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Climate Friendly Technology for Domestic Wastewater; Comparative Study of Activated Sludge Process and Facultative Pond

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Abstract

This study compared greenhouse gas (GHG) emissions from activated sludge process (AS) and facultative pond (FP). The GHG emissions were estimated from 4 centralized wastewater treatment plants in urban areas of Thailand. The study was conducted by collecting data for 3 years to estimate GHG emissions by the IPCC method. The results show that AS had low methane (CH_4) emissions. GHG emissions from electricity consumption were the major source of GHG emissions accounting for 46 - 79% of total GHG emissions at the study sites. Total GHG emissions of AS and FP were 0.13 - 0.32 and 0.17 - 0.30 $kgCO_2eq/m^3$, respectively. The AS had lower direct GHG emissions than the FP, although there were indirect GHG emissions from electricity consumption.

Keywords : Domestic Wastewater; Facultative Pond; Greenhouse Gas Emissions; Greenhouse Gas Emissions from Wastewater Treatment Plants

Introduction

According to Intergovernmental Panel on Climate Change (IPCC) reports, GHG emission from the waste sector corresponds to approximately 3% of the anthropogenic emissions on a global scale, and wastewater treatment constitutes approximately 20% of the waste sector [1]. The source of GHG emission from wastewater treatment plants (WWTP) can be classified into two types: (1) Direct GHG emission such as carbon dioxide (CO_2), Methane (CH_4) and Nitrous oxide (N_2O), produced from the biological wastewater treatment process. CH_4 from wastewater was found to contribute 5% of the global CH_4 emissions [2]. The Major source of CH_4 generation is anaerobic process. However, CH_4 emissions in partial aerobic process can occur, they are not zero and substantial for some plants receiving sewage from expansive sewer networks [3]. N_2O is produced by the Nitrification and Denitrification processes. N_2O emission occurs mainly in the activated sludge units (90%) while the remaining 10% come from the grit and sludge storage tanks [4]. The IPCC report states that CO_2 emissions from wastewater are not considered because these are of biogenic origin that turned back it to the atmosphere [5]. The other source of GHG emission is (2) Indirect GHG emission from energy consumption and added chemical processes [6]. The GHG emissions of AS system from the previous studies were 0.71 - 3.3 $kgCO_2eq/m^3$ [1, 2, 7, 8]. The factors that affect GHG emission such as temperature affect to the rate of digestion and CH_4 production. An increase of population affected the consumption of protein and the concentration of nitrogen entering to WWTP increased accordingly.

In Conference of the Parties 26 (COP26) in 2021, Thailand announces the Net-zero policy. As a result, the measurements for which the Thai government is taking action in the wastewater sector are the collection of untreated sewage into the treatment system and increasing the number of domestic WWTP. The study and

data collection of Thailand's GHG emissions in 2016, showed that the wastewater treatment and discharge system is one source of GHG emissions in the waste sector, accounting for approximately 49.55% of GHG emissions from the waste sector [9]. The GHG emissions estimated by the average wastewater quality of the country such as wastewater and Biochemical Oxygen Demand (BOD) generation rate for calculating CH_4 emission and protein consumption for calculating N_2O emission. However, the estimation of GHG emissions from each WWTP has not been sufficiently studied in Thailand because the calculation excludes GHG emissions from electricity consumption at WWTP.

There are 117 centralized WWTPs in Thailand but only 98 sites are still in operation. Facultative Pond (FP) and Activated Sludge (AS) are 43.6 and 32.5% of total WWTP, respectively [10]. The urban area of Thailand uses the AS system for domestic wastewater treatment because it produces better quality of effluent and lower requirement of land than other systems. On the other hand, the rural area uses the FP because of low operating costs and low electricity consumption. The aim of this study is to determine the climate friendly technology by comparison of GHG emissions from AS and FP. The direct and indirect GHG emission from WWTP in urban areas were estimated. The results indicated the amount of GHG in WWTP and confirmed the measures taken by Thailand's Pollution Control Department for using aerobic wastewater treatment technology to reduce GHG generation. Moreover, the estimation GHG emission from each WWTP can be used as a guideline for GHG emission reduction in wastewater sector of Thailand in the future.

Materials and Methods

1. Study site

The study sites are Din Daeng and Rattanakosin, Nonthaburi WWTP and Pattaya WWTP. There is a selection of WWTP in urban areas with different wastewater treatment processes under the AS system (i.e., biological AS with nutrients removal, two-stage AS, extended aeration with oxidation ditch and conventional AS) and a variety of wastewater data shown in Table 1. The 4 WWTP type of this study are accounting for 55.3% of AS systems and 17.9% of total WWTP in Thailand. In this study, wastewater characteristics and specific data that were used for the calculations such as electricity consumption, flow rate, population, BOD and total Nitrogen (TN) were collected from each WWTP. The average data are presented in Table 1.

2. Methodology

Methodology for calculating GHG Emissions is according to IPCC 2019 [3]. The researchers adjusted the calculation formula according to be Thailand's WWTP information. The GHG Emission in this study was classified into two type such as Direct GHG emission and Indirect GHG, as follows:

2.1 Direct GHG emission

CH_4 emission is originated from biological process in WWTP, even in the AS tank that aeration is available all the time. The volume of CH_4 from WWTP may be small, which can be caused by other processes that are not the aeration process such as primary treatment or sewer network [3]. The CH_4 emission is figured out by multiplying activity data and Emission Factor (EF).

The step of CH_4 emission estimation starts with calculation activity data as Equation 1 which was modified from IPCC 2019. The different WWTP processes result in methane emissions. CH_4 emission should be reflected in the calculation of total organics in wastewater (TOW) [3].

$$TOW = P \times BOD \times I \times 0.001 \times 365 \quad (1)$$

Where: TOW is the total organics in wastewater (kg BOD/year) which is a function of human population and BOD generation per person. P is amount of population in the service area (persons). BOD is BOD_5 removed in wastewater treatment processes (g/person/day). I is correction Factor for additional industrial BOD discharged (Thailand has collected wastewater into centralized WWTP, for which the default value from the IPCC is 1.25) and 0.001 is conversion from grams of BOD to kg of BOD. The emission factor (EF; kg CH_4/kg BOD) for CH_4 emission is a function of the

Table 1 The design criteria data and characteristics of wastewater of study sites (collected data from January 2018 to December 2020)

Details	Study sites			
	Din Daeng	**Rattanakosin**	**Nonthaburi**	**Pattaya city**
Type of WWTP	*Biological AS with Nutrients Removal*	*Two-Stage AS*	*Extended Aeration with Oxidation Ditch*	*Conventional AS*
Capacity of wastewater (m^3/day)	*350,000*	*40,000*	*38,500*	*65,000*
HRT (hr)	*24*	*24*	*10*	*24*
Electricity consumption (kWh/day)	35,040	9,300	2,958	28,404
Flow rate (m^3/day)	194,062 - 266,989	15,173 - 32,101	11,436 - 22,238	49,265 - 80,103
Population (person)	419,899 - 452,469	33,194 - 37,459	252,491 - 257,132	47,753 - 49,202
BOD_{inf} (mg/L)	34.65 - 70.56	48.60 - 78.70	32.65 - 54.80	21.73 - 90.90
BOD_{eff} (mg/L)	3.26 - 5.14	6.23 - 10.59	5.40 - 15.20	4.84 - 15.90
TN_{inf} (mg/L)	12.69 - 18.36	3.11 - 9.09	2.35 - 13.42	11.27 - 27.45
TN_{eff} (mg/L)	7.96 - 8.63	1.51 -7.32	5.14 - 11.90	4.90 - 10.00
BOD removal efficiency (%)	89.6	85.9	80.8	81.0
TN removal efficiency (%)	43.6	52.7	13.1	58.0

Note: The italic letter is the design criteria data and the normal letter is the collection data for WWTP.

maximum CH_4 producing capacity (B_o) and the methane correction Factor (MCF), as shown in Equation 2. The B_o can be produced from a given quantity of organics as expressed in BOD (the default value from the IPCC = 0.6 $kgCH_4/kgBOD$). The MCF indicates the extent to which the CH_4 producing capacity (B_o) is realized in each pathway or system (The default value for a centralized and aerobic treatment plant = 0.03). However, the default data such as I, B_0, MCF and EF are the average data from literature review in other studies by IPCC [3]. The IPCC reviewed and accepted data from measurement of CH_4 emissions from full-scale domestic WWTP and defined them as averages for each type of WWTP.

$$EF = B_o \times MCF \quad (2)$$

$$CH_4 \text{ emission} = TOW \times EF \quad (3)$$

N_2O emissions are a by-product of the biological total Nitrogen removal by Nitrification and Denitrification process in the AS tank [6]. N_2O is generated from 2 sources; N_2O from domestic WWTP (N_2O $Plants_{DOM}$) and N_2O from domestic wastewater effluent (N_2O $_{EFFLUENT, DOM}$) (Figure 1). Firstly, the activity data from total nitrogen in domestic wastewater (TN_{DOM}) for N_2O $Plants_{DOM}$ and $N_{EFFLUENT, DOM}$ for N_2O $_{EFFLUENT,DOM}$ could be calculate according to the Equation 4.

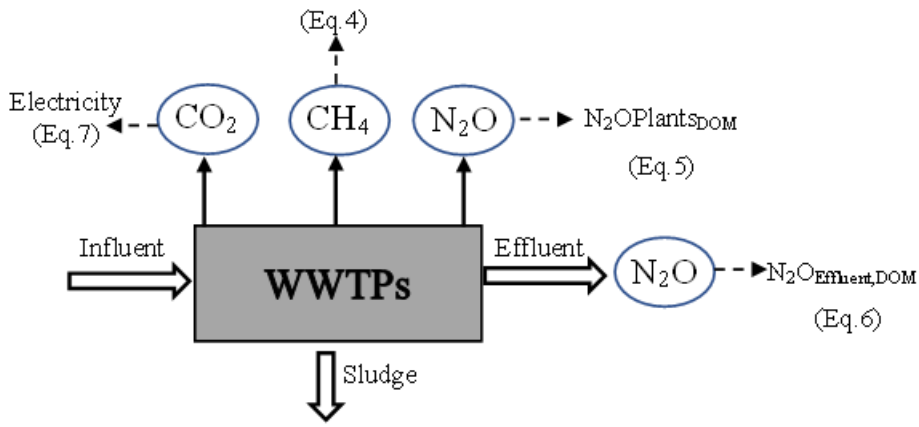

Figure 1 Schematic diagram of Greenhouse Gas emissions from wastewater treatment systems

TN_{DOM} or $N_{EFFLUENT,DOM}$ = Q x TN x 0.001 x 365 (4)

Where: Q is Flow rate of each WWTP (m^3/day). TN is concentration of Nitrogen removal in process (for TN_{DOM}) or concentration of Nitrogen in effluent (for $N_{EFFLUENT,DOM}$) (mg/L).

The N_2O emission from WWTP (N_2O $Plants_{DOM}$) and N_2O from wastewater effluent (N_2O $_{EFFLUENT,DOM}$) could be figured out by multiplying activity data as TN_{DOM} or $N_{EFFLUENT,DOM}$ (kg N/year) and Emission Factor (EF) as Equation 5 and 6, respectively.

N_2O $Plants_{DOM}$ = TN_{DOM} x EF_{plants} x (44/28) (5)

$N_2O_{EFFLUENT,DOM}$ = $N_{EFFLUENT,DOM}$ x $EF_{EFFLUENT}$ x (44/28) (6)

Where: The Factor 44/28 is the conversion of kg N_2O-N into kg N_2O. The EF of N_2O emission is default value from IPCC 2019 [3] and is classified by type of treatment system and discharge pathway. EF_{plants} from centralized and aerobic treatment plant is 0.016 kgN_2O-N/kgN. $EF_{EFFLUENT}$ use for discharge to freshwater, estuarine, and marine discharge is 0.005 kgN_2O-N/kgN.

2.2 Indirect GHG Emission

Indirect GHG Emission is calculated from amount Emission Factor ($kgCO_2$/kWh) and electricity consumption (kWh/day) from pumping station, aeration process and return sludge, see Equation 7. The Emission Factor uses default data for the grid changed to energy that imported to supply to WWTP, recommended by Thailand Greenhouse Gas Management Organization (TGO) at 0.477 $kgCO_2$/kwh.

GHG Emission = Electricity Consumption x EF (7)

Results and Discussion

1. Direct GHG emission

For this study, GHG emissions are estimated in the unit of $kgCO_2eq/m^3$ of wastewater (3 years average). Direct GHG emission of WWTP such as CH_4 and N_2O are caused by biological wastewater treatment processes. The results of the estimation of direct GHG emissions are shown in Figure 2. The highest direct GHG emissions from Pattaya is 0.12 $kgCO_2eq/m^3$, due to increased BOD values in some months that results in a high amount of BOD and TN per capita as well. Followed by Din Daeng, Rattanakosin and Nonthaburi are 0.08, 0.06 and 0.05 $kgCO_2eq/m^3$, respectively. In 2020, TN influent from Nonthaburi WWTP was less than TN effluent. These results may be due to unknown errors. Therefore, the result of N_2O emission only show N_2O from domestic wastewater effluent. The N_2O is the major direct GHG emission from Din Daeng, Nonthaburi and Pattaya WWTP. The Rattanakosin WWTP has lower N_2O emission than CH_4 emission due to the data collection in 2019 and 2020, found that TN is less due to the lower population of the area (35,356 and 33,194 PE, respectively from 37,454 PE in 2018).

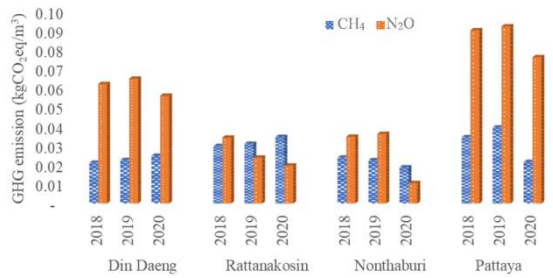

Figure 2 Direct GHG emission of each WWTP

In addition, the responsibility area of Rattanakosin is also a tourist attraction but with the epidemic situation of COVID-19, the tourists numbers decreased. There are also resulting in lower protein consumption. Therefore, the N_2O emission is decreased accordingly. The degree of TN removal showed a good correlation with direct N_2O emission [6]. N_2O is generated as a by-product of Nitrification or an intermediate product of Denitrification. There are many factors affecting N_2O emission such as temperature and dissolve oxygen (DO) concentration of wastewater [3]. In addition, the increase of population in the WWTP services area has resulted in an increase in protein-containing diets, which cause higher nitrogen concentrations in wastewater and may also lead to higher N_2O emissions from WWTPs [11]. However, N_2O emission occurs in small quantities but have a high Global Warming

Potential (GWP), which are the main GHG emissions in WWTP. N_2O emission in this study ranged from 0.3 - 0.9 $kgCO_2eq/m^3$. These results are in the same range as N_2O emissions from WWTP in India (0.2 - 0.4 $kgCO_2eq/m^3$) [12]. In addition, the large uncertainty range for N_2O emission is 0.05 - 25% of TN load [13]. In addition, BOD removal efficiency is related to GHG emissions. Table 1 in the Materials and Methods topic, shows that BOD removal efficiency was 89.6, 85.9, 80.8 and 81.0% for Din Daeng, Rattanakosin, Nonthaburi and Pattaya, respectively. WWTPs with higher BOD removal efficiency have lower CH_4 emissions.

The variation in CH_4 emissions is related to the BOD_5 removal process, if there have a good efficiency from the plant, that will be more gas emissions [2]. The different AS type has similar BOD removal efficiency. Some of the AS system in Thailand is designed to have a nutrient removal system such as Rattanakosin where have 2 aerobic tanks for removing BOD and another tank for removing nutrients such as Nitrogen and Phosphorus. The advantage of AS systems is good quality effluent and low land requirement that compared to other system. The disadvantage is high electricity consumption, sludge disposal is required on large scale and must have experienced person to control the system [14]. Table 2 show the comparison strengths and weaknesses of each AS type.

