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Comparative Carbon Footprint and Ecological Footprint of Loss and Gain of Forest and Agriculture Area due to Large-Scale Water Development Project

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Abstract

Quantitative evaluation of environmental loss and gain of forest and agriculture area were analyzed from the large-scale water development project in Thailand, The Increasing Volume of Water of Mae Kuang Project. It was found that after the project was completed, forest land will be increased and remove carbon dioxide in the atmosphere for about 7,106 tCO_2e. Ecological footprints in forest areas found footprints in the uptake of carbon dioxide from the reforestation areas have increased for about 1,476 ha_G. Agriculture land will be increased and remove carbon dioxide in the atmosphere for about 42,087 tCO_2e. Ecological footprints in the uptake of carbon dioxide from the agriculture areas have increased for about 2,834 ha_G. In terms of ecological footprints, about 4 and 11.27 times better use of land due to more forest area and better irrigation. From this study, it was found that footprints in forest and agriculture areas have a more positive impact than a negative impact. If construction is completed with better water management and able to deliver water to irrigation areas which helps increase the chances of absorbing more carbon dioxide from plants that can be cultivated throughout the year.

Keywords : water development project; carbon footprint; ecological footprint; Thailand

Introduction

Large-scale water development project in Thailand is required by law to conduct the environmental impact assessment (EIA) on the project prior to the approval of the project construction. According to Office of Natural Resources and Environmental Policy and Planning (ONEP) [1], large-scale water development project is defined as dam or reservoir with more than 100 million cubic meter of water or area contain more than 15 square kilometer of water or project with irrigated area of more than 80,000 rai (128 square kilometer when 1 rai equals 1600 square meter). Normally the project owner is required to conduct the environmental impact assessment (EIA) by following templates guided by ONEP with 4 main environmental impacts to be studied; impact on physical resources, biological resources, human use value and quality of life value. The Increasing Water Volume in Mae Kuang Udom Tara Project was being developed under the Royal Irrigation Department. Prior to the project construction, the EIA was conducted and report was published in 2009 with 4 main environmental impacts [2].

For the environmental impacts on physical value, one of the studies is the loss of natural forest and local agricultural plantation to be replaced with the project area (offices and other activities related of the project). This impact evaluation is in the form of monetary value of wood mass loss from tree cutting, the EIA however, did not quantitatively evaluate ecological loss due to the project. Also, the EIA report estimated the increasing irrigated area downstream of the project due to more water accessibility and again, did not quantify positive environmental impact to the irrigated area. These conventional impact study can be further evaluated and presented in the more up to date parameters of ecological and carbon footprints.

In this study, the environmental loss and gain from the large-scale water development project were being quantified in terms of ecological footprint (area base) and mass of carbon dioxide equivalent (kgCO_2e or tonCO_2e) or carbon footprint. This evaluation is to present another angle of environmental impact presentation of the large-scale project towards sustainability development goal.

Materials and Methods

Case study: Increasing Water Volume of Mae Kuang Udom Tara Project

From [2], the project of increasing water volume was being constructed by deviate 113 million cubic meter of water per year from Mae Tang river into Mae Ngat reservoir and then, 160 from Mae Ngat million cubic meter of water per year to Mae Kuang reservoir, as shown in Figure 1. Water from Mae Kuang reservoir was then flow into Mae Ping river, the main river in Northern Thailand. The project was expected 160 million cubic meters of water at Mae Kuang reservoir and improve water stability downstream within the area and then improve water management within northern Mae Ping river basin. The increasing of irrigation area was shown in Figure 2.

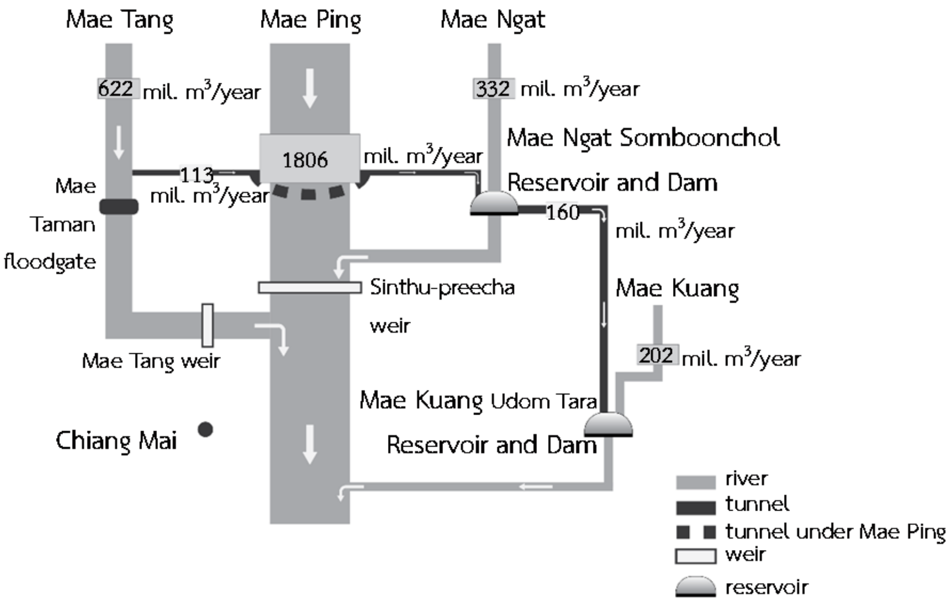

Figure 1 Schematic diagram of the Increasing Volume Water of Mae Kuang Reservoir Project (Adapted from the project's EIA report [2])

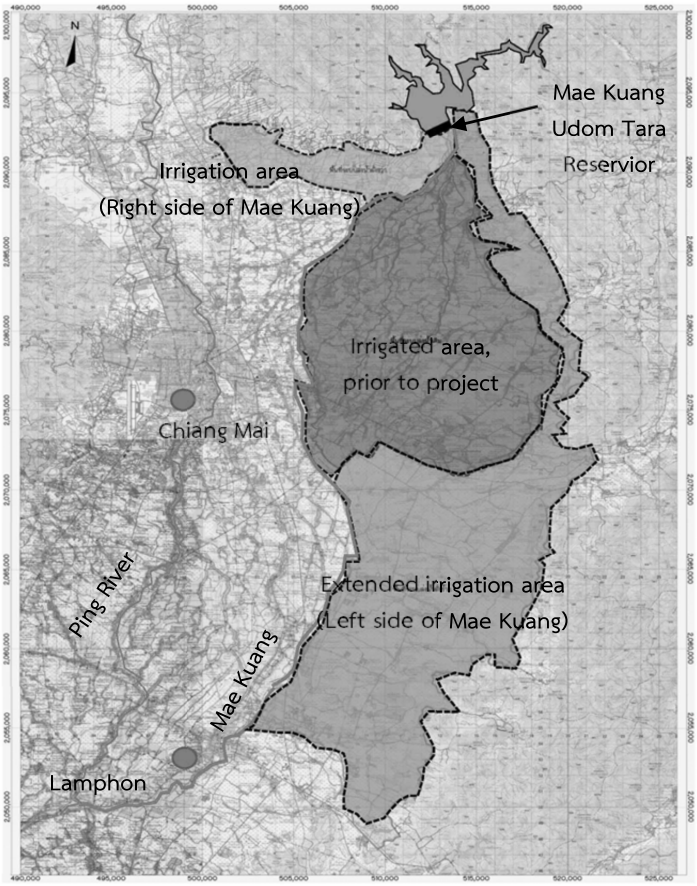

Figure 2 Increasing irrigation area after the project completion (Adapted from [3])

Calculation of greenhouse gas emission and removal

The assumption in this study was that when designated forest area is cleared for any anthropogenic project, potential use of atmospheric CO_2 due to plant photosynthesis in that area is demolished. Wise versa, after the project construction and the reforest planting program for more trees under the EIA agreement is succeeded, potential removal of atmospheric CO_2 occurs due to photosynthesis. Another point is that CO_2 uptake increases in irrigation area due to more accessibility of water from the large-scale water project.

The greenhouse gas emission due to the loss and gain of forest area was estimated based on carbon footprint calculation; footprint equals to activity data multiplied by emission factor. The emission factor used in this study was based on Guyana's Forest Carbon Monitoring System [4]. Based on [4], the emission factor applied to this study was of deforestation with change to infrastructure (high potential for change); 1,042.0 $tCO_2e\ ha^{-1}$ and to agriculture area of 1,141.9 $tCO_2e\ ha^{-1}$. The forest replanting program causing increasing in forest area, which increase the atmospheric CO_2 removal and the removal factor is 0.95 tCO_2/rai/yr for forest with local trees (slow growing) [5]. The large-scale water development project also increased the irrigation area downstream and this also caused better atmospheric CO_2 removal due to more effective plantation, compared to the 'before project' time frame. Atmospheric CO_2 removal was estimated with same removal factor.

Calculation for ecological footprint

For the concept of ecological footprint of losing forest area for the anthropogenic project, ecological footprint (EF), in area unit was calculated based on conventional calculation of EF from [6] and modification of 35% carbon sequestration from ocean, ecological footprint based on global agricultural ecological zone (EF-GAEZ) from [7] as,

$$EF_{forest} = \frac{CF_{forest} \times (1 - F_{CO_2})}{S_{CO_2-Nation}} \times YF_f \times EQF_f$$

When *EF* is ecological footprint [in global hectare, ha_G], CF_{forest} is greenhouse gas based on land use change [tCO_2e], FCO_2 is CO_2 adsorption rate of reservoir, 35%, $SCO_{2\text{-}Nation}$ is greenhouse gas sink in forest, in Thailand [tCO_2/ha], YF_f is yield factor of forest, in this case $SCO_{2\text{-}Nation}/SCO_{2\text{-}world}$. *EQF* is equivalent factor [ha_G/ha]. Equivalent factor of the forest, EQF_f is based on [8] and for forest, EQF_f is 1.26 and agricultural area, *EQF* is 2.51.

Sequestration rate of forest in Thailand

The $SCO_{2\text{-}Nation}$ in this study was from [9] after [10]. The carbon sequestration of semi-evergreen forest, 14.1% of the forest in Thailand, was 7.53 $tCO_2e/ha/yr$ while 3.51 $tCO_2e/ha/yr$ from mixed-deciduous forest, 53.9% of the forest in Thailand was reported. The average of 4.34 $tCO_2e/ha/yr$ was then used as $SCO_{2\text{-}Nation}$.

Sequestration rate of world forest

Based on [7], the world sequestration rate from 26 forest biomes around the world and was reported 0.95 metric tonnes of carbon per hectare per year. The data was then converted to be 0.95x44/12 equals to 3.48 $tCO_2e/ha/yr$.

Yield Factor for agricultural area

For agricultural area loss from this project, they were mostly fruit plantation for longan and mango. From FAOSTAT [11], primary fruit data for Thailand was 9.06 t/ha and 1.32 t/ha for world average (on year 2017). Yield factor for agricultural area in this study was 9.06/1.32 equals 0.68. Based on the estimation in the project's EIA report, increasing area for plantation of rice, soybean, potatoes, garlic and vegetable were reported. The yield factors were then calculated differently for each types of plants using 2017 FOASTAT data.

Results and Discussion

Based on the EIA report [2], area loss and gain due to project development were presented in Table 1. Since the project was mostly for construction of tunnel to deviate water from Mae Tang river to reservoirs, less forest land was used compared to other water development projects. The total area loss was 601,800 square meters. Irrigation area gain from this project was about 94,510,000 m^2 and 1,280,000 m^2 for foresting. When carbon footprint was calculated correction factor was used for 85% survival rate for foresting (normal practice, [12]) and 75% irrigation area was used for more realistic atmospheric CO_2 removal mechanism.

Figure 3 shows the estimation of carbon footprint from area loss and gain due to the project development. For forest, loss of potential atmopheric CO_2 removal of 2,104 tCO_2e due cut of forest plants. However, since forest rehabilitation project was established and maintained for at least 11 years following the project, 7,106 tCO_2e was calculated to be removed from atmosphere due to new area of forest at Mae Tang national forest and at Mae Taman floodgate area. For the agricultural area loss due to the project, 4,305 tCO_2e emitted to atmosphere. However, after project completion, 42,087 tCO_2e of etmospheric CO_2 will be potentially removed due to increasing irrigation area.

Another way to present this information was by calculating ecological footprint of the project in the unit of global hectare, as shown in Figure 4. By using carbon footprint presented in Figure 3, ecological footprint due to lossing land both forest and agricultureal area were 496 ha_G and 276 ha_G, reprectively. However, the forest rehabilitation and increasing irrigation area improve the ecological footprint for 1,972 ha_G and 3,110 ha_G, respectively.

From Figure 3 and 4, this study proposed another environmental impact presentation by showing values of forest and agricultural area loss and gain, not only for their monetary value but for improvement of environmental condition in the form of carbon footprint and ecological footprint.

Table 1 Area loss and gain from the Increasing Water Volume Project

Type	Area m^2
Loss to roads, construction area, tunnel portal and pumping station area	
Forest	210,400
Agriculture area (fruit plantation and corn)	391,400
Gain	
Forest: rehabilitation project at Mae Tang national forest and at Mae Taman floodgate area	1,280,000
Agriculture: increasing irrigated area downstream	94,510,000

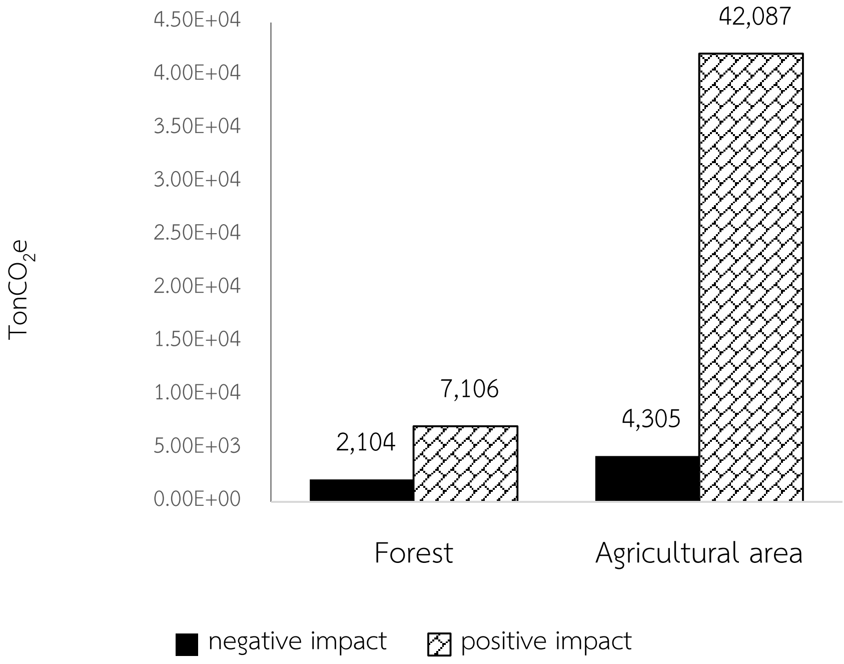

Figure 3 Carbon footprint from area loss and gain

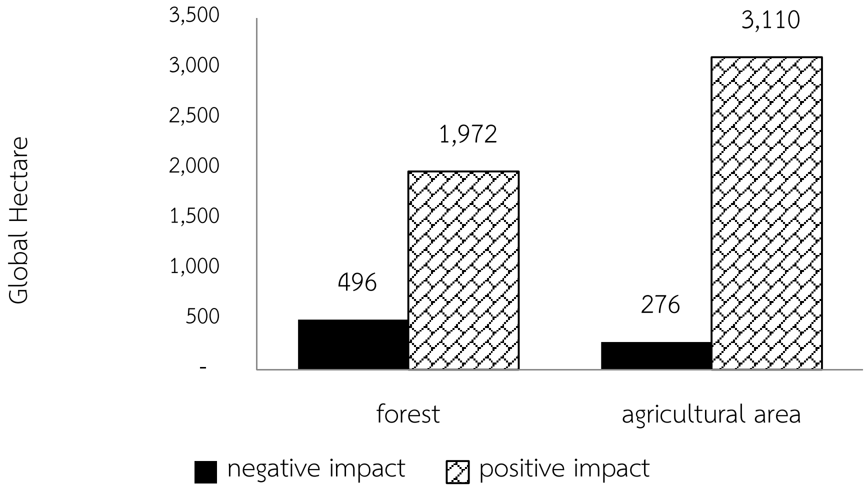

Figure 4 Ecological footprint in global hectare from area loss and gain

Conclusion

This study proposed another environmental impact presentation by showing values of forest and agricultural area loss and gain, not only for their monetary value but for improvement of environmental condition in the form of carbon footprint and ecological footprint. For carbon footprint, 3.38 times of CO_2e removal from the atmosphere in the area affected due to forest rehabilitation and 9.77 times of CO_2e removal from the atmosphere due to more effective agricuture because of better water accessibility and more irrigation area. In terms of ecological footprints, about 4 and 11.27 times better use of land due to more forest area and better irrigation.

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Removal of Gaseous Benzene by Photocatalytic Oxidation Process Using TiO_2 Film Coated on Glass Sheets under UVC Irradiation

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Abstract

Benzene is well known as a toxic and carcinogenic air pollutant, which is mainly emitted from industrial processes, vehicles, and residential activities. TiO_2-based photocatalysis is becoming one of the most promising solutions for the treatment of benzene in the ambient air. The present study aims to investigate the photocatalytic activity of TiO_2 film coated on glass sheets for the degradation of gaseous benzene under ultraviolet C (UVC) irradiation. TiO_2 thin film coated glass sheets were prepared through polyvinylpyrrolidone (PVP)-modified sol-gel method coupled with the doctor blade coating technique. It was found that the obtained TiO_2 film consisted of well-shaped TiO_2 particles with good adherents on a glass surface. There was no crack formation found in the film. The average film thickness was 1.187 µm. The maximum removal efficiency of benzene in the photocatalysis test was 4.5 and 6.4 times higher than that of the adsorption and direct photolytic tests, respectively, within 12 h. Moreover, the higher numbers of TiO_2 coated sheets, the higher photocatalytic benzene degradation, was obtained.

Keywords : air pollutant; benzene; photocatalysis; titanium dioxide; ultraviolet C

Introduction

Nowadays, air pollution is increasingly concerned as an important environmental issue. In this sense, volatile organic compounds (VOCs) emitted from industrial and residential activities are considered as one of a major group of air pollutants [1]. Among various VOCs, benzene has been recognized as one of the most dangerous carcinogenic substances, which can pose the highest cancer risk in human [2].

Gaseous benzene can be emitted from three main sources, including the residential activities (e.g. cooking, cleaning, and cigarette smoke), the chemical production processes (e.g. detergents, paints, glues, gasoline, coal, and heating oil production) and the vehicular emission especially in the high traffic areas [3, 4]. Most people can begin to detect the benzene odor at 61 ppm in the air and can identify it as benzene at 97 ppm in the air [5].

Short-term inhalation exposure to benzene can lead to negative effects on human bodies such as anesthesia, headache, tremors, and temporary loss of consciousness. Long-term inhalation exposure to benzene can lead to cancer and aplastic anemia in humans because red and white blood cell productions are inhibited [6]. Consequently, it is necessary to develop an effective solution for the treatment of benzene in the ambient air.

Based on the previous researches, gas-phase heterogeneous photocatalysis has been proven as a promising technology for benzene removal because of its distinguished properties over the conventional techniques such as cost-effectiveness, easy for operation, environmental protection, and applicable measurements [7, 8].

Over the last few decades, titanium dioxide (TiO_2) has attracted significant attention as a semiconductor photocatalyst for air purification from many researchers, scientists, and engineers. This is due to its appropriate band position, simple preparation, commercial availability, inexpensive, and high oxidizing power [9]. TiO_2-based photocatalysis is initiated by irradiation of light (wavelength < 388 nm) over the TiO_2 photocatalyst. UV light is a common source for UV irradiation. After irradiating of UV light, the electrons-hole pairs are generated results in formation of hydroxyl radicals ($^{\bullet}OH$) on the TiO_2 surface. $^{\bullet}OH$ are powerful and non-selective species, which can degrade the organic pollutants to obtain more readily biodegradable intermediate species and final harmless products [10].

There are several reports about the degradation of gaseous benzene by the TiO_2-based photocatalytic oxidation process under UV irradiation. TiO_2 film coated on supporting materials is more suitable for large scale applications than TiO_2 powder because they can be easily reused and separated from the treatment system. For example, Ku et al. (2007) reported that the photocatalytic degradation of gaseous benzene by using TiO_2 coated on glass exhibited higher performance than TiO_2 coated on stainless steel because glass is a nonconductive material. It does not affect the electron flow in TiO_2 molecules. On the other hand, stainless steel is a conductive material. The cations (e.g. Cr^{3+} and Fe^{3+}) can be transferred to the interface of TiO_2 and stainless steel, which lead to electron-hole recombination, and decrease the photocatalytic activity [11]

Xie et al. (2016) reported photocatalytic degradation of benzene by using TiO_2 thin film coated on soda-lime glass. PVP with molecular weight of 58,000 was used as a binder in sol-gel method. TiO_2 was coated on glass by dip coating technique. It was found that the optimal PVP content was 6% by weight. Photocatalytic activity of 6%-PVP TiO_2 film was 4.62 times higher than that of TiO_2 film without PVP [12]. The use of PVP as the binder of TiO_2 in the work of Xie et al. (2016) is interesting, but with dip coating, the thickness of TiO_2 is not easy to control and it is not suitable to the actual applications on the existing window glass or building.

This study focuses on the removal of benzene in the air by TiO_2-based photocatalytic oxidation process. TiO_2 photocatalyst was prepared by PVP-modified sol-gel method and fabricated on soda-lime glass sheets by the doctor blade technique, a process that can be adopted to mass production. The properties of TiO_2 film were characterized by scanning electron microscope (SEM) and energy-dispersive X-Ray spectroscopy (EDS). The comparative study of benzene removal in different reaction conditions (e.g. adsorption, direct photolysis, photocatalysis) and different numbers of TiO_2 coated glasses were performed under UVC irradiation.

Materials and Methods

Chemicals and Materials

Titanium butoxide (Sigma-Aldrich, 97% purity), PVP powder (Sigma-Aldrich, average M_w of 1,300,000), acetylacetone (Carlo Erba Reagents, 99.5% purity), and methanol (RCI Labscan) were used as Ti precursor, binder, stabilizing agent, and solvent for synthesis of TiO_2, respectively. The transparent glass sheets (2 mm thickness) were cut into 5 cm × 15 cm and used as a material for TiO_2 coating. A solvent (2-propanol) from RCI Labscan was used for washing of glass sheets before coating with TiO_2. Benzene (PanReac Quimica SAU, C_6H_6, 99.8% purity) was used to prepare the benzene vapor as a target compound in all experiments.

