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Improvement of solar septic tank performance by recovering waste heat from an air conditioner (AC) unit

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ABSTRACT

One of the valuable alternative approaches to improving overall energy efficiency is to capture and reuse the "lost or waste heat" from an AC unit. A waste heat recovery (WHR) unit could be integrated to a septic tank unit with high energy efficiency. The combination of waste heat energy with the solar septic tank (SST) is considered a novel technique to improve efficiency of the on-site treatment systems. This study aimed to develop an appropriate design of SST integrating WHR and to evaluate energy efficiency and treatment performance. From the overall results, temperatures of the pilot-scale SST integrated with the WHR could increase up to about 45°C. The system performance resulted in the effluent TCOD, BOD_5 and TSS concentrations of 100, 30 and 18 mg/L, respectively. The effluent *E. coli* and total coliform concentrations were found to be lower than the WHO guideline, which were about 2–3 log. The application of the household scale waste heat recovery unit for the septic tank unit is recommended in this study.

Keywords: Solar septic tank; Treatment performance; Waste heat; Air conditioner

1. Introduction

The WHO/UNICEF Joint Monitoring Program (JMP) for Water Supply, Sanitation and Hygiene reported that 4.5 billion people, mostly in developing countries, still lack access to basic sanitation facilities [1]. On-site wastewater treatment systems such as cesspools or septic tanks are mostly used for black water (excreta combined with flush water treatment in most developing countries). The treatment efficiencies of those on-site wastewater treatment systems are quite low with organic and pathogen reductions of around 10%–50% [2–4]. To improve the treatment performance, an innovative and practical technique to use solar energy in the septic tank, called as "Solar Septic Tank (SST)" is considered as an effective sanitation technology for inactivating pathogens, converting organic wastes into methane biogas and alleviating the environmental concerns associated with fecal sludge handling. Increasing temperatures in the septic tank should be a reasonable measure to enhance anaerobic digestion and pathogen inactivation. Pussayanavin et al. [5] and Polprasert et al. [6] reported that more than 70% removal efficiencies of total chemical oxygen demand (TCOD) and biological oxygen demand (BOD_5) by operating temperature at 40°C in septic tanks, which were significantly different from the TCOD and BOD_5 removal efficiencies in conventional septic tanks, which were about 50%–60%. Similarly, Pussayanavin et al. [4] reported that the organic and solid removal efficiencies in septic tanks were found to be better when operating at temperatures above 30°C. Because unreliable climate and cloudy skies could reduce effectiveness of the SST, another external source of heating is required.

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The air conditioner absorbs heat from inside household and accommodation and recirculates it by cool air. The heat energy (considered as waste heat) that the air conditioner absorbs from rooms is released into the atmosphere, but it can be otherwise used in more effective and efficient ways. Recovering waste heat from an AC system has conventionally been used in many applications on industrial field. More than 80% of the electrical energy used by a household AC is converted into heat, which is considered as energy losses. Theoretically, a properly designed heat recovery unit from an AC can recover 50%–90% of the heat for use in heating water. The waste heat from air conditioners is used to produce hot water or steam. The system consists mainly of four parts: (1) evaporator, (2) absorber, (3) condenser, (4) generator to capture waste heat discharged from the refrigerant cycle of an air conditioner and transfers the heat energy into a water heater tank. Thus, to overcome the limitation of the SST, a simple novel waste heat recovery is proposed and introduced to achieve better treatment efficiency. This technology is considered to be cost-effective because heat from the household AC is used to heat the waste inside the SST. It also helps to increase efficiency of the air conditioning system which could reduce the payback period in the long run. The recovered waste heat energy is best utilized to supplement energy supplied to the SST by using a heat exchanger to extract waste heat from the AC system and produce hot water. Temperature of the extract waste heat can vary depending on the available energy that is utilized when the AC is under operation. The main objective of this study was to develop an appropriate design of SST integrating waste heat recovery (WHR) and to evaluate energy efficiency and treatment performance with respect to bio-degradation rate and pathogen inactivation.