2. Indirect GHG emission

Indirect GHG emission depend on the proportion between the flow rate of influent wastewater and electricity consumption control, which must be maintained to be consistent. For example, Din Daeng is the largest sites. However, there is an energy efficient design for return sludge that uses gravity flow principles to reduce energy consumption. The average of electricity consumption in each WWTP and value of indirect GHG emission are shown in Table 3. The highest electricity consumption also has the highest indirect GHG emissions which are Rattanakosin, Pattaya, Nonthaburi and Din Daeng, respectively. Excluding the Nonthaburi WWTP, it operates only 10 hours per day. It is possible to explain more GHG emission from electricity consumption at small scale WWTP than at large scale WWTP. These results are according to the previous studies, which found that the energy consumption was 0.43 and 0.33 kWh/m^3 from medium and large-sized WWTP, respectively [15]. The average electricity consumption of conventional AS in different countries was 0.2 - 1.9 kWh/m^3 [16]. All of the previous studies results can be concluded that the smaller WWTP tend to have higher specific electricity consumption per inlet wastewater, resulting in higher GHG emissions than larger WWTP [15-17]. The details of WWTP in the literature review are shown in Table 2.

Table 2 The strengths and weaknesses of each AS type

information	Site study			
	Din Daeng	Rattanakosin	Nonthaburi	Pattaya city
Type of AS	Biological AS with Nutrients Removal	Two-Stage AS	Extended Aeration with OD	CAS
specific nutrient removal process	yes	yes	no	no
BOD removal Efficiency (%)	89.6	85.9	80.8	81.0
TN removal Efficiency (%)	43.6	52.7	13.1	58.0
Electricity consumption (kWh/day)	35,040	9,300	2,958	28,404

Note: OD is Oxidation Ditch, CAS is Conventional Activated Sludge

Table 3 The details of study sites and the comparison with WWTP in the literature review

sites	Population (person)	Type of system	Energy consumption (kWh/m^3)	indirect GHG emission ($kgCO_2eq/m^3$)
Din Daeng (HRT=24hr)	419,899 - 452,469	AS-N	0.150	0.072
Rattanakosin (HRT=24hr)	33,194 - 37,459	Two-Stage AS	0.457	0.218
Nonthaburi (HRT=10hr)	252,491 - 257,132	EA with OD	0.176	0.084
Pattaya (HRT=24hr)	47,753 - 49,202	Conventional AS	0.421	0.201
Greek (Medium) [15]	10,000 - 100,000	EA, whereas few had CAS&ASD	0.43	-
Greek (Large) [15]	> 100,000	CAS&ASD	0.33	-
Australia [16]	-	CAS	0.46	-
China [16]	-	CAS	0.269	-
USA [16]	-	CAS	0.33 - 0.60	-
Japan [16]	-	CAS	0.30 - 1.89	-

Note: AS-N is Biological AS Process with Nutrients Removal, CAS is the conventional activated sludge, EA is Extended Aeration, OD is Oxidation Ditch and ASD is anaerobic sludge digestion

3. Total GHG emissions of each WWTP

The figure 3 shows the percentage of total GHG emission from each WWTP. The major source of GHG emission in WWTP is electricity consumption with 46, 79, 63 and 63% of total GHG emission in Din Daeng, Rattanakosin, Nonthaburi and Pattaya, respectively. The largest electricity consumption was from the secondary treatment or aeration tanks that were caused by continuous aeration [16, 18]. The aeration process requires an air blower or aerator for additional air to help aerobic bacteria to biodegrade the organic substances, which means a lot of electricity consumption [11]. Also, 60% of GHG emission in the extended aeration AS is electricity consumption for the blower and air pump [1].

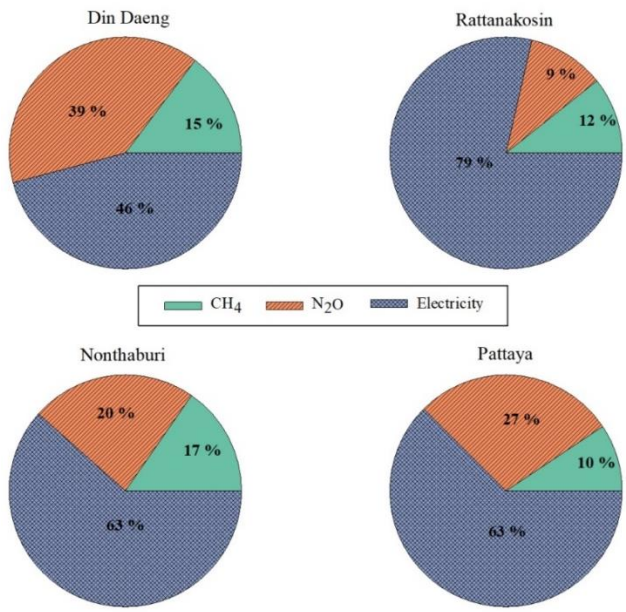

Figure 3 Total GHG emission of each WWTP

4. Alternatives for climate friendly systems

In developing countries, facultative pond treatment technology (FP) is very popular for domestic wastewater treatment. However, anaerobic ponds and FP are the major sources of direct GHG emission with 66% and 33% of the total contribution, respectively [2]. In the case that the countries are planning to build WWTP. They should consider using climate friendly technology. This study also compared GHG emissions from the AS and FP systems. The characteristics of wastewater from each WWTP (Din Daeng, Rattanakosin, Nonthaburi and Pattaya) have been assessed for GHG emission using FP treatment technology (not AS). The estimation method and Emission Factor for GHG emissions were applied from default data of IPCC. The GHG emission from FP is only direct GHG emission (CH_4 and N_2O) because electricity is not consumed. The results of the comparison GHG emission are shown in Figure 4. The GHG emissions from AS were 0.16, 0.20, 0.13 and 0.32 $kgCO_2eq/m^3$ and GHG emission from FP were 0.21, 0.24, 0.17 and 0.30 $kgCO_2eq/m^3$ for Din Daeng, Rattanakosin, Nonthaburi and Pattaya, respectively. The FP system mostly expresses higher GHG emission than the AS system. The major GHG emissions is CH_4, which is higher than those in the AS system. It can be concluded that the AS system has fewer GHG emissions than other wastewater treatment systems. Due to the available aeration process, the amount of GHG generated will be reduced. However, the increased electricity consumption for wastewater treatment must affect to the price of electricity. According to the previous research, they studied GHG emission from FP. When the FP system is upgraded to Sequencing Batch Reactor (SBR), the SBR is a type of AS system. The results show that the GHG emission from FP is double the GHG emission of SBR [7]. Therefore, for an aerobic process, indirect GHG emission from electricity consumption is higher than for FP.

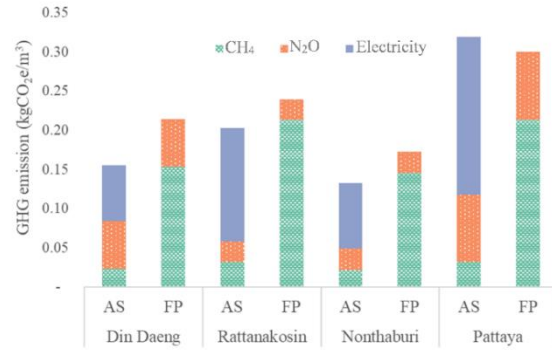

Figure 4 Comparison of GHG emission from the AS and FP by characteristics of wastewater data from each WWTP (the average data in 2018 - 2020)

However, the AS system still has a lower total GHG emission because of the absence of CH_4 emissions. On the other hand, the Pattaya WWTP shows that wastewater treated by AS has higher GHG emissions than wastewater treated by FP because there are already a lot of direct GHG emissions. When direct GHG emission is combined with indirect GHG emission, the total GHG emissions are higher than treatment by FP.

Conclusions

The GHG estimation by the IPCC method is based on the wastewater quality data of each WWTP, such as the biological wastewater treatment process (shown in BOD and TN values), population in the area of responsibility, flow rate of wastewater entering the system and the electricity consumption in the system which if there is good wastewater management will reduce gas emissions. The major source of GHG emission from the AS system is electricity consumption. The direct emission as N_2O emission was higher than CH_4 emission due to the AS system's continuous aeration process. The comparison of AS and FP revealed that AS system have lower total GHG emission than FP system. Although the AS system is considered a source of GHG emission from electricity consumption.

The uncertainty of the estimation is due to the fact that this research was only used to estimate GHG emissions using the IPCC method and we conducted it during the COVID-19 situation, so there was no field visit to collect data and wastewater samples. The limitation of electricity consumption data is that there are no monthly data collections or other treatment sub-unit information. There should be more data collection for a thorough study of GHG emissions from electricity consumption. The suggestion from the study is to analyze the wastewater samples to compare with the assessment according to the IPCC Methods.

Consequently, the selection of wastewater treatment systems that encourage the reduction of GHG emissions must consider the suitability of the area and the amount of wastewater that the system can support in each area. In addition, there is necessary to consider the cost of electricity consumption. However, the main purpose of WWTP is to treat wastewater in accordance with legal standards. The operation of the WWTP, which has the main goal of reducing GHG emissions may be difficult and have a high cost.

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References

[1] Yapicioglu, P. 2021. Minimization of greenhouse gas emissions from extended aeration activated sludge process. Water Practice and Technology. 16(1): 96-107.

[2] Bahi, Y., Akhssas, A., Khamar, M., Bahi, L. and Souidi, H. Estimation of greenhouse gas (GHG) emissions from natural lagoon wastewater treatment plant: Case of Ain Taoujdate-Morocco. At E3S Web of Conference 150 at Salé, Morocco on November 20-22, 2019.

[3] Intergovernmental Panel on Climate Change (IPCC). 2019. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Volume 5. Institute for Global Environmental Strategies, Switzerland.

[4] Campos, J., L., Valenzuela-Heredia, D., Pedrouso, A., Val del Río, A., Belmonte, M. and Mosquera-Corral, A. 2016. Greenhouse Gases Emissions from Wastewater Treatment Plants: Minimization, Treatment, and Prevention. Journal of Chemistry, 2016: 1-12.

[5] Devia, Y.P. and Agustini, D.T. Greenhouse Gas Emission from Domestic Wastewater Treatment and Discharge in East Java Province – Indonesia. At 6th International Conference on Civil, Offshore and Environmental Engineering (ICCOEE2020) at Borneo Convention Centre, Kuching, Sarawak, Malaysia on July 13-15, 2021.

[6] Parravicini, V., Svardal, K. and Krampe, J. 2016. Greenhouse Gas Emissions from Wastewater Treatment Plants. Energy Procedia. 97: 246-253.

[7] Coster, M.N. and AWT New Zealand Ltd. 2009. Greenhouse gas emissions from wastewater treatment schemes - New Zealand case study examples. Available from: https://www.waternz.org.nz/Article?Action=View&Article_id=1013# [Accessed 2022 Jan 18].

[8] Chai, C., Zhang, D., Yu, Y., Feng, Y., & Wong, M. 2015. Carbon Footprint Analyses of Mainstream Wastewater Treatment Technologies under Different Sludge Treatment Scenarios in China. Water. 7(12): 918-938.

[9] Ministry of Natural Resources and Environmental. 2021. Mid-century, long-term low Greenhouse Gas Emission Development Strategy. Available from: https://unfccc.int/documents/307950 [Accessed 2022 Feb 1].

[10] Pollution Control Department. 2021. Thailand State of Pollution Report 2020. Pollution Control Department., Bangkok.
[11] Zhan, X., Hu, Z. and Wu, G. 2017. Greenhouse Gas Emission and Mitigation in Municipal Wastewater Treatment Plants. IWA Publishing., London.
[12] Kate, T.R. 2019. Greenhouse Gas Emission from Wastewater Treatment Plant. International Journal of Civil Engineering and Technology (IJCIET). 10(09): 81-89.
[13] Kampschreur, M.J., Temmink, H., Kleerebezem, R., Jetten, M.S.M. and Loosdrecht, M.C.M. 2009. Nitrous oxide emission during wastewater treatment. Water Research. 43: 4093-4103.
[14] Pollution Control Department. 2017. Domestic Wastewater Treatment System Manual. Pollution Control Department., Bangkok.
[15] Goliopoulos, N., Mamais, D., Noutsopoulos, C., Dimopoulou, A. and Kounadis, C. 2022. Energy Consumption and Carbon Footprint of Greek Wastewater Treatment Plants. Water. 14(320): 1-12.
[16] Bodik, I. and Kubaska, M. 2013. Energy and Sustainability of Operation of a Wastewater Treatment Plant. Environment Protection Engineering. 39(2): 15-24.
[17] Siatou, A., Manali, A. and Giaks, P. 2020. Energy Consumption and Internal Distribution in Activated Sludge Wastewater Treatment Plants of Greece. Water. 12(1204): 1-15.
[18] Kyung, D., Kim, M., Chang, J. and Lee W. 2015. Estimation of greenhouse gas emissions from a hybrid wastewater treatment plant. Journal of Cleaner Production. 95: 117-123.

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Investigation of Microplastics Contamination in Domestic Wastewater

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Abstract

This research aimed to study types and quantify of microplastics contaminated in domestic wastewater. For this study, two areas were studied including influent wastewater and effluent receiving canal. The first study area was the influent wastewater defined as grey water discharged from 3 residential types: dormitories, apartments, and condos. The second study area was the effluent receiving canal at the points located upstream, midstream, and downstream. Microplastics analysis was adapted from the method designated by National Oceanic and Atmospheric Administration (NOAA). The results show that the analyzed data were correlated in both (e.g., amount, color) and polymer type of microplastics. The amount of microplastics size of 300 µm was more than microplastics size of 500 µm. The amount of microplastics size of 300 µm and 500 µm were in the range of 0.43±0.09 - 1.33±0.36 items/L and 0.30±0.05 - 1.07±0.37 items/L, respectively. In addition, the amount of microplastics increased along with the distance of canal from the effluent discharge point. As the distance increases, the higher dispersion of microplastics was existed. The shapes of microplastics were found to be fiber types the most, followed by fragment types, film types, sheet types and sphere/pellet types. Transparent color was the most common color of microplastics, generated from the washing synthetic textile products. For the results of the polymer-type identification by Fourier Transform Infrared Spectroscopy (FTIR) analysis, Polyethylene (PE), Polypropylene (PP) and Polyethylene terephthalate (PET) were the polymer types found at the highest proportion in all samples.

Keywords : Microplastics; Domestic wastewater; FTIR

Introduction

Plastic is a material invented by humans and has been continuously developed with various techniques. Plastics are extensively used in our daily life (clothes, construction, agriculture, packaging) because they are lightweight, durable and cheap price [1, 2]. They are widely used whether in the household, community or industry that make plastics demand increase every year. According to the Thailand Pollution Situation Report in 2020 from the Pollution Control Department, it was found that plastic waste and residues into the sea were approximately 34,318-51,477 tons, which was about 26,800-40,200 tons more than in 2019.

Because of this, plastic waste is a problem and contaminants accumulated in the environment for a long time. Such the long time of accumulation in the environment, the large plastic items would decompose into the smaller fragments via different pathways such as photodegradation, biodegradation and weathering [3, 4], becoming as “Microplastics”. Microplastics (MPs) are defined as synthetic polymers with dimensions less than 5 mm. [5, 6] In addition, microplastics could occur in another way, which were *created* by the manufacturer to be a certain *small* size for a particular purpose. The main source for the release of microplastics is domestic wastewater from human activities in daily life such as microbeads used as ingredients in cosmetics

and personal care products [7], and microfibers from washing of synthetic textiles [8]. When Microplastics entering the wastewater treatment system, which is mostly biological treatment process. The size of non-removable microplastics is 20-300 micrometers [9, 10]. It is difficult to remove by biological treatment system. Because of its small size, low density and light weight that makes release into natural water. Moreover, the characteristics of microplastics are not readily biodegradable and absorb Persistent organic pollutants (POPs) that act as vectors for the contamination of other environments. It affects to environment and human health [11-13].