Preparation of Sol-Gel TiO_2 Film

TiO_2 films were prepared by PVP-modified sol-gel method [13]. PVP (0.8 g) and methanol (20 ml) were mixed until a homogeneous solution was obtained. Titanium butoxide (4 g) and acetylacetone (1.175 g) were added dropwise into the obtained solution and stirred for 30 min. After that the solution was mixed in the ultrasonic mixer (50 Hz) to ensure that the mixture was homogeneous. The glass sheets were washed by 2-propanol and then dried in the oven (105 °C) for 1 h. The obtained TiO_2 sol was coated on both side of glass surface by doctor blade technique. The adhesive tape strip was used to control the film thickness. A glass rod was used to spread the TiO_2 solution on glass surface. The coated glasses were placed in an oven (105 °C) for 1 h. The dried films were then calcined at 500 °C for 2 h. Morphological appearances and elementary components of TiO_2 coated glass were characterized by a JSM-6610 LV scanning electron microscope (SEM) coupled with an oxford INCA EDS.

Experimental Setup

The experiments were conducted in a batch reactor, as shown in Figure 1. A batch reactor is an acrylic rectangular chamber with volume of 14.9 L. A rubber septa was established on the top of the chamber as an injection port and gas sampling port. A small electrical blower was turned on during experiment to ensure the well mixing in the chamber.

All of the experiments were performed at initial concentration of gaseous benzene of 100 ppm which was prepared by injection of liquid benzene with amount of 5.4 µL into the chamber. Effect of reaction conditions which were studied in this work including adsorption, direct photolysis, and photocatalysis. All of the experiments in this study were investigated with

16 glass sheets, excepted the experiment of effect of number of TiO_2 coated glass sheets.

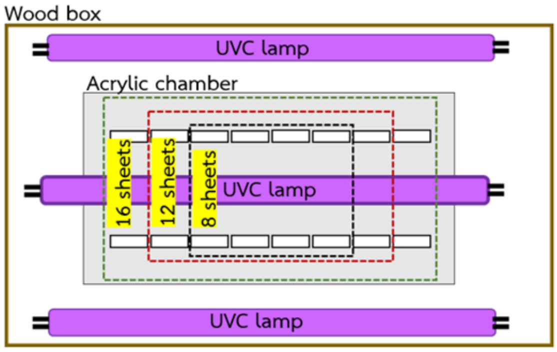

Figure 1 Top view of the experimental setup

For adsorption test, the TiO_2 coated glass sheets were placed in the chamber. The chamber was kept in the wood box without UV irradiation (dark condition) for a period of time of 12 h. For photolysis test, the uncoated glass sheets were placed in the chamber. The chamber was kept in the dark condition until equilibrium adsorption. After that, three UV lamps (Philips, TUV F17T8, 18W, light intensity = 27 µW/cm^2) with wavelength of 253.7 nm (data provided by the supplier) were turned on for a period time of 7 h.

For photocatalysis test, the TiO_2 coated glass sheets were placed in the chamber, and the experiment was carried out as the same method as photolysis test. In case of effect of number of TiO_2 coated glass sheets, the uses of 8, 12, and 16 TiO_2 coated glass sheets in photocatalysis test were carried out and compared.

Sampling and Analysis of Benzene

A gas sample (1 ml) was withdrawn from the rubber septa by a gas syringe at every time interval of 30 min. A gas chromatograph instrument (Shimadzu, GC-14B) equipped with a capillary column (RTX-502.2, 0.53 mm inner diameter, 105 m length, 3 µm film thickness) and a flame ionization detector (FID) was used for measurement of benzene concentration. Nitrogen gas was used to carry samples through a column. The temperatures of injection port, column, and detector were set up at 100 °C, 100 °C, and 150 °C, respectively.

Results and Discussion

Characterizations of TiO_2 Film

Figure 2 shows the cross-sectional-view images of glass sheets before and after coating. TiO_2 film showed good adherence on the surface of a glass sheet. There was no TiO_2 powder fell out of the film. The color of a thin film was milky white. The coated surface area of TiO_2 film on each side of a glass sheet was 52.0±0.5 cm^2, which was successfully controlled by the adhesive tape strip.

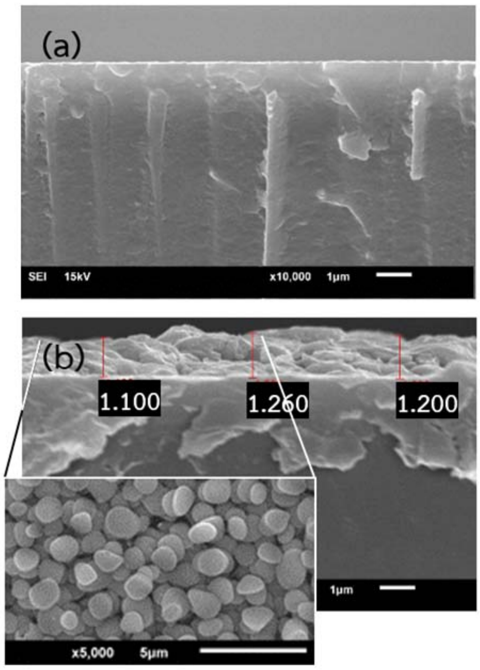

Figure 2 SEM cross-sectional-view images of (a) bare glass sheet and (b) TiO_2 coated glass sheet (inset is a top-view image of TiO_2)

For the bare glass sheet, the surface was smooth without an impurity layer covered on it. For TiO_2 coated glass sheet, the glass surface was covered thoroughly by the well-shaped TiO_2 particles without crack existing, because the influence of PVP in the preparation of TiO_2 sol could be slow down the evaporation of methanol, leading to the prevention of cracking [12]. The average thickness estimated from three different sites on the surface of TiO_2 film was 1.187±0.081 μm.

XRD pattern of the fabricated TiO_2 film shows crystalline phase of anatase (Figure 3). Sirirerkratana et al. (2019) also reported that TiO_2 thin film prepared by sol-gel method and coated on glass substrate were composed of anatase phase [13].

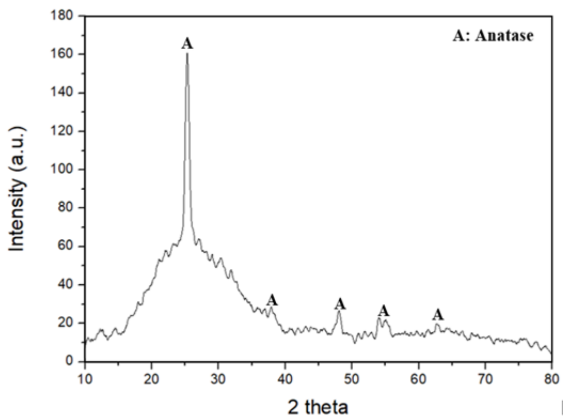

Figure 3 XRD pattern of fabricated TiO_2 film

The elemental compositions were obtained by EDS of three different points on the surface of a bare glass and TiO_2 coated glass sheets (Table 1). For the bare glass sheet, the elemental composition is in agreement with the typical composition of soda-lime glass, which composed of SiO_2, Na_2O, CaO, MgO, Al_2O_3 and the smaller amount of other compounds [14]. For the TiO_2 coated glass sheet, the elemental composition mainly composed of Ti and O.

Effects of Reaction Conditions on Benzene Removal

From the leakage test by addition of carbon dioxide into the reactor, no leakage was found in the reactor. The removal efficiencies of gaseous benzene under different reaction conditions were compared and presented in Figure 4.

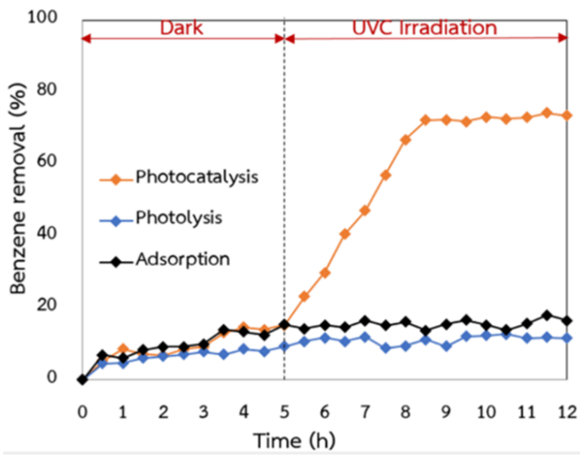

Figure 4 Removal efficiencies of benzene in different reaction conditions

From the adsorption experiment, the removal efficiencies slightly increased up to 15.4% during 5 h. After that, the efficiencies were not significantly changed. It could be noted that the adsorption of benzene onto the acrylic reactor wall and the TiO_2 film had reached equilibrium at 5 h. For the photolysis experiment (bare glass sheets), benzene was adsorbed onto the acrylic reactor wall and the removal efficiency was stable at 3.5 h (dark condition). The reactor was kept in the dark condition until 5 h to ensure that the adsorption had reached equilibrium. After that, the UVC irradiation was performed for 7 h. It was observed that the efficiency was not significantly changed.

Table 1 Elemental compositions of bare glass sheet and TiO_2 coated glass sheet

Sample	%Weight									
	Ti	O	Na	Mg	Si	Cl	Ca	C	Sn	Al
Bare glass sheet	0.00	44.02	8.21	2.23	33.10	0.00	5.70	3.25	3.16	0.34
TiO_2 coated glass sheet	40.01	46.73	2.10	0.25	5.56	0.42	1.34	3.57	0.00	0.00

In case of the photocatalysis experiment (TiO_2 coated glass sheets), the reactor was kept in the dark condition until 5 h for adsorption. The remaining benzene concentration was 85.97 ppm. After that, the reactor was irradiated by UVC for another 7 h. During the irradiation of UVC, the removal efficiencies of benzene in the photocatalysis experiment were higher than those of the photolysis experiment because the irradiation of UVC over the TiO_2 photocatalyst could generate the free radicals, resulting in the degradation of benzene molecules through oxidation process. The maximum efficiencies of 75% was observed at 3.5 h of UVC irradiation in the photocatalysis experiment.

Chang and Seo (2014) also reported the same results that the decomposition rate of benzene vapor in UVC-TiO_2 photocatalytic system (wavelength of 254 nm) was much higher than that of UVC direct photolysis [15]. He et al. (2014) reported that the reaction pathways for degradation of benzene by hydroxyl radical ($^{\bullet}OH$) involve three main steps. In the first step, benzene molecules in the air are adsorbed onto the TiO_2 surface and then react with •OH to generate phenol as the first intermediate species. Phenol molecules can also react with $^{\bullet}OH$ to form the subsequent intermediate species. In the second step, oxidation reaction of the intermediates can generate the ring-opened compounds with higher carbon numbers. These species can be subsequently degraded into the smaller aliphatic compounds. In the final step, the remaining species can be mineralized to be CO_2 and H_2O [10].

Effects of Number of TiO_2 Coated Glass Sheets on Benzene Removal

The relationship between removal efficiencies of gaseous benzene by using 8, 12, and 16 TiO_2 coated glass sheets and irradiation time is revealed in Figure 5.

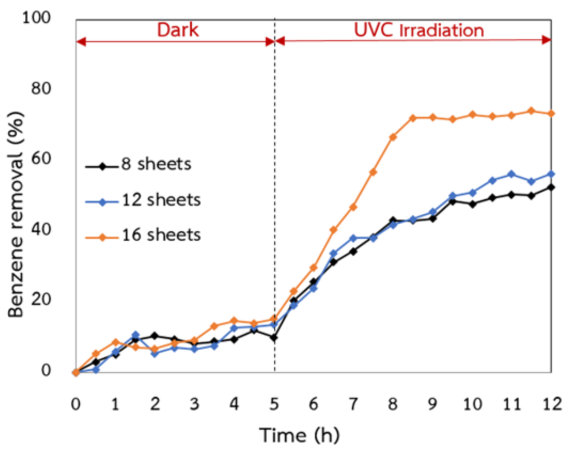

Figure 5 Removal efficiencies of benzene by using different numbers of TiO_2 coated glass sheets

Conclusions

TiO_2 sols prepared through the PVP-modified sol-gel method can be coated as a thin film on the surface of glass sheets. Doctor blade coating followed by calcination is a promising technique to control the uniform thickness of TiO_2 film. The maximum efficiency for degradation of gaseous benzene was 75%, which was observed in the presence of TiO_2 and UVC irradiation. The benzene removal efficiency can be enhanced by increasing number of the TiO_2 coated sheets which is related to the surface area on supporting materials.

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Management Model of Mobile Phone Waste of Selling and Repair Shops in Municipality of Ratsada Subdistrict, Mueang District, Phuket Province

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Abstract

The objectives of this study were to 1) study the management model of mobile phone waste of operators, repair shops and mobile phone dealers and 2) study the problems / suggestions of operators, repair shops and mobile phone dealers. This study was a survey research using questionnaire to study the mobile phone management model of mobile phone repair shop and service provider. Data from June - August 2017 were analyzed for frequencies and percentages. There were 26 establishments in the municipality of Ratsada Muang Phuket. Most entrepreneurs were male. In terms of age, 57.70% and 23.08% were in the range of 26-30 years and 31-35 years old, respectively. Their educations are mostly of Diploma / equivalent level 53.85% and 76.92% had been in business for 1-5 years. The study of mobile phone management model indicated that the major part of mobile phone was the circuit board and the mask accounted for 18.52%. For the management of the wastes, 92.30% ownership of establishments were responsible and 40.94% know how to properly handle by reusing. Problem and suggestions of mobile phone management model emphasized the need to receive information; 92.30% of the respondents wanted to receive news from television, 30.77% had problems of handling mobile phone wastes, 61.54% had problems because they had no place to store and no knowledge of management, 25.8% wanted to solve the problem by training, 29.83% needed training were collectors or managers of mobile phones. About 80.77% of entrepreneurs supported the municipality. In the case of the mobile phone screening project, 57.70% of the respondents were willing to pay for the service. The entrepreneur wanted to have a business responsibility for the disposal and storage of mobile phones in the future.

Keywords : Mobile Phone Waste; Operators; Repair Shops and Mobile Phone Dealers; Reuse

Introduction

Presently, some many modern technologies and advances that occur to meet the needs and convenience of human daily life. With the variety of technology developing rapidly, it causes the unceasing consumption of electronic products and it was distributed to all people. The development of the electronic. Industry makes many types of electronics obsolete quickly.

Technological advancement also speed up electronic products outdate rapidly, which make the highest change rate. The average service life of mobile phones is 18 months. Lifespan combined with the number of mobile phone users, that currently, more than 1 billion people worldwide are increasing while e-waste is also increasing at the same time [1]. According to the Pollution Control Department which collects statistics data of electronic waste 2016, it was found that, in Thailand, there was an increase in the amount of e-waste more than 20 million units and is likely to increase by 10 percent per year, especially mobile phones have a high volume of 10.9 million pieces. It was considered such highest amount because of these electrical appliances and electronic devices have developed rapidly and had a short service life. Most electronic waste contains hazard heavy metals such as lead, mercury, cadmium, arsenic, sulfur, and other chemicals. Besides, it is found that a large amount of electronic waste is smuggled from foreign countries into Thailand. The electronic waste was sent to the villagers in the community to sort, disassemble, and then metals were sold. The remaining of electronic waste was disposed of by incineration or landfill. In this regard, an improper incineration and disposing of electronic waste would cause environmental, community and health problems as well as safety in the occupation of those directly involved.

Moreover, people or electronic products users still lack knowledge and understanding of the dangers of electronic waste. These things, though, have been closed to them, they do not know the e-wastes' impact to health. Therefore, they do not know what the harmful will occur [2].

Ratsada Subdistrict Municipality is a community that provides relatively high expansion of services in commerce and industries due to the expansion of the adjacent area, Phuket Municipality. This Subdistrict Municipality still cover sufficient space for economic growth, as seen by the population growth and many projects of housing estate development [3]. The number of mobile phone repair and sell shops had been increased to meet the needs of the people. These shops have provided repairing services for the damaged mobile phones. If there is a good management model, which is the basic knowledge to manage mobile phone waste problems. The problems and dangers of electronic waste affecting humans and the environment will be reduced.

The study of management of mobile phone wastes generated by the sale and repair phone shops in Ratsada Subdistrict Municipality, Mueang District, Phuket Province aimed to get information about mobile phone waste disposal management. Then, the information was assessed in terms of consistency with the proper methods that do not affect health and the environment. The problems/suggestions from the operators of the mobile phone sale and repair shops were studied. The study results could be used as a guideline for operators to protect their health from the hazardous substances which have limited content releasing into the environment.

A study of the management of mobile phone waste is repaired and sale phone shops in Ratsada Subdistrict Municipality, Mueang District, Phuket Province aim to get information about mobile phone disposal management of repaired and sale phone shops. Then the information was assessed consistent with the proper methods and do not affect health and the environment. The problems/suggestions from operators of mobile phone repair and sale shops were studied. The results of this research can be used as a guideline for operators to protect their health from hazardous substances and these substances were limited in releasing into the environment.

The study area covered the mobile phone repair and distribution shops in Ratsada Subdistrict, Mueang District, Phuket Province. There was a total of 26 shops in 6 villages [4] as follows

1. Ban Koh Sirey, including, Nong May mobile, Nishakorn mobile, Roumpol mobile, Taweelab, and Kit Phadoong Suesarn.
2. Ban Bang Chi Lao including Eufa mobile, T.N shop 2, and Master mobile.
3. BanGugu including, D-day mobile, Mister mobile, Charoenpol mobile, J.K telephone, and Mai mobile.
4. Ban Thung Kha Paniang Teak, including, Master mobile 2, and Tep I.T.
5. Ban Lak Kongsi, including, No name mobile, P.T mobile, and Moji phone.
6. Ban Ta rue mai, including, Cyber phone, Choke mobile, Tepi mobile, Tawee silp suesarn, Variety phone, No one best technology, and Pe Ko mobile.

Materials and Methods

This research was the survey research. Data taken from the operators of mobile phone sale and repair shops were collected by using questionnaires. The sampling area was in Ratsada Subdistrict Municipality, Mueang District, Phuket Province. The study steps are as follows

1. Study of the information about mobile phone wastes and how to manage them by reviewing the related documents and research in various publications; including books, articles, journals, and internet. The relevant important topics were summarized and embraced in this study.
2. Scoping the study area including 26 mobile phone repair and sale shops in Ratsada Subdistrict Municipality, Muang District, Phuket Province.
3. Creating tools for research

   1) Tool characteristics: It is a closed-end and open-ended questionnaire with the choosing answer and fills in the blank.

   2) Create a tool with the following steps; Collect related questions, define the format of the closed-end and open-ended questionnaires. The questionnaire consists of 3 parts: Part 1 is about general information of the respondents. Part 2 is about the management method of mobile phone waste in the mobile phone repair and sale shop. Part 3 is about problems/suggestions for managing mobile phone waste. The questionnaire used for collecting data has a reliability of 0.825. (Cronbach' s Alpha)
4. Scoping targets with a specific audience (Purposive Sample), which must be the operator of the mobile phone repair and sale shops in Ratsada Subdistrict Municipality, Mueang District, Phuket Province. All the shops were surveyed because there was a small number of shops, so the researcher collected data from all 26 shops.
5. Data collection and data analysis: The data were collected by questioning the target group, namely, operators of mobile phone

repair and sale shops in Ratsada Subdistrict Municipality, Mueang District, Phuket Province. Finally, the obtained data were analyzed and calculated the frequency and percentage.

Results and Discussion

General Information

General information of the operators of 26 mobile phone repair and sale shops in the studied Subdistrict Municipality are as follows; they were male as 57.70%, the highest percentage was the age in the range of 26-30 and 31-35 years old as for 23.08%. The most educational level was diploma/equivalent as 53 53%. The operation time of the business mostly in 1-5 years, accounted for 76.92%.

The shop owners mostly open the shop and operate the mechanic themselves. The studied entrepreneurs had knowledge with ability in particular fields, so they could do the mechanic work. The service time of the shops was in the range of 1-5 years.

This study result was consistent with the results of Waewsri (2014) [5] on the decision factors of the consumer in Bangkok on buying a smartphone indicated that modernity was the concept of buying and using smartphones of consumers. Another factor was machine intelligence. Such factors were the causes of smartphones changing, so that there were several mobile shops increasing today.

Type of Mobile Waste

As shown in Table 1, there were 2 types of mobile phone debris existing the most composites ie, circuit board and phone mask, represented equally as 18.52%, followed by batteries 17.78%, liquid crystal 16.30%, speakers 11.11%, keypad 7.41%, signal conductor 5.18%, microphone 2.96%, voltage adaptor 2.22%. Type of mobile phone waste is presented in Figure 1.

Table 1 Mobile Phone Waste in Mobile Phone Repair and Sale Shops

No.	Type of mobile phone waste	Frequency (F)	Percent (%)
1	Circuit board	25	18.52
2	Liquid crystal display	22	16.30
3	Speakers	15	11.11
4	Microphone	4	2.96
5	Phone mask	25	18.52
6	Keypad	10	7.41
7	Signal conductor	7	5.18
8	Voltage adaptor	3	2.22
9	Batteries	24	17.78
Total		**135**	**100**

Figure 1 Type of mobile phone waste (A) Phone mask (B) Liquid crystal display (C) Batteries (D) Speakers (E) Microphone (F) Circuit board (G) Keypad

As stated above, two types of mobile phone scraps were circuits and mask accounted for 18.52%, which is consistent with the study of Chanthongmae (2007) [6] who studied hazardous waste management of electric repairing shops in Phuket Municipality, Phuket Province. They found that the most hazardous waste presented was the circuit as the circuit is the main part of various devices making function on a mobile phone work. So, the circuit is necessary part of the mobile phone. The mobile mask frequently changes due to it is broken. If the mobile phone is damaged, it is necessary to fix it by professional persons. Most of professional persons have a long time working and more experience in fixing. The least common type of mobile phone scraps was the voltage adaptor accounted for 2.22%. The voltage adaptor is a simple device used to charge the battery. It is less damage along with the service life of a mobile phone. When changing or repairing mobile phones, mobile phone waste cannot be reused. The shop owner is responsible for managing mobile phone waste. Since the shop owner is the operator and the mechanics, it is the responsibility of managing the mobile phone waste.

Mobile Waste Management

Regarding mobile phone waste management, 4 types of waste management including reuse, selling, municipal proper disposal, recycle are presented in Table 2.