2. Materials and methods

A pilot-scale SST integrated with a WHR system was constructed at the Asian Institute of Technology, Thailand (Fig. 1). The SST system shown in Fig. 1a consisted of a 1,000-L modified septic tank and a 12 m^2 vacuum tube solar

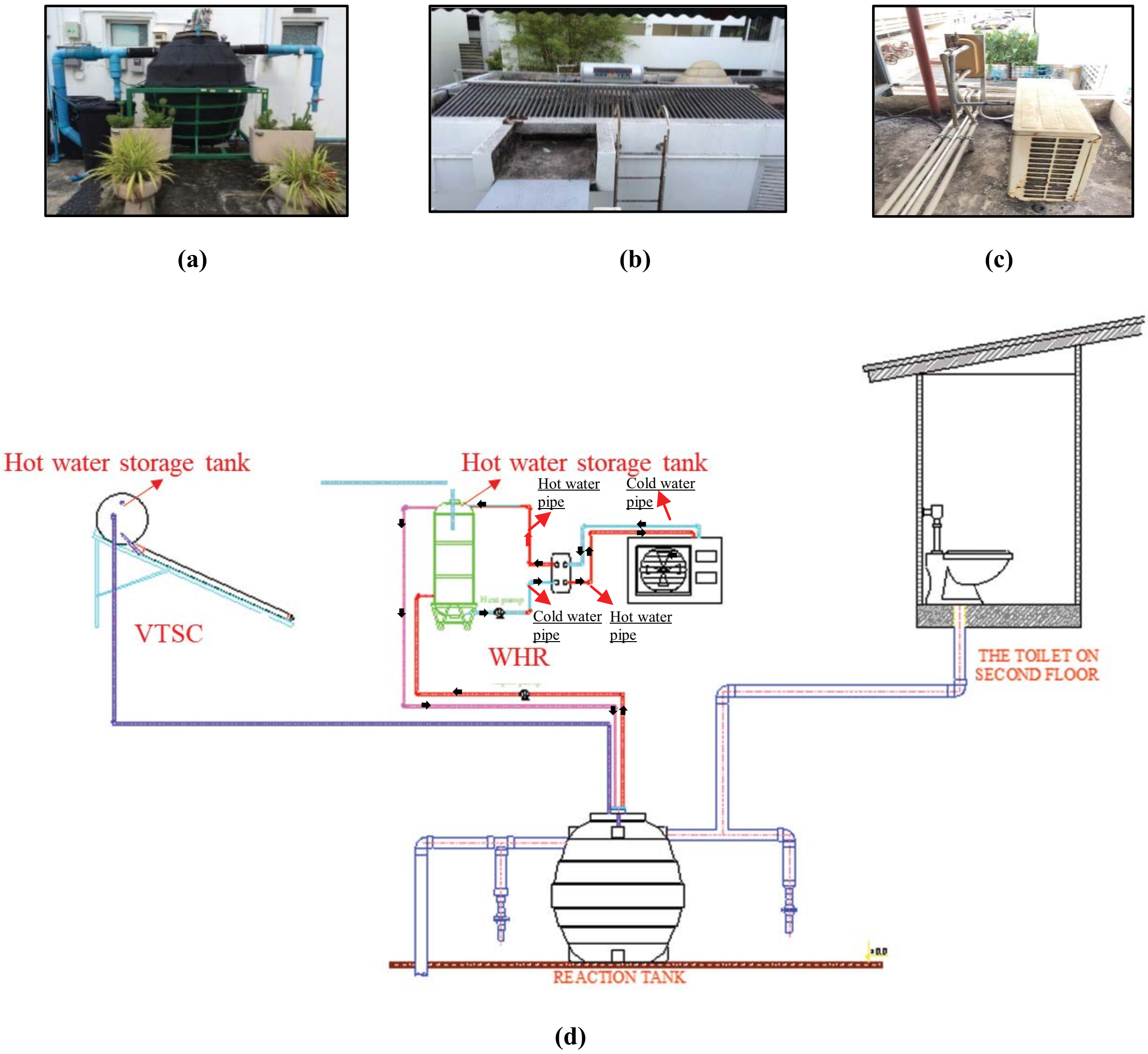


Fig. 1. (a) SST, (b) VTSC, (c) waste heat recovery unit, (d) SST with WHR unit.