Accordingly, this study aimed to investigate microplastic contamination in domestic wastewater generated from human activities in daily life. To understand the situation of microplastics contaminated in domestic wastewater and to recommend for preventing and reducing the impact of microplastics contaminated in domestic wastewater.

Material and Methods

Sampling site

To determine microplastics contaminated in domestic wastewater, It was divided into two study areas. The sampling points are illustrated in Figure 1. The first study area was the grey water which is un-treated wastewater (e.g., washing, bathing), generated from the households, divided into 3 residential types: dormitories, apartments, and condos. The second study area was the nearby bang khen canal where received wastewater categorized as upstream, midstream, and downstream points. The length of the canal at the sampling point was 2,182.48 m. Surrounding the canal was close factories and people's residences.

Sample collection and preservation

The eleven sampling points were sampled (5 replicates per sampling point). Water samples were collected through a rotary pump 12V/DC 8A with a volume of 50L. The pump head is placed at a depth of 30 centimeters from the water surface during collection and pumped to filter the sample through a stacked arrangement of 5.6-mm (No. 3.5) and 0.3-mm (No. 50) stainless steel mesh sieves. Then, the residue on the strainer was transferred into a glass bottle. Each sample was stored at 4 °C in a refrigerator. The water samples collected during December 2021 to March 2022.

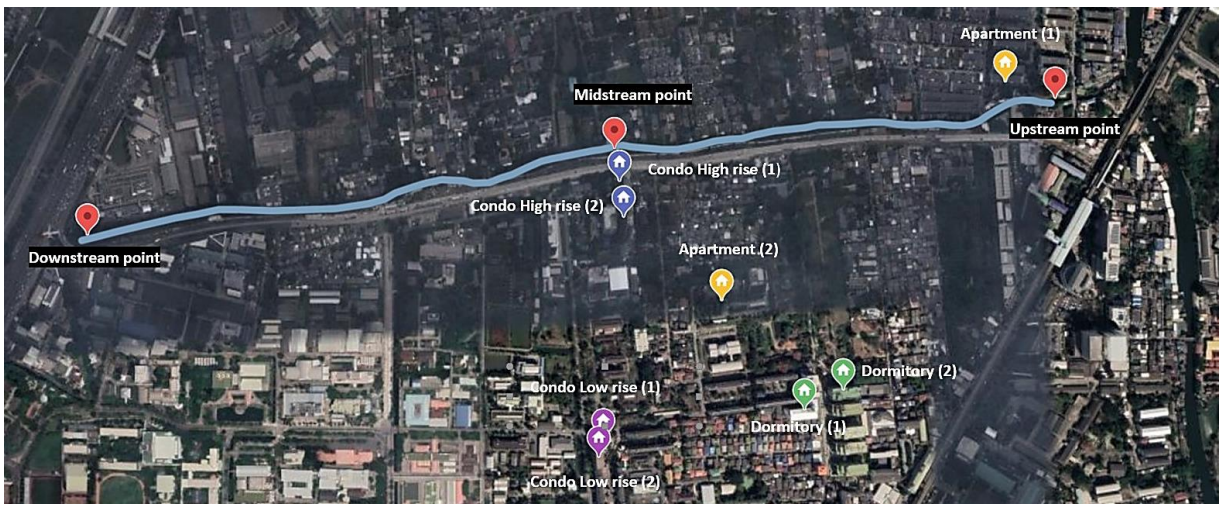

Figure 1 The sampling points of domestic wastewater and receiving to canal

Microplastics analysis

In this study, microplastic analysis was adapted from National Oceanic and Atmospheric Administration (NOAA) method [14]. After collection, Each sample was poured through a stacked arrangement of 5.6-mm (No. 3.5), 0.3-mm (No. 50) stainless steel mesh sieves and transferred all to the 400 mL beaker by distilled water. The sample beaker was dried in a 90 °C drying oven for 24 hours or longer to sample dryness. To digest the organic matter mixed into the sample, 30% Hydrogen peroxide (H_2O_2) 20 mL and 0.05 M Ferrous sulfate ($FeSO_4$) 20 mL were added to the beaker [15]. The mixtures were heated at 75 °C for 30 minutes. Then, 5M sodium chloride (NaCl) was added with the ratio of 6 grams per 20 mL of sample water into the sample beaker. The sample was transferred into the glass funnel and left overnight for settling. After that, the microplastics were floated on top of the surface and filtered through a 0.3 mm. stainless steel mesh sieve. The filtered samples were transferred to a Petri dish and dried at 90 °C for 24 hours.

Microplastics identification

All microplastic particles were examined under a stereomicroscope (Olympus, SZ61TR) at 40X magnification and identified the physical characteristics of microplastics (e.g., shapes, sizes and colors) and counted the amount of microplastics (Items/L) [16]. The composition of microplastic particles were identified by using Fourier transform-infrared spectrophotometry (FT-IR, Bruker Alpha II) attenuated total reflectance (ATR) technique, with 64 scans at a resolution of 8 cm^{-1} in wave range 4000-650 cm^{-1} [17]. It appeared as a transmission spectrum and was compared with standards of polymer spectra to define the composition of microplastic particles in a sample.

Results and Discussion

Amount of microplastics

The results of microplastic amount in domestic wastewater are shown in Table 1. The amount of microplastics were counted under a stereomicroscope (Olympus, SZ61TR) with three replicates per sample. Comparing the size and amount of microplastics found in the domestic wastewater among residential types, the amount of microplastics with size ranges < 300 µm was more than microplastics with size range > 500 µm. For the canal water samples, at the point where the effluent discharged into the canal of such point called as upstream, midstream, and downstream points, respectively.

Table 1 Amount of microplastics found in domestic wastewater

Sample	Amount of microplastics found in domestic wastewater (items/L)		
	Size < 300 µm	Size > 500 µm	Total of mixed size
Domestic wastewaters from residential types			
dormitory (1)	0.43±0.09	0.30±0.05	0.37±0.10
dormitory (2)	0.77±0.12	0.69±0.38	0.73±0.27
Apartment (1)	1.33±0.36	1.07±0.37	0.92±0.36
Apartment (2)	1.00±0.22	0.71±0.31	0.85±0.29
Condo Low rise (1)	1.27±0.46	1.01±0.53	1.19±0.49
Condo Low rise (2)	1.11±0.34	0.69±0.19	0.90±0.29
Condo High rise (1)	1.08±0.07	0.79±0.04	1.48±0.06
Condo High rise (2)	1.16±0.16	0.94±0.17	1.80±0.19
Sampling points along the canal counted from the effluent discharge point to the canal			
Upstream point	0.55±0.17	0.36±0.21	0.46±0.19
Midstream point	0.59±0.27	0.39±0.17	0.49±0.24
Downstream point	0.73±0.24	0.30±0.06	0.52±0.29

The result show that the amount of microplastics with size ranges < 300 µm was found to be more than the amount of microplastics with size range > 500 µm. The result was in the same trend as the wastewater generated by the residential type. Consistently, the size ranges of 20-300 µm was the most size range of microplastics, followed by 300-1,000 µm and 1,000-5,000 µm [18].

Furthermore, microplastics with the size range of 20-300 µm entering to the wastewater treatment plant that could not be eliminated by the treatment process, then released into the natural water source [9, 10].

Shape of microplastics

Microplastics could be classified into six categories based on their shapes: fibers, fragments, films, sheets, granules/pellets, and foams [19]. All collected particles were visualized under a stereomicroscope (Olympus, SZ61TR).

Microplastic shapes found in domestic wastewater are shown in Figure 2. For all microplastic shapes from 3 residential types including 8 sampling points, fiber was the most common shape type (74.9%) followed by fragment (16.84%), film (7.77%), sheet (0.99%) and granules/pellet (0.12%). For all microplastic shapes from the discharge points into the canal; fiber was the most common shape type (61%) fragment (29.98%), film (6.15%), sheet (0.97%) and granules/pellet (1.9%) in orders. The correlation for the shape of microplastics between the domestic wastewater from residential types and the discharge points into the canals were consistent. The most common types were fibers followed by fragments, films, and others. It also was consistent with the most prevalent types of microplastics observed in the water were fiber types and fiber types are the main source of primary microplastics [20, 21].

In addition, the result was similar to the fiber and fragments type the origin and pathway of microplastics could be inferred based on their shapes because certain shapes may be more prolifically shed from particular products [23-25].

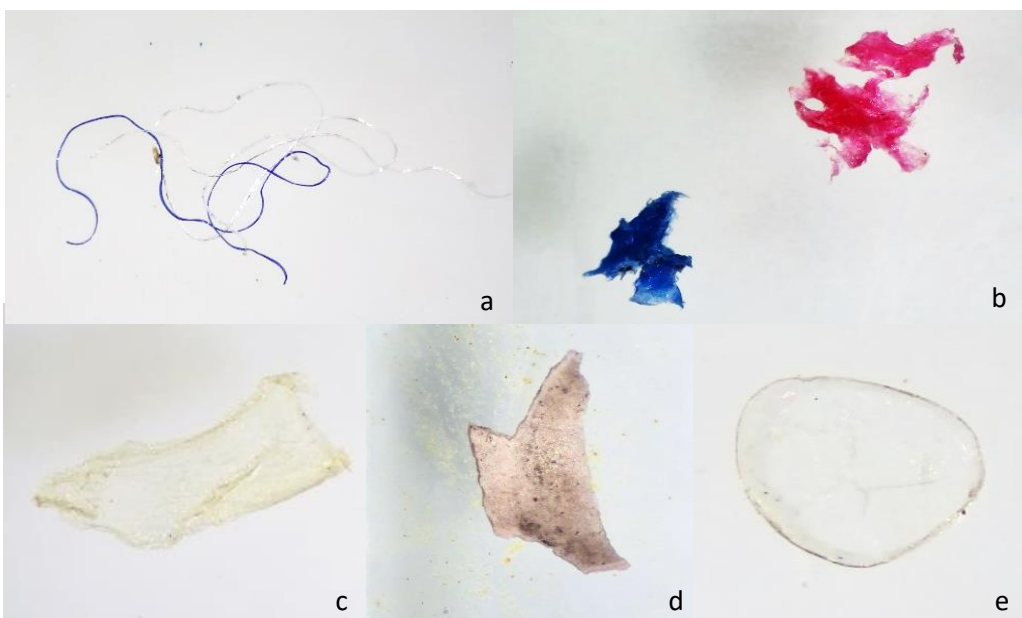

Figure 2 The shape of microplastics in the domestic wastewater: (a) Fibers, (b) Fragment, (c) Film, (d) Sheet and (e) Granule/Pellet

Fiber type originated from the synthetic fiber such as clothes and textiles could be shredded innumerably to the tiny fibers by washing in daily life [26]. Fragment type originated from packing plastic products via the physical or chemical process breaking down large plastic to small plastic pieces [27]. Film type originated from plastic wrapping [28]. In addition, this study did not found plastic microbeads generated by the personal care or cosmetic products. In consistent with the law to stop using plastic microbeads (manufacture, import, or sell) in Thailand, being effective since January 1, 2020. This law is under Thailand's Roadmap on plastic waste management 2018-2030 of the Pollution Control Department.

Color of microplastics

The color of microplastics are rarely used to identify potential sources because color can be changed due to digestion process [29]. Microplastics have been reported in a range colors, including; transparent, white, red, orange, yellow, purple, blue, grey, brown and green [30, 31]. Dark, white, and transparent particles may be underrepresented during visual inspection thus, all collected particles were visualized under a stereomicroscope (Olympus, SZ61TR).

For all microplastic colors from 3 residential types including 8 sampling points, transparent was the most common color (70.32%) followed by red (9.15%), blue (6.72%), yellow (4.44%), black (3.41%), white (3.19%), purple (2.26%) and green (1.72%), respectively. For the microplastic colors of the upstream, midstream and downstream water samples, transparent was the most common color (61%) followed by blue (9.93%), black (9.47%), white (5.69%), yellow (4.44%), red (3.75%), green (0.55%) and purple (0.54%), respectively. Correlatively, both domestic wastewater and nearby canal water (influenced by wastewater) presented the transparent as the most common color. The study results illustrated the transparent color as the most common found in domestic wastewater was alike as other research study presented the transparent color of microplastics in the oceans, where the problem was the end of microplastics pathway. In addition, color was more likely to affect aquatic organisms such as fish because such transparent color is similar to their natural food items such as planktons [32].

Polymer types of microplastics

Fourier transform infrared Spectro-photometry (FT-IR, Bruker Alpha II) was used to identify type of polymer contained in the microplastic particles. It appeared in the form of a transmission spectrum (shown in Figure 3) and compared with the standard spectra of each polymer. For the results, Polyethylene (PE), Polypropylene (PP), and Polyethylene terephthalate (PET) were the polymer types found in the highest proportion contaminated in domestic wastewater from residential types and the canals where received the effluent.

Moreover, the type of polymers can predict theirorigins. For example; Polyethylene Terephthalate (PET) originated from packaging materials, produce polyester fiber, fabric, and cording for textiles. Polyethylene (PE) and Polypropylene (PP) originated from food packaging plastic packaging [33, 34]. These plastic polymers are widely used in daily life.

Conclusion

Microplastics were found in all domestic wastewater generated from households and the nearby canal where received the effluent from households. The experimental result of both study areas were consistent. The amount of microplastics with size range < 300 µm was more than microplastics with size range > 500 µm. The shape of microplastics of samples were found for 5 types. Fiber was the most common shape type followed by fragments, films, sheets, and granules/pellets. Fibers originated from washing synthetic textile. Transparent was the most common color. For the results of the polymer-type identification by Fourier Transform Infrared Spectroscopy (FTIR) analysis, Polyethylene (PE), Polypropylene (PP) and Polyethylene terephthalate (PET) were the polymer types found in the highest proportion of all samples. These plastic polymers were widely used in daily life.

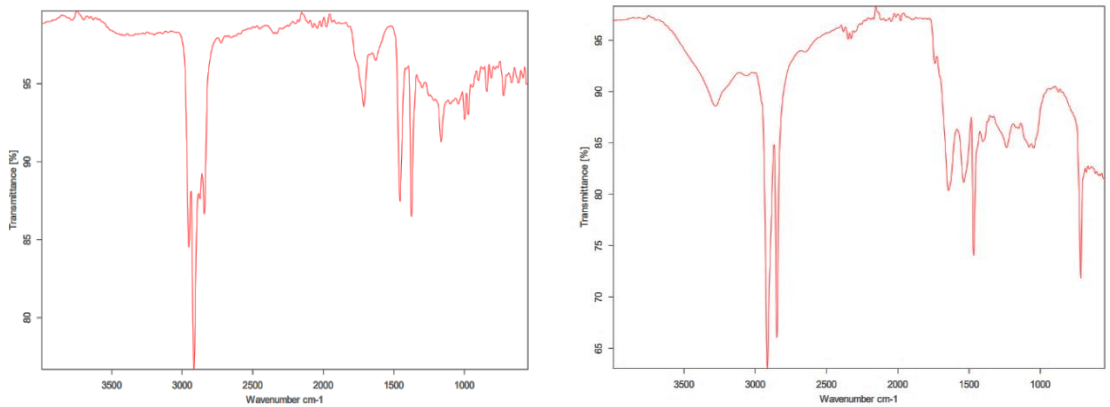

Figure 3 Examples IR spectra of microplastic particles found in domestic wastewater samples, which were identified by FTIR spectroscope

References

[1] Plastics Europe and European Association of Plastics Recycling (EPRO), 2017. Plastics – the facts2017. https://www.plasticseurope.org/en/resources/publications/274-plastics-facts-2017.

[2] Mao, Y., Li, H., Gu, W., Yang, G., Liu, Y. and He, Q. 2020. Distribution and characteristics of microplastics in the Yulin River, China: Role of environmental and spatial factors. Environmental Pollution, 265, 115033.

[3] Andrady, A.L. 2017. The plastic in microplastics: A review. Marine pollution bulletin, 119(1), 12-22.

[4] Li, W.C. 2018. The occurrence, fate, and effects of microplastics in the marine environment. In Microplastic Contamination in Aquatic Environments, 133-173.