Table 2 Mobile phone waste management

No.	Type of mobile phone waste	Mobile phone waste management								Total	
		Mixed discarding		Reuse		Selling		Proper municipal disposal			
		F	%	F	%	F	%	F	%	F	%
1	Circuit board	-	-	21	80.77	5	19.23	-	-	**26**	**100**
2	Liquid crystal display	-	-	3	13.04	20	86.96	-	-	**23**	**100**
3	Speakers	1	5.88	13	76.47	3	17.65	-	-	**17**	**100**
4	Microphone	3	20	9	60	3	20	-	-	**15**	**100**
5	Phone mask	8	32	1	4	16	64	-	-	**25**	**100**
6	Keypad	-	-	11	64.71	6	35.29	-	-	**17**	**100**
7	Signal conductor	-	-	9	60	6	40	-	-	**15**	**100**
8	Voltage adaptor	-	-	3	37.5	5	62.5	-	-	**8**	**100**
9	Batteries	20	80	-	-	4	16	1	4	**25**	**100**
Total		32	18.71	70	40.94	68	39.77	1	0.58	171	100

Note: F = Frequency

However, as seen in Table 2 the most conventional mobile phone management included at least 2 means indicated as follows. Circuit board employed reuse 80.77%, selling 19.23%. Liquid crystal employed reuse 13.04% and selling 86.96%, Speakers employed 76.40%, selling 17.65%, and mixed discarding 5.88%. Microphones employed reuse 60.00%, selling 20.00%, and mix-discarding 20.00%. Phone mask employed reuse 4%, selling 64%, and mix discarding 32%. Keypad carried out reuse 64.71% and selling 32.59%. Signal conductors carried out reuse 60%, selling 40%. Voltage adaptor had reuse 32.5% and selling 67.5%. Batteries were mostly handled by mixed discarding 80%, selling 16% and properly disposing 4%. The most common method of managing a mobile phone waste was reuse accounted for 40.94% followed by selling as for 39.77% and only 0.58% for proper municipality disposal. Noting that such management methods could reduce the amount of mobile phone waste as well as disposal of mobile phones that affect the environment, which is consistent with the study results of Hunsom (2007) [7] conducted a study on the simultaneous recovery of precious metals from the mobile phone batteries by using acid leaching process. The heavy metals of mobile batteries were separated and used again. From such research hydrochloric acid provide the best leaching result. The heavy metal from leaching must be extracted into the pure metal which is utilized as a catalyst in the future.

Regarding the waste management responsibility, mobile phone waste, due to changing or repairing mobile phones, could not be reused. The shop owner is responsible for managing mobile phone waste. Since the shop owner is the operator and the mechanics, it is the responsibility of managing the mobile phone waste. As shown in Table 3, presents that the person who are responsible for managing the mobile phone waste was the owner accounted for 92.30 percent, and payee/ repairman that account for 7.70%.

Table 3 The person who responsible for managing the mobile phone waste

No.	The person who responsible for managing the mobile phone waste	Frequency	Percent
1	Owner	24	92.30
2	Payee/ Repairman	2	7.70
Total		**26**	**100**

Operator Requirement

Based on this study, it indicated that the operators of repair and sale shops need information about mobile phone waste management in a proper way accounted for 92.30%. The media for information about mobile phone waste management was television as for 30.77%. The operator faced problems with mobile phone waste management about 61.54%. Most of the problems was the lack of storage place and knowledge of mobile phone waste management about 25%. The solution needed was the knowledge of training method accounted for 29.83%. Most of the respondents required the collecting and mobile phone waste management from Ratsada Subdistrict Municipality as for 80.77%. If there is a project about mobile phone waste sorting, they were willing to pay for the service fee, accounted for 57.70%. The operators extremely required the service organization for collection and disposal of mobile phone waste in the future accounted for 24.14%.

In addition, the study of awareness and behavior on mobile phone waste management, case studies of the youth in Bangkok, showed that the youth group who received the information had higher awareness of waste management than those who did not receive the information. The television media provided higher awareness of waste management than other media sources as television is a communication device that many people living in various areas can access thoroughly in time and reliable. Television media can display video and audio at the same time. This makes people more understand the information than other media.

Regarding the problems faced by the operator about no place for storage of the mobile phone waste. Since the business area is not spacious, mobile waste do not need storage. Another problem was the lack of management knowledge which is consistent with the study results of Tantipalakul (2016) [9] who researched the situation of electronic waste management of government and people in Bangkok. It revealed that the people still lack knowledge and understanding about electronic waste management as the law is not evident, the penalties are not serious, and lack of strong law enforcement. Most entrepreneurs want a solution to the problem by getting knowledge through training arranged by the relevant departments. Most of respondents (80.77%) want training by the Ratsada Subdistrict Municipality. Regarding the knowledge on hazardous waste management, Pollution Control Department had prepared a guide for the management of community hazardous waste for the administrators of local government organization. It is used as a guideline for management planning. Because Ratsada Subdistrict Municipality, who is responsible for all Ratsada Subdistricts, has sufficient knowledge and has the power to supervise the area, therefore, there is a project about providing knowledge about mobile phone waste management. There is a meeting with village leaders and related persons to attend and create preventive measures, control, supervise and exchange knowledge on mobile phone waste management to reduce the occurrence of impacts. The owners want to establish the workplace that is seriously responsible for the disposal and storage of mobile phone waste, in the future, accounted for 24.14%. It has to be cooperated in all relevant sectors, including government, private sectors, and shop owners to reduce the impact caused by mobile phone waste. In the future, the government should organize activities to raise awareness and impact of mobile phone waste for people. There are measures to control and should support the data collection in all areas or other municipalities to compare the various data. The private sector is factories, which are registered legally, that provide waste disposal services and unused materials. This includes the phone manufacturers that are responsible for managing the mobile phone waste. The result is consistent with Ongardvanich (2012) [11] who studied the responsibility of manufacturers to manage electric waste and electronic products in Thailand. The result showed that in many industrial countries, especially the European Union, legislation has long been in line with the manufacturer's responsibility. Manufacturers are designated to be responsible for managing electric waste and electronic products. Because the manufacturer knows best about the manufactured product. Therefore, manufacturers have a role in the product from the beginning of the procurement of raw materials until the management of the produced waste. Operators are responsible for sorting and disassembling mobile phone parts for easy handling and collection for proper disposal.

Conclusion

A study of the mobile phone waste management method of mobile phone repair and sale shops In Ratsada Subdistrict Municipality, Mueang District, Phuket Province, found that the circuit boards and phone masks were the higher component than other parts as mobile phone wastes generated equally as for 18.52%. The business owner was responsible for managing the mobile phone wastes for 92.30%. Management method employed reuse as for 40.94%. According to the study of problems/ suggestions on the management of mobile phone waste, the needs for useful information was 92.30%. Needs to receive the information on television was 30.77%. Problem of managing the mobile phone waste was 61.54%. Such problems was due to lack of storage space and lack of management knowledge 25%. Solution to problems by knowledge training was 29.83%. Ratsada Subdistrict Municipality was the main unit that collected and managed the mobile phone waste accounted for 80.77%. If there is a project about mobile phone waste sorting, they were willing to pay a service fee, accounted for 57.70%.

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Flood Risk Mapping Using HEC-RAS and GIS Technique: Case of the Xe Bangfai Floodplain, Khammoune Province, Lao PDR

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Abstract

Xe Bangfai (XBF) is one the main tributaries of the Mekong river in central Lao PDR, where is vulnerable to flooding, was influenced by monsoon in northeastern and southwestern parts of country. The heavy rainfall often occurs over several consecutive days resulting in a rise in the level of the Mekong River. In this study, the flood frequency of different magnitudes was analyzed using the Gumbel's distribution method. The flood depth value was simulated for different return periods using HEC-RAS model and GIS program was used to create the flood risk maps in Xe Bangfai floodplain. It was found that peak flow in each flood frequency of 2, 6 and 35 years return period as 3,746.57, 4,505.99 and 5,877.60 m^3/s respectively. These peak flow in each flood frequencies were selected for simulation of water surface profiles at lower part of XBF. The result from model simulation were used for flood hazard analysis and generated flood risk maps using GIS tool. The flooded areas by 2, 6 and 35 years return flood shown as 49,534.0, 53,800.0 and 56,047.0 hectares respectively. The large vulnerable area for 2, 6 and 35 years return period on crop land were 25,456.00, 28,054.00 and 29,443.00 hectares, respectively and followed by the forest area were 17,588.00, 19,062.00 and 19,852.00 hectares respectively. The vulnerability area analysis was shown that the 2 years return flood inundated 30,000.00, 16,567.00 and 2,889.00 hectares, respectively of crop land, forest and; and water respectively.

Keywords : Flood risk; HEC-RAS; GIS; Xe Bangfai floodplain

Introduction

Natural disasters in Lao People's Democratic Republic (Lao PDR), especially the form of floods and droughts, the most vulnerable areas are the low-lying areas along the Mekong River and its major tributaries. Xe Bangfai (XBF) is one the main tributaries of the Mekong river in central Lao PDR, where is vulnerable to flooding. The flooding occurs due to heavy rain during the rainy season (August to September) when the tributaries of XBF river rising up and also the rising water from Mekong river flowing into the low basin area of XBF [1]. The flooding has impact on the social, economic and environment in this area.

The flood risk assessment [2] requires a clear understanding of the causes of a potential disaster, which includes both the natural hazard of a flood, and the vulnerability of the elements at risk, which are people and their properties. Flood risk assessment therefore consists of understanding and quantifying this complex phenomenon. The assessment of the expected flood damage consists of four primary steps including (1) hydrological frequency analysis; (2) hazard assessment; (3) hazard exposure analysis; and (4) damage assessment. In this methodology, the hydrological frequency analysis is based upon the historical records and provides an estimate of exceedance probability or recurrence interval of the flood of a particular magnitude. The hazard assessment includes the assessment of risks posed by a flood event in terms of tangible and intangible damages. After identifying the potential hazards, the next step in the assessment process includes the estimation of extent and severity of the damages in terms of hazard exposure analysis, usually defined by flood water depth and the velocity. Flood hazards are categorized based on water depth and they are as follows: Low (0-1 m), Medium (1-3 m), High (3-6 m) and very high (>6 m) [3]. The damage assessment involves estimating the impact of the likely exposure in terms of the costs of replacing and restoring the affected areas.

Flood frequency analysis is one of the important aspects of a hydrological study which is based on the frequency distribution of flow data that is used to calculate statistical information (mean values, standard deviation, skewness, and recurrence intervals) and to estimate future its occurrences. This information will provide the likelihood of several discharges as a function of the recurrence interval exceeding a set probability [4]. Flood frequency analysis is essential for providing hazard probability of flood risk assessment as well as for determining design flood for sites along the river such as design the flood control structure (e.g dams, levees, gate, floodways, and channels) to protect the expect flood event [5]. It is a necessary tool for water resources management and water infrastructure design [6]. There are several types of theoretical probability distributions (or frequency distribution functions) that have been successfully applied to hydrologic data. The most popular theoretical probability distributions have been the lognormal, log Pearson Type III and Gumbel distributions [7]. Gumbel's distribution [8] is one of the statistical approaches that is mostly used to analyze flood data. It is also used to predict hydrological events such as flood. It is widely used in flood frequency study. This distribution can be used to represent the distribution of the maximum or minimum of water level, discharge, and other parameters such as precipitation in particular year that there was a list of maximum or minimum values for the past ten years [9].

Recently, numerical modeling has applied to study flood (HEC-RAS; ISIS; [10, 11]). Several previous studies have improved the capacity of the flood modelling. The model is used in flood risk mapping and has been developed to simulate flood areas (i.e., [12, 4]). HEC-RAS is a hydrological model [13]. It was developed at Hydrologic Engineering Center (HEC), U.S Army Crop of Engineers. It was designed to perform a one-dimensional steady flow, one and two-dimensional unsteady flow river hydraulic calculations, sediment transport/mobile bed computations, water temperature analysis and generalized water quality modeling [14]. The HEC-RAS system contains four one dimensional river analysis components; 1) Steady flow water surface profile 2) Unsteady flow component 3) Movable boundary/sediment transport computations and 4) Water quality analysis. For HEC-GeoRAS is set of ArcGIS tools specifically designed to process geospatial data for use with the Hydrologic Engineering Center's River Analysis System (HEC-RAS). The extension allows users with limited GIS experience to create an HEC-RAS import file containing geometric data from an existing digital terrain model (DTM) and complementary data sets [15].

The study of flood risk analysis and risk management in lower Xe Done (XD) [4] was shown that he flood frequency analysis was done by using log Pearson type III and Gumbel distribution method to obtain the maximum discharge at the various return periods (2, 5, 10, 50, 100 and 200-year). The results from flood frequency analysis by Log Pearson Type III for 2, 5 and 10-year were a little higher than the results from Gumbel methods but for the other return periods (50, 100, and 200-year) Gumbel provide a higher value. Therefor the Gumbel results were used for model and the results from flood frequency analysis of 2 and 100-year return period were selected as the input to one dimensional hydraulic HEC-RAS model for simulation of water surface profiles at lower part of XD, then used the result from model simulation used for flood hazard and vulnerability, and risk analysis and produced those maps using GIS tools. The objectives of this study were: i) To analyze the flood frequency in Xe Bangfai floodplain area ii) To generate a flood risk map in Xe Bangfai floodplain using HEC-RAS model.

Materials and Methods

Study Area

Xe Bangfai river (XBFR) is the main tributaries of the Mekong river that located in central of Lao PDR. It was located in the latitude 16'40'00'N to 18'0'0' N and longitude 104'20' 0 'E to 106'30'0' E. It has a surface area 10,064 km^2 with length of the main river 360 km. Xe Bangfai bridge station is automatic runoff monitoring station (Figure1). The XBFR was originated at the Lao -Vietnam border at Boualapha district, westward to the Mekong at the border Xebangfai and Nong Bok district in Khammoune province. The catchment of Xe Bangfai covers several districts in Khammoune provinces, namely Boulapha, Gnomralat, Mahaxai, Xebangfay and Nongbok, and cover small part of a few districts in Savanhnaket, namely Xaibouly, Vilabuly and Artsaphone [16]. For the site of study focus on the lower part of XBF in Nongbok and Xe Bangfai district, Khammoune province because this area is prone to floods every year and causing damage to many villages in this area as illustrated in Figure 1.

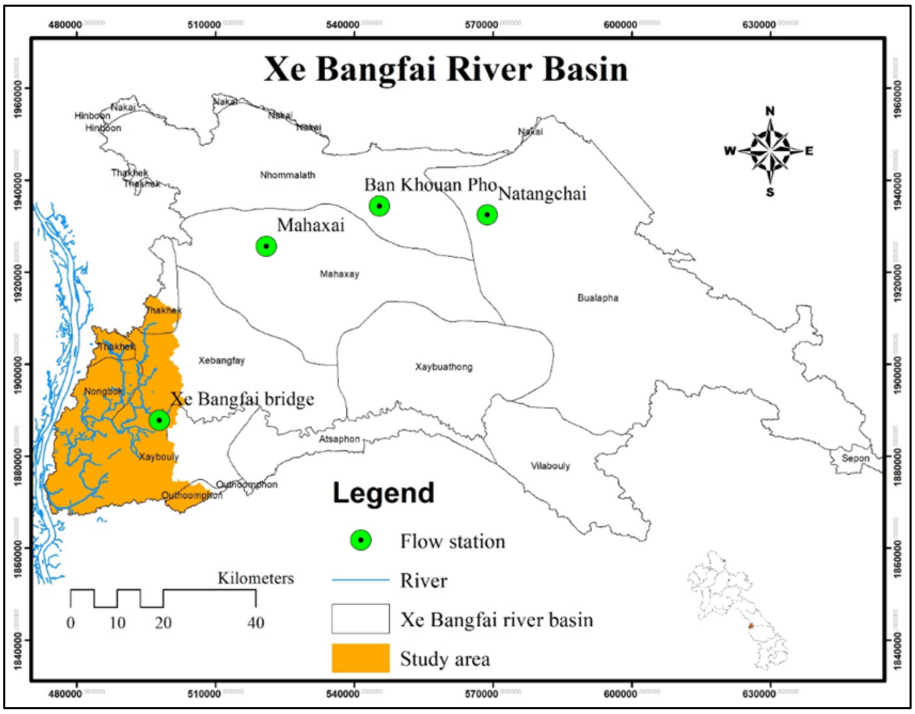


Figure 1 Location of the study area

Methods

There are three main parts of methodology for flood frequency analysis and flood risk mapping which shown in the conceptual framework (Figure 2). The details are follows as;

Data Collection

Input data was required for HEC-RAS model are daily rainfall, DEM, cross section, flow direction and stream banks. The daily rainfall, daily water level data and daily runoff data from 1994 to 2014 year were collected from Department of Meteorology and Hydrology (DMH). There are 77 cross-sections that surveyed by Department of Meteorology and Hydrology which covers floodplain area starting from Xe Bangfai bridge station to outlet and digital elevation model (DEM) with 10 x 10 m resolution was collected from Natural Resource and Environment Institute.

Flood frequency analysis in Xe Bangfai floodplain

Flood frequency analysis is important in a hydrological study and uses the frequency distribution flow data to calculate statistical information and estimate future possibility of occurrences. This information will predict the likelihood of several discharges as a function of recurrence intervals or exceeding probability. This study, flood frequency analysis of different magnitudes (2, 6 and 35 years return period) was calculated using Gumbel's distribution and the maximum observed river flow records at Xe Bangfai bridge station which has a recent period from 1994 to 2014. After calculated, the comparison peak flow in the past of observe river flow records at Xe Bangfai bridge station with flood flow of different magnitudes (2, 6 and 35 years return period) then to selected the representative of normal, medium and high peak flow to use for model in order to simulated flood event in future.

Model application for flood risk mapping in Xe Bangfai floodplain

1. **HEC-GEORAS and GIS application**

HEC- GEORAS is set of ArcGIS tools specifically designed to process geospatial data for use with the Hydrologic Engineering Center's River Analysis System (HEC-RAS). The extension allows users with limited GIS experience to create an HEC-RAS import file containing geometric data from an existing digital terrain model [17]. For this study, it was used for pre-processing geometric data (RAS GIS import file). The RAS geometric menu was used for pre-processing geometric data to create the RAS layers of XBF river, the RAS layer was created from DEM 10 x 10 m. The RAS layers were used for geometric data development. The ArcGIS was used to extract the complete geometric dataset (stream centerlines, river banks (both left and right), the flow path centerlines, cross section cut lines and storage area of XBF river.

2. **HEC-RAS application for runoff calculation**

HEC-RAS is a widely used software application that perform one-dimensional and two-dimensional hydraulic calculations for a full network of natural and construction channel, floodplain areas, etc. The HEC-RAS system contains four one dimensional river analysis components [18]:

- Steady flow water surface profile
- Unsteady flow simulation
- Sediment transport computations; - water quality analysis.

Water surface profiles ware computed from one river cross section to the next section using the energy equation (1):

$$Y_2 + Z_2 + \frac{a_2 v_2^2}{2g} = Y_2 + Z_2 + \frac{a_2 v_2^2}{2g} + h_e \quad (1)$$

Where Y_1, Y_2 is depth of water at cross sections; Z_1, Z_2 is elevation of the main channel inverts; V_1, V_2 is average velocity; a_1, a_2 is velocity weighting coefficient; g is gravitational acceleration and h_e is energy head loss.

(1) Development and running of HEC-RAS to calculate the surface water profile

The geometric data of XBF river (RAS import file) created by HEC-GEORAS was imported in the geometric data editor in HEC-RAS as shown in Figure 2.

The modification and edition were done in this stage to improve the model. For each cross section had been modified, the measured flow and water level data were at Xe Bangfai bridge station entered using the unsteady flow data editor as upstream and downstream.

(2) Calibrated and validation

Calibration was done by adjusts the model's parameters mainly for roughness (Manning's η values). These values were adjusted to reproduce each stage hydrograph until the desired results are achieved. In general, for a free-flowing river, roughness decreases with increased water level and flow. Validation was

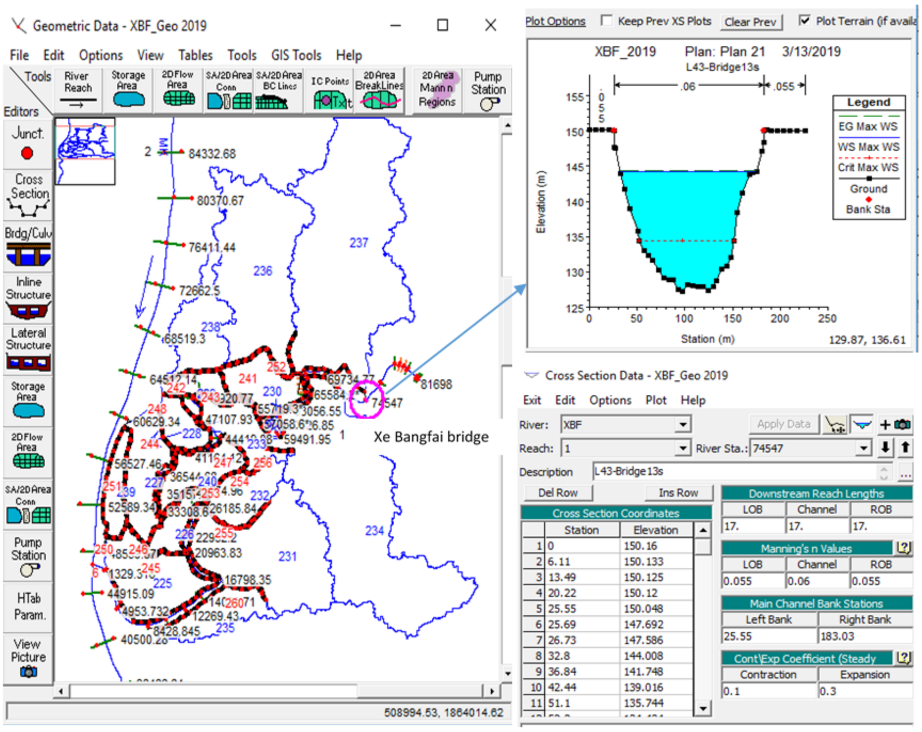


Figure 2 Model schematization of XBF model (Left) and HEC-RAS Floodplain cross section (Right)

done by using the hydrograph of the observed water level data in the year 2011 at Xe Bangfai bridge station used the daily observed water level data at Xe Bangfai at bridge station. The Coefficient of Determination (R^2) and Nash-Sutcliffe efficiency (NSE) were used for validation, to assessed the model's performance.