collector (VTSC) (or a set of modular vacuum tubes that are connected to a header pipe) was used to absorb solar radiation and transfer energy to SST unit (Fig. 1a). To supply an external heat source to the SST unit, a hot vaporized refrigerant conduit between compressor and condenser of a 20,000 British thermal unit (BTU)-air conditioner in a restaurant was installed with the WHR unit (Fig. 1c). The WHR unit consisted of five main parts including plate heat exchanger (design for 6,500 kJ/h of energy generation) connected to an existing refrigerant of an air conditioner, air vent valve, 200 L-hot water circulate pump (a/c), hot water storage tank and digital controller/sensors. Temperatures inside the SST were increased by circulating the hot fluid through a heat transfer equipment (copper coil). The hot water was automatically pumped at a rate of 5 L/min when temperatures of the hot fluid become more than 40°C. Temperatures inside the SST and ambient temperature were monitored by sensors (PT-100 type HDP/7) and a temperature indicator box. The data of solar radiations were obtained from a meteorological station of Department of Energy, Environment and Climate Change at Asian Institute of Technology. The pilot-scale SST integrated with WHR unit (Fig. 1d) was operated at an average hydraulic retention time (HRT) of 24 h and received black water from a public toilet of an academic building. The influent and effluent samples (composite sampling) were collected for analyses of TCOD, BOD_5, TSS, *E.coli* and total coliform concentrations according to the Standard Methods [7] . The average concentrations of TCOD, BOD_5, *E. coli* and total coliform of the toilet wastewater during the operation period were found to be 8,370; 1,535 mg/L; 10^6 MPN/100 mL, respectively. The pilot-scale SST received black water from four female public flush toilets (6–10 L water/flush) with more than 40 users/d. To investigate the efficiencies (in term of overall treatment performance and energy) of the WHR unit, the experiments were conducted for about 6 months from the summer (starting from February) to monsoon seasons (after mid-June). The operation period of the restaurant and the air conditioner was from 8 am to 6 pm daily. To monitor the generated energy from the WHR unit, a thermometer was installed in the hot water storage tank and the temperature was recorded every 30 min in the data logger.

The generated energy from the VTSC and the WHR units was calculated by the following equation [8]:

$$P(\text{kW}) = \frac{V(\text{L}) \times \gamma\left(\frac{\text{kg}}{\text{L}}\right) \times C\left(\frac{\text{kJ}}{\text{kg} \times \text{K}}\right) \times \Delta T(\text{K})}{t} \quad (1)$$

where P = generated energy (kW); V = volume of hot water storage tank, (L); γ = density (kg/L); C = specific heat of water