[5] Cole, M., Lindeque, P., Halsband, C. and Galloway, T.S. 2011. Microplastics as contaminants in the marine environment a review. Marine pollution bulletin, 62(12), 2588-2597.

[6] He, D., Luo, Y., Lu, S., Liu, M., Song, Y. and Lei, L. 2018. Microplastics in soils: Analytical methods, pollution characteristics and ecological risks. TrAC Trends in Analytical Chemistry, 109, 163-172.

[7] Waller, C.L., Griffiths, H.J., Waluda, C.M., Thorpe, S.E., Loaiza, I., Moreno, B., Pacherres, C.O. and Hughes, K.A. 2017. Microplastics in the Antarctic marine system: an emerging area of research. Science of the total environment, 598, 220-227.

[8] De Falco, F., Di Pace, E., Cocca, M. and Avella, M., 2019. The contribution of washing processes of synthetic clothes to microplastic pollution. Scientific reports, 9(1), 1-11.

[9] Talvitie, J., Mikola, A., Setälä, O., Heinonen, M. and Koistinen, A. 2017. How well is microlitter purified from wastewater?–A detailed study on the stepwise removal of microlitter in a tertiary level wastewater treatment plant. Water research, 109, 164-172.

[10] Sol, D., Laca, A., Laca, A. and Díaz, M. 2020. Approaching the environmental problem of microplastics :Importance of WWTP treatments. Science of the Total Environment, 740, 140016.

[11] Teuten, E.L., Saquing, J.M., Knappe, D.R., Barlaz, M.A., Jonsson, S., Björn, A., Row land, S.J., Thompson, R.C., Galloway, T.S., Yamashita, R. and Ochi, D. 2009. Transport and release of chemicals from plastics to the environment and to wildlife. Philosophical transactions of the royal society B: biological sciences, 364(1526), 2027-2045.

[12] Hartmann, N.B., Huffer, T., Thompson, R.C., Hassellöv, M., Verschoor, A., Daugaard, A.E., Rist, S., Karlsson, T.,

Brennholt, N., Cole, M. and Herrling, M.P. 2019. Are we speaking the same language? recommendations for a definition and categorization framework for plastic debris. Environmental Science and Technology, 53, 1039-1047.

[13] Zeng, E.Y. ed. 2018. Microplastic contamination in aquatic environments: an emerging matter of environmental urgency. Elsevier.

[14] Masura, J., Baker, J., Foster, G. and Arthur, C. 2015. Laboratory Methods for the Analysis of Microplastics in the Marine Environment: Recommendations for quantifying synthetic particles in waters and sediments.

[15] Gündogdu, S., Çevik, C., Güzel, E. and Kilercioglu, S. 2018. Microplastics in municipal wastewater treatment plants in Turkey: a comparison of the influent and secondary effluent concentrations. Environmental Monitoring and Assessment, 190(11), 1-10.

[16] Crawford, C.B. and Quinn, B. 2017. Microplastic identification techniques. Microplastic Pollutants, 219-267.

[17] Ribeiro-Claro, P., Nolasco, M.M. and Araújo, C., 2017. Characterization of microplastics by Raman spectroscopy. Comprehensive Analytical Chemistry, 75, 119-151.

[18] Chetsukchai, P., Wongpanit, W. and Kiatwongwong, S. 2019. Progress of microplastic study in Andaman Sea coastal. Science Asia, 336-343.

[19] Wu, C., Zhang, K. and Xiong, X. 2018. Microplastic Pollution in Inland Waters Focusing on Asia. Freshwater Microplastics, 85-99.

[20] Obbard, R.W. 2018. Microplastics in polar regions: the role of long-range transport. Current Opinion in Environmental Science & Health, 1, 24-29.

[21] Kooi, M. and Koelmans, A.A. 2019. Simplifying microplastic via continuous probability distributions for size, shape, and density. Environmental Science & Technology Letters, 6(9), 551-557.

[22] Fu, Z. and Wang, J. 2019. Current practices and future perspectives of microplastic pollution in freshwater ecosystems in China. Science of the Total Environment, 691, 697-712.

[23] Cheung, P.K. and Fok, L. 2016. Evidence of microbeads from personal care product contaminating the sea. Marine Pollution Bulletin, 109(1), 582-585.

[24] Helm, P.A. 2017. Improving microplastics source apportionment: a role for micro plastic morphology and taxonomy?. Analytical Methods, 9(9), 1328-1331.

[25] Rochman, C.M., Brookson, C., Bikker, J., Djuric, N., Earn, A., Bucci, K., Athey, S., Huntington, A., McIlwraith, H., Munno, K. and De Frond, H. 2019. Rethinking microplastics as a diverse contaminant suite. Environmental toxicology and chemistry, 38(4), 703-711.

[26] Allen, S., Allen, D., Phoenix, V.R., Le Roux, G., Durántez Jiménez, P., Simonneau, A., Binet, S. and Galop, D. 2019. Atmospheric transport and deposition of microplastics in a remote mountain catchment. Nature Geoscience, 12(5), 339-344.

[27] Liu, K., Wang, X., Fang, T., Xu, P., Zhu, L. and Li, D. 2019. Source and potential risk assessment of suspended atmospheric microplastics in Shanghai. Science Total Environmental, 675, 462-471.

[28] Zhang K, Gong W, Lv J, Xiong X. and Wu, C. 2015. Accumulation of floating microplastics behind the Three Gorges Dam. Environmental Pollution, 204, 117-123.

[29] Jiang, C., Yin, L., Li, Z., Wen, X., Luo, X., Hu, S., Yang, H., Long, Y., Deng, B., Huang, L. and Liu, Y. 2019. Microplastic pollution in the rivers of the Tibet Plateau. Environmental Pollution, 249, 91-98.

[30] Bergmann, M., Mützel, S., Primpke, S., Tekman, M.B., Trachsel, J. and Gerdts, G. 2019. White and wonderful? Microplastics prevail in snow from the Alps to the Arctic. Science advances, 5(8), 1157.

[31] Frias, J., Pagter, E., Nash, R., O'Connor, I., Carretero, O., Filgueiras, A., Viñas, L., Gago, J., Antunes, J., Bessa, F. and Sobral, P. 2018. Standardised protocol for monitoring microplastics in sediments. Deliverable 4.2.

[32] Nadal, M.A., Alomar, C. and Deudero, S. 2016. High levels of microplastic ingestion by the semipelagic fish bogue Boops boops (L.) around the Balearic Islands. Environmental Pollution, 214, 517-523.

[33] Zhao, S., Zhu, L. and Li, D., 2015. Microplastic in three urban estuaries, China. Environmental Pollution, 206, 597-604.

[34] Hernandez, E., Nowack, B. and Mitrano, D.M. 2017. Polyester textiles as a source of microplastics from households: a mechanistic study to understand microfiber release during washing. Environmental science & technology, 51(12), 7036-7046.

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Reduction of Microplastics in Washing Machine Effluent by Filtration Technique

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Abstract

Microplastic fibers are produced by washing clothes made of synthetic fibers. Such microplastic fibers are found in wastewater treatment systems and always flowing out into the rivers and seas resulting in environmental contamination. The purpose of this research was to study the efficiency of filters for reducing the amount of microplastic fibers in washing machine effluent by equipping a small cartridge filter at the end of the washing machine's drain hose. Five types of filters were used with the filter mesh size of 5-40 µm and a stainless-steel filter with the filter mesh size of 100-500 µm. Wastewater samples were collected from the washing machine before and after it was filtered to assess the efficiency of reducing microplastic fibers. The results showed that most of the types of microplastic fibers found were Polyethylene terephthalate (PET) and Nylons, which are plastics commonly used in the synthetic fibers. For one washing machine wash, an average of all microplastics can be released. 807.98±629.70 Items/L, with the majority of microplastics having fiber shapes, amounting to 806.86±628.99 Items/L, or 99.86% of all microplastics. From the study of the efficiency of filters, it was found that the most effective filter for reducing the amount of microplastic fibers was the smooth polypropylene filter 5 µm with an efficiency of 96.44%, but clogging easily. It is not suitable to use stainless steel filters modified to a sieve size in the range of 100-500 µm because the efficiency was 63.04%, which was not very high efficiency. Nonetheless, the flow rate was better than other types of filters. If using a suitable type of filter, it should be improved to increase efficiency.

Keywords : Microplastics; Microfibers; Filtration; Washing machine effluent

Introduction

Microfiber is the type of microplastic particle found in the first highest proportion in raw sewage and wastewater treatment processes in domestic [1]. The most common types of microfibers are Polyester, Polyamide, Elastane, including Rayon. For the source of the activity or the source of microfibers discharge from household wastewater to wastewater treatment processes, such as washing synthetic fabrics. Which is difficult to effectively treat by wastewater treatment systems. It would cause microfiber particles contaminated in the treated wastewater (effluent) discharging into the natural water sources ecosystems or may lead to further contamination and accumulation in the food chain.

Textile wastewater has been widely reported as a potential source of microplastics [2, 3]. Polyester garments are part of the microplastic problem. During cloth washing, plastic fibers with the size of 10 microns (µm) to 2-3 millimeters (mm) in diameter, collectively known as 'Microfibers', were released from the fabric materials [4]. Mixed in the washing water It always slips through the sewage system into rivers and floats out to the sea [4]. Will enter the food chain starting from small to large animals [5].

Although there are none of current studies confirming how microplastic parts

affect human health, Microplastics tend to absorb various toxic chemicals into their bodies while floating in the water. When entering the body of food chain organisms such as fish, plants, etc.; the toxins that accumulate within these microplastics may further affect human health [1]. Acrylic laundry may release more than 700,000 microfibers per wash with an average load of 6 kg of laundry [6].

At present, there are many ways to remove microplastics such as sedimentation, microfiber trap devices in washing machines such as Cora Ball, including starting to invent proper microplastic filtration using various techniques.

The purpose of this study was to study the types of filters, which is suitable to reduce the number of microplastics in the washing machine effluent, that further to reduce the release of microplastics in the effluent from wastewater treatment systems into natural resources. This can reduce the impact occurred onto the environment.

Materials and Methods

Sampling methods

The HITACHI single-tank top-loading washing machine model SF-130XWV was used in this study. The water of 90 liters and the cloth with an average weight of 9 kg were added to the washing machine. A small cartridge filter (Cartridge Filter of Housing) was added at the end of the washing machine's drain pipe, and the effluent before entering the filter was collected as 10 water sample, 5 replicates. The collecting filtered water was brought to analyze the efficiency of the filter types.

Filter types study

To study the efficiency and suitability of microplastic filters, the ready-made filters bought in the market were used. The types of filters used including:

1. Yarn Filter Cartridge 5 µm
2. Polypropylene, Smooth Filter Cartridge 5 µm
3. Polypropylene, Pleated Filter Cartridge 5 µm
4. Stainless steel Filter Cartridge 40 µm
5. Polypropylene, Orange Peel Surface Filter Cartridge 50 µm

The one-stage and two-stage filtration were performed to determine which was the most efficient. When the filter is installed, sample water was collected before and after passing through the filter. To study the efficiency of microplastics filtration, The effluent that passed through the filter must flow evenly and do not clog until the washing machine stops working.

Figure 1 Installation of a two-stage filter system

Analysis of microplastics

Microplastics were analyzed by the density separation method modified by the Oceanic and Atmospheric Administration Nation (NOAA) [7]. In the first step, a 1,000 ml of water sample was filtered with a stainless-steel mesh sieve No. 50 (330 µm.) Then, it was collected on the sieve into a 600 ml beaker and baked at 105 Degree Celsius for 24 hours. The second step, the organic matter was decomposed by

adding 20 ml of iron (II) sulfate ($FeSO_4$) and 20 ml of 30% hydrogen peroxide (30%: H_2O_2) into the annealed sample beaker. The chemical reaction causes the white foam to appear, and as the temperature decreases, the foam was disappeared. The third step, the sample was heated at 75 Degree Celsius for 30 minutes, NaCl 6 g was added and distilled water was sprayed around the beaker. The sample was stirred repeatedly for 5 minutes. The Fourth step, the sample was transferred from a beaker to a glass funnel and left for 24 hours. Then, the microplastics were floating on top of the surface.

Data analysis of microplastics

Microplastic images were analyzed using an Olympus SZ51 stereoscopic microscope to count the number of microplastics and differentiate the shape of the microplastics with the naked eye, and a Fourier Transform Infrared Spectroscopy (FTIR) was used to identify the types of Microplastics.

Results and Discussion

For the types and amount of microplastics from washing machine effluent, most microplastic fiber was found, and mixed with fragments and film forms slightly. This is consistent with the research study abroad [8] indicated that washing machine effluent were found to contain microplastics more fiber types than others, and washing accounts for 12% of microplastic discharging.

Counting and characterization of microplastics were analyzed to represent the number of microplastics found in washing machine effluent. Each form of microplastics found in washing machine effluent could be identified as shown in Table 1.

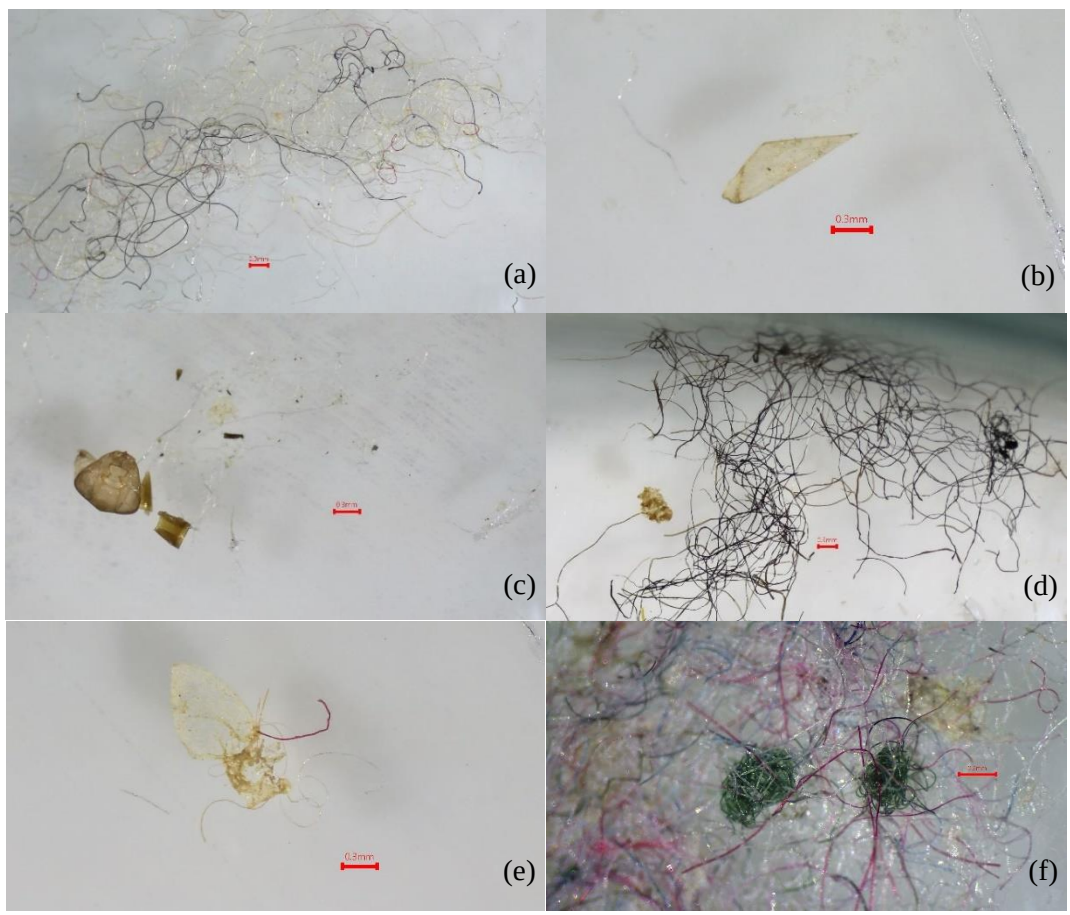

Figure 2 Shape of microplastics found in washing machine effluents
a : Fibers , b : Fragment , c : Films , d : Fibers , e : Fragment , f : Fibers

Table 1 Shape and amount of microplastics found in washing machine effluent for 10 samples, 5 replicates

Sample	Total amount of microplastics (Item/L)	Shape of microplastics			
		Fibers (Item/L)	Films (Item/L)	Spheres (Item/L)	Fragment (Item/L)
1	939.0±365.35	937.4±365.35	0.2±0.45	0.0±0.0	1.4±1.14
2	416.6±173.24	415.6±173.09	0.2±0.45	0.0±0.0	0.4±0.55
3	2,295.6±454.37	2,292.6±455.22	0.2±0.45	0.0±0.0	2.8±1.92
4	356.6±97.97	356.0±98.81	0.0±0.0	0.0±0.0	0.6±0.89
5	1,473.4±848.21	1472.4±849.05	0.0±0.0	0.0±0.0	1.0±1.22
6	319.8±86.01	319.6±86.09	0.0±0.0	0.0±0.0	0.2±0.45
7	773.4±206.60	771.4±207.40	0.2±0.45	0.0±0.0	1.8±1.30
8	552.8±319.79	552.2±319.19	0.0±0.0	0.0±0.0	0.6±0.89
9	560.4±210.71	559.6±210.90	0.2±0.45	0.0±0.0	0.6±0.89
10	392.2±243.01	391.8±242.95	0.0±0.0	0.0±0.0	0.4±0.55

Based on the results of the quantitative analysis of microplastics in the washing machine effluent, the average amount of microplastics is 807.98±629.70 Items/L, which includes microplastics with fiber shapes as follows; Fibers 806.86±628.99 Items/L, Films 0.10±0.11 Items/L, Spheres 0.00±0.00 Items/L and Fragment 0.98±0.81. Items/L. The results were calculated as the percentage of each shape of microplastics found in washing machine effluent of 10 samples: 99.86% Fibers, 0.01% Films, Spheres 0.00%, and fragment 0.12%, indicating that the majority of these microplastic fibers are obtained from wastewater through washing rather than splintering or from cleaning products [9, 10].