(3) Simulation of flood flow for 2, 6 and 35 years return periods

After the model has been calibrated, the flood flow for 2, 6 and 35 years return periods were entered in the steady flow data editor. Flood flow data and boundary condition was entered from upstream to downstream. Then running the model to calculated the water profile of XBF floodplain

(4) Post processing and flood risk mapping

Post processing is floodplain delineation base on the data contain in the HEC-RAS-GIS output file (name for the analysis, RAS GIS export file, TIN, output directory, output geodatabase, dataset name, and raster cell size). Using HEC-GEORAS functionalities, The RAS result datasets contain the cross section cut lines and bounding polygon for each water surface profile were used further in the analysis after being successfully created. Post-processing of RAS results was generated GIS layers for inundation and other parameters mapping.

Results and Discussions

Flood frequency analysis in Xe Bangfai floodplain

The results of 2, 6 and 35 years return period flood frequency analyze based on maximum peak flow recorded at Xe Bangfai bridge from year 1994-2014 (21 years) using the Gumbel's Distribution. Flood frequency shown that the peak flow for 2, 6, and 35 years return period provide a value as 3,746.57, 4,505.97 and 5,877.60 m^3/s respectively. The comparison peak flow in the past of observed river flow records and these peak flows indicated that 2 years is representative of low - normal peak flow, 6 years is representative of medium flow and 35 years is the high peak flow. Therefore, these results were used for model in order to simulate flood event in future.

Flood risk analysis and mapping in Xe Bangfai floodplain

1. **Unsteady flow simulation**

After simulating the flow in HEC-RAS model by unsteady flow analysis, the model performs the relationship between stage (water level) and flow of Xe bangfai simulated data. The result from model the stage maximum value as 145.34 meters (including mean sea elevation), the average mean sea level was 123.55 MASL, flow value as 5185.12 m^3/s, the period at max in August as present in Figure 3.

2. **Calibration and validation**

The Manning's η values were chosen for model calibration. For Manning's η values for different land use values between 0.022-0.06. The calibration of XBF floodplain was increased in the Manning's η value indicates that the water levels have increased some locally at the upstream. For validation was done by using the hydrograph of the observed data from 1/1/2011 to 31/1/2011 (1 year). The validation result show that the comparison between the simulated daily water level and the observed data is well as presented in Figure 4 and scatter plot in Figure 5.

The simulated daily water level matches the observed value for the validation period with Coefficient of Determination (R^2) value as 0.96 and Nash-Sutcliffe efficiency (NSE) value as 0.88, the performance of observed and simulated daily water level for the calibrated period was considered very good [9]. However, the daily simulation in some months was slightly underestimated and some month overestimated with water level more than 2.5 maters in some location of reached.

3. **Flood risk map for 2, 6 and 35 years return period**

After model was calibrated and validated, the flood flow imports in HEC-RAS, the simulation was done by steady flow simulation. After modelling and simulation steps, flood risk mapped using HEC-GEORAS. The results of flood risk assessment based on model simulation of observed flow in year 2011, 2, 6- and 35-years flood return period in XBF floodplain were summaries in Table 1.

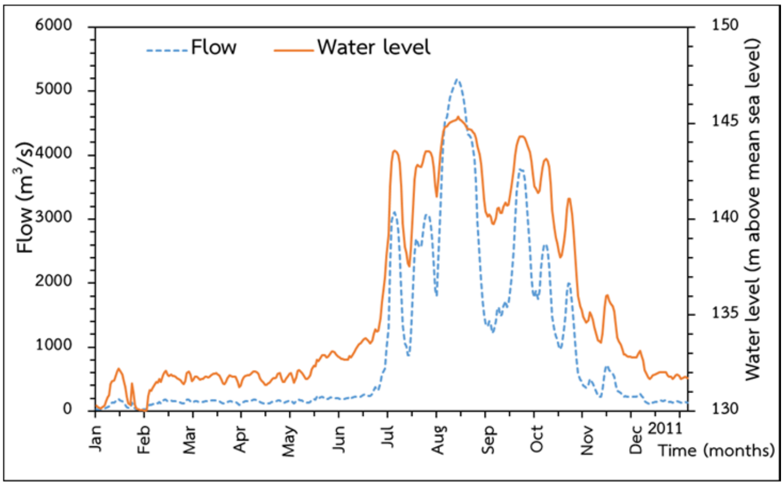


Figure 3 Relationship of stage and flow at Xe Bangfai floodplain

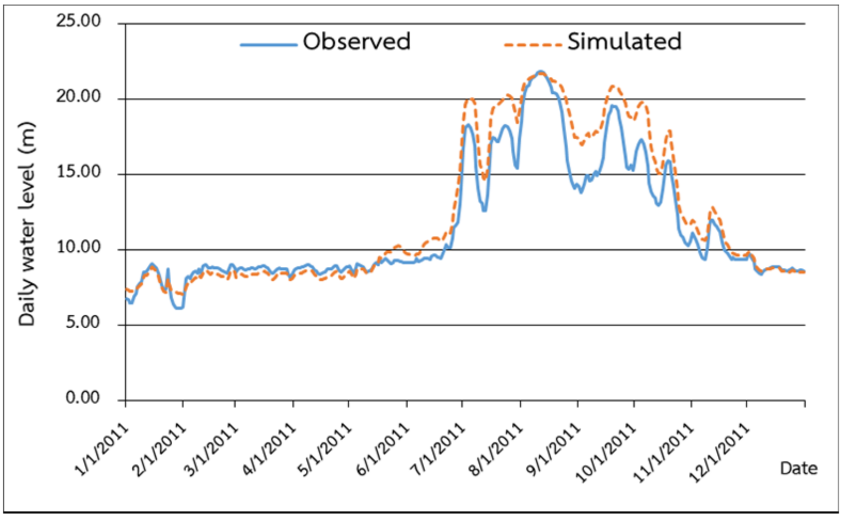


Figure 4 Comparison of measured hydrograph with HEC-RAS simulated time series for the validation period

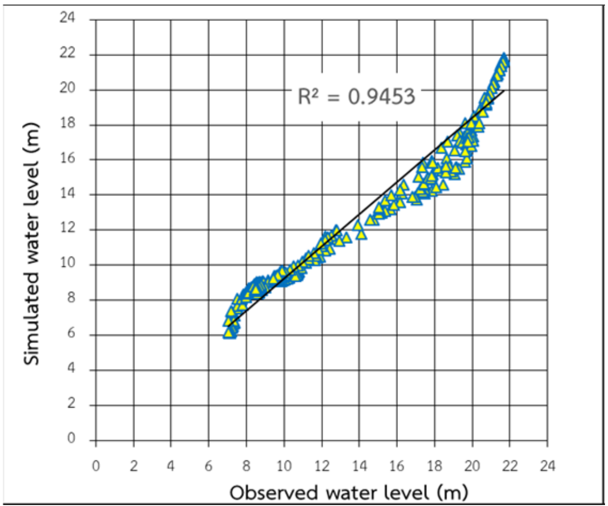
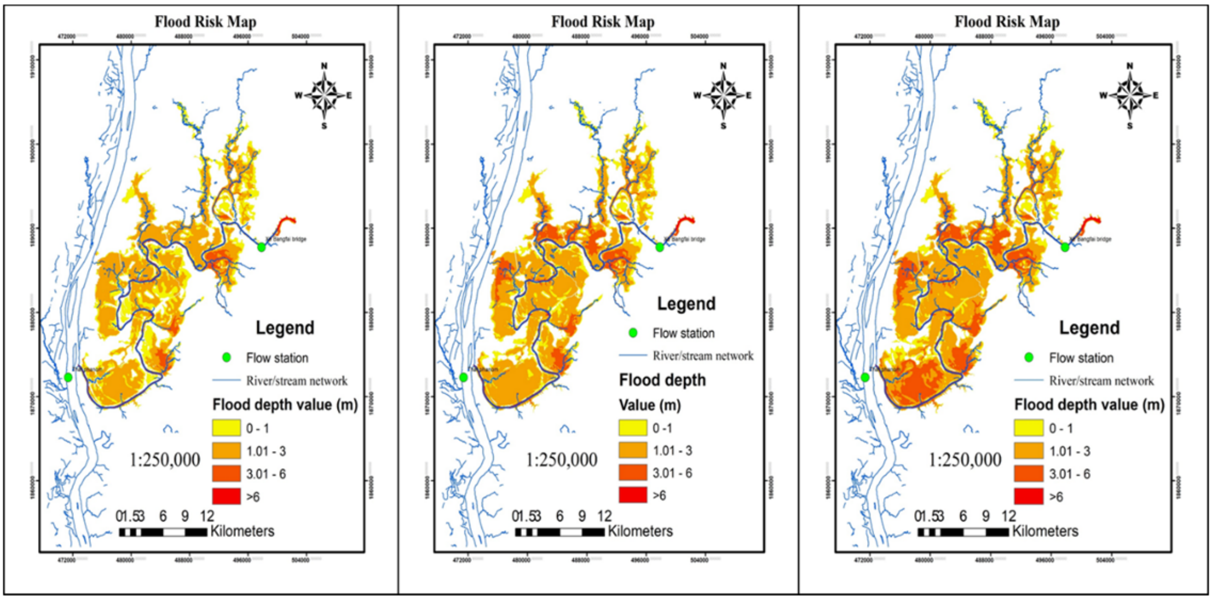


Figure 5 Scatter pots of observed and HEC-RAS simulated daily water level time series for the validation period

Table 1 Classification of flood depth and areas according to flood hazard

Flood depth range (m)	Flooded area (ha) in each return periods		
	2 Years	6 Years	35 Years
Low (0-1)	10,362	8,012	7,237
Medium (>1-3)	19,517	22,060	21,295
High (>3-6)	3,692	7,077	10,352
Very high (>6)	15,963	16,651	17,163
Total	**49,534**	**53,800**	**56,047**

From Table 1, the flood highest damage area in medium level >1-3 meter and every return period. The flooded areas at low (0-1) flood depth tend to decrease from 2 to 35 year return period due to 2 year return flood was frequent occurred with the demonstrated near the main Xe Bangfai river, a long length river with a low channel slope, and land area surrounding is very flat where can be damaged large area. In contrast, the return flood of 6 and 35 years indicated that the flood area that showed high water level (>3-6), it can be extreme damage large area because high volume of flood. It was observed that even if there were not different of flooded area in each return period but, it showed that the flooded area in 2 years return period will frequency damaged in the same area as illustrated in Figure 6.



(a) (b) (c)

Figure 6 Flood mapping area on 2 years (a), 6 years (b) and 35 years (c) return period

Figure 6 shows flood risk maps of 2, 6 and 35 years return period with effects 49,534.0, 53,800.0 and 56,047.0 hectares respectively. From map of 6, 35 years return period were indicated that the flood area that shown high water level (>3-6 m) was demonstrated near the main Xe Bangfai river. It can be extreme damage large area because high volume of flood.

Flood vulnerability areas were prepared based on the intersection of land use with flood area boundaries for each flood event simulation. The vulnerability analyzes results in Table 2 shown that 2 years return flood inundated 30,000.00, 16,567.00 and 2,889.00 hectares, respectively of crop land, forest and; and water respectively. It mostly has a high proportion of crop land especial paddy rice, inundated by 2, 6 and 35 years return flood respectively. These areas mostly covered by paddy rice where the local people rely on, it is important for further consideration for flood mitigation. The flood risk map provides information of flood risk areas include flood depth, flooded area. Thus, it can be presenting and understanding of the risk and vulnerability that can be utilize to planners and decision-makers lead to improved project planning for flood risk management.

Table 2 Classification of flood risk according to flood hazard area with vulnerable land use in 2015

Land use types	Flood Depth (m)	Flooded area in different return periods (ha)		
		2 yrs	6 yrs	35 yrs
Forest land	0-1	8,046	9,048	3,470
	1.01-3	5,332	5,380	9,717
	3.01-6	3,113	3,500	4,768
	>6	76	239	1,069
	Total	**16,567**	**18,167**	**19,024**
Crop land	0-1	17,524	19,512	6,325
	1.01-3	8,015	8,067	20,409
	3.01-6	4,255	4,833	7,042
	>6	206	228	235
	Total	**30,000**	**32,640**	**34,011**
Wetland	0-1	828	711	130
	1.01-3	765	767	971
	3.01-6	1,257	1,405	544
	>6	39	21	1,258
	Total	**2,889**	**2,904**	**2,903**
Settlements	0-1	27	32	39
	1.01-3	18	22	30
	3.01-6	8	12	8
	>6	0	1	7
	Total	**53**	**67**	**84**
Other land	0-1	12	12	4
	1.01-3	8	7	14
	3.01-6	4	4	6
	>6	1	1	0
	Total	**26**	**24**	**24**

Conclusion

This study, the flood frequency analysis for Xe Bangfai floodplain using 21 years' annual peak flow at Xe- Bangfai bridge station which was performed that the highest peak flow occurs in the period from July till early October. The 2011 flood record was assessed to have a return period of 2, 6 and 35 years, these years return period were representative of low, medium and high peak flow.

The flooded areas by 2, 6 and 35 years return flood shown as 49,534.0, 53,800.0 and 56,047.0 hectares respectively. The large vulnerable area for 2, 6 and 35 years return period on crop land were 25,456.00, 28,054.00 and 29,443.00 hectare, respectively and followed by the forest area were 17,588.00, 19,062.00 and 19,852.00 respectively. The flood risk maps, 2, 6- and 35-years' flood indicated that the flood highest damage area in medium (>1-3) and some area with the water depth greater than 6 maters in XBF floodplain. Flood vulnerability areas were almost in paddy rice area in every return periods magnitude.

Acknowledgement

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Determination of Microplastics in Soil and Leachate from the Landfills

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Abstract

Microplastics (MPs) from soil and leachate at the landfill sites located around the gulf of Thailand were determined. The 12 soil samples and 10 leachates from the landfills were collected and were analyzed by using the density separation technique. The average of MPs from soil samples and leachates were 1457.99±489.71 Items/1Kg.dryweight and 20.90±4.96 Items/1Kg.dryweight, respectively. There are 5 specific plastic shapes, including fibers, films, sphere, granules and irregular were determined from the microplastics. Resulting from Fourier Transform Infrared Spectroscopy (FTIR) analysis is indicated that 3 main types of microplastics from the landfill are Polyethylene (PE), Polypropylene (PP), and Polyethylene Terephthalate (PET). This was confirmed by the types of plastic wastes found in the landfills. As a result, microplastics can occur in the landfill whether the age of the landfills is still young. This research could be concluded that the landfills were one of the main sources for releasing microplastics to the environment. The further study, the degradation rate and the other routes of plastics that may cause microplastics contaminated in the environment will be studied.

Keywords : plastic wastes; microplastics; soil and leachate; landfills; water source; FTIR

Introduction

Plastics are the synthetic materials that being used since 1900. From 1950 to 2012, the amount of plastics produced were rapidly increased from 1.7 to 288 million tons. According to the growth trend, the amount of plastics in 2020 will be 540 million tons [1]. As a result of plastics increasing, an environmental impact has widely grown up as well. However, plastics take more than 100 years to be decomposed. Therefore, it is possible that a lot of plastic waste remaining for the disposal [2]. In Thailand, 16.83% of waste is plastic and most of them are single-use plastics. Only 79% of single-use plastics correctly disposed of in the landfills. The remaining was leaked to the environment. Also, the illegal landfills can cause plastic leaking to the environment.

The route of plastic leaking starts from land to a canal or a river and then ends up in the ocean [3]. After long exposure to the sun, plastics in the ocean break into very small pieces. These small pieces are called "Microplastics (MPs)", which the sizes are less than 5 mm [4]. Most MPs can be found in the ocean because the surface is exposed to the sun [5]. According to the reports, MPs were found in both soil and water zones, for example; beach, river, canal, lake, and the sea [6]. Moreover, MPs were also found in water, from Waste Water Treatment Plants (WWTPS) around 1-7 pieces [7]. As reported by the study, one plastic bottle of water can break into 10,000 pieces of MPs [8]. According to the above mentioned, it leads to future problems about the huge amounts of MPs in the environment.

Nowadays, MPs problem affects ecosystems in Thailand. In 2016, there were 355 of sea animals founded dead in the Gulf of Thailand e.g. whale, dolphin, manatee, and sea turtle. The investing report revealed that all of them had pieces of plastics in their digestive system which caused the death. In addition, MPs waste was found on beaches, soil sediments, and mussels at Chao Lao and Kung Wiman Beaches, Chanthaburi province. The discovery of MPs waste in the environment conforms with many studies worldwide [9].

The sustainable solution for reduction of MPs should be controlled at the source. In the previous studies, MPs sources from some sources such as sea water and soil sediments from the Gulf of Thailand were already studied. However, the MPs from the landfill sites has not been determined yet. In this study the landfill sites are focused to determine MPs from the waste problems which may affect the ecosystems and the environments.

Materials and Methods

Sampling Methods

The samples were collected from 12 landfill sites. Leachate and soil samples were collected at 10 locations in each landfill site. For leachate, the samples were collected by taking from a leachate pond. In addition, soil samples were collected by using hand auger with the depth of 10-20 cm. Then, all samples were stored at the 4 Degree Celsius refrigerator.

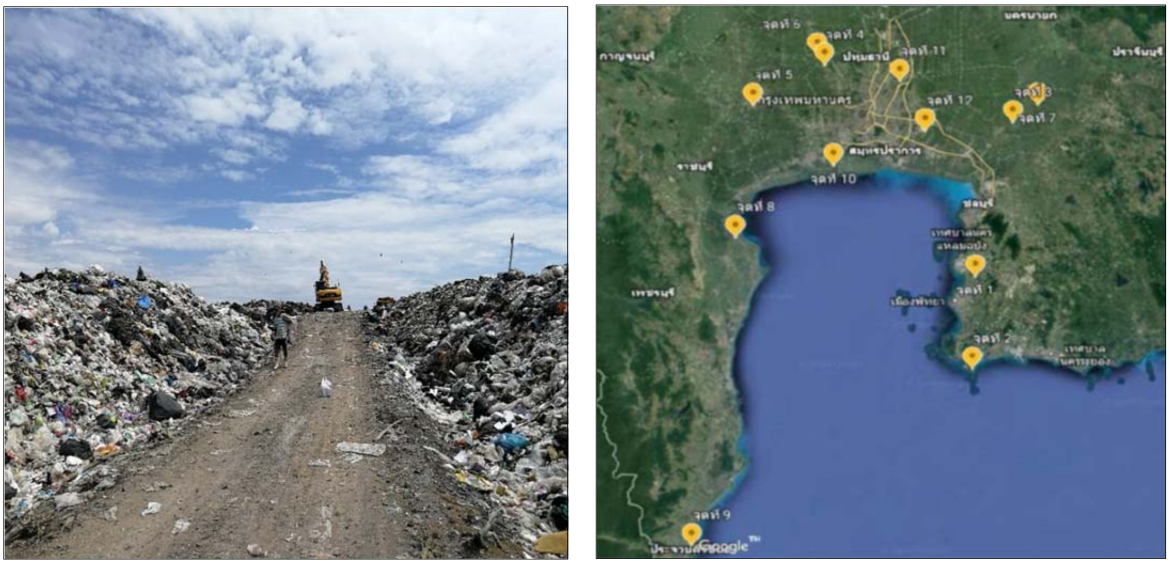

Figure 1 The landfill areas that all samples were collected

Analysis of microplastics from the samples

In this study, MPs were identified by using density separation technique [10], which was adopted from National Oceanic and Atmospheric Administration; NOAA method [11]. The first step, a stainless-steel mesh sieves no.50 (330 μm) was used to separate sample. The second step, the separated sample was added into a beaker and then baked at 90 degree Celsius for 24 hours. For the landfill soil samples, in the first step the samples were mixed with ZnCl, waited for a moment, scooped the top layer for the sample, and then followed the second step. The third step, the organic compounds in sample was removed by the addition of the mixture solution of 0.05M Fe^{2+} and hydrogen peroxide (30%). A chemical reaction was activated by increasing the ambient temperature to 75 degree Celsius for 5 minutes. As the white foam appeared, temperature was reduced until the foam was disappeared. The fourth step, the sample was heated repeatedly at 75 degree Celsius for 30 minutes. The fifth step, NaCl was added with the ratio of 3 grams of NaCl per 20 milliliters of sample. The last step, sample was transferred from a beaker to a glass funnel and left for 24 hours. Then, the MPs were floating on top of the surface.

Figure 2 Determination of microplastics from soil and leachate samples

Data analysis of microplastics

A Fourier Transform Infrared Spectroscopy (FTIR) model Alpha-E (Bruker) is used to identify the types of plastics waste [12]. The MPs images are analyzed by using a stereoscopic microscope. Variances of microplastic abundances are analyzed by one-way ANOVA (p-value < 0.05).

Results and Discussion

For the determination of microplastics from soil and leachate from the landfills, it was found that there are amount of microplastics contamination. The amount of microplastics from landfill soils were around 686.45-2278.44 Items/1Kg.dryweight with the average number of microplastics at 1457.99±489.71 Items/1Kg.dryweight (p<0.05. In addition, the amount of microplastics from landfill leachates were around 13.50-27.50 Items/1Kg.dryweight with the average number of microplastics was 20.90±4.96 Items/1Kg.dryweight. Compared to the reports of microplastic contamination in the soil from China such as North Yellow Sea and The Gorges Reservoir, it was found that the average values of microplastic were 37.10±42.70 Items/1Kg.dryweight and 82.00±60.00 Items/1Kg.wetweight, respectively [13-14]. In addition, there were reports from the other continents such as the North Tunisian from Mediterranean Sea showed that an average value of microplastics was 316.03±123.74 Items/1Kg.wetweight [15]. Anyway, it was found that the MPs found in this study is higher than the other studies. This may be indicated that the landfill sites in Thailand might contain the amount of plastic waste than from the other countries. Also, all samples are directly collected from landfills, which plastic waste is remained for such a long time and possible rapidly transformed to MPs. MPs adsorbed into landfill's soil and then solute to leachate pond. From 12 landfills, only 1 landfill is a sanitary-landfills the remaining are open dumping, which can cause plastic waste leaking to the environment. The quantity of microplastics from landfill's leachate and landfill's soil are shown in Table 1.