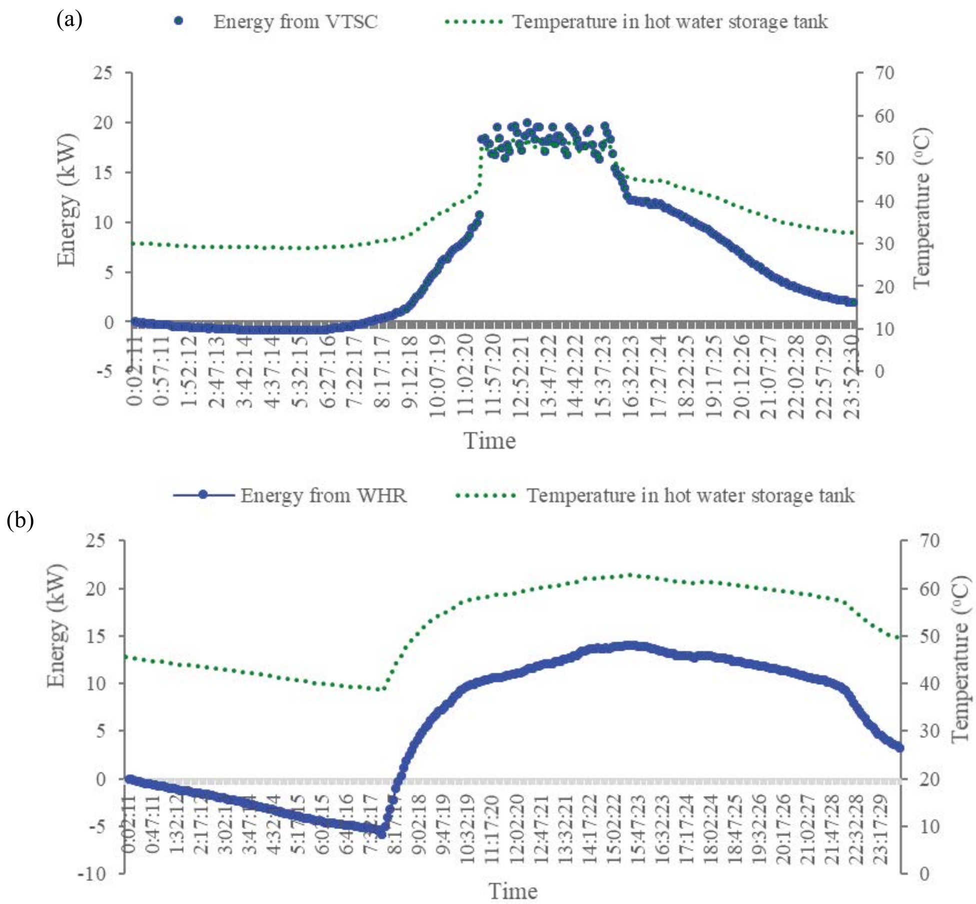


Fig. 2. Temperatures and energy profiles of (a) VTSC and (b) WHR.

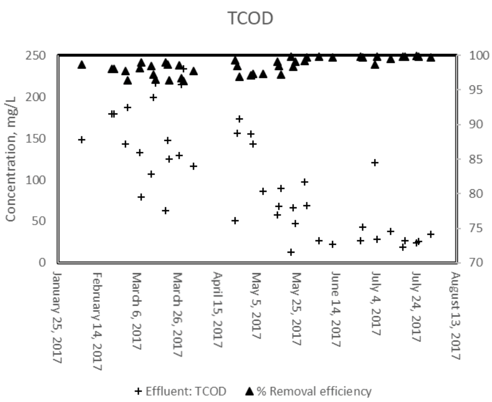
(kJ/kg K); ΔT = difference in temperature between time i and j and t = time (s).

3. Results and discussion

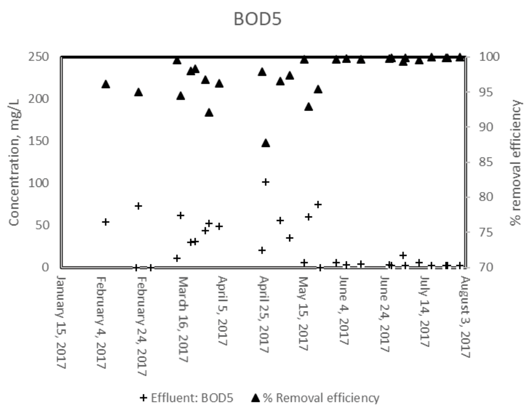
According to the data collected by the meteorological station, the intensity of solar radiation profile was quite high with the peak at noon time of around 900 W/m^2, while the morning and evening periods it was about 100–600 W/m^2. The ambient temperatures fluctuated in the range of 27°C–35°C depending on season and time of day. Figs. 2a and b show the temperatures and energy profiles of (a) the VTSC and (b) the WHR units, respectively. The supplied temperatures from the VTSC hot water storage tank increased from the morning until afternoon and decreased with decreasing solar radiation intensity in the evening; the maximum temperature of 55°C occurred during the period from 11 to 15 h, while the average temperature being 37°C. Heat recovery from the air conditioning showed more stable temperature profile with the average temperature being 48°C; while the maximum temperatures of 59°C were obtained during 12–21 h, during the office working period.

The average net energy generated from the VTSC was more than 5 kW, depending on the solar radiation and climatic conditions, while the average net energy generated from WHR unit was found relatively higher, which was about 10 kW.

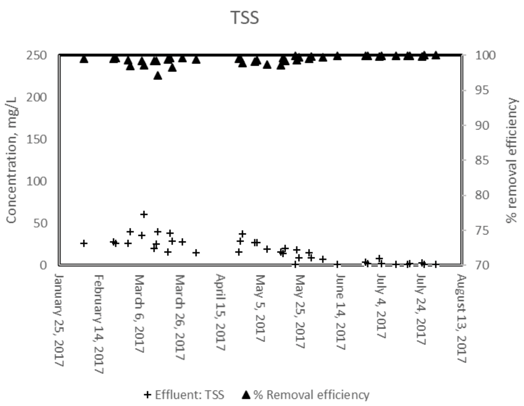
Accordingly, temperatures inside the SST during the operation period of February to July 2017 were found to fluctuate in the range of 35°C–55°C, with the average being 40°C. Similarly, depending on ambient temperatures, climatic condition and operation period of the air conditioner, the power input to the SST were found in the range of 1–24 kWh, with the average being 5 kWh. The negative power inputs were due primarily to energy losses from the SST caused by effluent flow and heat dissipation from the system. The negative power input means any heat transfer that increases the energy of a system is negative. During monsoon period, Koottatep et al. [9] reported that performance of the SST (without the WHR unit) was not ineffectively and resulting in high negative power input of more than 3 kWh. The pilot-scale SST integrated with the WHR unit could effectively remove TCOD, BOD_5 and TSS about 90%–98% (Fig. 3), probably because there were high biological reactions to degrade the organic compound in the liquid portion, which contributed to the decrease of the TCOD and BOD_5 concentration in the effluent (Figs. 3a and b). The pilot-scale SST received energy from the WHR unit to increase/