For the FTIR analysis, a total of 10 microplastic samples in washing machine effluent were mixed between PET and Nylons. They are commonly used as ingredients in the synthetic fiber production causing shedding during washing. This is consistent with the research study abroad [11] that measured the number of microfibers loosened from synthetic textiles from three materials (acrylic, nylon, and polyester) knitted using different gauges and techniques. All textiles were found to be shedding. It has been shown that loose fabric structures are more prone to shedding. For the additional study, [12] microplastics contained in water treated by three Australian wastewater treatment plants and particle characterization by FTIR analysis, PET microplastics (Polyethylene terephthalate) are the highest fibers or 80% of all microplastics, and irregular shape Polyethylene was 20% of all microplastics. This may be caused by the use of cosmetic and pharmaceutical products. Including cleaning washing clothes containing plastic fibers [12].

For the number of microplastics, it was found that the wastewater from the washing machine before passing through the filter contained about 319.8±86.01 - 2,295.6±454.37 Items/L, or the average number of microplastics which was 851.47±232.82 Items/L, which was a small number of microplastics more than in the research [6] finding that when washing clothes with an average load of 6 kg, more than 700,000 microfibers were released per wash, and [8] was found that washing containing the ingredient of synthetic fibers at one time can release up to 640,000 - 1,500,000 microfibers depending on the fabric types. It has the possibility that in each experiment, there will have different microplastic values. Because the type of fabric in each wash was not the same, this study did not specify the type of fabric and want to use common fabrics used in daily life to simulate and suit the daily life of people in general.

When installing one-stage and two-stage filtration systems found that the number of microplastics was reduced to 35.4 - 416.6 Items/L, or the average number was 103.18±52.34 Items/L, showing that the number of microplastics could be reduced. which can be thought of as efficiency in the removal of microplastics in the range of 55.63% - 96.44% as shown in Table 2.

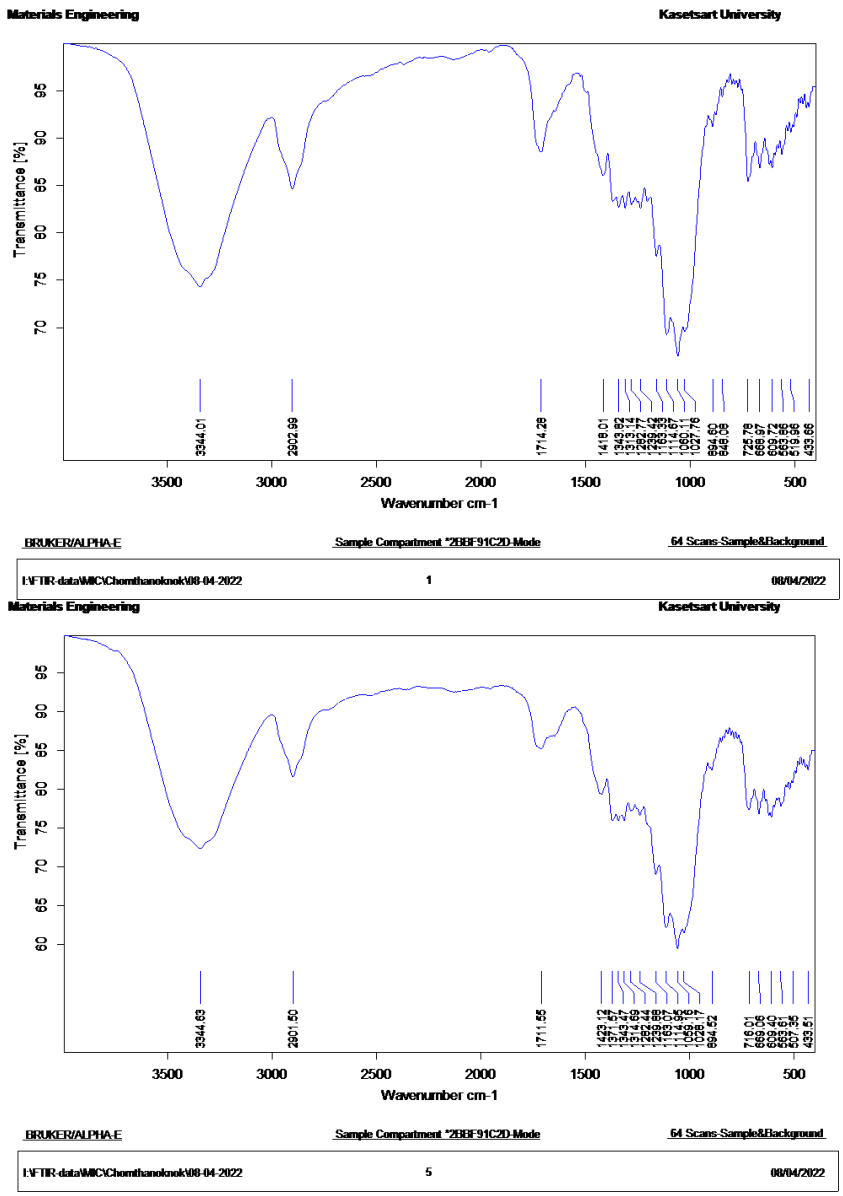

Figure 3 Example of FTIR curve of microplastics in washing machine effluent indicates the type of plastic

Table 2 presents that the Yarn Filter Cartridge 5 µm having the lowest efficiency of 55.63%. After filtration, there was still a large number of fiber microplastics. The most effective filter element was the Polypropylene, Smooth Filter Cartridge 5 µm with an efficiency of 96.44%, of which the efficiency was good, but it was necessary to take into account the practical use. Polypropylene, Smooth Filter Cartridge was easily clogged, caused washing machine stop working which was unable to continue, Therefore, it was not suitable for use with very high concentration wastewater. Next, the Pleated Filter Cartridge 5 µm had 90.07% with an efficient stable water flow rate. While Stainless steel Filter Cartridge 40 µm had 95.45% efficiency which was considered high efficiency and the washing machine could continue to operate normally, with a constant water flow rate.

Table 2 Filter efficiency study of One-stage and Two-stage filter system

Filter types	Average amount of microplastics before filter installation (Items/L)	Average amount of microplastics after filter installation (Items/L)	Efficiency (%)
One-stage filter system			
Yarn Filter Cartridge 5 µm	939.0	416.6	55.63%
Polypropylene, Smooth Filter Cartridge 5 µm	2,295.6	81.8	96.44%
Polypropylene, Pleated Filter Cartridge 5 µm	356.6	35.4	90.07%
Stainless-steel Filter Cartridge 40 µm	1,473.4	67.0	95.45%
Polypropylene, Orange Peel Filter Cartridge 50 µm	319.8	94.4	70.48%
Two-stage filter system			
Yarn Cartridge - Yarn Cartridge	773.4	73.4	90.51%
Yarn Cartridge - Pleated Cartridge	552.8	59.0	89.32%
Yarn Cartridge - Sieve	560.4	59.4	89.40%
PP Orange Peel - Pleated Cartridge	392.2	42.0	89.29%

The Orange Peel Filter Cartridge 50 µm had filtration efficiency of 70.48%. Due to the filter sieve size of 50 µm, the effluent can flow through more easily than other filters.

It was found that clogging is easy from the 1-stage filtration, because the size of the microplastic was larger than the filter sieve size and the filter used was more suitable for clean water. Therefore, the 2-stage filter was performed and found that the efficiency might not be much different from the one-stage filtering, but only causing better water flow.

Figure 4 shows the properties of the filter that filters out of the washing machine only once. The efficiency of filters of the same filter sieve size was different. This may be due to different filtering surface areas. The materials used to make the filters are different. The Yarn Filter Cartridge may release fibers during filtering due to its synthetic nature, just like the clothing used in the experiment.

From the research results obtained from the use of ready-made filters which is suitable for clean water for use in microplastic filtration, it was found that it was not suitable for practical use in microplastic filtration. The researcher modified the filter by using a stainless-steel mesh with a filter sieve size range of 100-500 µm, which is a suitable sieve size for filtering microplastics, of which the average length of microplastics is 360-660 µm [8] (Table 3).

Figure 4 Filters that have been used to filter microplastics in washing machine waste once
A: Yarn Filter Cartridge 5 µm, B: Polypropylene Smooth Filter Cartridge 5 µm,
C: Polypropylene Pleated Filter Cartridge 5 µm, D: Stainless steel Filter Cartridge 40 µm

Table 3 Study results on filtration efficiency of modified stainless-steel filters for 5 replicates

Filter types	Average microplastic weight before filter installation (g/L)	Average microplastic weight after installing the filter (g/L)	Efficiency (%)
One-stage filter system			
Stainless, Sieve (smooth) 100 µm	0.0059±0.001	0.0027±0.001	61.09%
Stainless, Sieve (smooth) 300 µm	0.0059±0.001	0.0028±0.000	48.55%
Two-stage filter system			
Stainless, Sieve (smooth) 300 µm - 100 µm	0.0065±0.001	0.0025±0.001	63.04%

The result of the efficiency on filtering with a self-modified stainless filter showed that the modified stainless filters were less effective than the ready-made filters, but the flow of effluent discharged from the washing machine was constant. Effluent water flows easily and does not stop the washing machine as it did when tested with a ready-made filter, which blocks the flow of water that the washing machine cuts off the operation due to the inability to drain water. Stainless steel filters are therefore more suitable for use in micro-plastic filters than general ready-made filters.

Conclusion

Reduction of Microplastics in washing machine effluent by filtration technique was studied. For washing characteristic by washing machine, for 1 time of washing uses water 90 liters for an average load of 9 kg of laundry, microplastics were released on the average of 807.98±629.70 Items/L of which the most component consisted of Fiber-shaped microplastics averaged 806.86±628.99 Items/L or 99.86% of all microplastics.

By FTIR analysis, it revealed that the main component was PET and Nylons microplastics, as today's garments use synthetic fibers based on PET and Nylons for better properties. Comparing all-ready-made filters used for microplastic filtration, the 5 µm smooth PP filter was the most efficient at 96.44%, which is a better filter for clean water. However, when used to filter water with microplastics, it could clog quickly, and there is a problem with the flow rate. As a result, the washing machine stops working. Therefore, it is not appropriate to filter microplastics.

For the application of the modified stainless-steel filters used in the 2-stage filtration test, the efficiency was 63.04%, which was not very high efficiency. But with the better flow rate than other types of filters, it was suitable to be further developed for better efficiency.

References

[1] Kittipongwiset, S., Petcharak, A., Lowatcharin, J. and Phonprasert, J. 2019. Microplastic pollution in raw wastewater and wastewater treatment systems. Environmental Journal, 23(1).

[2] Browne, M. A., Crump, P., Niven, S. J., Teuten, E., Tonkin, A., Galloway, T., and Thompson, R. 2011. Accumulation of microplastic on shorelines worldwide: sources and sinks. Environ Sci Technol, 45(21), 9175-9179.

[3] Essel, R., Engel, L. and Carus, M. 2015. Sources of microplastics relevant to marine protection in Germany. Umweltbundesamt. 64: 1-46.

[4] Srisathit, T. 2020. Plastic Diary: Because every time you wash your clothes We released microfibers.

[5] Eriksson, C. and Burton, H. 2003. Origins and biological accumulation of small plastic particles in fur seals from Macquarie Island. Ambio, 32(6), 380-384.

[6] Napper, I. E. and Thompson, R. C. 2016. Release of synthetic microplastic plastic fibres from domestic washing machines: Effects of fabric type and washing conditions. Mar Pollut Bull, 112(1-2), 39-45.

[7] Masura, J., Baker, J., Foster, G. and Arthur, C. 2015. Laboratory Methods for

the Analysis of Microplastics in the Marine Environment. National Oceanic and Atmospheric Administration, U.S. Department of Commerce. 1-30.

[8] De Falco, F., Di Pace, E., Cocca, M. and Avella, M. 2019. The contribution of washing processes of synthetic clothes to microplastic pollution. Sci Rep, 9(1), 6633.

[9] Habib, D., D. C. Locke and L. J. Cannone. 1998. "Synthetic fibers as indicators of municipal sewage sludge, sludge products and sewage treatment plant effluents." Water, Air, and Soil Pollution: 1-8.

[10] Zubris, K. A. V. and B. K. Richards. 2005. "Synthetic fibers as an indicator of land application of sludge." Environmental Pollution. 138(2): 201-211.

[11] Carney Almroth, B. M., L. Astrom, S. Roslund, H. Petersson, M. Johansson and N. K. Persson. 2018. "Quantifying shedding of synthetic fibers from textiles; a source of microplastics released into the environment." Environ Sci Pollut Res Int. 25(2): 1191-1199.

[12] Ziajahromi, S., P. A. Neale, L. Rintoul and F. D. Leusch. 2017. "Wastewater treatment plants as a pathway for microplastics: Development of a new approach to sample wastewater-based microplastics." Water Res 112: 93-99.