Table 1 The quantity of microplastics from landfills

Landfills	Leachate (items/1kg-Dry Weight)	Soil (items/1kg-Dry Weight)
Takhian Tia	27.00	1112.25
Samae San	18.00	1076.39
Chachoengsao	26.00	1703.92
Sai Noi	18.50	1495.42
Nakornpathom	22.50	2278.44
Bang Khla	18.50	1180.1
Ban Lam	13.50	686.45
Prachuap Khiri Khan	15.00	898.86
Pan Thai Nor Ra Sing	27.50	1445.8
Nong Prue	22.50	1617.78
Sai Mai	-	1860.87
Nonthaburi	-	2139.65

Characteristics of microplastics were classified into 5 shapes including; films, fibers, spheres, granules and irregular. As a result of this study, we found microplastics shapes from 12 sampling points of landfills' soil which were 396.33±148.26, 262.94±107.35, 16.47±13.72, 464.00±255.52, 318.26±149.35 Items/1Kg.dryweight respectively. In order of most to least, we found; granules 32%, films 27%, irregulars 22%, fibers 18% and spheres 1%. Next result of leachate, we found microplastics shapes from 10 sampling points of landfill's leachate which were 5.85±2.59, 3.55±1.62, 0, 9.80±1.86, 1.70±1.14 Items/1Kg.dryweight respectively. Ranking of microplastics shapes were granules 47%, films 28%, fibers 17%, irregular 8% and spheres 0%. All of microplastics are smaller than 5 mm, from plastic waste break into pieces [16]. Shape of MPs can be traced from plastic goods. For example; films are from plastic bags and others plastic packages. They are thin and transparent so it easily breaks when exposed to the sun. Granules, spheres, and irregulars are from plastic containers e.g. a bottle of water, food storage container and beads. Fibers shapes are from synthetic fibers e.g. fibers from washing clothes and sewage from textile industry [17]. These plastics wastes were small and very light weight, which were easy to disperse into the environment. The sample shape of microplastics is shown in Figure 3.

The researcher sent the microplastics samples to be examined by using FTIR at the Department of Materials Engineering, Kasetsart University. The results showed that the microplastics obtained from landfill's soil and landfill's leachate samples, which have 3 type of plastic component: PE, PP and PET. By specifying the type of plastic will use the graphs obtained from the analysis of microplastics samples. To compare with the standard graphs of 3 types plastics, that are consistent. Makes it possible to specify what kind of plastics are there in the microplastics samples. The sample graph from landfills' soil sample is shown in Figure 4.

Figure 3 The samples of microplastics from experiment

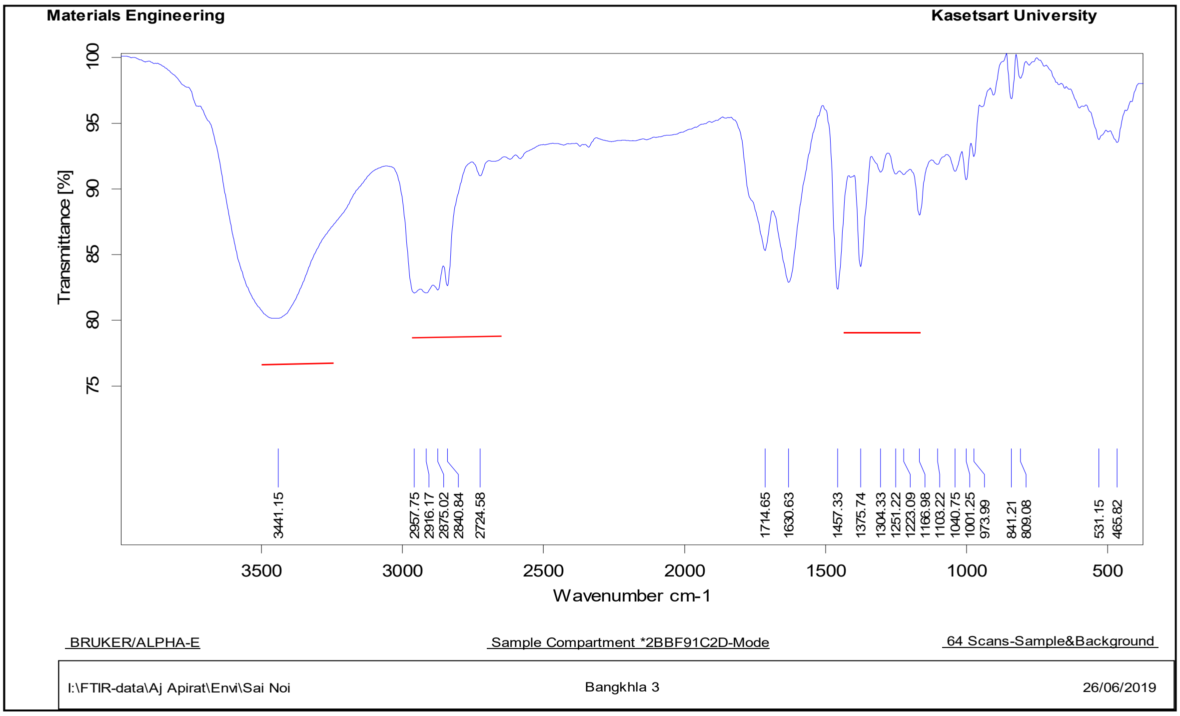

Figure 4 The example of microplastic analysis graphs by using the FTIR

From the sample graph data of landfills' soil analyzed with FTIR, we found 3 peak points with the red line. This data will be used including values between peaks point, to be compared with the standard graphs of all 3 type plastics as described. The result of this sample graph can be identified as PE, PP and PET plastics in the landfill's soil sample. If the values in the graph being analyzed did not correspond to the standard graph Indicating, which may be of the other materials. Since soil and leachate samples were likely to have a variety of materials mixed in as well.

Conclusion

The average MPs amount from soil and leachate samples in the landfills were 1457.99±489.71 Items/1Kg.dryweight and 20.90±4.96 Items/1Kg.dryweight, respectively. This MPs in the landfill soil are very high. The study revealed that 5 shapes of MPs in the landfill are granules, films, irregulars, fibers, and spheres. Percentages of shapes in the samples were as following; landfills' soil, granules 32%, films 27%, irregulars 22%, fibers 18%, and spheres 1%. In leachate, the percentage of the shapes are granules 47%, films 28%, fibers 17%, irregulars 8%, and sphere 0%. Furthermore, 3 plastic components were identified in the samples including PE, PP, and PET which related to the types of plastic wastes found in the landfills. This leads to strong conclusion that microplastics are from the plastic wastes in landfills. On the other hand, landfills are one of the sources for microplastics possibly leaked to the environment. In the future study, an approach solution to control plastics waste from the landfills should be mentioned. The sustainable control of plastic wastes should be cooperated between industrial sectors, where plastics are manufactured, and the consumer in which the plastics waste are produced and ended up into the landfills.

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Emission Characteristics during Combustion of Torrefied PET-Biomass Composite Pellets

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Abstract

Most of polyethylene terephthalate (PET) bottles, though, has been taken into a recycling system, it still has some problems after preparation and the mechanical process. Waste of PET from the mechanical process is useless and non-recyclable. Pelletizing of such PET waste with biomass such as teak sawdust (TS), eucalyptus sawdust (ES), and corncob (CC) were investigated. Torrefaction of PET-biomass composite pellets was manipulated after pelletizing. Proximate and ultimate analysis as well as the high heating value were deployed to analysis. Moreover, emission characteristics during the combustion of samples of non-torrefied and torrefied pellets; PET/TS, PET/ES, and PET/CC were studied in a lab-scale fixed bed reactor. Emission of flue gas (O_2, CO_2, CO, SO_2, and NO_x) and gaseous pollutants (polycyclic aromatic hydrocarbons; PAHs and aromatic hydrocarbons such as benzene, toluene, ethylbenzene, and xylene; BTEX) were determined. The results indicated that flue gases such as CO_2, CO and NOx were decreased in the samples of torrefied pellets. SO_2 could not be detected due to no sulfur content of the origin materials. The torrefied PET/TS and PET/ES pellets could reduce PAHs compared to the nontorrefied samples indicated as 0.07 and 0.03 g/Nm^3, respectively. While emissions of BTEX could not be detected in samples of torrefied PET/TS and PET/ES. Combustion of the torrefied PET/CC pellets caused emissions of PAHs and BTEX with the total concentrations of 6.45 and 0.01 g/Nm^3, respectively. Therefore, the torrefaction was a suitable pretreatment method for PET-biomass composite pellets and altered emission characteristics during the combustion.

Keywords : combustion; composite; gaseous emission; PET-biomass; pellets; torrefaction

Introduction

The increasing of polyethylene terephthalate (PET) bottles usage has been represented by the daily amount of PET wastes generated in the municipal solid waste stream. The PET recycling is a process of plastic utilization that turns the undesired PET wastes to the useful PET-plastics. Processes of mechanical recycling include collecting, sorting, separation of contaminants or other plastic, size reduction, milling, washing, sterilizing, and drying [1]. This process can be turned PET bottles to flake-PET for producing goods with up- or down-cycling of PET-plastics. Nevertheless, it occurred the undesired materials such as PET waste. In general, PET waste was found in the forms of sludge, debris, tiny pieces of PET, dust, and microplastic [2]. There was the secondary waste released from the processes and occurred in a general waste of a mechanical recycling plant which was useless and non-recyclable.

Energy recovery of plastic wastes by combustion can be made in several types of incinerators to provide energy in the forms of steam, heat and/or electricity [3, 4]. Alternatively, plastic wastes are gasified to give synthesis gas (syngas) and pyrolysed to give liquid fuel, which used to generate steam via combustion boilers or after removal of impurities, particles, and tar, to produce electricity in the gas engine, and for high efficiency electricity production in a gas turbine or fuel cell [3]. In addition, PET waste from a mechanical recycling plant had high energy potential and good in physical-chemical properties which can be used to improve the high heating value for solid fuels such as refuse derived fuel (RDF), solid recovered fuel (SRF), and processed engineer fuel (PEF). There are alternative solid fuels commonly used in industrial scale [4]. However, PET waste was not suitable to convert as a liquid fuel form via pyrolysis due to terephthalic acid and benzoic acid contaminants in a liquid fuel form occurred [3].

Pelletizing is a process of handling powder-like materials such as PET sludge, debris, tiny pieces of PET, dust, and micro-plastic that lead the preferable material resources from the existing PET recycling facilities. Fuels pellets can be specifically tailored for ease of transportation and for different uses where industrial heat is required. This makes suitable alternatives to fossil fuels. Moreover, PET waste differ from the conventionally alternative solid fuels (RDF, SRF, and PEF) in terms of PET production initiated with the best material possible as the main feedstock, then the selected industrial, commercial usage, and known of recycling and by-products turn-back as fuels. The preference of using PET waste as an the raw material in fuel pellets is to improve the mixture and thus achieve the desired qualified specifications of solid fuels [5]. Moreover, as a replacement for fossil fuels such as oil, coal, gas, and solid waste fuels and alternative solid fuels, PET waste can be burned to generate electricity with a smaller carbon footprint [6].

Torrefaction is considered one of dominant thermal treatment techniques to produce an alternative fuel to solid fuel market share with coal and other alternative fuels. Torrefaction is the process of low-temperature treatment which was carried out in a temperature range of 200-300 $^{\circ}$C with a residence time of 10-30 min [7]. Properties and thermogravimetric behavior of PET and biomass composites pellets were relevantly discussed [2]. In addition, the emission characteristics during these solid fuels (PET-biomass composite pellets) combustion have not been yet studied. The present study aimed to investigate the physico-chemical and thermal properties of the non-torrefied and torrefied PET-biomass composite pellets. Emissions analysis under the combustion was performed in a lab-scale fixed bed combustor. Flue gas and gaseous pollutants emitted from an exhaust included carbondioxide (CO_2), carbonmonoxide (CO), sulfurdioxide (SO_2), oxides of nitrogen (NOx), and oxygen (O_2), 13 substances of polycyclic aromatic hydrocarbons; PAHs and aromatic hydrocarbons such as benzene, toluene, ethylbenzene, and xylene; BTEX were undertaken.

Material and Method

PET waste received from the mechanical recycling plant for PET-plastics in Surin province, which contain different sizes of <1.0 to 2.5 mm in diameter. Biomass such as teak sawdust (TS), eucalyptus sawdust (ES), and corncob (CC) received from the sawmills and agricultural areas nearby Naresuan University, Phitsanulok province. In this study, PET waste had been used as a major material for pelletizing amounted for 85% by weight. Biomass had been used as an additive material that was about 15% by weight.

Hydraulic press machine was used to be a tool for pelletizing with a condition of hydraulic pressure of 100 kg/cm^2, at temperature of 100 $^{\circ}C$, and time of 2 min for each pellet production. Properties of raw materials and pellets such as proximate and ultimate analysis and drop shatter index (DSI) were determined as well as the analyses of calorific value of samples used a bomb calorimeter (LECO, AC-500).

The torrefy reactor was made of the stainless steel (304L) tube equipped with screw cover and sealer to prevent torrefy-gas leakage. The gas outlet was connected with an air pump for controlling gas flow rate ranged of 1-10 L/min. Prior to testing, 10 g of PET-biomass composite pellets put inside the torrefy reactor placed at the top of heat source (flame). The condition of torrefaction temperature set at 225 $^{\circ}C$ (measuring by an infrared thermometer, Aeropak, AIT-42R), an air pump was operated at 1 L/min of gas flow rate (under the vacuum condition), and residence time of 10 min. After the torrefy reactor was cooled at room temperature, samples were collected and kept in plastic bags for further tests.

Combustion test

Figure 1 illustrates the experimental setup for combustion test and gas sampling. The lab-scale fixed bed combustor made from stainless steel (304L) tube (2.5 inch of a diameter) equipped with ceramic heaters, type-k thermocouples, and PID controller. The combustion temperature set around 850 $\pm$ 20 $^{\circ}C$. The sample of pellets was feeding at the top of combustor with the rate of 0.5 g/min. The gas sampler was connected and equipped with cotton filter, cooling system, XAD-4 absorber (Sigma-aldrich), gas flow meter, air pump, and exhaust to a fume hood. Flue gas and gaseous pollutants were sampled by isokinetic condition at 1 L/min flow rate passed through the flue gas analyzer (Testo-350H) and 2 L/min flow rate of gaseous pollutants passed through and absorbed by XAD-4 resin. In addition, the flue gas analyzer connected in a series from the exhaust pipe was continuously analyzed for O_2, CO_2, CO, NOx, and SO_2.

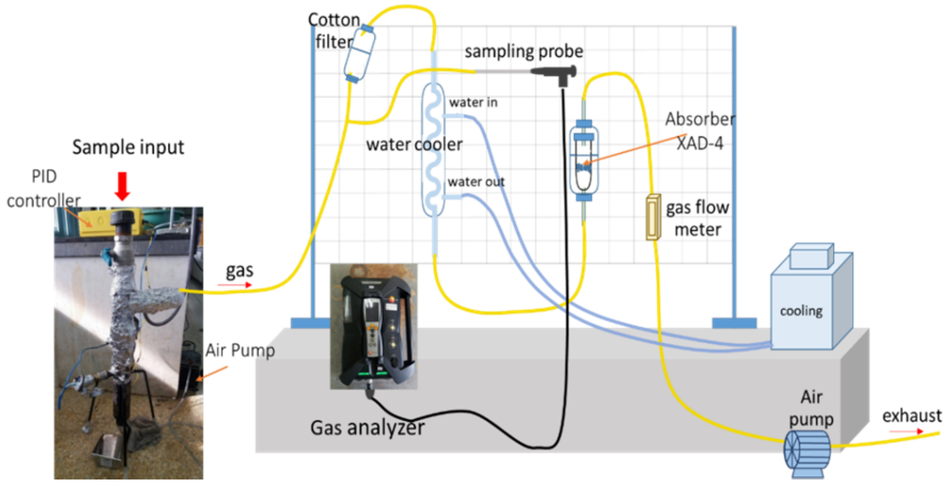

Figure 1 Experimental setup for combustion test and gas sampling

Gaseous pollutants analysis

Gaseous pollutants (PAHs and BTEX) were sampled at 5-10, 15-20, and 25-30 min of the operation time. PAHs and BTEX were extracted from XAD-4 resin using the Soxhlet extraction apparatus with the mixture of solution of hexane: dichloromethane with the ratio of 1:1 (250 ml) and the extraction time for 24 hr with temperature of 65 °C. Then, the volume of solution was reduced to 1 ml by using a vacuum evaporator and purified the solution by filtering through a nylon micro-filter. Analysis of 13 substances of PAHs included Acenaphthylene, Fluorene, Phenanthrene, Anthracene, Pyrene, Benzo (a) anthracene, Chrysene, Benzo (b) fluoranthene, Benzo (k) fluoranthene, Benzo (a) pyrene, Dibenz (a,h) anthracene, Benzo (g,h,i) perylene, Indeno (1,2,3-cd) pyrene, and 5 substance of BTEX using gas-chromatography mass spectrometer (Shimadzu, QP2010Plus). Figure 2 presents non-torrefied and torrefied pellets of (a, b) PET/TS, (c, d) PET/ES, and (e, f) PET/CC.

Results and Discussion

Properties of raw materials are shown in Table 1. PET waste samples contained lower moisture content (MC) than biomass samples. However, the highest ash composition occurred in the PET sample because it was composted of sludge, debris, sand, machinery cake, other plastic contaminants, etc. The volatile matter values were in the range of 89-92% for all of raw materials. Elemental analysis results indicated that PET waste had lower of C and O elements than biomass samples. Terephthalate polymer mostly contained of C and H and less of O element in chemical formula. Sulfur (S) element was not found in all of raw materials of this study, which suitable for combusting without SO_2. A PET sample had the highest ratio of C/H as 12.7 and other biomass raw materials resulted as TS (C/H = 7.52), ES (7.04), and CC (6.72) (Table 1). In addition, values of HHV and LHV of PET were 18.52 and 17.82 MJ/kg, TS were 19.56 and 18.03 MJ/kg, ES were 18.41 and 16.92 MJ/kg, and CC were 17.95 and 16.42 MJ/kg, respectively. Moreover, the experimental results indicated that PET waste could provide an energy-rich portion for composite pellets and suitable for thermo-chemical conversion process.

Pelletizing of PET-biomass composite

PET/TS, PET/ES, and PET/CC pellets produced by hydraulic press machine at the condition of 100 kg/cm^2 of hydraulic pressure,

Table 1 Proximate and ultimate analysis of raw materials

Test	Properties of materials			
	PET	TS	ES	CC
Proximate (%)				
MC	1.09	7.42	8.35	5.51
Ash	7.17	3.46	1.47	2.22
VM	91.77	89.12	90.18	92.27
Ultimate (%)				
C	38.41	47.58	44.22	42.91
H	3.02	6.32	6.28	6.39
N	0.08	0.06	0.16	0.27
O	21.54	51.56	51.56	50.41
S	ND	ND	ND	ND
C/H	12.7	7.52	7.04	6.72
O/C	0.56	1.08	1.12	1.17
HHV (MJ/kg) [a]	18.52	19.56	18.41	17.95
LHV (MJ/kg) [a]	17.82	18.03	16.92	16.42

ND: not detected, MC: moisture content, Ash: ash content, VM: volatile matter, HHV: Higher heating value, LHV: Lower heating value, and [a]The values of HHV and LHV were calculated according to the formula of Nhuchhen and Afzal, 2017 [8].

100 °C of temperature, and 2 min of press time. Pellets dimension had the length of 2.4 cm and 0.8 cm of diameter (an average pellets density of 1.66 g/cm^3) with an average weight of 2 g per piece. Figure 2 shows the non-torrefied and torrefied pellets with different compositions of biomass. TS, ES, and CC portions of pellets were illustrated different colors from dark brown to light brown. After torrefaction process at 225 °C, for 10 min and 1 L/min of airflow rate under vacuum condition. The determination of physical abilities of pellets revealed that torrefaction of pellets increased durability of pellets body resulted by DSI values as seen in Table 2. High heating values (HHV) of PET-biomass composite pellets were determined by bomb calorimetric technique. The results indicated that torrefaction decreased HHV values of all samples. The reduction of HHV might be induced by the releasing of volatile matter and organic components during torrefaction. Whereas, the durability of pellets increased in DSI values because PET melted and formed in terms of adhesive inside the pellets. This also indicated strong adhesion between PET and biomass. However, in the case of torrefied biomass prior pelletizing with plastics resulted in inconsistent with this study. Chiou et al., 2015 [9] reported that the torrefied biomass composition with polypropylene (PP) had negative results in tensile strength and elongation at break values. The addition of weak adhesive material such as the torrefied biomass caused debonding to occur at the interface between filler and polymer matrix.

