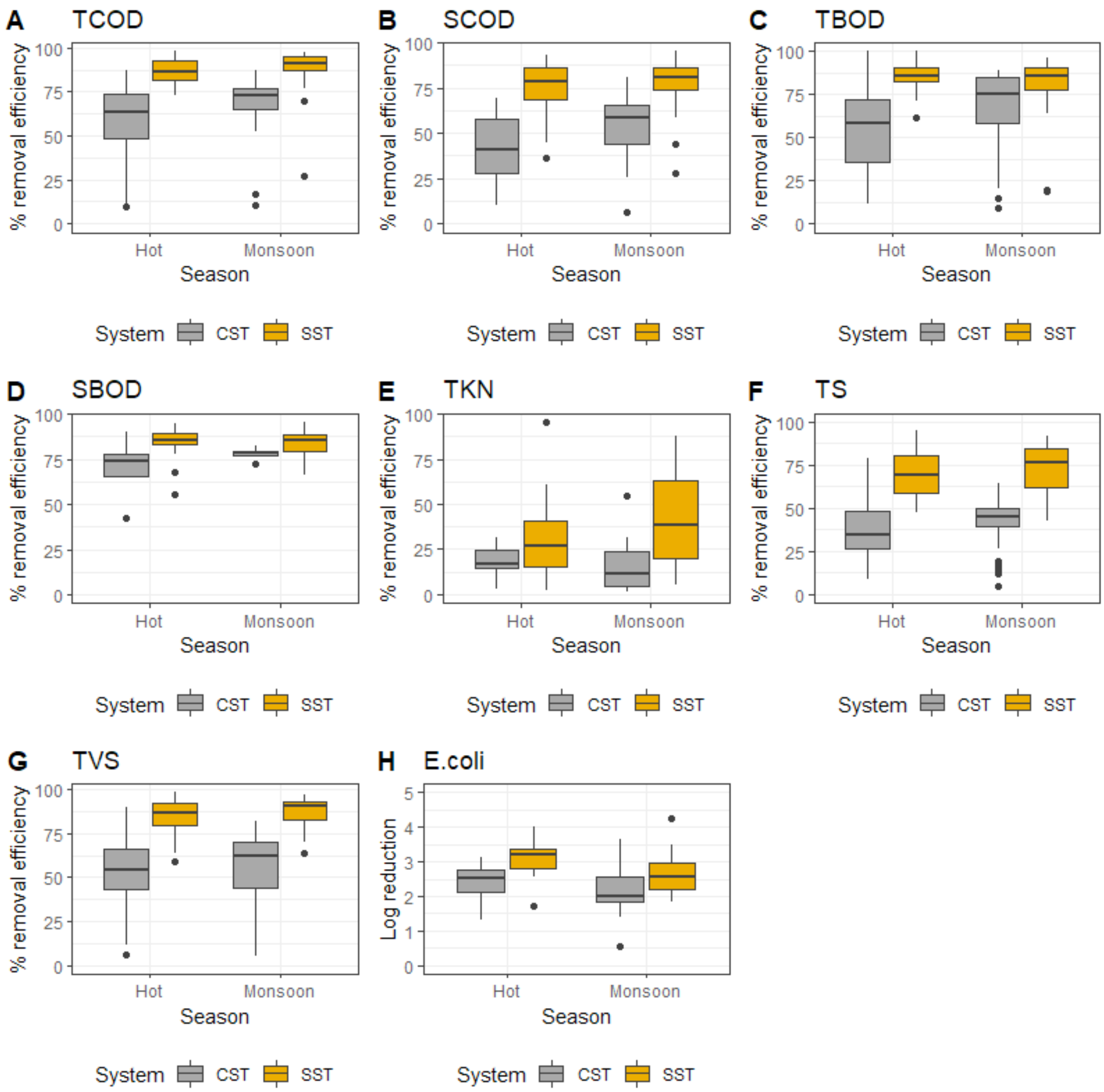
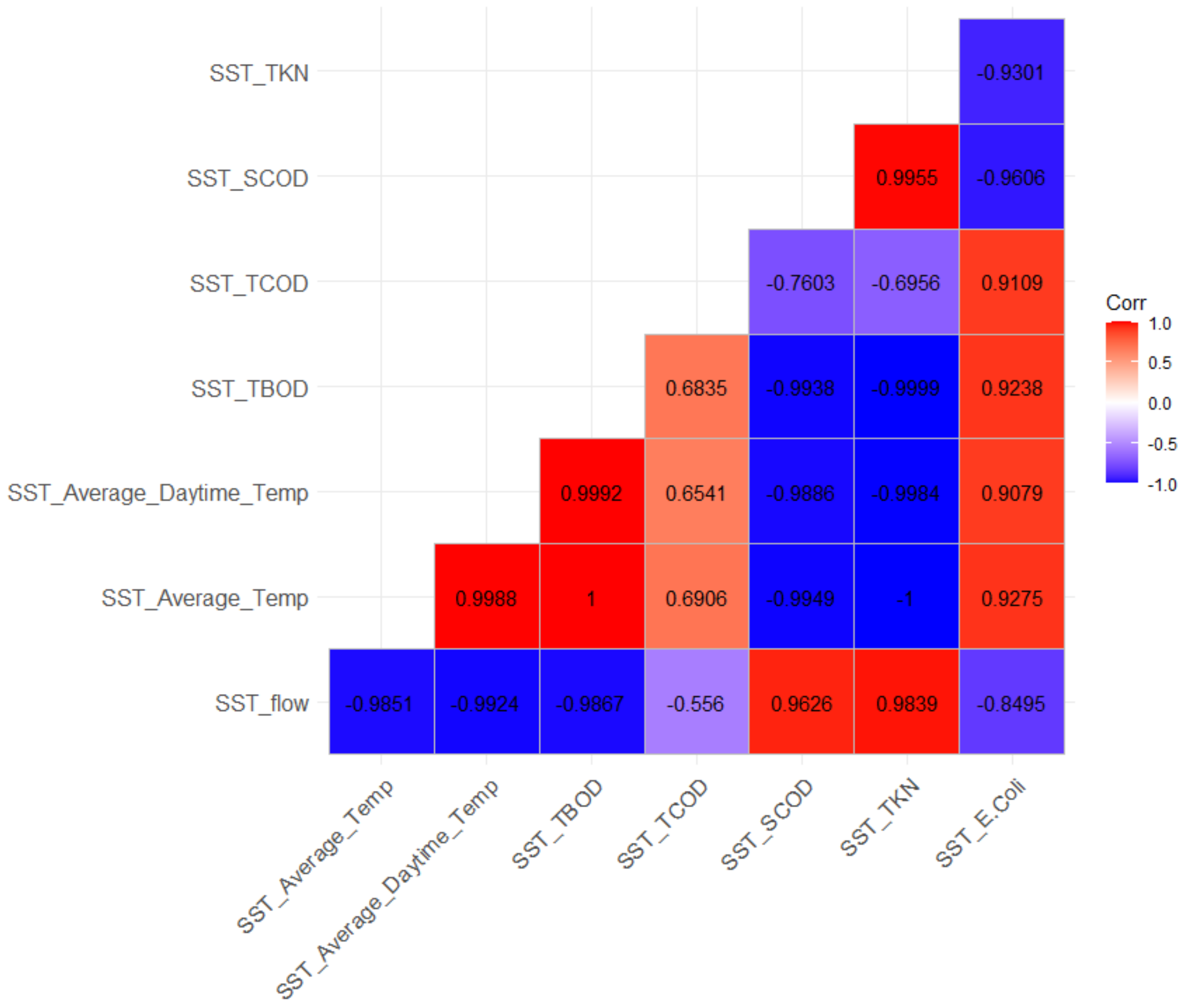