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Quantity and Physical Composition of the Marine Debris on Phetphoom Beach, Ban Koh Siray, Muang District, Phuket Province, Thailand

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Abstract

The objectives of this research were to study the quantity and physical composition of the marine debris on Phetphoom beach, Muang District, Phuket Province. This area is important for fishery of fishermen. Marine debris is an important problem causing destructions of marine resources or marine ecosystems. The period of collecting samples is 2 months from April to May 2020. The samples were collected 4 times a month from the beginning to the end of the beach. It stretches along the beach for a distance of 760 meters. The survey method is International Coastal Cleanup. The beach waste is classified into three categories, which are general waste, recyclable waste and hazardous waste. Organic waste was not collected because it can decompose naturally. The quantitative and physical composition of marine debris were analyzed by descriptive statistics in percentage values. The results were found that there was no statistical difference between the types and amounts of beach waste on Phetphoom beach in April and May in each survey. Because it was beach waste caused by daily consumption and fishery. Regardless of the change in monsoon winds, all types of marine debris were always found in the sampling, but in varying ratios. Among all types of marine debris found, general waste was the highest amount at 62.45 percent, followed by recyclable waste at 34.63 percent and hazardous waste at 2.97 percent, respectively. The composition of marine debris that were found the most were general wastes in large pieces such as food packaging/bags (potato chips), spoons, forks, knives, plastic bags, plastic glasses, foam floats and beverage boxes (paper). Whereas the hazardous waste was found the least such as batteries, lighters, and light bulbs. According to the study of marine debris composition, the results showed that marine debris had to be disposed in order to reduce the pollution effects towards marine lives and other creatures including with marine ecosystem affecting marine food chain and quantity of marine lives. The fishermen would have less income because they could harvest less marine lives. The recommendation should be that beach regulations and laws are strictly enforced down on the beach and in the sea. Public relations on marine debris and prevention of waste for people, fishermen, tourists and beach residents. Marine debris is everyone's business and the importance of marine debris prevention is more important than solving marine debris problems. Regulations on garbage collection and disposal systems should be set up at the beach and communities nearby the beach in collaboration with the local administrative organization.

Keywords : Physical Composition; Marine Debris; Beach

Introduction

The problem of marine debris is an important issue that has been paying attention to all over the world. It affects the abundance of ecosystems and marine resources [1]. Global estimates show that 80% of marine wastes is sourced from the land-based activities, especially improperly managed wastes and residual wastes; and another 20 percent comes from marine activities [2]. In 2021, Thailand is ranked as the 10th country as for the highest amount of plastic waste discharging to the sea [3].

At present, the trend of using plastics and synthetic materials reflects 60-80% of the marine litter, consisting of plastic, and in many areas plastics can be accounted for 90-95% of the total waste. Commonly, it is known that microplastic is very small and difficult to be stored and disposed. In addition, microplastic has the property of being hard to decompose which is easy to contaminate, distribution, accumulation and residual in the environment [4]. The current increase of marine debris is due to a number of factors, including economic expansion, marine tourism to increase the number of stores and marine accommodation [5].

Phetphoom Beach is the place consisting of restaurants, Abalone Farm and a small jetty for traveling to various islands. There is a problem of marine debris hitting the beach caused by human activities. Therefore, this study is necessary to survey the quantity and type of marine debris around Phetphoom Beach, Muang District, Phuket Province in order to collect the information for planning and managing marine debris.

Methodology

Study Area

Petchphoom beach locates in the East of Village 1, Ban Koh Sirey, Ratsada Subdistrict, Muang District, Phuket Province, where is about 4 kilometers away from the downtown, the distance of Petchphoom beach for researching trash problems is 760 meters. GPS was used to determine the survey location and to show the map of the survey points for collecting beach waste samples at Phetphoom beach, as shown in (Figure 1).

Figure 1 Study Area at Phetphoom beach

Survey Method, According to International Coastal Cleanup, and Required Rules

According to the International Coastal Cleanup, and Required Rules, the sampling pointes were set along the beach of about 100-metre distance away from the river or the canal without cleaning around.

Time Period

The quantitative and physical composition of marine debris for 2 months, from April 2020 to May 2020, 4 sampling times for each month as stated in Table 1. in order to the correct information according to ICC standard, factors depend on tidal currents.

Table 1 Record date of beach waste sampling

No.	April sampling date	No.	May sampling date
1	Saturday, April 4, 2020	1	Monday, May 4, 2020
2	Sunday, April 12, 2020	2	Tuesday, May 12, 2020
3	Monday, April 20, 2020	3	Wednesday, May 20, 2020
4	Monday, April 27, 2020	4	Tuesday, May 26, 2020

Sample

This is the survey research aiming for the quantity and physical composition of marine debris along the Phetphoom beach, which was divided into 3 categories; mixed,

recyclable and hazardous wastes, with an exception of organic trash, eg. seaweed, as this type of trash can decompose naturally.

Sampling Area Observation

Methods used in this quantitative and physical composition of Phetphoom marine debris were as follows.

1) Extract the exact sampling spots from the whole beach distance, collect all pieces of trash, divide the trash into different categories using physical and quantitative composition, record the results, and mark all pieces of trash that were unable to be relocated.

2) Divide the trash into different categories using physical composition, weigh the trash and record the results in the result form.

Equipments

Equipment include measure tape of 50 meters, trash sacks, GPS device, rubber gloves, sanitary masks, balance, camera and a pair of trash pliers.

Analysis

The quantity and physical composition of the marine debris were calculated with descriptive statistics and the percentage.

The percentage of the trash = (The trash amount of each type x 100)/The total amount of the trash

Results and Discussions

Type, quantity and physical composition of beach wastes around Phetphoom Beach

The survey taken place during April-May 2020 discovered totally 3,715 pieces of marine debris, being equivalent to 104.44 kilograms in total. All marine debris pieces were divided into 3 different categories: general wastes, recyclable wastes and hazardous wastes. The general wastes contained 2,311 pieces as of 48.99 kilograms estimated as 62.20%, producing as the largest number among such 3 categories. Next, the recyclable wastes contained 1,291 pieces as of 51.18 kilograms estimated as 34.75%. Lastly, the hazardous wastes contained 113 pieces as of 4.27 kilograms estimated as 3.04%. These results are displayed in Figure 2.

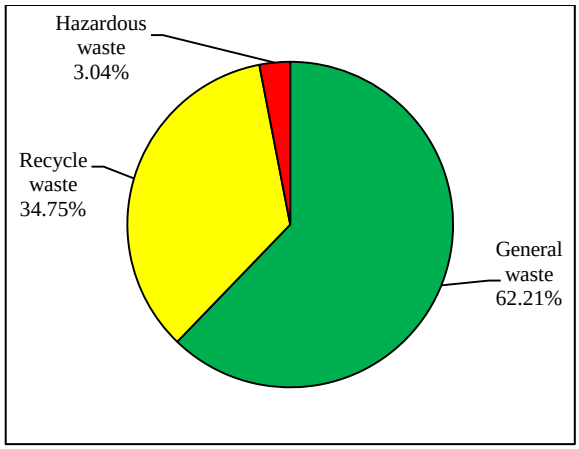

Figure 2 Percentage of marine debris type along Phetphoom Beach

From the results of the study, it was found that the composition of the waste can be classified as follows as shown in Table 2.

Table 2 The waste composition of Petchphoom Beach waste

Type	Physical Composition of Waste
General waste	Cigarettes, Food snacks (including potato chip snacks), Lunch boxes made of foam and Plastics, Straws made plastic, Cups made of plastic, Utensils, plastic bags for food containing, Paper dishes, Paper cups, Dishes and cups made of foam, Buoys, Fishing tools, Plastics bottles, Driving tools, Balloons, Beverage packages made of paper, Construction material, Tires, Clothes, Shoes, ornaments, Toys, Dolls, Coat hanger, Toothpaste tubes, Earwax pickers, etc.
Recycle waste	Lids made of plastics and metal, Plastics bottles, Glass bottles, Beverage cans, Pieces of paper, etc.
Hazardous waste	Batteries, Lighters, Diaper, Syringes, Medical tools, Sanitary masks, Chemical pens, etc.

Type and quantity of wastes along Phetphoom beach, April 2020

Collection of marine debris on April 5, 12, 20 and 27, were made depending on the tidal occurrence. On April 5, 12, 20, 27 the quantity of wastes were 544 pieces, 559 pieces 338 pieces and 321 pieces, respectively, total

amount of wastes was 1,764 pieces. The largest numbers of pieces was from the general waste category, followed by the recyclable wastes and hazardous waste, respectively, as displayed in Table 3.

Table 3 The marine debris quantity collected of April, 2020

Marine debris type	Marine debris quantity (number of pieces)				Total (pieces)	Weight (Kg)	Percentage (by pieces)
	April 4, 2020	April 12, 2020	April 20, 2020	April 27, 2020			
General waste	357	235	364	228	1,186	29.18	67.23
Recycle waste	183	114	161	82	540	18.35	30.61
Hazardous waste	4	10	13	11	38	2.37	2.16
Total	**544**	**359**	**538**	**321**	**1,764**	**49.90**	**100**

Analysis results of waste types studied in April 2020, it was found that general wastes had the highest volume accounted as 67.23%, followed by recyclable wastes accounted as 30.61%, and hazardous wastes, accounted as 2.15%, as shown in Figure 3.

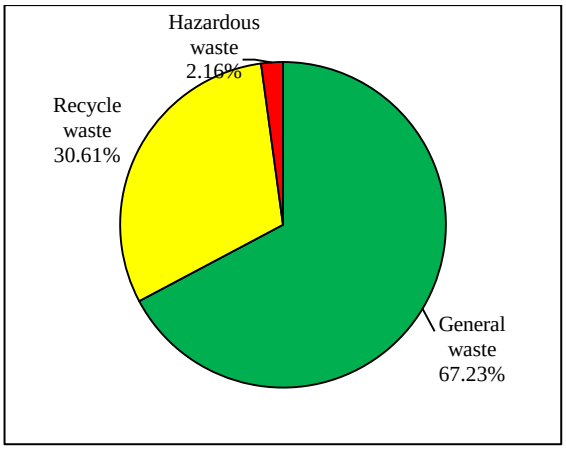

Figure 3 Quantity of marine debris in April 2020

Based on the study of marine debris existed along Phetphoom beach in April 2020; 1,764 pieces of marine debris which was the most general waste accounted as 67.23%, followed by recyclable wastes accounted as 30.61%, and hazardous waste. accounted as 21.6%. Composition of marine debris along Phetphoom beach in April is shown in Figures 4-6.

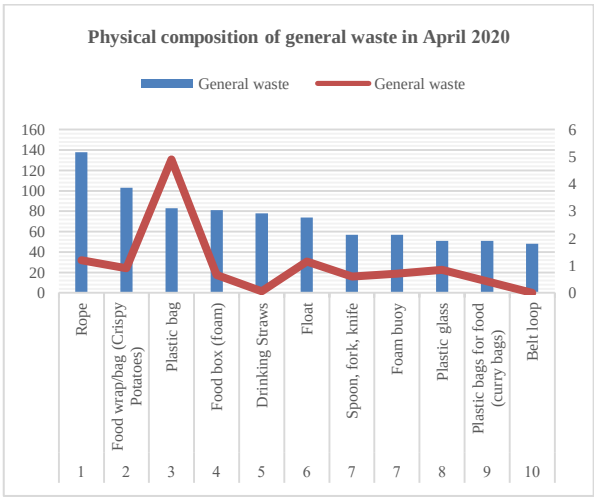

Figure 4 Physical composition of general waste in April 2020

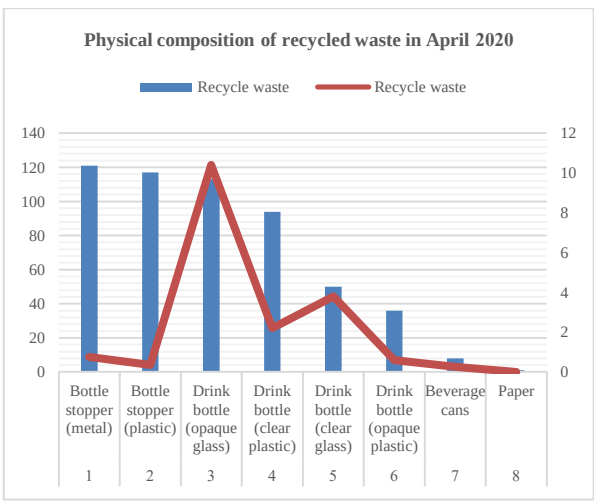

Figure 5 Physical composition of recycled waste in April 2020

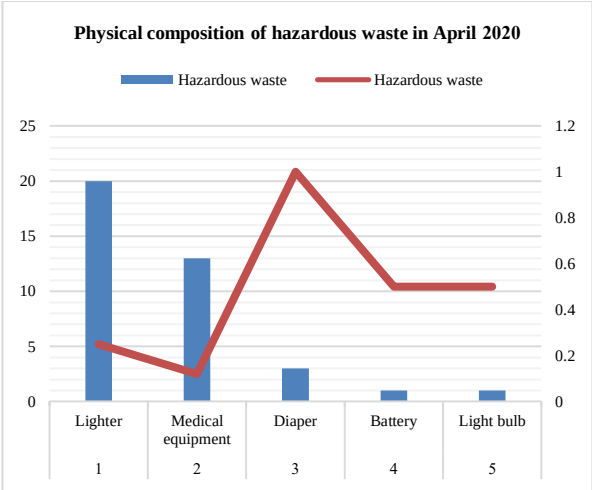

Figure 6 Physical composition of hazardous waste in April 2020

Figures 4-6 show that general wastes had the highest amount of rope, followed by food wrappers/bags (chips), copied bags, food boxes (foam), straws, floats, spoons, forks, knives, foam buoys, plastic glasses, plastic bags for food (curry) and fasteners, respectively. The most common recyclable wastes were bottle caps (metal), followed by bottle caps (plastic), beverage bottles (opaque glass), bottles, beverage bottles (clear plastic), beverage bottles (clear glass), beverage bottle (opaque plastic), beverage cans and paper. Hazardous waste consisted the largest volume of lighters, followed by medical equipment, diapers, batteries and light bulbs.

The analysis of waste composition in April 2020, it was found that the most common types of waste were rope, followed by food wrappers (chips), plastic bags, food boxes (foam), beverage straws, and buoy. In addition, the study by Jayla M. Blanke et al. (2561 most of the waste is plastic followed by foam, rubber, glass, metal and aluminum) [7]. Noting that most of the waste is linked to activities; industry and fishery, respectively, and others. Recyclable waste was the most bottle caps (metal), followed by plastic bottle caps. and beverage bottles (opaque glass). Hazardous waste was found for lighters at the most, followed by medical equipment and diapers.

Type and amount of beach rubbish along Petchaphum, May 2020

The study of marine debris in May 2020, beach wastes were collected four times a month, on 4, 12, 20 and 26 May 2020, taking into account for tidal times. The study on May 4, 12, 20 and 26 were marine debris 663 pieces, 614 pieces, 391 pieces and 283 pieces, respectively; in total amount of 1,903 pieces of marine debris, collected along Phetphoom beach. The most common types of beach waste of four sample collections were general waste, followed by recyclable waste and hazardous waste, as shown in Table 4.

Table 4 The marine debris quantity collected of May sample collection

Marine debris type	Marine debris quantity (number of pieces)				Total (pieces)	Weight (Kg)	Percentage (by pieces)
	May 4, 2020	May 12, 2020	May 20, 2020	May 26, 2020			
General waste	356	348	206	215	1125	19.81	57.66
Recycle waste	273	245	171	62	751	32.83	38.49
Hazardous waste	34	21	14	6	75	1.90	3.84
Total	**663**	**614**	**391**	**283**	**1951**	**54.54**	**100**

Analysis results by types of waste studied in May 2020, general waste was the highest quantity of 1,951 pieces, represented as 57.66%, followed by the recyclable wastes represented as 38.65% and hazardous waste represented as 3.84% as shown in Figure 7.

The study of marine debris existed along Phetphoom beach in May 2020, a total of 1,951 pieces of marine debris were found represented as the most general waste for 57.67%, followed by recyclable waste represented as 38.49% and hazardous waste represented as 3.84%. Composition of beach rubbish along Phetphoom beach in May 2020 is shown in Figures 8-10.