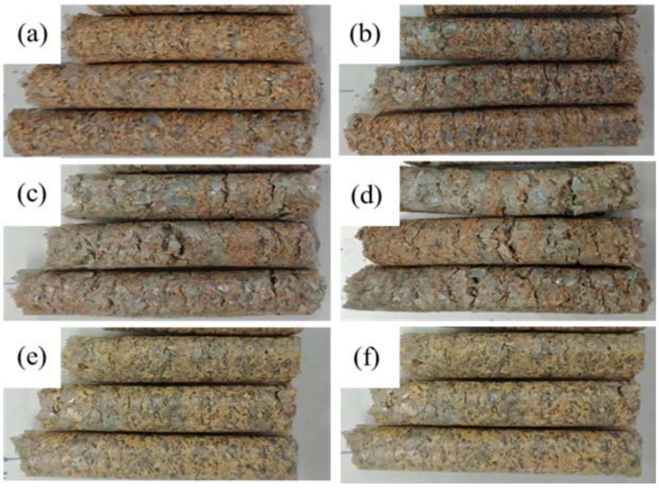

Figure 2 Non-torrefied and torrefied pellets of (a, b) PET/TS, (c, d) PET/ES, and (e, f) PET/CC

Table 2 Characterization of non-torrefied and torrefied PET-biomass composite pellets

Pellets	Test	Non-torrefied pellets	Torrefied pellets
PET/TS	HHV [a]	22.38	21.86
	DSI	0.9988	0.9999
PET/ES	HHV [a]	22.20	21.60
	DSI	0.9976	0.9994
PET/CC	HHV [a]	21.84	21.68
	DSI	0.9974	0.9997

[a] *HHV (MJ/kg) analyzed by a bomb calorimeter., DSI : Drop shatter index (≥ 0.95)*

Flue gas emitted during combustion

Flue gas emitted during combustion of PET-biomass composite pellets tested in the lab-scale fixed bed combustor is shown in Table 3. Flue gas including O_2, CO_2, CO, NOx, and SO_2 was analyzed. Prior fuel pellets were feeding into the combustor, O_2 concentration showed stabilized result about 20 ± 2%. After feeding the fuel pellets, O_2 emitted from the combustion of non-torrefied pellets and torrefied pellets were in the ranges of 4.71-9.90 and 8.14-11.85%, respectively. Emission of SO_2 was none due to the original materials had no sulfur content. Gases including CO_2, CO, and NOx were decreased in the tests of torrefied PET/CC pellets. However, the results of CO_2 and CO were unstable in the overall period of the operation time. CO concentration emitted over the threshold limitation of the standard because of the effect of incomplete combustion during the tests. Concentration of CO emission was in the ranges of 2,941-12,337 ppm. The limitation of

Table 3 Flue gas analysis of pellets combustion

Sample	Time (min)	Non-torrefied pellets			Torrefied pellets		
		CO_2 (%)	CO (ppm)	NOx (ppm)	CO_2 (%)	CO (ppm)	NOx (ppm)
PET/TS	5-10	3.55	2,614	289	2.25	6,661	152
	15-20	2.54	4,772	106	2.34	12,220	144
	25-30	5.50	1,436	220	3.87	10,364	81
	Average	3.86	2,941	205	2.82	9,748	126
PET/ES	5-10	1.92	1,135	69	4.09	11,587	148
	15-20	8.09	14,579	47	2.32	11,312	141
	25-30	4.66	5,410	108	3.46	14,111	65
	Average	4.89	7,041	75	3.29	12,337	118
PET/CC	5-10	9.91	10,603	76	1.19	1,175	56
	15-20	2.76	15,361	47	3.98	12,813	70
	25-30	6.60	1,501	133	0.91	1,502	61
	Average	6.42	9,155	85	2.03	5,163	52

this study was operated in the lab-scale fixed-bed reactor which was not preferred owing to the short residence time of flue gas inside a reactor, bad mixing condition, and low combustion efficiency. Nevertheless, NOx emissions were in the ranges of 52-205 ppm that as the result of fuel-N for NOx formation during the tests. For NOx remaining in flue gas emitted by the production of torrefied pellets (PET/TS, PET/ES, and PET/CC), it might be noticed that torrefaction could not completely eliminate fuel-N in the composite pellets. Otherwise, some portions in the composite pellets such as substances with low-temperature of volatilization could be eliminated under the process of torrefaction [7].

Emissions of PAHs and BTEX

Figure 3(a) illustrates emissions of PAHs concentration from combustion tests of the non-torrefied and torrefied PET/TS, PET/ES, and PET/CC. Total concentration of PAHs in non-torrefied pellets and torrefied pellets of PET/TS, PET/ES, and PET/CC were 8.85 and 0.07, 2.34 and 0.03, and 6.46 and 6.45 g/Nm^3, respectively. Phenanthrene was the highest pollutants found in samples of non-torrefied PET/TS, PET/ES, and PET/CC shown by the results of 3.57, 0.86, and 2.24 g/Nm^3, respectively, and followed by Pyrene > Anthracene > Fluorene > Acenaphthylene > Benzo (a) anthracene, Chrysene, Benzo (b) fluoranthene, Benzo (k) fluoranthene, Benzo (a) pyrene, Dibenz (a,h) anthracene, Benzo (g,h,i) perylene, and Indeno (1,2,3-cd) pyrene. Combustion test of the torrefied pellets of PET/TS and PET/ES presented the reduction of PAHs emissions compared to the tests of non-torrefied with the results of the total concentration of 0.07 and 0.03 g/Nm^3, respectively. Combustion test of the torrefied pellets of PET/CC indicted the emissions of PAHs with the total concentrations of 6.45 g/Nm^3. It was similar to the results of non-torrefied pellets of PET/CC but

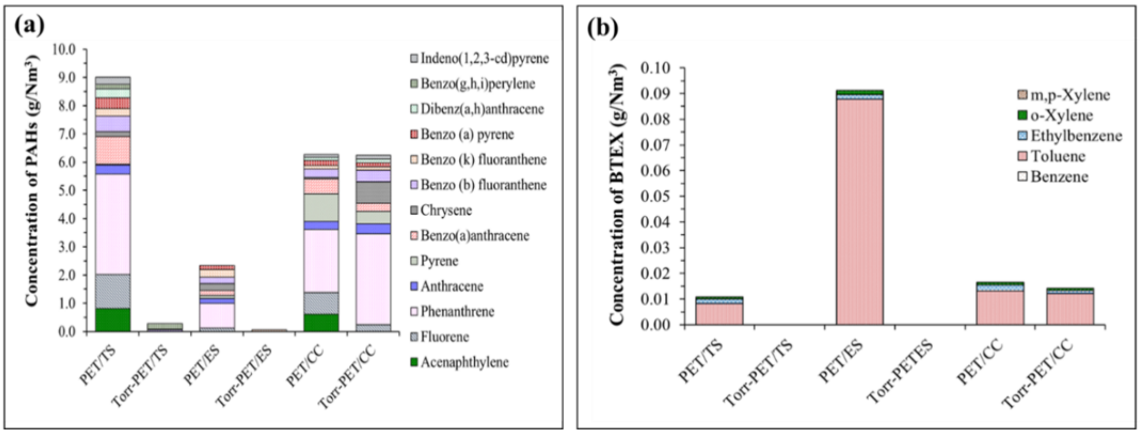

Figure 3 Concentrations of (a) PAHs and (b) BTEX emissions of pellets combustion

emission of Phenanthrene was higher than the torrefied pellets of PET/CC. In regard with the physical and chemical properties of corncob (raw material), it had no significant change at low temperature of torrefaction at about 225 °C and 10 min of residence time. This result was similar to Kanwal et al., 2019 [10] finding that there was no significant improvement in the physical and chemical characteristics of the torrefied corncob at low-torrefy temperatures of 200-225 °C.

The highest value of BTEX emission was found in the tests of non-torrefied pellets of PET/ES with the total concentration of 0.09 g/Nm^3 as seen in Figure 3(b). The tests of non-torrefied pellets of PET/CC and PET/TS were in the range of 0.02 and 0.01 g/Nm^3, respectively. For the tests of torrefied pellets of PET/TS and PET/ES, BTEX emission were not detected, while the test of torrefied pellets of PET/CC BTEX emission was slightly decreased to 0.01 g/Nm^3. The previous study reported that process of torrefaction played a role in decomposition of monocyclic aromatic hydrocarbons such as phenolic compounds from cellulose fiber. Torrefaction has the potential to increase the relative content of BTX compounds. However, the total values of BTX compounds decreased with the increase in torrefaction severity [11].

Conclusion

Pelletizing of PET waste with biomass was a good process for handling powder-like materials such as sludge, debris, tiny pieces of PET, dust, and micro-plastic as well as agricultural wastes i.e. sawdust to be a waste-to-energy challenge. The increasing of HHV occurred after pelletizing process and improved the properties of fuel pellets as well as PET-biomass composite pellets suitable for thermo-chemical conversion process. Torrefaction influenced physical properties of composite pellets by enhancing the durability of pellets and increased a value of DSI. Moreover, torrefy temperature at 225 °C played a role on PET melted and formed in terms of adhesive inside the pellets. The combustion tests of the torrefied PET-biomass composite pellets showed a significant in the alteration of gaseous emissions by reducing pollutants. The torrefied PET-biomass composite pellets could be utilized as a primary or secondary fuel sources in the stationary combustor with lower CO, NOx, and CO_2 emissions. In addition, the experimental results indicated that each test could not be detected emission of SO_2 due to the original materials had no sulfur content. The lower gaseous pollutants such as PAHs and BTEX had been found in all tests of the torrefied PET-biomass composite pellets.

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Control of Trihalomethane Precursors by Alum Coagulation

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Abstract

Natural organic matters (NOM) contamination is a worrisome challenge to water treatment plants. The use of alum and alum with PAC are common in treating surface water for household consumption. This study investigated the effect of coagulation by alum and alum with PAC on NOM, focusing on organic fractions and trihalomethane formation potential (THMFP). Water sample was collected from raw water reservoir for Bangkhla water treatment plant. It was found to contain 21.78 mgDOC/L with hydrophilic (HPI) fraction of 58.26% and hydrophobic (HPO) fraction of 41.74%. The presence of NOM was confirmed by FEEM technique where humic-like, fulvic-like and tryptophan-like substances were detected. Coagulation using alum (60 mg/L) and alum with PAC (60 + 60 mg/L) gave comparable results. DOC removal of 38.48% and 39.36% were achieved, respectively. The HPI and HPO fractions remained essentially the same as those of raw water. THMFP was reduced by 13.85 and 19.73%, respectively.

Keywords : Natural Organic Matters; organic fractions; Trihalomethane formation potential

Introduction

Characteristics and quality of surface water vary with topography, season, population and land use (industry and agriculture). Human activities result in contamination of biological and chemical waste. Surface water in urban or populated area is usually high in dissolved organic matter (DOM) and natural organic matter – (NOM). When surface water is used as raw water for water supply, NOM reaction with chlorine leads to formation of health hazard products. NOM also contributes to biological regrowth in the distribution system and producing color, taste and odor [1].

NOM is derived from the degradation of complex organic compounds and can be found in abundance in natural water. NOM can be broadly divided into 2 fractions; hydrophobic (humic) and hydrophilic (non-humic) substances [2]. Humic substances, dominating component in NOM, are comprised of humic and fulvic acids while non-humic substances include carbohydrates (polysaccharide), lipids and amino acids [1, 3]. Humic substances are mostly in soluble form but some maybe found as suspended particulate or adsorbed on the surface of other particles. NOM is not health hazard but when reacts with chlorine may form disinfection by product (DBP) such as trihalomethane (THMs) and haloacetic acid (HAA), known to be carcinogenic [4]. Factors influencing formation of DBPs are concentration and composition of NOM and water treatment methods [5]. Hydrophilic NOM was a more important source of the formation of THMs and HAAs than the corresponding hydrophobic NOM. Knowledge of NOM fractions is useful in identifying potential precursors of DBPs and the treatment strategies.

The content of dissolved organic carbon (DOC) is not sufficient for the characterization of NOM. Ultraviolet spectrum at 254 nm. is greatly absorbed by aromatic structure and is thus used for the determination of humic substance because aromatic carbon contents in humic are greater than those in non-humic materials [4]. Characterization of NOM by size, structure, functionality, hydrophobicity of NOM were suggested for DBPs study [6, 7]. UV_{254} and SUVA (Specific UV Absorbance, ratio of UV and DOC) is a good indicator of aromaticity of NOM and correlated with the formation of DBPs [8-10]. Fluorescence spectroscopy, size exclusion chromatography, polar fractionation have been utilized to provide insight into a better understanding of NOM characteristic and its tendency to form DBPs [11].

The results from previous studies have shown that in conventional treatment process (coagulation - flocculation / sedimentation / filtration / disinfection) organic matters are removed in the coagulation - flocculation step. Metal salt coagulant, provide positive ions, attract to negative charges on NOM [12]. Organic coagulants are effective for the removal of aromatic hydrocarbon. Aliphatic hydrocarbon is the most difficult to be removed by the method [13]. Removal of low molecular weight NOM can be enhanced by the use of coagulant together with Powder Activated Carbon (PAC). The porous structure of PAC provides higher surface area for adsorbing contaminant [14, 15].

This study investigated the control of THMs formation by alum coagulation. Raw water for Bang Khla water treatment plant was treated by alum and alum with PAC. The effects on NOM were compared, focusing on organic fractions and trihalomethane formation potential (THMFP). Organic content was determined as DOC. Organic components and structures were analyzed by UV_{254} absorption, SUVA, Fluorescence Excitation-Emission Matrix (FEEM). Resin fractionation of NOM based on the separation of hydrophilic and hydrophobic was also conducted.

Material and Methods

Water sample and analytical methods

Water samples were collected from raw water reservoir for Bang Khla water treatment plant, once a month from May 2019 to September 2019. The samples were used for coagulation-flocculation test. Raw and treated samples were analyzed for organic contents, analytical methods are as shown in Table 1.

Coagulation – Flocculation Test

Water sample was treated by coagulation process, using alum and alum with PAC at the optimal dosage obtained from pretest (60 mg-alum/L and 60 mg PAC/L). Alum $[Al_2(SO_4)_3 \bullet 18H_2O]$ and PAC were obtained from Bang Khla water treatment plant, Provincial Waterworks Authority (PWA). Test condition was as employed by Bang Khla water treatment plant ; 30 sec. of rapid mix at 100 rpm followed by 3 steps of slow mix (7.5 min at 60 rpm, 7.5 min at 45 rpm and 5 min at 25 rpm) then left to stand for settling for 30 min. Supernatant was collected and filtered through GF/c filter (0.45 micrometer pore size). Filtrate was analyzed for DOC, UV_{254} absorbance, Resin fractionation, FEEM and THMFP.

Table 1 Analytical methods for organic contents and organic fractions

	Analytical method	method No.*
DOC	TOC Analyzer, Shimadzu	5310 B
UV_{254}	Ultraviolet absorption	5910 B
SUVA	SUVA ($L\bullet m^{-1}\bullet mg^{-1}$) = $100 \times \left\{\frac{UV_{254}(cm^{-1})}{DOC\ (mg/l)}\right\}$	5910 B
FEEM	Excitation Emission Matrix spectroscopy Excitation @ 200-500 nm.; Emission @ 250-550 nm	**
THM	GC, Perkin Elmer Clarus600, ECD, Rtx-1701 column	6232 D

*APHA & AWWA Standard Methods for the Examination of Water and Wastewater [16]

** Park et al. 2019 [15]

Resin fractionation

The fractionation of NOM was achieved using the resin Nonionic DAX-8 (Supelite DAX-8, Supelco) type and the procedure adopted from Marhaba et al. (2003) and Chow et al. (2004) [17]. Prior to column packing, DAX-8 was washed with 0.1N NaOH for 1 day, then transferred to soxhlet extraction to extract contaminants in the resin with acetone (24 hr.) and then with hexane (24 hr.). The cleaned resin (approx. 15 mL) was soaked in methanol and packed in the glass column (10 mm.diameter x 500 mm.high) with glass fiber at the top and the bottom. To remove remaining contaminants, the column was rinsed sequentially (2 cycles) with 2.5 bed volume of 0.1N NaOH and 0.1N HCl followed by repeated rinsing with Milli-Q water until DOC of the effluent was less than 0.3 mg/L and EC of the effluent less than 10 µs/cm.

Water sample (500 mL), prefiltered with GF/c, was acidified to pH 2.0 with 0.1 N HCl and passed through the column at 3.0 mL/min flow rate to separate NOM into fractions. DAX-8 adsorbed strong Hydrophobic acids (HPO) while Hydrophilic (HPI) were eluted out in the effluent. The strong HPO acids was later eluted by rinsing the column with 0.1N NaOH. Both HPI and HPO fractions were analyzed for DOC, UV_{254} absorbance and FEEM. DOC of the DAX-8 effluent represented HPI fraction, DOC of final wash represented strong HPO acid fraction. HPO fractions was also estimated by calculation from DOC of raw sample where (stong HPOacid = DOC of raw water – HPI fraction).

Trihalomethane Formation Potential (THMFP)

THMFP is used to estimate the amount and reactivity of THM precursors in the water. It is defined as the total concentration of THMs (TTHM) formed when chlorine reacts with NOM present in water under specific test condition. TTHM is the sum of the concentrations of all the four regulated THM species: chloroform (CF), bromodichloromethane (BDCM), dibromochloromethane (DBCM) and bromoform (BF). (APHA 2005).

Under standard test condition, water sample was filtered, pH was adjusted and buffered to 7 ± 0.2 and dosed with appropriate amount of chlorine. After dosing, the sample was incubated for 7 days. THMs were purged from the sample and collected on an adsorbent trap and thermally desorbed into the inlet of a GC for analysis of the four THM species (CF, BDCM, DBCM, BF).

Results

Raw water characteristics

Water sample used in this study was from the water reservoir for Bang Khla water treatment plant. The reservoir is located adjacent to a shrimp farm causing contamination of dissolved organic matter (DOM) and natural organic matter (NOM). Table 2 shows analytical results of organic content in the raw water. DOC varied in a narrow range (16.81-24.75 mg/L), with the HPI fraction of 58.265 larger than that of HPO (41.74%). Organic content in surface water in Bang Khla was comparatively higher than in other regions. A study of water quality in Teharan surface water showed a very low DOC of 0.79-4.598 mg/L [18]. Water from a source in North England was reported to have 7.8-11.2 mgDOC/L [19]. The organic fractions distribution in Bang Khla reservoir was in agreement with those from the study conducted in Bangkok by Panyapinyopol *et al*. (2005), with HPI (66%) as the dominating fraction [20].

Considering the component of organic matter in the sample, UV_{254} absorbance indicated the presence of aromatic structure. The FEEM results in Figure 1 showed 3 peaks relevant to the target compounds. Peak A (Ex260-290 nm, Em 400-430 nm), peak C (Ex310-360 nm, Em 390-430 nm.) and peak T (Ex280-310 nm. Em 330-360 nm.) represent humic-like substance, fulvic-like substance and tryptophan-like substance, respectively [15, 21]. The highest intensity was observed at peak C, meaning that fulvic-like substance was present at the highest ratio.

Table 2 Analytical results of organic content in raw water for Bang Khla water treatment plant

	Unit	Range
DOC	mg/L	16.81 – 24.75
HPI	mg/L	12.69
HPO	mg/L	9.09
UV_{254} absorbance	cm^{-1}	0.191 – 0.348
SUVA	L/mg-m	1.14 – 1.41
THMs	µg/l as $CHCl_3$	0.716 – 0.922

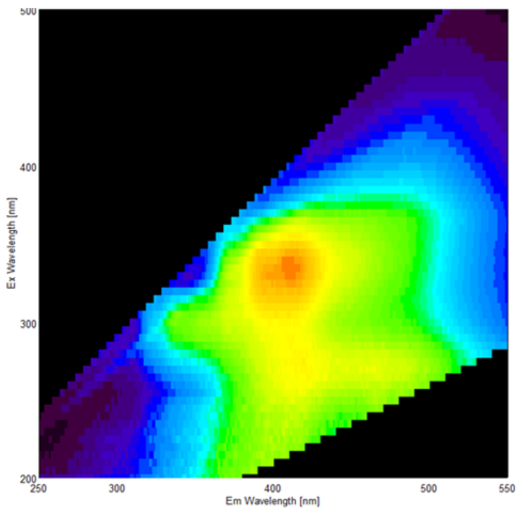

Figure 1 Fluorescence Excitation Emission Matrix of raw water for Bang Khla water treatment plant

The effects of alum coagulation on organic fractions

Raw water sample was treated by coagulation using alum (60 mg/L) and alum with PAC (60+60 mg/L). The doses applied were the optimal doses obtained from the pretest. The results in Figure 2 compare the amount of organic matter remaining in the treated samples. The decrease in DOC and UV_{254} absorbance revealed that dissolved organic matter and aromatic compounds were removed by coagulation. The addition of PAC yielded little changes. The small enhancing effect of PAC was also reported by Park et al. (2019) [15]. Comparison of the 38.48% and 39.35% DOC removal achieved by alum and alum with PAC to the 70.21% and 71.58% decrease in UV_{254} absorbance showed that aromatic compounds were more subjected to alum coagulation than the total organic matter. This was in agreement with the decrease in SUVA from 1.34 in raw water to 0.65 and 0.63 by alum and alum with PAC, respectively. This was because both alum and PAC have cationic functional groups while NOM has negative charge on the surface [22].

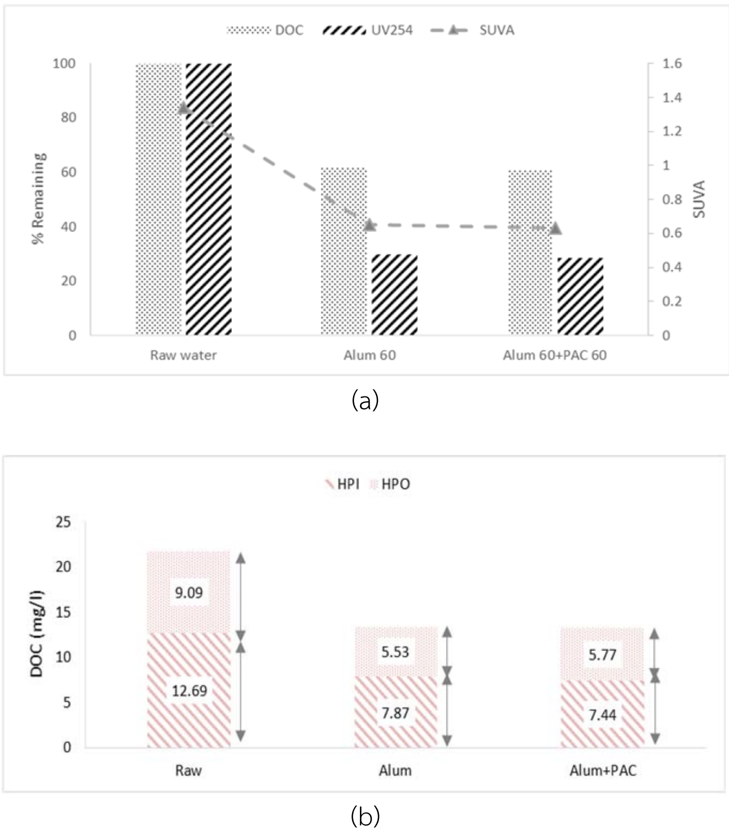

Figure 2 The organic contents of raw water and treated water (by alum coagulation and alum with PAC coagulation) a) DOC, UV_{254} absorbance and SUVA b) HPO and HPI fractions

The results from DAX-8 fractionation in Figure 2 b) shows that the fractions in treated water remain essentially the same as those in raw water.

THM Formation Potential

The results of THM analysis in Table 3 showed that in all samples the amounts of the 4 THM species followed the same trend. Chloroform was found to be formed in the highest amount while bromoform was the lowest. THMFP varied with the amount of precursors (DOC and NOM). THMFP decreased when NOM was removed. Coagulation with alum decreased THMFP by 13.85% (from 180.78 to 155.47 μg/L). PAC gave a better result, THMFP decreased by 19.73%.

Table 3 Trihalomethanes formation after 7 days of chlorine exposure.

THM (μg/L)	Raw water	Alum	Alum + PAC
CF	83.77	68.90	60.30
BDCM, μg/L	39.22	37.18	36.47
DBCM, μg/L	54.72	46.70	43.10
BF, μg/L	3.07	2.96	2.81
THMFP, μg/L	180.78	155.74	142.68

Conclusion

1. Organic content in raw water for Bang Khla water treatment plant was found to be 21.78 mgDOC/L, an average value obtained during May to September 2019. SUVA of 1.34 L/mg-m and FEEM analysis indicated contamination by NOM and humic substances. Resin fractionation by DAX-8 showed that hydrophilic (HPO) fraction was greater than hydrophobic (HPO) one at the rate of 58.26% to 41.74%.