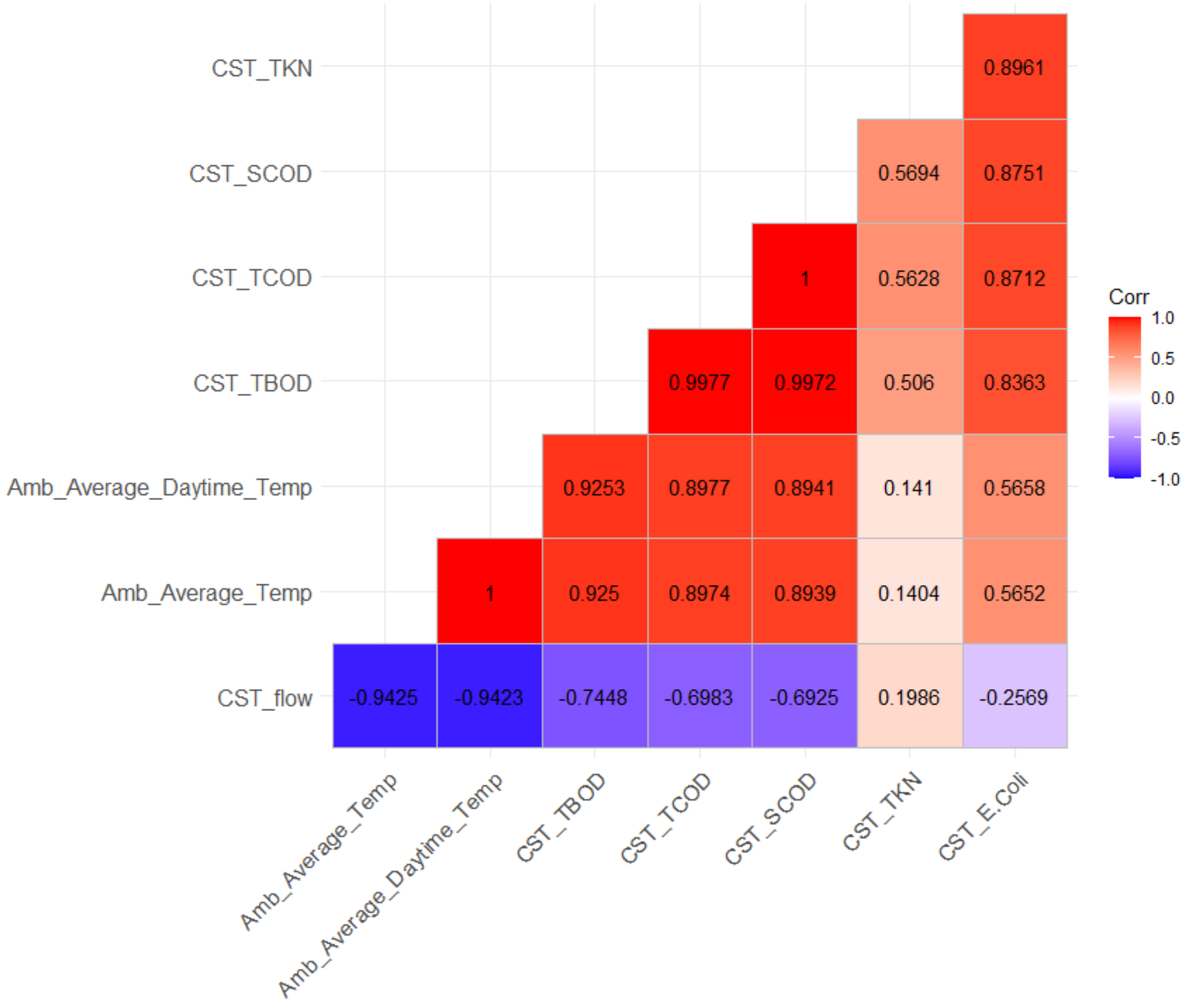
Fig.4. Comparison of treatment performance during hot and monsoon seasons