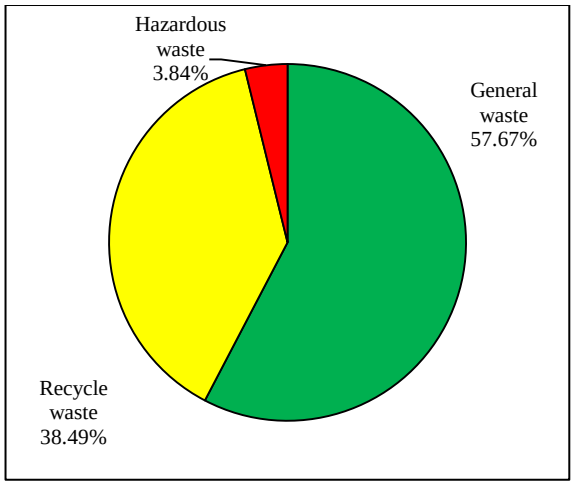

Figure 7 Quantity of marine debris in May 2020

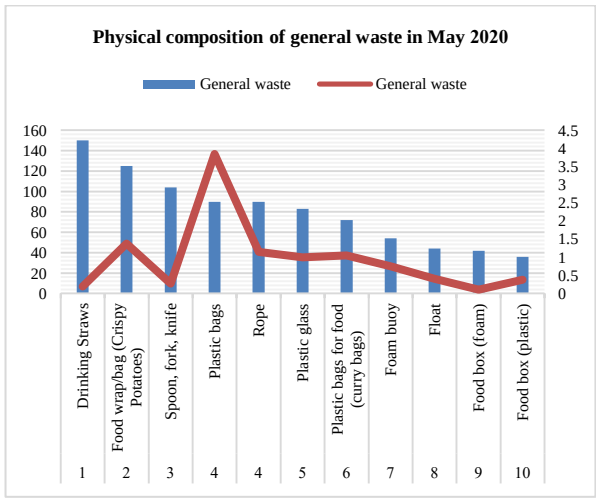

Figure 8 Physical composition of general waste in May 2020

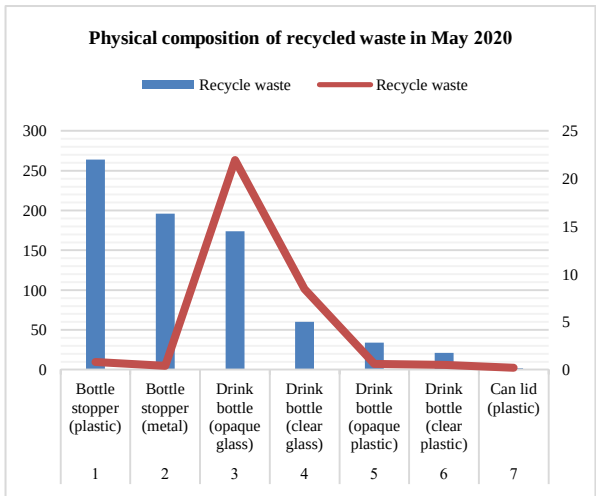

Figure 9 Physical composition of recycled waste in May 2020

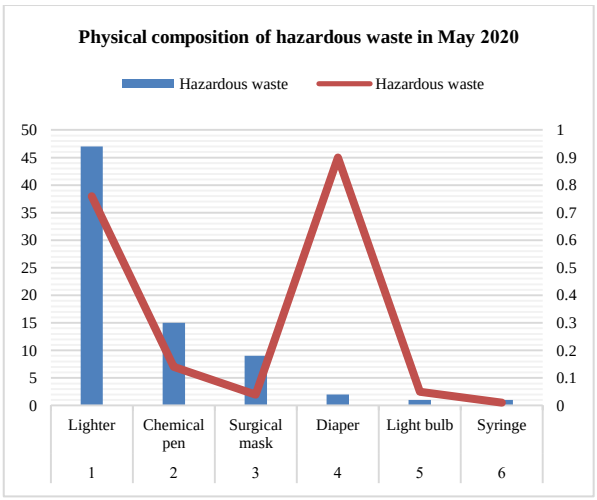

Figure 10 Physical composition of hazardous waste in May 2020

From Figures 8-10, general wastes consisted of straws/drinks at the most, followed by food wrappers/bags (chips), spoons, forks, knives, plastic bags, ropes, plastic cups, plastic bags for food. (curry), foam buoys, floating buoys, food boxes (foam) and food boxes (plastic), respectively. For the recyclable wastes, bottle caps (plastic)was found at the most, followed by bottle caps (metal), beverage bottles (opaque glass), beverage bottles (clear glass), beverage bottles. (Opaque plastic), beverage bottles (clear plastic) and can lids (plastic), respectively. For the hazardous wastes, the most found was lighters, followed by other medical equipment, diapers, light bulbs and syringes.

Compositions of marine debris in May 2020, general wastes most commonly found were beverage straws, food wraps/bags (chips), cutlery (plastic), plastic bags, ropes, plastic glasses. According to the study of Lisbeth Van Cauwenberghe et al (2013), assessment of the marine debris on the Belgian continental shelf, plastics were found to be the dominant category of small marine debris recorded, with more than 95% of the debris in all three marine sample compartments being plastic. In addition, the study by Yong ChangJang et al (2018) [9], composition and abundance of marine debris washed up on Sri Lanka's beaches, an average of 4.1 large (>25 mm) of marine debris and 158 small (5–25 mm) of marine debris were found per square meter of beach; packaging materials (55%) by application, followed by consumer goods (25%) and fishing

gear (20%) in terms of materials. For this study, plastics contributed the most (93%) of marine wastes, with the most common recyclable wastes were plastic caps, metal caps and beverage (opaque glass) bottles. Hazardous wastes found were lighters, followed by medical equipment, diapers, syringes and bulbs.

Wastes along Petchphum Beach were found the most in May 2020 about 1,951 pieces/month, and 1,764 pieces/month in April, 2020. The study by Bilal Mghili et al. (2020) present a total of 7,839 pieces of marine debris from five beaches. Polymers, followed by paper/ cardboard, metals, lumber, fabrics/textiles and glass/ceramics [10]. Based on the marine debris studied in April and May 2020, the large amount of rubbish was found at the beginning of the beach due to the existence of villas, residences, frozen fish and aquarium companies, and the occupation of the people in the community.

Conclusion

The study of type and amount of marine debris along Phetphoom Beach in April and May, 2020; marine debris classified as general wastes presented as the highest volume of 62.45%, followed by the recyclable wastes (34.63%), and hazardous wastes (2.97%), respectively. Composition of the general wastes were large pieces of marine debris such as food wrappers/ bags (chips), spoons, forks, knives, plastic bags, plastic glasses, foam buoys. For the recyclable wastes consisted of beverage boxes (paper). The composition of hazardous wastes were batteries, lighters, light bulbs. Recommendations should issue the strictly enforced beach regulations and laws in order to manage inappropriate behavior of individuals who dump different types of waste on the beach and in the sea. Public relations on marine debris and prevention of wastes for people, fishermen, tourists and beach residents. This research provides a way to develop marine waste such as ropes, nets or fisheries waste. There are entrepreneurs who have developed it into pieces such as bags for everyday use.

Reference

[1] Prempree, T., Wannarungsri, T., Kornkanitnan, N., Cherdsukjai, P. 2015. Type and quantity of floating marine debris from river mouths in the Upper Gulf of Thailand. In: 6th Proceeding of Marine Science Conference, Bangkok.

[2] Department of Marine and Coastal Resources. 2018. Types of marine debris. [online] accessible from: https://www.dmcr.go.th/detailLib/4058 (5 September 2020)

[3] Chanthamas, Y. and Israngkura, A. 2021. Disparity worsens ocean pollution https://tdri.or.th/2021/06/world_oceanday/

[4] Akkajit, P. and Ruamkaew, S. 2019. Microplastic waste on the west coast Phuket Province. Environmental Journal. 23(2).

[5] Sagulsawasdipan, K., Piyang, T. and Sawain, A. 2018. On Site Solid Waste Management Guidelines for Marine Tourism: A case Study of Bo-Hin Farmstay, Sikao District, Trang Province.

[6] UNEP/IOC United Nation Environmental Programme/Intergovernmental Oceano-graphic Commission) (2009) Guidelines on Survey and Monitoring of Marine litter. IOC Technical Series NO. 83.

[7] Jayla M Blanke, Michael K Steinberg 2, James P Donlevy 2. 2021. A baseline analysis of marine debris on southern islands of Belize. Marine Pollution Bulletin. 172 (112916).

[8] Lisbeth Van Cauwenberghe, Michiel Claessens, Michiel B Vandegehuchte, Jan Mees, Colin R Janssen. 2013. Assessment of marine debris on the Belgian Continental Shelf. Marine Pollution Bulletin. 73(1): 161-169.

[9] Yong ChangJang, R.R.M.K.P. Ranatunga, Jin Yong Mok, Kyung Shin Kim, Su Yeon Hong, Young Rae Choi, A.J.M. Gunasekara. 2018. Composition and abundance of marine debris stranded on the beaches of Sri Lanka: Results from the first island-wide survey. Marine Pollution Bulletin. 128: 126-131.

[10] Mghili, B., Analla, M., Aksissou, M. and Aissa, C. 2020. Marine debris in Moroccan Mediterranean beaches: An assessment of their abundance, composition and sources. Marine Pollution Bulletin. 160 (111692).

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Development of Bobae Wholesale Garment Night Flea Market on Public Footpath of Phadung Krungkaseam Canal Bank and Krungkaseam Road, Bangkok, Thailand

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Abstract

With regard to the survey, Bobae night flea market has its own significant problems namely the usage of market spaces and the vendors/workers' activities. This research objective, therefore, is to study the problems and developmental needs of this flea market to determine layout and guidelines that will solve the significant problems and make the usage of Krung Kaseam Road and pavement for the greater benefit in supporting the community's economy. This research is a qualitative type using in-depth interviews with residents and businessmen in the area, as well as buyers and vendors of the flea market. Preliminary study was used to compose a proposal to seek for opinions of the experts and representatives of the 4 stakeholders about the new flea market layout and development guidelines before ultimate conclusion of researchers. Summary from the in-depth interviews showed major problems that need development agreed by 70-100% of all the sample groups namely traffic, walkway and pavement, security system, cleanliness, and inadequate facilities such as toilets, trash bins, CCTV, fire extinguishers, lighting, car park, taxi station, publicity signs, the adjustment on activities of vendors/workers in this flea market that interfere public spaces and households as well as an improvement in management of this flea market. The ultimate proposal of development shows a new market's layout and guidelines that aim to orderly and solve all these significant problems of Bobae night flea market, therefore, reducing conflicts and negative impacts on all parties, supporting in growth of community's economy and trade.

Keywords : Bobae market; wholesale; night flea market; development

Introduction

The purpose of this qualitative research is to study the significant problems and needs of the flea market development on the Bobae wholesale night flea Market (00.00-05.00 am) located in public area (footpath and surface of Krung Kaseam Road) to summarize the developmental guidelines of the Bobae night flea market. The background and significant are as follows:

Bobae area is located in inner Bangkok, Thailand at the intersect area of Maha Nak canal and to Phadung Krung Kaseam canal, and along Lan Luang Road on the north to Bamrung Muang road on the south. (shown in Figure 1)

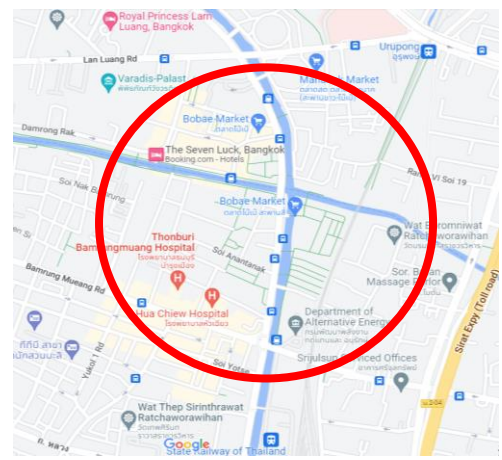


Figure 1 Bobae area

Bobae District, commonly known as "Bo Bae Market", has been the country's largest garment wholesaler area more than 70 years and exist before the second world war. Jirapha Thanachaisakul talks about the development of clothing trade in Bobae area and the emergence of stalls on public areas of the district [1]. At present, the trade value is around ten thousand million bahts per year depending on the economic and trade situation in each period. Over the past 3 decades, the volume of trade and the number of ready-to-wear traders in the district has increased dramatically in line with the trading growth while the space of the district is limited. This situation has made the price and rent go higher, incurred an encroachment on public areas both on the bridge over the Phadung Krung Kaseam canal and on the sidewalks along the canals during the daytime. In the night-time, not only footpath but also Krung Kasem Road's surfaces are used for setting up trading stalls, parking, area for transportation waiting, and set up a shopping cart to sell food/drinks or other products to accommodate both buyers and vendors in the market.

The reason that the government of district allows merchants to set up stalls on public space during daytime or at night is to alleviate the needs of small clothing merchants for increasing the opportunity and income equality along with promoting of trade and the economic development in the district [2]. This is because the number of small merchants exceeds the area of the district to accommodate (The pavement along the canal and the pavement on the other side, including the area on the road). The preliminary survey of the researcher in Bobae area during the time of the night flea market found many problems as follows:

(1) The installation of stalls on the pavement causing buyers/vendors and people to use the road as an unsafe walkway.

(2) Disorder of transport and vehicles parking in the market area obstruct the traffic, and increase traffic congestion.

(3) The lighting in some areas of the flea market is not enough. Theft and crime are more likely to occur. At the same time, there is no security guard at the market.

(4) The electrical connection of the stalls from the houses on Krung Kasem Road is at risk of a short circuit leading to fire.

(5) There are not enough facilities in the market area such as toilets, fire extinguishers, trash cans, and parking lots.

(6) The market area is unhygienic. There are garbage dumps outside the bins and on the streets.

From the observations around the Bobae night flea market, significant problems were found. A suitable way to improve and develop the Bobae night flea market for all stakeholders on problems to make the usage of public spaces on the pavement and Krung Kaseam Road for maximum benefit of the community is the origin of this research.

The consumer behaviour refers to the desire to buy, compare, and evaluate products / services to meet the needs [3] and a process which taking place before and after making a decision to purchase goods and services. Therefore, it is important that entrepreneurs take into account and study for application [4]. In political science, public policy means the affairs of the state/state enterprise. It is an activity that involves a large number of people which affects the development of the country [5].

Francis found that good public spaces come from a variety of factors: Easy access and connection, there is a beautiful/safe condition and image and there are users, activities taking place in the area. It has been developed to provide the greatest benefit to the user [6]. Thai market has evolved with the expansion of settlements. In the past and in the early days, trading area were around the riverbanks by rowing boats and markets were set up in dense communities. Later, when it was transported by road, markets and shops are located along roads or community sites [7] and the meaning of a flea market is a place where goods are exchanged or traded that are not organized as a regular market [8].

Jitaporn Sakkomolphithak found that the current market is a new style. It is a market that meets changing needs and lifestyles especially teenagers and working age groups prefers more attractions and entertainment and like on creative things. Most of the items are unique clothing, apparel and daily necessities including various services [9] and the activity was related to 3 things: Activity source, Activity type and activity system. It states that the activity system is a matter of individual behaviour, the activity

system is a pattern of behaviour of individuals, families, businesses and institutions, such patterns affect spatial patterns [10, 11].

Vance found that many manufacturers-to-all consumer contacts are very difficult to reach directly because of the geographical distance. The need for wholesalers (to act as intermediaries in order to supply the market and the demand for products to the producers) is necessary and they can help consumers access the product at a specific time [12].

Ariya Arunin discussed the concept of "public reclaim their street", which presented an example of public road management in different countries according to the use of space as follows: 1) pedestrian that abolishes the use of vehicles on that road and creates an environment on the commercial district in the middle of the city, 2) democratic street is accessible street to people of all classes, 3) livable/sociable street make the street area livable, safe and support people interaction, 4) centre of dining and entertainment that promotes evening dining and entertainment for a vibrant city, 5) woonerf is a lively street and gives pedestrians priority [13].

Duangchan Apawacharut Charoenmuang suggested bringing the idea of returning the road to pedestrians as the main guideline in implementing the “Walking Road Project” to take advantage and do activities, reduce pollution and accidents, save money on energy and as well as promote the trade and tourism. This concept became widely known in Thailand with the start of the “7 Wonders at Silom” street-event in Bangkok [14].

Prayoon Kanchanadul defined "public service" in the Administrative Law book as an activity under the control of the state. Its purpose is to meet the needs of the people. Public arrangements and procedures are always subject to change to suit the times and the private sector has the right to benefit from public services equally [15].