(a) TCOD



(b) BOD_5



(c) TSS

Fig. 3. Treatment performance of the pilot-scale SST integrated with waste heat recovery system.

maintain the high wastewater temperature and activating bacteria growth. It was found that an increase in wastewater temperature within the range of 40°C–45°C could enhance the treatment efficiency of the SST (Pussayanavin et al. [5]). The average HRT of 24 h was sufficient for the solid sedimentation, hence, the TSS removal efficiency was found to be relatively high, resulting in low TSS concentrations in the effluent (Fig. 3). The average TCOD, BOD_5 and TSS concentrations of the SST integrated with the WHR unit were 100, 28 and 18 mg/L, respectively, suitable for discharge into nearby water courses [10]. After 6 months, there is substantial reduction in TCOD and BOD_5, indicating progressive degradation of organic matter. It was observed that the TCOD and BOD_5 effluent concentration values decreased over time, which the average values were about 36 and 4, respectively. The progress of TCOD and BOD_5 removal after the after 6 months periods are shown in Figs. 3a and b.

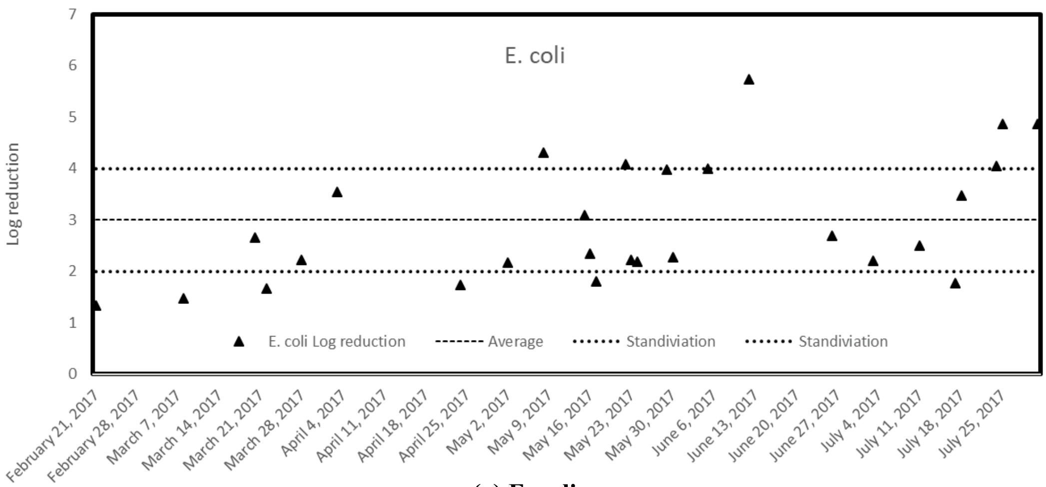
The inactivation efficiencies of *E. coli* and total coliforms in the SST were about 2–5 log reduction (Fig. 4), with the average being 3 log. Consequently, the *E. coli* and total coliform concentrations in the SST effluent were found to be about 3 log, less than those in the 30°C septic tanks which were 4–5 log (Koottatep et al. [2]). It was apparent that the increased temperatures of about 45°C in the SST integrated with the WHR unit had effects on the pathogen inactivation efficiencies.

The above results suggest the technical feasibility in applying the SST integrated with the WHR unit in treating black water from households to reduce pollution problems and protecting public health.