The removal efficiencies of the SST and CST of the five main important parameters, namely TCOD (SST_TCOD and CST_TCOD), TBOD (SST_TBOD and CST_TBOD), SCOD (SST_SCOD and CST_SCOD), TKN (SST_TKN and CST_TKN) and *E. coli* log reduction (SST_ *E. coli* and CST_ *E. coli*), were further evaluated by analyzing the yearly relationship between operational conditions of the wastewater flow (SST_flow and CST_flow), the average of SST temperature (SST_average_temp), the average of SST daytime temperature, (SST_average_daytime_temp), the ambient temperature (Amb_Average_Temp) and the daytime ambient temperature (Amb_Average_Daytime_Temp) during the operation of the system, which could exhibit the influence between these parameters and system performance (Fig. 5). The results indicated that there were high positive correlation values (corr) between the SST temperature (SST_Average_temp and SST_Average_Daytime_Temp) for TBOD (0.992 and 1, respectively) and *E. coli* log reduction (0.9725 and 0.9079, respectively) of SST, and the correlation between the ambient temperature (Amb_Average_temp and Amb_Average_Daytime_Temp) and TCOD, SCOD and TBOD of CST were found in high correlation values rangeing between 0.8939-0.9253. For the relationships between wastewater flow and removal efficiencies, the SCOD and TKN removal efficiencies of the SST were high correlation values, while, weak relationships between wastewater flow and the TCOD, SCOD, TBOD, TKN and E.coli were observed. It seems that the TBOD removal efficiency and pathogen inactivation of the SST and TCOD, SCOD and TBOD removal efficiencies of the CST were mainly influenced by the operating temperatures.