2. NOM was removed by coagulation process, using alum at 60 mg/L, 38.48% DOC removal and 70.21% decrease in NOM (determined by UV_{254} absorbance) were achieved. HPO and HPI fractions remained essentially the same as in the raw water. Addition of PAC (60 mg/L) yielded no significant difference in organic removal by alum.

3. Trihalomethane formation potential was found to be related to DOC and NOM. THMFP of the treated sample was decreased by 13.85% by alum and 19.73% by alum with PAC.

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Current State of Onsite Wastewater Treatment Systems of Rafts and Riverfront Buildings in Kanchanaburi, Uthai Thani and Phetchaburi Province, Thailand

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Abstract

Deterioration of water quality in rivers is quite a concern in Thailand especially in the provinces where there is high intensity of river-related tourism industry. In such provinces, rafts and riverfront buildings, serving as tourism services (i.e. restaurants, hotels and water activities), generate and directly discharge partially or even untreated wastewater into rivers causing damage to the waterbodies. Although most of the buildings have installed onsite wastewater treatment systems (OWWTs), they are not capable of providing effluent with good water quality. Where OWWTs are not applicable, especially on rafts, wastewater is directly discharged into the water bodies. Current state of OWWTs of the rafts and riverfront buildings is critical in order to cope with the deteriorated water quality of the rivers. In this study, we explored types and treatment efficiencies of OWWTs in three provinces in Thailand including Phetchaburi, Kanchanaburi and Uthai Thani Province. The investigation indicated that the types of OWWTs were traditional cesspools and commercial septic tanks whose effluent quality was not suitable for direct discharge. Wastewater management options were recommended for the rafts and riverfront buildings.

Keywords : onsite wastewater treatment; raft; riverfront building

Introduction

Rivers and canals have been involved in Thai culture ever since the old Siam Era. In the past, the Siamese people lived along rivers, canals and creeks owing to the benefit of the waterways including ability to access water resources for daily life activities, transportation and trading. Nowadays, rivers, canals and creeks have become important for Thai tourism industry which, in total, accommodated 2.3% of the total gross domestic product in 2018. These days, in addition to riverfront houses, there are rafts and riverfront hotels, restaurants and tourist attractions increasing in numbers to serve the increasing amounts of tourists. Kanchanaburi and Phetchaburi Province have high number of rafts and riverfront buildings open for tourist services (i.e. hotel, restaurant, water activities). The rafts and riverfront buildings unavoidably generate wastewater and, often, they do not have functional onsite wastewater treatment systems (OWWTs) resulting in deteriorated water quality of the waterbodies. Furthermore, it has potential to cause outbreaks of waterborne diseases such as diarrhea, typhoid, cholera and etc. which come with the fecal matters contaminated in the effluent [1].

In Thailand, it is required by law (Building Control Act, B.E. 2522) to have OWWTs for categorized buildings. Following the law, most of the buildings in Thailand usually install some forms of OWWTs. The effluent is usually either followed by centralized wastewater treatment wherein there are coverage of centralized wastewater treatment plants or discharged directly to the environment [2] as shown in **Figure 1**. The most frequently used OWWTs are one- and two-cesspools and commercial septic tanks. Treatment efficiencies of these treatment systems are quite low owing to the anaerobic mechanism [3]. Thus, subsequent treatment processes are needed in order to satisfy water quality standards for the effluents. In the case of rafts and riverfront buildings, a bill enacted by Thai Marine Department requires that appropriate toilets, storage tanks and further on-land treatments are required and direct discharge of the wastewater is strictly prohibited. However, in reality, those rafts and riverfront buildings do not have the appropriate ways to deal with the wastewater or OWWTs are not properly maintained resulting in poor effluent quality. OWWTs are often overlooked and are not taken care which cause the treatment system to underperform. Most of the raft and riverfront buildings release the effluents of onsite wastewater treatment, or even untreated wastewater, directly into waterbodies causing deteriorated water quality which indirectly damages tourism industry and other harmful results as aforementioned.

Data of types and current state of OWWTs (current condition, maintenance routine and treatment efficiencies) are crucial to prevent the deteriorated water quality of the rivers, canals and creeks wherein there are tremendous number of rafts and riverfront buildings. In this study, we explored the types and treatment efficiencies of onsite wastewater treatments of actual riverfront restaurants, hotels and houses in three provinces in Thailand including Phetchaburi, Kanchanaburi and Uthai Thani Province wherein there are tremendous number of rafts and riverfront buildings. In addition to wastewater samples, questionnaire survey was conducted to the landlords where the water samples were taken. Based on the data we collected, suitable wastewater treatment systems and management options of wastewater generated from rafts and riverfront buildings were recommended.

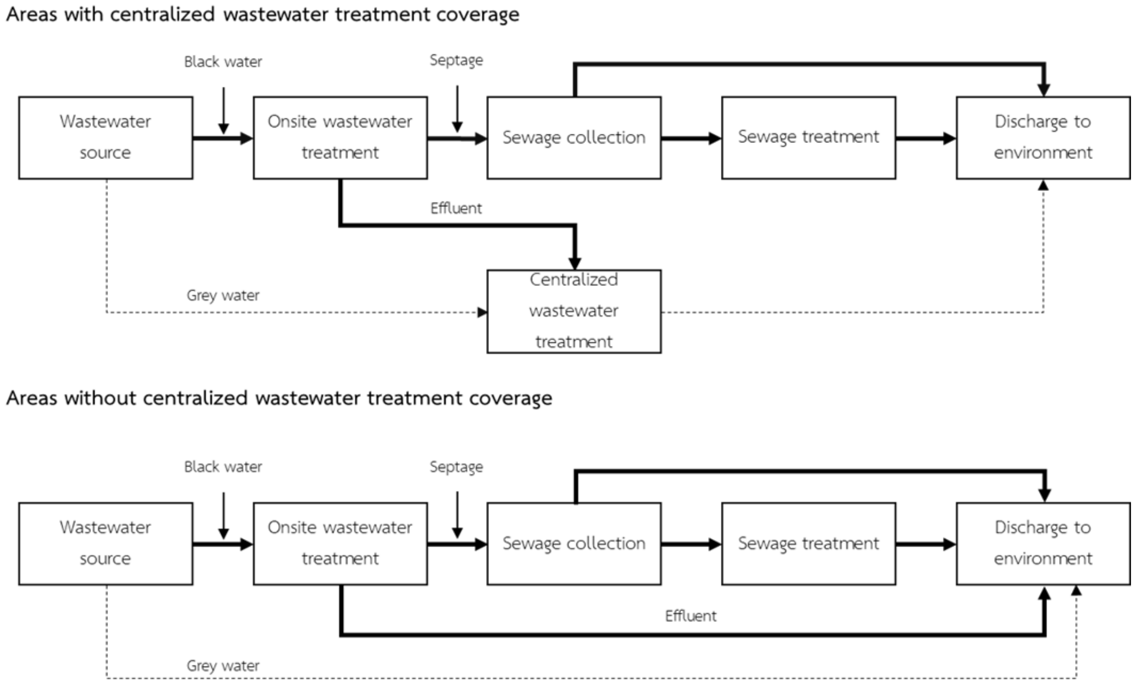

Figure 1 Domestic wastewater management in Thailand (modified from Boontanon and Buathong [4])

Materials and Methods

Sampling sites

One-time samplings were conducted and wastewater samples were collected from OWWTs of multiple rafts, riverfront houses, restaurants and hotels in Phetchaburi, Kanchanaburi and Uthai Thani province, Thailand on 21st, 23rd and 30th May 2019, respectively. The OWWTs in the sampling sites were one cesspools (OCPs), two cesspools in series (TCPs) and commercial septic tanks. To calculate the treatment efficiencies, wastewater quality parameters were compared between the samples collected in the first cesspool and second cesspool (in the case of TCPs) and in the septic tanks and effluent of septic tanks. As for OCPs, since the effluent seeped out below the cesspool, treatment efficiency of OCP was not considered.

Phetchaburi Province is an important tourism province of Thailand. It is located south-east of Bangkok. There are several waterfalls, mountains and famous beaches. Our sampling sites were located in the Bangtaboon Watershed (Bangtaboon Sub-district), Banlaem District in the province. Since it is located in between Amphawa and Cha-am, the sub-district had quite a potential to become popular tourism destination [5]. Consequently, on both sides of Bangtaboon River, there are resorts, hotels and restaurants open to accommodate the increasing tourists.

Kanchanaburi Province is famous for beautiful forests and rivers. Tourists can enjoy living and relaxing with nature. One of the most popular activity in Kanchanaburi is water activities especially rafting in rivers like Khwa Noi and Khwa Yai River. Nowadays, the province is quite popular for both Thai and foreign tourists and there are high number of hotels, restaurants and traveling rafts. Due to high intensity of tourism, water quality of the rivers is deteriorated as well as the tourism business.

In the past, people in Uthai Thani Province lived in riverfront houses and spent daily activities along rivers. This so called "The way of housing raft" has been done for almost a hundred years. Moreover, this has created occupations for the people (i.e. raft repair). Nowadays, installing new rafts in the rivers is strictly prohibited in the province due to the deteriorated water quality of rivers. This deterioration is due to the fact that domestic wastewater generated in the rafts is discharged directly into the waterbodies.

Water parameters

Wastewater samples were analyzed by 5-d biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), total phosphorus (TP) and fecal coliform (FC). Analytical methods and significance of each parameters are shown in **Table 1**.

Calculations of treatment efficiencies of OWWTs were conducted for TCPs and CSTs comparing influent (wastewater in the first tanks of TCPs and in the CSTs) and effluent (the second tanks of TCPs). As for OCPs, calculation was impractical since effluent of OCPs could not be sampled.

Questionnaire survey

Questionnaire survey was conducted with the goal to collect the data of type of rafts/riverfront buildings, type of onsite wastewater treatment systems, knowledge of landlords regarding the wastewater treatment system, as well as operation and maintenance of wastewater treatment system. The questionnaire consisted of basic information of the sampling site including types (building or raft), types of establishment, number of persons or customers per day, types of OWWTs. In addition, a set of question designed to evaluate knowledge of landlords regarding OWWT (**Table 2**) was given to the landlords.

Table 1 Water parameters

Water parameters	Significance	Analytical methods
BOD_5	Organic pollution	5-day BOD test (5210-B)
COD	Organic and inorganic pollution	Closed reflux, titrimetric (5220-C)
TKN	Nutrient contamination	Macro-Kjeldahl (4500-Norg B
TP	Nutrient contamination	Digestion and colorimetry (4500-P)
FC	Fecal contamination	MPN technique

Table 2 Questions designed to evaluate knowledge of landlords regarding OWWTs

Question	Answer		
	Yes	No	Comment
1) Do you have OWWTs installed in your raft/building?			
2) Do you litter other waste (i.e. tissue paper, sanitary napkin) to the toilet?			
3) Do you momentarily remove septage from OWWTs?			
4) Do you know the effect of using high conc. detergent on OWWTs?			
5) Have you ever noticed abnormality of OWWTs?			

Results and Discussion

Type and treatment efficiency of onsite wastewater treatment systems in the study areas

There were 19 sampling sites from three provinces. The sampling sites consisted of residences, restaurants, hotels and general stores (**Table 3**). In Phetchaburi Province, since restaurants and hotels were newly built to accommodate the increasing number of tourists, most of the OWWTs were commercial septic tanks. In Kanchanaburi, most of the OWWTs were TCP and commercial septic tanks. In Uthai Thani provinces, the sampling sites were located in the old town and OWWTs consisted of mostly OCPs. In total, the percentages of OWWTs in this study were 37%, 26% and 37% for OCPs, TCPs and commercial septic tanks, respectively.

Calculations of treatment efficiency were done in terms of BOD_5, COD, TKN, TP and FC for TCPs and commercial septic tanks. As for OCPs, the calculation was not feasible as described above. Wastewater quality parameters are presented in **Table 4**. Wastewater samples in OWWTs had high concentrations of organic and nutrient (mean BOD_5, COD, TKN and TP were 347.6 mg/L, 1226.8 mg/L, 37.5 mg/L and 218.8 mg/L, respectively) as well as fecal indicator (mean FC was 1.79 10^7 MPN/100 mL). The parameters were similar to the design criteria of OWWT recommended by Meier [6] with an exception of TP. Meier [6] recommended the design criteria for TP as 38 mg/L. In this study, the concentrations of TP were much higher than the criteria (about 6-fold higher). This high concentration of TP should have been a result of use of dish washing, laundry and cleaning detergents which were also discharged into OWWTs.

Treatment efficiencies of TCPs calculated for the 7^{th} sample of Kanchanaburi and 1^{st} sample of Uthai Thani (**Table 4**) in terms of BOD_5, COD, TKN, TP and FC were 51.0%–86.2%, 4.7%–61.2%, 71.3%–88.4%, 0.0%–88.6% and 0.0–2.8 log removal, respectively. Although the removal rates were expected, the effluents were still higher than the provided effluent standards (Building Effluent Standards B.E. 2537). This indicates that effluents of TCPs could be a potential harm to the waterbodies if there were not enough soil attenuation.

Treatment efficiencies of commercial septic tanks calculated for the 3^{rd}, 5^{th} and 7^{th} sample of Phetchaburi (**Table 4**) in terms of BOD_5, COD, TKN, TP and FC were 72.9%-73.7%, 78.8%-87.9%, 0.0%-51.3%, 8.7%-70.7% and 0.3-2.4 log removal. BOD_5 removal rates of commercial septic tanks were higher than that of TCPs while other parameters had comparable removal rates. Although BOD_5 removal rate was higher, the effluent still had quite high BOD_5 concentration (82.5-202.5 mg/L) and still higher than effluent standards. Moreover, since commercial septic tanks discharged the effluent directly into waterbodies without any attenuation, they may cause significant water quality problems to the receiving rivers.

Table 3 Number of types of rafts and riverfront buildings

Types	Phetchaburi	Kanchanaburi	Uthai Thani	Total
Residence	1	0	1	2
Restaurant	2	4	1	7
Hotel	3	3	0	6
Store	1	0	3	4

Table 4 Wastewater quality and treatment efficiency of onsite wastewater treatment system in Phetchaburi, Kanchanaburi and Uthai Thani Province

Province	No.	Type of onsite wastewater treatment system	BOD (mg/L, %)			COD (mg/L, %)			TKN (mg/L, %)			TP (mg/L, %)			Fecal coliform (MPN/100 mL, log removal)		
			Influent (mg/L)	Effluent (mg/L)	Removal efficiency (%)	Influent (mg/L)	Effluent (mg/L)	Removal efficiency (%)	Influent (mg/L)	Effluent (mg/L)	Removal efficiency (%)	Influent (mg/L)	Effluent (mg/L)	Removal efficiency (%)	Influent (MPN/100 mL)	Effluent (MPN/100 mL)	Removal efficiency (log removal)
Phetchaburi	1	CST	110.0	-	-	1160.0	-	-	87.4	-	-	207.1	-	-	1.40E+07	-	-
	2	OCP	203.8	-	-	1060.0	-	-	68.6	-	-	386.9	-	-	5.40E+05	-	-
	3	CST	770.0	202.5	73.7	2080.0	440.0	78.8	31.5	89.6	-	401.9	307.0	23.6	1.10E+08	4.00E+05	2.4
	4	CST	187.0	190.0	-	800.0	460.0	42.5	33.6	54.6	-	294.5	296.8	-	4.00E+05	4.80E+04	0.9
	5	CST	383.8	82.5	78.5	840.0	120.0	85.7	79.1	38.5	51.3	148.3	43.4	70.7	3.50E+05	1.70E+05	0.3
	6	OCP	110.0	-	-	480.0	-	-	28.7	-	-	235.2	-	-	1.60E+05	-	-
	7	CST	710.0	192.5	72.9	5600.0	680.0	87.9	25.9	29.4	-	124.7	113.9	8.7	4.70E+05	1.60E+05	0.5
Kanchanaburi	1	OCP	280.0	-	-	360.0	-	-	24.5	-	-	293.8	-	-	7.00E+04	-	-
	2	OCP	230.0	-	-	320.0	-	-	11.2	-	-	105.0	-	-	2.20E+06	-	-
	3	OCP	630.0	-	-	1460.0	-	-	18.2	-	-	365.0	-	-	3.50E+05	-	-
	4	CST	500.0	750.0	-	1600.0	880.0	45.0	17.4	17.5	-	256.2	282.2	-	6.10E+05	4.60E+05	0.1
	5	OCP	650.0	-	-	750.0	-	-	16.8	-	-	53.7	-	-	5.40E+06	-	-
	6	CST	220.0	340.0	-	140.0	200.0	-	16.2	4.5	72.2	27.4	19.5	28.8			-
	7	TCP	490.0	240.0	51.0	1980.0	230.0	88.4	80.9	11.2	86.2	413.0	118.7	71.3	2.10E+07	3.40E+08	-
Uthai Thani	1	TCP	485.0	188.3	61.2	3320.0	380.0	88.6	63.0	65.1	-	224.5	213.9	4.7	1.60E+08	2.70E+05	2.8
	2	OCP	158.3	-	-	520.0	-	-	67.9	-	-	290.8	-	-	3.50E+05	-	-
	3	OCP	50.0	-	-	180.0	-	-	16.8	-	-	32.8	-	-	6.80E+04	-	-
	4	OCP	311.7	-	-	500.0	-	-	11.9	-	-	122.0	-	-	1.70E+06	-	-
	5	OCP	125.0	-	-	160.0	-	-	12.6	-	-	173.8	-	-	4.60E+06	-	-

Remark* OCP – One cesspool
TCP – Two cesspools in series
CST – Commercial septic tank

From the previous survey [4, 7], BOD_5 removal rate of OCPs, TCPs and septic tanks were in the range of 43%–59% with the effluent BOD_5 concentrations of 849-1,436 mg/L which were quite similar to this study reported. This indicates that although OWWTs in the rafts and riverfront buildings could operate as intended, removal rate was not enough and effluent should not be discharged directly into the waterbodies.

Questionnaire survey

Results of questionnaire survey aimed to evaluate knowledge of landlords regarding OWWTs in the sampling areas are presented in **Table 5**. The results indicated the followings;

- 26% of the sites littered into toilet

  Unwanted debris that go into OWWTs through littering in toilets can clog and result in short circuiting and ultimately poor effluent quality. In our survey, littering in toilet was quite difficult to control since the sampling sites were mostly restaurants and hotels. Prohibition might not be effective to customers. However, the landlords of the sites usually put signs and bins for littering in the toilets.
- 63% of the sites momentarily removed septage from OWWTs

  Periodic removal of septage is also important in maintaining good effluent quality from OWWTs. Since settleable solid and suspended solid are retained in the tanks, overtime, accumulated solids reduce the effective volume of the tanks and result in short wastewater retention time which ultimately deteriorate effluent quality. Most of the OWWTs at sampling sites momentarily removed septage from OWWTs. The removal frequency ranged from once in two months to two years. Such a high variation in period of septage removal comes from the fact that some sampling sites were commercial and some were residential wherein commercial sites had more frequent septage removal period.
- 16% of the sites realized the effect of concentrated detergents on operation of OWWTs

  Using concentrated cleaning detergents which are either highly acidic or basic can cause significant problems to OWWTs since they are harmful to microorganisms inside OWWTs. From the survey, there were only three sites where were aware of this issue.
- 42% of the sites had noticed abnormality of OWWTs

  Only 42% of the sampling sites had noticed the abnormality of OWWTs. This is quite a concern because if the abnormality occurred, the problems would be unnoticeable and resulted in poor removal rate of the OWWTs. Since most of the OWWTs rely on microorganisms which are sensitive to environmental stresses (i.e. organic overloading, off-pH, high acid or base), it is crucial to do regular check irregular circumstances occurred around the OWWTs (i.e. overflowing wastewater, irregular smell, toilets not flushed properly).

Table 5 Results of questionnaire survey

Questions	Yes*	No*
1) Do you have OWWTs installed in your raft/building?	19	0
2) Do you litter other waste (i.e. tissue paper, sanitary napkin) to the toilet?	5	14
3) Do you momentarily remove septage from OWWTs?	12	7
4) Do you know the effect of using high conc. detergent on OWWTs?	3	16
5) Have you ever noticed abnormality of OWWTs?	8	11

Remark * – Numbers represent the number of sampling sites.

Recommendations for wastewater management in rafts and riverfront buildings

In riverfront areas, OWWTs which rely on natural attenuation by soil should not be allowed. This is due to the fact that, in such areas, groundwater level is usually quite shallow. As such, there is insufficient depth/distance of natural attenuation. Furthermore, as seen in our results, effluent water quality of such systems is quite poor and not complied with water quality standards. For commercial septic tanks, the effluent should be followed by either on-land additional attenuation process or released to centralized wastewater treatment system. Small-scale constructed wetlands or drain field and effluent distribution box with appropriate setback-distance would be examples of alternative attenuation processes.

Type of OWWTs plays a vital role to prevent surface water contamination since most of OWWTs of riverfront buildings directly discharge the effluent into the waterbodies. The existing OWWTs in our survey (OCPs, TCPs and commercial septic tanks) had quite low removal rate in terms of BOD_5. Although it is to be expected from anaerobic process, the effluent quality is not complied building effluent standards. The appropriate OWWTs should have high removal rate and have the ability to stabilize pathogens. Thus, the OWWTs should be the combination of treatment processes and disinfection in series. An example is septic tank-anaerobic filter-aeration tank and disinfection. This OWWTs may not be practical in the area where the density of riverfront buildings is low, i.e. Uthai Thani, because capital and operation and maintenance cost are quite high. However, in denser areas, i.e. Kanchanaburi Province, this OWWT might be practical considering that it can cover the wastewater generated in the area and can serve as a semi-centralized wastewater treatment system.

Nutrients, nitrogen and phosphorus, are essential for aquatic plants including weeds, algae and phytoplankton. Since the concentrations of nutrients, especially phosphorus, were unexpectedly high, the discharge of the effluent can cause eutrophication [8]. The phenomenon does not only cause nuisance but also potential anaerobic condition in the waterbodies in the night when there is no photosynthesis. Additionally, the plants increase the organic loading to the waterbodies when they die out. Potential source of the nutrients in the OWWTs could be the fact that grey water, resulted from washing, bathing and laundry, was also discharged into the OWWTs in the sampling sites. This situation is worsened because the existing OWWTs were not designed to receive high concentration of nutrients. As a consequence, the nutrients were left untreated in the effluent and potentially stimulate eutrophication in the receiving waterbodies.