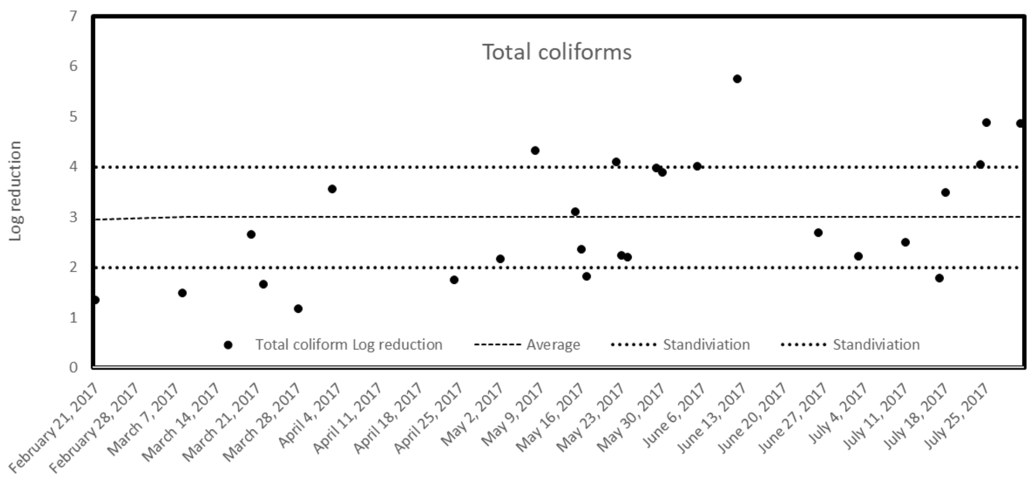
4. Conclusions

The results obtained from this study could be summarized as follows:

- Temperatures of the pilot-scale SST integrated with WHR unit were found to be about 45°C, depending on the available energy sources and climatic condition, while the average effluent concentrations of TCOD, BOD_5 and TSS were found to be 100, 30 and 18 mg/L respectively.



(a) E. coli



(b) Total coliforms

Fig. 4. Pathogen inactivation in the pilot-scale SST integrated with waste heat recovery system.

- The effluent *E. coli* and total coliform concentrations of the pilot-scale SST integrated with WHR unit were found to be about 3 log, lower, than those of the conventional septic tanks without heating.
- The treatment performance of the SST integrated with WHR unit suggested its technical feasibility in heating black water to improve environment condition and public health protection.
- The practical application of the SST integrated with the WHR unit for the individual household or the convenient store for the community scale is proposed as the concept design for a sustainable onsite wastewater treatment system.

Acknowledgements

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References

[1] 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, Available at: http://www.unwater.org/publications/whounicef-joint-monitoring-program-water-supply-sanitation-hygiene-jmp-2017-update-sdg-baselines/.

[2] T. Koottatep, R. Eamrat, T. Pussayanavin, C. Polprasert, Hydraulic evaluation and performance of on-site sanitation systems in central Thailand, Environ. Eng. Res., 19 (2014) 269–274.

[3] N. Surinkula, T. Koottatep, C. Chaiwong, T. Singhopon, Modified cesspool system with upflow sludge tank and low-cost photobioreactor treating blackwater, Desal. Wat. Treat., 91 (2017) 329–335.

[4] T. Pussayanavin, T. Koottatep, C. Polprasert, Modeling for prediction of sludge accumulation in septic tanks, Ramkhamhaeng Int. J. Sci. Technol., 1 (2018) 41–48.

[5] T. Pussayanavin, T. Koottatep, R. Eamrat. C. Polprasert, Enhanced sludge reduction in septic tanks by increasing temperature, J. Environ. Sci. Health, Part A, 50 (2015) 1–9.

[6] C. Polprasert, T. Koottatep, T. Pussayanavin, Solar septic tanks: a new sanitation paradigm for Thailand 4.0, ScienceAsia, 44S (2018) 39–43.

[7] American Public Health Association/American Water Works Association/Water Environment Federation, Standard Methods for the Examination of Water and Wastewater, 21st ed., Washington, USA, 2005.

[8] Metcalf & Eddy, Wastewater Engineering: Treatment and Resource Recovery, 5th ed., McGraw-Hill, New York, 2014.

[9] T. Koottatep, T. Pussayanavin, C. Polprasert, Development of a Solar Heating System for Improving Performance of On-site Sanitation Systems: the IWA S2Small2017 Conference on Small Water & Wastewater Systems and Resources Oriented Sanitation.

[10] Ministry of Natural Resources and Environment of Thailand: MNRE, Definition of standard of wastewater discharge from domestic wastewater treatment plant in Thailand, Royal Thai Government, Thailand, 2010.