SST_TKN
SST_SCOD
SST_TCOD
SST_TBOD
SST_Average_Daytime_Temp
SST_Average_Temp
SST_flow
-0.9301
0.9955
-0.9606
-0.7603
-0.6956
0.9109
0.6835
-0.9938
-0.9999
0.9238
0.9992
0.6541
-0.9886
-0.9984
0.9079
0.9988
1
0.6906
-0.9949
-1
0.9275
-0.9851
-0.9924
-0.9867
-0.556
0.9626
0.9839
-0.8495
SST_Average_Temp
SST_Average_Daytime_Temp
SST_TBOD
SST_TCOD
SST_SCOD
SST_TKN
SST_E.Coli
Corr
1.0
0.5
0.0
-0.5
-1.0

(a) SST



(b) CST

Fig. 5 Relationships between operational conditions (Temperature and daytime temperature and wastewater flow) and removal efficiencies of SST and CST (Correlation coefficient with a unit-free measure ranges from -1 to +1)

For the prototype of a single family, the SST system was estimated to cost about US$ 740 (or about 28% of the total cost), while the commercial solar heated water with other accessories (electric-circuit controller and circulating pump) would cost about US$ 1,840 (72%), or the total investment of the integrated system would be in the range of US$ 2,580. However, it should be noted that the field test (or prototype unit) should thus be an integral part of the design process and not be used only to consider as a final product and the commercialized product.

Conclusions

The results of this study demonstrated the SST to be an effective on-site treatment technology in reducing organic-chemical, solid pollutants and *E. coli* from the black water. During the three years of continuous operation, the SST unit could achieve the treatment efficiencies of 88$\pm$9% for TCOD and 83$\pm$13% for TBOD, and, the SST had TCOD, SCOD, TBOD and SBOD removal efficiencies in the range 20-30% higher than those of the CST. Further, at the mean operating temperature of 42 ^{o}C, the SST effluent characteristics typically achieved discharge standards of Thailand although occasional failures were observed during the monsoon season. The treatment efficiencies of the SST during the hot and monsoon seasons were consistently significantly better than those of the CST. The operating temperature of the

SST had a high positive correlation values (corr) with TBOD (0.992 and 1, respectively) and *E. coli* log reduction (0.9725 and 0.9079, respectively).

Acknowledgements

This study was financially supported by the Bill & Melinda Gates Foundation, Seattle, WA, grant number OPP1029022, and the Engineering and Physical Sciences Research Council (EPSRC), UK, grant numbers EP/P029329/1 and EP/K038885/1, in which grateful acknowledgements are made.

References

American Public Health Association/American Water Works Association/Water Environment Federation., 2017. Standard Methods for the Examination of Water and Wastewater. 23rd edition. Washington, U.S.A.

Connelly, S.; Shin, S.G.; Dillon, R.J.; Ijaz, U.Z.; Quince, C.; Sloan, W.T.; Collins, G. 2017. Bioreactor Scalability: Laboratory-Scale Bioreactor Design Influences Performance, Ecology, and Community Physiology in Expanded Granular Sludge Bed Bioreactors. *Front. Microbiol.,* ***8***, 664.