Management options for old areas

In the old area where OWWTs had been installed for a long time (i.e. Uthai Thani Province: "The way of housing rafts"), installing new and appropriate OWWTs or change/ modification of existing OWWTs are quite difficult or even impractical. However, the effects of the existing OWWTs on surround water resources are lacking and conclusive evidence on this issue is not clear. Thus, wastewater management option in this area could be done by monitoring the effect of existing OWWTs on the receiving waterbodies in order to point out the environmental burden of OWWTs. Further monitoring work should be done in terms of both organic pollution and fecal indicators. Previous study [9] recommended fingerprint compounds indicating the fecal contamination as the followings: Cl-to-Br ratio, sterol and stanol, and fecal coliform. In addition to fingerprint compounds, dyes can be used to track movement of effluent of the existing OWWTs. Once the effects of OWWTs are apparent, legal action can be placed.

Management options for newly developed areas

In newly developed areas, OWWT of choice is usually commercial onsite treatment system. The reliability of the commercial onsite treatment is widely accepted since they are available in sizes, desired treatment efficiencies and easy to install. However, for black water, the expected treatment efficiency of 90% achieved by aerobic commercial septic tank is insufficient to provide high quality effluent to meet the water quality standards. Since the effluent of traditional OWWTs (i.e. OCPs, TCPs and septic tank) still contained significant concentrations of such parameters, alternatives with higher efficiency OWWTs are recommended. Although aerobic septic tanks which are capable of higher effluent quality are commercially available, it is not suitable to treat black water owing to high organic loading of the wastewater. To treat black water, OWWTs should consist of anaerobic process (withstand high loading), aerobic process (good effluent quality) and disinfection process (stabilization of pathogens). Moreover, treating combination of grey and black water might be reasonable to obtain lowered loading rate. Successful implementation of such system can be seen in Japan, small-scale wastewater treatment system which treats combined grey and black water are installed at houses in rural areas. The system is called Johkasou which is essentially the combination of anaerobic and aerobic system and is capable of BOD_5, nutrients and pathogen removal [10]. To implement such a sophisticated system, subsidy and periodic maintenance are provided by Japanese Government (Japanese Building Standard Act).

Where it is impractical to implement sophisticated OWWTs whether it is due to space limitation or capital and maintenance cost are too high, conventional OWWTs must be installed on-land and have a sufficient setback-distance to allow appropriate soil attenuation. In New York, USA, prior to installation of septic tank and drain field, it is required to analyze soil samples and groundwater level whether the location is suitable for septic tank and drain field or not. In addition, the setback-distance of at least 50 feet from wells and rivers should be provided [11]. Soil condition, in which OWWTs are installed, should have hydraulic conductivity in an appropriate range in order to adsorb contaminants and unpleasant odor which can prevent ground- and surface water contamination [12, 13]. Mallin [14] also concluded that locations and density of septic system were also factors for environmental contamination of septic tanks.

Management options for onsite wastewater treatment systems for rafts

Onsite wastewater treatment system options for rafts are quite limited considering the fact that rafts can bear limited amount of weight and have limited space. In addition, most OWWT have quite low treatment efficiencies rendering the effluent not suitable for direct discharge. Therefore, an appropriate wastewater management for rafts should be holding tanks and regular transportation of the wastewater to central sewage treatment plants. As such, toilets on the rafts should be water efficient in order to minimize the generated wastewater which can prolong the wastewater holding period prior to transportation to centralized sewage treatment plants.

Conclusions

Investigation of types, efficiencies and suitability of OWWTs of rafts and riverfront buildings in Phetchaburi, Kanchanaburi and Uthai Thani Province indicated that most of the OWWTs in the areas were OCPs, TCPs and commercial septic tanks. The effluents of the systems were not suitable for direct discharge into the rivers. Management options of the wastewater can be done in several ways including proper installation of OWWTs, especially those rely on soil attenuation, restriction of direct discharge to the waterbodies. Alternatives such as Japanese Johkasou for combined grey and black water or combination of treatment processes have the potential to provide good effluent quality. Where OWWTs are not applicable, i.e. floating rafts, storage tanks can be installed incorporation with low-water-use toilets prior to collection and transportation to centralized sewage treatment plants. Intensive monitoring of the effects of OWWTs on waterbodies should be further investigated using tracing methods, chemical ratios and fingerprint compounds to draw a conclusive evidence and point out the problem of existing OWWTs. Finally, maintenance of OWWTs is crucial for OWWTs operation. Although OWWTs are designed in such a way that can provide good enough effluent quality for direct discharge, the OWWTs cannot operate as intended without proper maintenance owing to the fact that most of OWWTs rely on biological degradation which is quite sensitive to stresses including overloading, short circuiting, toxic chemicals and etc.

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Influence of Temperature and pH on Short-term Estimation of Biochemical Oxygen Demand

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Abstract

This research aims to study the influence of temperature and pH on short-term Biochemical Oxygen Demand (BOD_{st}) by measuring an oxygen uptake rate of activated sludge sample (microbe) taken from a return sludge pipe in an oxidation ditch at Maharaj Hospital, Nakhon Ratchasima Province, Thailand. The experiment was conducted by filtering solid materials and aerating sludge for not less than 12 hours without adding any substrates for sludge to enter the endogenous respiration condition. 20 mg/mL (13 mg COD/mL) of sodium acetate was used as a readily biodegradable COD substrate (rbCOD) and dosed to 2.2 liters of sludge sample. Final COD concentration was between 3.0-33.9 mg COD/L. Temperature, pH, oxygen and oxygen uptake rate were recorded every 3 seconds using an ultimate hybrid respirometer. Two experimental conditions were conducted, including uncontrolled and controlled conditions. The controlled experiment was conducted at 20 ^{O}C, 25 ^{O}C and 30 ^{O}C (± 0.5 ^{O}C) and pH was adjusted to 7.8±0.1 using NaOH 0.05N and HCl 0.05 N, while the uncontrolled experiment was conducted in the range between 25.6-27.6 ^{O}C and pH was adjusted to 7.0-9.6.

The experimental results showed the linear relationship between BOD_{st} and COD substrate concentration for each sample of both conditions. The slope of the uncontrolled system was equal to 0.37 (r^2 = 0.9917); while for the controlled system, the average slope was equal to 0.31 (r^2 = 0.9950). In addition, it was also found that when temperature was increased, the experimental duration was shorter from 9.7 minutes (20 ^{O}C) to 7.0 minutes (30 ^{O}C) at COD concentration was 5.3 mg/L. Furthermore, the research results showed that temperature did not affect the estimated accuracy of BOD_{st}, of which the temperature range of 20-30 ^{O}C cover increasing temperature of wastewater throughout the year, while pH had a direct effect. Obviously, the findings of this research would be highly beneficial to develop a hybrid respirator system that can be used to analyze BOD_{st} of wastewater and effluent in the activated sludge wastewater treatment system for practical plant operations, which is called the BOD on-line Analyzer.

Keywords : BOD_{st}; Activated sludge; Respiration; Oxygen uptake rate

Introduction

It is generally known that 5-day Biochemical Oxygen Demand (BOD_5) is a standard parameter for assessing biodegradable organic compounds contaminated in water that requires 5 days for analysis. There are other alternative methods that take shorter time, for example, Chemical Oxygen Demand (COD) and Total Organic Carbon (TOC). However, it is difficult to resign the indication of BOD and do it more precisely than with five-day BOD (BOD_5) in every case [1] as it correlates with a bio-process and concentration level of organic compounds degraded [2]. Short-term Biochemical Oxygen Demand BOD_{st} estimation using a technique of respiration measurement takes a significant shorter time to analyze and it is developed continuously in the automatic measurement tools.

Data from a respiration measurement technique is not only used to estimate BOD_{st}, but also used to estimate kinetic parameters of microbes in the wastewater treatment process of activated sludge widely, [3-8] in the mathematical model development of activated sludge treatment progress [9]. Due to high accuracy of the measurement comparing with an expensive analysis tool, a technique of respiration measurement provides fast result; a duration of 1-1.5 hours can categorize kinetic parameter value of sample sludge without having to analyze concentration of substrate in laboratory [10, 11].

A method to interpret oxygen uptake rate (OUR) of microbes is called Short-term BOD (BOD_{st}), which is conducted by calculating area under the respiration curve called a respirogram (Figure 1). This means an amount of oxygen required to biodegrade organic matter that is easily decomposed per volume of wastewater and time which takes less than 60 minutes, fast enough to apply in controlling and monitoring progress of activated sludge treatment. The area under the curve of OUR by microorganism under exogenous conditions was evaluated using Equation (1) [12].

$$BOD_{st} = \int_{0}^{tfin} OUR_{ex}(t)dt \qquad (1)$$

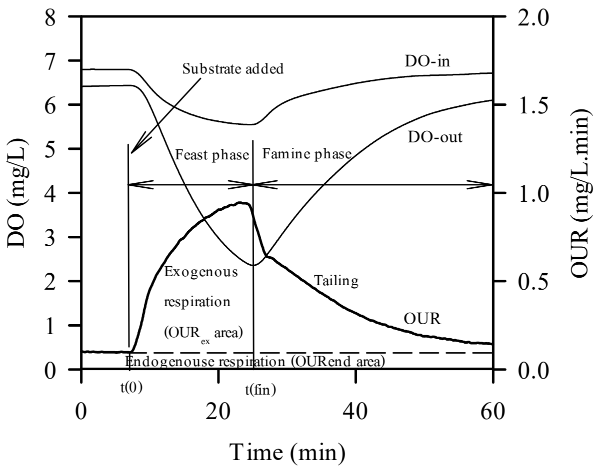

Figure 1 Respirogram

Respirogram is a data of oxygen uptake rate of microbes in sample sludge which consists of 2 parts including endogenous respiration (OUR_{end}) and exogenous respiration (OUR_{ex}). Endogenous respiration is respiration of microbes under condition without substrate from outside, but activated sludge model 1 (ASM1) explained that endogenous respiration used substrate, part of which is from microbial decay, called Death-regeneration which is a lower part of the graph [13].

After adding acetate to sample sludge, oxygen uptake rate will increase rapidly to the maximum oxygen uptake rate (OUR_{max}) which is related to amount of microbes in the sludge. Exogenous respiration can be divided into 2 phases including feast, which OUR_{max} level is stable until all substrates are used and after that, oxygen uptake rate will decrease rapidly. Then, it is famine, which oxygen uptake rate gradually decreases to starting value, this graph is called tailing. It's caused by microbes taking back substrate kept in polymer form to use again.

Materials and Methods

Activated sludge samples were taken from the sewage wastewater treatment system (oxidation ditch) in Maharaj Hospital, Nakhon Ratchasima Province. Sludge solid materials samples were filtered and aerated for not less than 12 hours without adding any substrates until reaching the endogenous respiration phase. The remaining substrate in the water would be used by microbes. An initial sludge concentration was 4,995 mg/L. 20 mg/mL (13 mg COD/mL) of sodium acetate of was used as a readily biodegradable COD substrate (rbCOD) and dosed to 2.2 liters of sludge sample. Final COD concentration level was varied into 4 dilutions; 3.0, 5.3, 10.6, 20.4 and 33.9 mg/L. pH was adjusted using NaOH 0.05N and HCl 0.05 N. The OUR data of sludge samples was collected using an ultimate hybrid respirometer. An overview of the instrument of measuring oxygen uptake rate experiment using hybrid respirometer machine is shown in Figure 2. It consisted of the aeration vessel and the respiration chamber with volume of 1.53 and 0.67 L. A pH electrode was placed on the aeration vessel and two polarographic dissolved oxygen electrodes were placed in the measuring chamber. The signal data from all electrodes was computed continuously by Labview 8.2 software package (National Instruments). Record data of temperature, pH, oxygen and OUR were collected in every 3 seconds. The value of OUR was calculated from DO mass balance around the respiration chamber using Equation (2) [12] below:

$$OUR = \frac{dS_{O,2}}{dt} + \frac{Q}{V_2}\left(S_{O,1} - S_{O,2}\right) \qquad (2)$$

Where Q is sludge circulation rate (L/min) and V_2 is respiration chamber volume (L). $S_{O,1}$ and $S_{O,2}$ are concentrations of oxygen flowing into and out of the respiration chamber [14]. Two experimental conditions were conducted, including controlled and uncontrolled conditions. The controlled experiment was conducted at 20 ^{O}C, 25 ^{O}C and 30^{O}C (± 0.5 ^{O}C) and pH was adjusted to 7.8±0.1 using NaOH 0.05N and HCl 0.05 N, while the uncontrolled experiment was conducted in the range between 25.6-27.6 ^{O}C and pH was adjusted to 7.0-9.6. Dissolved oxygen (DO) was controlled at 6-7 mg/L. Experiments were repeated 5 times continuously in each concentration of substrate. At the end of each experiment, the suspended solids of sludge samples, (MLSS) were analysed by following a standard method (American Public Health Association (APHA, 2005)) [15]. The area under the curve of OUR by microorganism under exogenous conditions was evaluated using Equation (2), with Microsoft Excel, Origin Pro and Sigma Plot programs used for computation.

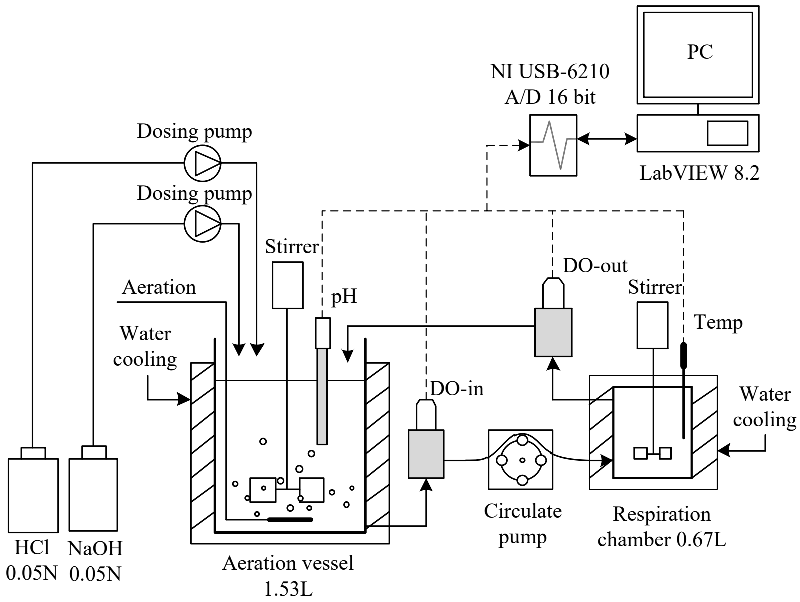

Figure 2 Ultimate hybrid respirometer [5]

Results and Discussion

The OUR data of sludge samples was collected using an ultimate hybrid respirometer. The experiment measuring oxygen uptake rate of uncontrolled sample sludge was conducted at temperature between 25.6-27.6 °C and pH 7.0-9.6, while the controlled experiment was conducted at temperature of 20 °C, 25 °C and 30 °C (±0.5 °C) and pH of 7.8±0.1. A sludge sample with an initial concentration of 4,357±461 mg/L was used in the experiment. 20 mg/mL (13 mgCOD/mL) of sodium acetate was used as a readily biodegradable COD substrate (rbCOD) and dosed to 2.2 liters of sludge sample. Final COD concentration level was varied into 5 dilutions; 3.0, 5.3, 10.6, 20.4 and 33.9 mg/L. Figure 3 shows an example of respirogram of oxygen value tendency and oxygen uptake rate from adding substrates with COD concentration of 5.3 mg/L operated at the temperature of 30°C for 5 times continuously. The results of BOD_{st} estimation from all experiments calculated by equation (1) are shown in Table 1.

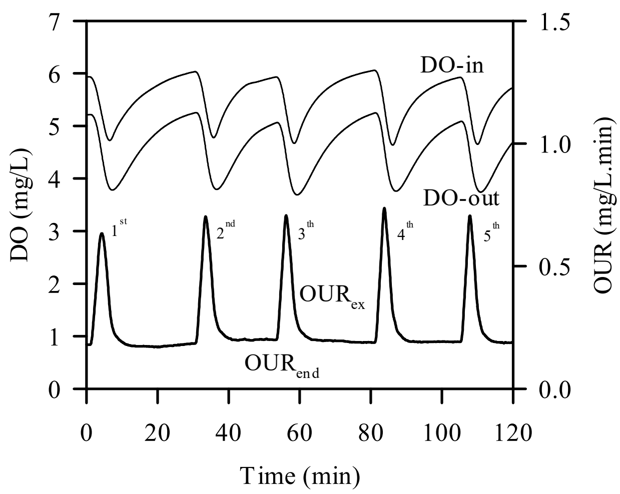

Figure 3 Example of oxygen uptake rate respirogram of 5 continuous experiments (COD substrate = 5.3 mg/L, Temperature = 30°C)

Table 1 Result of BOD_{st} estimation

COD substrate (mg COD/L)	BOD_{st} (mg/L)			
	Uncontrolled (temperature 25.6-27.6 ^{O}C and pH 7.0-9.6)	Controlled temperature and pH 7.8 ± 0.1		
		20 ± 0.5^{O}C	25 ± 0.5^{O}C	30 ± 0.5^{O}C
3.0	0.84 ± 0.05	0.91 ± 0.06	0.75 ± 0.03	0.82 ± 0.04
5.3	1.78 ± 0.06	1.80 ± 0.07	1.59 ± 0.15	1.58 ± 0.07
10.6	4.17 ±0.09	3.60 ± 0.07	3.54 ± 0.11	3.29 ± 0.20
20.4	8.13 ± 0.14	6.43 ± 0.34	6.65 ± 0.11	6.79 ± 0.17
33.9	12.07 ± 0.47	9.93 ± 0.25	10.27 ± 0.16	10.05 ± 0.14
Slope	0.3679	0.3022	0.3102	0.3062
r^2	0.9917	0.9931	0.9958	0.9930

According to data in Table 1, it was found that the uncontrolled experiment has lower r^2 than controlled experiments with 3 temperature levels. Higher slope was found to be significantly different from the controlled experiment. The slope of controlled condition for all experiments was similar meaning that temperature has lower effect on reliability of BOD_{st} estimation than pH. Therefore, pH should be constant control throughout the experiment. For the uncontrolled experiments, pH changed in the wide range from 7.0 to 9.6. Figure 4 is comparison of linear relations of the uncontrolled and controlled experiments, showing the linear relationship between BOD_{st} and COD substrate concentration for each sample. It was found that the controlled experiments at temperature of 20-30^{O}C had an average slope of 0.3062. R^2 for all experiments was high and similar (r^2 = 0.9930-0.9958). Reliability and validity of BOD_{st} estimation were also considered from the Yield (Y), which could be calculated from Y = 1 – Slope [16]. The experiments of uncontrolled and controlled temperature and pH would have Y equal to 0.63 and 0.69 mg cell (COD)/mg COD. It can be seen that the controlled experiment had value of Y that was close to the yield referred in the activated sludge model 1 (ASM no.1) of 0.67 mg cell (COD)/mg COD at the standard temperature of 20^{O}C [13] and the results were consistent with the study by Saensing, P. and Kanchanatawee, S. [5], Premanoch, P. [7] and Muller et al. [16] of 0.69 mg cell (COD)/mg COD.

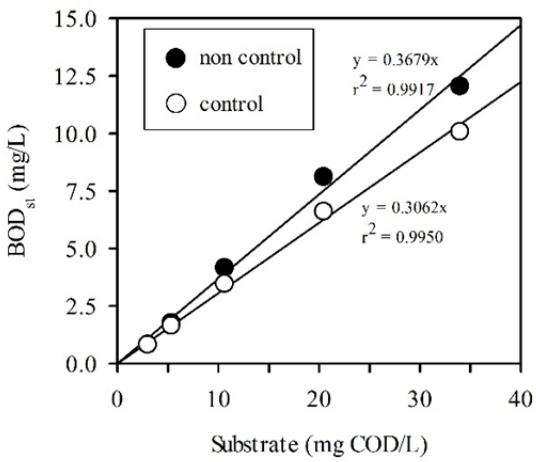

Figure 4 Comparing linear relations of uncontrolled and controlled experiments

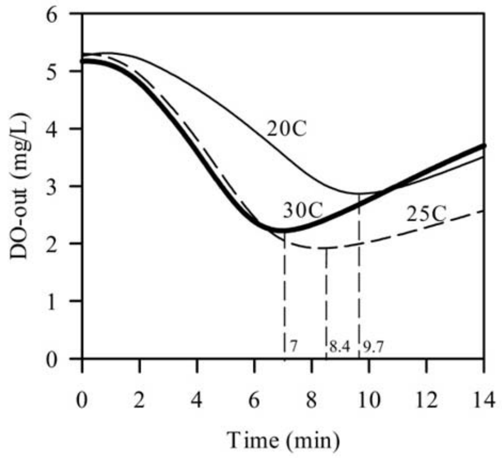

Figure 5 Influence of temperature on experimental duration

Moreover, the temperature affected to a duration of experiment that could reflect by DO-out peak in Figure 5. It was found that when temperature increased, it made experiment duration shorter. When comparing the experimental results with COD of 5.3 mg/L at 20 ^{O}C, 25 ^{O}C and 30^{O}C, the experiment duration would be equal to 9.7, 8.4 and 7.0 minutes, respectively.

Conclusions

In conclusion, the findings indicated that controlling pH has higher influence on the reliability and validity in BOD_{st} estimation using respiration measurement than controlling temperature. The experiment of uncontrolled temperature and pH has lower linear relation (r^2 = 0.9917) than controlled experiment (r^2 = 0.9950). It shows that BOD_{st} estimation requires controlling stable pH while increasing temperature will reduce the duration of OUR measurement without any influence on BOD_{st} estimation.

The reliability and validity could be considered from the Yield of 0.69 mg cell (COD)/mg COD of experiments with the controlled temperature and pH which was close to the referred value in activated sludge model 1 (ASM1) [13] at the standard temperature of 20^{O}C equal to 0.67 mg cell (COD)/mg COD. The results of this experiment were consistent with the previous researchers [5, 7, 15] using the same principles and techniques (0.69 mg cell (COD)/mg COD). However, the development of instrumentation is needed. For example, an oxygen electrode with automatic computation functions will further reduce the time consumed in experimentation and provide greater accuracy as well as increased stability, ease of use and convenient maintenance.

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