Chaiwong, C., Koottatep, T., Polprasert, C. 2020. Comparative study on attached-growth photobioreactors under blue and red lights for treatment of septic tank effluent, Journal of Environmental Management, ***260***.

Connelly, S., Pussayanavin, T., Randle-Boggis, R. J, Wicheansan, A., Jampathong, S., Keating, C.,Ijaz, U.Z.,Sloan, W.T. and Koottatep. T. 2019. Solar Septic Tank: Next Generation Sequencing Reveals Effluent Microbial Community Composition as a Useful Index of System Performance, *Water*, ***11***(12), 2660.

Heinss, U., Larmie, S.A. and Strauss, M. 1999. Characteristics of Faecal Sludges and Their Solids-Liquid Separation. EAWAG/SANDEC, Rio de Janeiro, Brazil.

I.O.R. Areias, C.M.F. Vieira, H.A. Colorado, G.C.G. Delaqua, S.N. Monteiro, A.R.G. Azevedo. 2020.Could city sewage sludge be directly used into clay bricks for building construction? A comprehensive case study from Brazil, Journal of Building Engineering, ***31***.

Gray D.M.D. 2004. Pathogen Destruction Efficiency In High Temperature Digestion, IWA, United Kingdom.

Keating, C.; Chin, J.P.; Hughes, D.; Manesiotis, P.; Cysneiros, D.; Mahony, T.; Smith, C.J.; McGrath, J.W.; O'Flaherty, V. 2016. Biological phosphorus removal during high-rate, low-temperature, anaerobic digestion of wastewater. *Front. Microbiol*, *7*, 226.

Koottatep, T., Eamrat, R., Pussayanavin, T., Polprasert, C. 2014. Hydraulic Evaluation and Performance of On-Site Sanitation Systems in Central Thailand. Environ Eng Res., **19**(3), 269-274

Koottatep, T., Phuphisith, S., Pussayanavin, T., Panuvatvanich, A., & Polprasert, C. (2014). Modeling of pathogen inactivation in thermal septic tanks. Journal of Water, Sanitation and Hygiene for Development, 4(1), 81–88.

Massoud, M.A., Akram, Tarhini, A. and Nasr, J.A. 2009. Decentralized Approaches to Wastewater Treatment and Management: Applicability in Developing Countries, Journal of Environmental Management, **90**, 652–659.

Ministry of Natural Resources and Environment of Thailand: MNRE. (2010). Definition of standard of wastewater discharge from domestic wastewater treatment plant in Thailand. Thailand: Royal Thai Government.

Pussayanavin, T., Koottatep, T., Eamrat, R., Polprasert, C. 2015. Enhanced Sludge Reduction in Septic Tanks by Increasing Temperature, Journal of Environmental Science and Health, Part A, ***50***, 1-9.

Polprasert, C., Rajput, V.S. 1982. Septic Tank and Septic Systems. Environmental Sanitation Reviews. Environmental Sanitation Information Center. Asian Institute of Technology, Thailand.

Polprasert, C., Koottatep, T., Pussayanavin, T. 2018. Solar septic tanks: A new sanitation paradigm for Thailand 4.0. *Sci. Asia*. ***44***, 39–43

Ryals, R., McNicol, G., Porder, S., Kramer, S., 2019, Greenhouse gas fluxes from human waste management pathways in Haiti, Journal of Cleaner Production, ***226***, 106-113.

Sarathai, Y., Koottatep, K.; Morel, A. 2010. Hydraulic characteristics of an anaerobic baffled reactor as onsite wastewater treatment system, Journal of Environmental Sciences, ***22***(9), Pages 1319-1326

Yilei Shi, Lu Zhou, Yangyu Xu, Hongjie Zhou, Lei Shi. 2018. Life cycle cost and environmental assessment for resource-oriented toilet systems. Journal of Cleaner Production

196, 1188-1197.

World Health Organization (WHO) and the United Nations Children's Fund (UNICEF), 2017. Progress on Drinking Water, Sanitation and Hygiene 2017 update and SDG baselines from http://www.unwater.org/publications/whounicef-joint-monitoring-program-water-supply-sanitation-hygiene-jmp-2017-update-sdg-baselines/