Sankhun Sattayamongkol compared the management of the Srinakharinwirot University flea market according to the point of view of products, vendors and consumers. The results of the research showed that merchandisers pay more attention to the general management and marketing mix of the university flea market that it is very important in planning, managing, motivating and controlling which affects the products, vendors in the flea market. As for consumer research on the marketing mix of this flea market, it was found that the product should focus on the quality of the product and the novelty, unlike the general market, as well as the good service of the supplier. In terms of price, some products are more expensive than outside of the university and should be adjusted. The area of the market should improve the corridors not to be cramped and have signposts – layout, toilet should be cleaned up. In terms of promoting sales, consumers consider public relations to be too little [16].

Manassinee Boonmeesri-sanga reported the development of pedestrian in Pranburi 200 years market. The study found that this walking street market has the potential to become a tourist attraction through community participation. Due to the readiness of the attraction and participation of the people of the community. There are some facilities but need to be improved more such as parking, toilets, signposts, etc. As for the 200-year pedestrian road development guidelines, it was found that there should be improvements in 6 aspects, namely Attraction, Facilities, Accessibility, Store management, personnel management, and community participation management [17].

From review, we will find that Bobae market look like other markets that expansion according to economic and community conditions. The differential are the products sold are not diverse, but have various clothes according to the needs and lifestyles in different periods and focuses on wholesale sales.

Methods and Tools

This is qualitative research using surveys and in-depth interviews. The objectives of this research are as follows:

(1) Study the problems and needs for development of Bobae night flea market of its community and those involved in the flea market.

(2) To find a guideline for further market development.

(3) To propose an alternative to using the public space for maximum benefit in the garment business and development of Bobae community.

Conceptual framework of research is shown in Figure 2

Figure 2 Conceptual framework of research

(1) Main study area of this research are Bobae night flea market which locates on public footpath along Phadung Krung Kaseam canal and on Krung Kasem Road as shown in Figure 3. The width (road plus footpath of both sides) and the length of this night flea market are 21 and 700 metres, respectively.

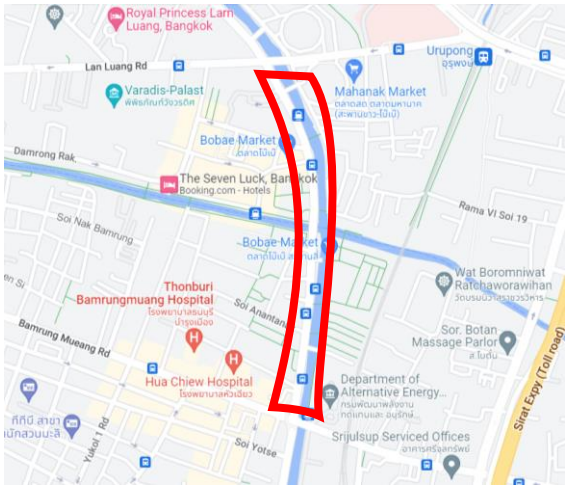


Figure 3 Study Area of Bobae night flea market

(2) The scope of types of flea markets according to the opening-closing period study and research on the Bobae flea market is only the flea market that starts from 00.00 – 05.00 AM, not including the market that opens during the day time. Bobae night flea market approximately has 1,800 vendors and 1,000 customers each day and have 3,000 residents around the market.

(3) Scope of research project's period is from December 2020 to October 2021

(4) Scope of research are about the "people, activities, areas and facilities-services" which related to the problems and needs of Bobae night flea market development by studying the problems and needs of development of this market from stakeholders. This research will conclude layout and guidelines for the development of market.

(5) The scope of the informant is divided into:

(5.1) Key contributors is the sample of subgroups from the population studied in Bobae area and using random method to find sample in each subgroup in the population studied. As qualitative research using in-depth interview method, the number of samples are depended on data from interview. According to the type of the research and method of interview, this research should have more than 5 samples in each subgroup. However, this research used 20 samples in each subgroup for a better outcome. The samples (by random sampling) are categorized as follows:

1) 20 vendors of Bobae night flea market
2) 20 buyers/consumers in the Bobae night flea market
3) 20 residents of Bobae area
4) 20 Bobae's businessmen who are not vendors of night flea market

(5.2) Secondary contributors or consultants scrutinizing the format and development of the flea market, such as academics specializing in marketing, society, environment, urban planning, as well as representatives of the 4 sample groups who gave their opinions regarding proposals of Bobae night flea market development after the stage of data gathering and analysing the results from key informants in in-depth interviews.

For the interview with key informants regarding the Bobae night flea market, there are 35 questions about the flea market which are divided into 5 main categories: 1) transportation, access, parking, and cargo handling system 2) area and location management 3) arrangement of facilities in the flea market or nearby 4) management of security in the flea market

5) management of the marketing mix (4 p's) of the flea market, i.e. flea market product management, price management, place, flea market distribution management, promotion.

Results and Discussion

The needs of each group for the development of the Bobae night flea market are as follow:

Residents in Bobae districts
1. Organizing the layout of the flea market/ stall. 100% Agreed
2. The arrangement of the walkways. 100% Agreed
3. Traffic regulation, cars, transport. 100% Agreed
4. Cleanliness and waste management. 100% Agreed
5. Social distancing during the COVID-19 epidemic. 100% Agreed
6. Toilet additions and improvements. 100% Agreed
7. Arrangement of security guards. 100% Agreed
8. Arrangement of private car parking spots. 95% Agreed
9. Safer traffic management. 95% Agreed
10. Arrangement of fire protection devices. 95% Agreed
11. Arrangement of the flea market administrative division. 95% Agreed
12. Improving electrical and lighting connection. 85% Agreed

Businessman in Bobae area
1. Organizing the traffic, cars, transport. 100% Agreed
2. The arrangement of security guards. 100% Agreed
3. Safe traffic management. 100% Agreed
4. Flea market/stall layout arrangement. 95% Agreed
5. Corridor arrangement. 95% Agreed
6. Cleanliness and waste management. 95% Agreed
7. Arrangement of a private car park. 95% Agreed
8. Determining the setting of the stall frame. 85% Agreed
9. Improvements in electrical and lighting connections. 85% Agreed
10. Arrangement of service parking spots. 85% Agreed
11. Arrangement of fire protection equipment. 85% Agreed
12. Helping to develop online commerce. 85% Agreed

Buyer in Bobae night flea market
1. Organizing the layout of the flea market/stall. 100% Agreed
2. The arrangement of the corridors. 100% Agreed
3. Traffic arrangements, cars, transport vehicles. 100% Agreed
4. Cleanliness and waste management. 100% Agreed
5. Social distancing during the COVID-19 epidemic. 100% Agreed
6. Adding and renovating toilets. 100% Agreed
7. Arrangement of parking spots. 100% Agreed
8. Arrangement of parking spots for private cars. 100% Agreed
9. The arrangement of security officers. 100% Agreed
10. Safe traffic management. 100% Agreed
11. Arrangement of fire protection equipment. 100% Agreed
12. The arrangement of the Flea Market Supervisor. 100% Agreed

Vendor in Bobae night flea market
1. Organizing the corridor. 100% Agreed
2. The arrangement of the traffic. 100% Agreed
3. Cleanliness and waste management. 100% Agreed
4. Restroom additions and renovations. 100% Agreed
5. Private car park arrangement. 100% Agreed
6. Security guards. 100% Agreed
7. Safe traffic management. 100% Agreed
8. Fire protection equipment arrangement. 100% Agreed
9. The arrangement of the flea market administration department. 100% Agreed
10. Panel rental price level improvement. 100% Agreed
11. Helping to develop online trade. 100% Agreed

12. The arrangement of the market/stall layout. 95% Agreed

Table 1 shows the result of opinions of the merging 4 sample groups, the importance of problems and needs for development are ranked according to the percentage agreed upon.

Table 1 Summary of the opinions from the in-depth interviews of the all 4 sample groups

No.	Question/issue	% Agreed	% not Agreed	% No Answer
1	Prepared as a walking street market	43.75	56.25	0
2	Adjust the stall framing interval	85.00	15.00	0
3	Make signs and map of the market Layout	77.50	22.50	0
4	Organize the layout of the stalls	97.50	2.50	0
5	organize the corridors	98.75	1.25	0
6	Organize traffic within the market	100.00	0	0
7	improve electrical wiring	88.75	11.25	0
8	Change the market time from 00.00-05.00am.	17.50	77.50	5.00
9	improve the garbage	98.75	1.25	0
10	Improve the noise	47.50	51.25	1.25
11	screening for COVID	87.50	10.00	2.50
12	Make more bathrooms	96.25	3.75	0
13	Renovate food @ beverage outlets	61.25	38.75	0
14	Improved waiting seats	51.25	48.75	0
15	Make a living room for those who come from far away	5.00	92.50	2.50
16	Organize foreign exchange points and ATMs	12.50	87.50	0
17	arrange a parking spot	90.00	10.00	0
18	Provide cargo cart service	43.75	56.25	0
19	Arrange for a long-distance transport agent	28.75	71.25	0
20	provide parking	97.50	2.50	0
21	provide security personnel	100.00	0	0
22	improve traffic safety	98.75	1.25	0
23	Improve the fire protection system.	95.00	5.00	0
24	Set up a department of supervision and first aid.	93.75	6.25	0
25	Add a variety of shops and products	27.50	66.25	6.25
26	improve the quality of the clothes sold	22.50	70.00	7.50
27	Improve food/beverage quality	67.50	21.25	11.25
28	Adjust the rental price/stall fee	58.75	6.25	35.00
29	improve the price of clothes sold	13.75	77.50	8.75
30	Improve food/beverage prices	13.75	77.50	8.75
31	Organize various product zones	70.00	23.75	6.25
32	Organize online trading	82.50	11.25	6.25
33	improve market publicity	72.50	17.50	10.00
34	Organize a promotional festival	46.25	45.00	8.75
35	arrange a price reduction event	55.00	38.75	6.25

Principles and tools that creating guidelines for the development of the Bobae Night flea Market are several tools which help point out the way to do it, that are:

(1) Considering from barchart of % agreed on topics should be developed in Bobae night flea market, in case of use 70% agreeable, the item of upper than 70% shown in Figure 4 and the items agreed lower than 70% shown in Figure 5.

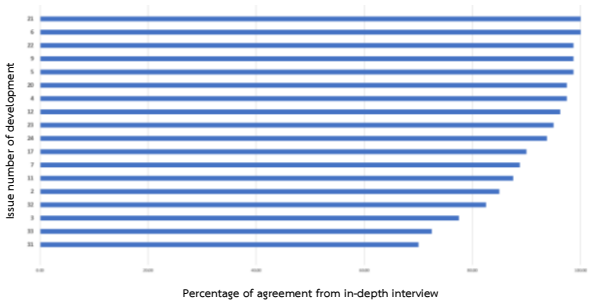


Figure 4 Bar chart of the most important issues (agreed to improve more than 70%)

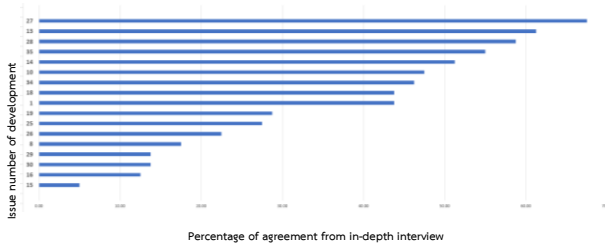
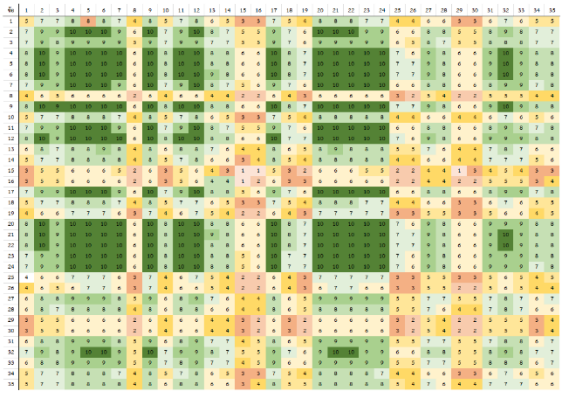


Figure 5 Bar chart of the medium and less important issues (agreed to improve less than 70%)

(2) The analysis of results from the Correlation Matrix tool (the tool which help to understand the data set and the direction of the relationship between the data through reference covariance) [18] generated from the summarized statistical values of each questions to calculate the avarage shown in Figure 6.

Based on the Correlation Matrix tool, it was found that the key issues that should be developed were those highly correlated to other issues (e.g., dark green boxes in correlation matrix show the mean correlation at the level of 91-100%) and select related issues with other issues at the highest level (Item calculates the mean obtained in each box within the colour grid of the image.) Correlation Matrix is the mean of the percentage agreed upon from the in-depth interview data on 2 related issues and shown in



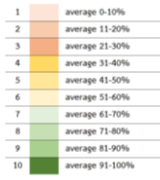


Figure 6 The results of the correlation of two factors shown by the Correlation Matrix tool

the item number box along the line, vertical and horizontal. From considering the results of the Correlation Matrix of 35 different issues, it was found that the issues correlate with other issues at a high level (Dark green box) are issues 2, 4, 5, 6, 7, 9, 11, 12, 17, 20, 21, 22, 23, 24, etc. All these issues are those should be brought in development before other items.

(3) Finding a development approach from SWOT analysis (It is a tool to help analyse the internal and external environment of organization for use in strategic planning and action plans [19] and marketing mix allocation principle (A tool to help analyse market factors and formulate strategies and marketing plans for success and growth [20].

SWOT Analysis of Bobae night flea market to define development guidelines

STRENGTH
- **Reputation for cheap wholesale sources**
- **Located in the heart of Bangkok**

WEAKNESS
- **traffic jam**
- **walkways are inconvenient, risk of accidents.**
- **not enough facilities: toilets, fire extinguishers, trash bins, parking lots, rest area, food zone**
- **No security personnel**
- **Car accidents from**

OPPORTUNITY
- **BMA allows night market**
- **The popularity of the Bobae Night Market is high.**
- **The demand of clothing products is always present.**
- **BMA is improving the landscape on both sides of Khlong Phadung Krung Kasem.**

THREAT
- **Limited space**
- **No support from Community member**
- **less disciplined Vendors and workers causes problems**
- **Uncertain government policies**
- **Lack of management, unlike the private market**

MARKETING MIX

PRODUCT (Bobae night flea market)
- **area and layout of night flea market**
- **stall (shop) and goods**
- **facilities**
- **services and behavior of vendors**
- **market's orderly and cleanliness**
- **safety**

PRICE
- **price of main goods (garment)**
- **price of services, food and beverage**
- **fee and rent of stall (shop)**

PLACE (distribution - channel)
- **onsite channel**
- **online channel**

PROMOTION
- **advertising and public relation**
- **management of discount program**
- **festival to promote flea market**

Proposal for the development of the Bobae night flea Market layout.

Preparation for proposal to improve the market layout must start from considering the current layout (year 2021) (Figures 7 and 8).

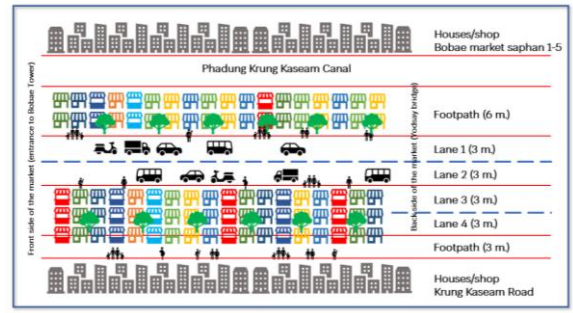


Figure 7 The current (2021) Bobae Night Market layout (top view) which will be used for comparison with the new layout of proposal

Note 1. There is no speed limit for cars running through Krung Kaseam Road near Bobae Night Market.

2. Total stall area = 8,100 square meters (calculated)

3. Number of panels according to standard panel sizes (1.5 meters x 3 meters) can be arranged = 1,800 stalls (calculated)

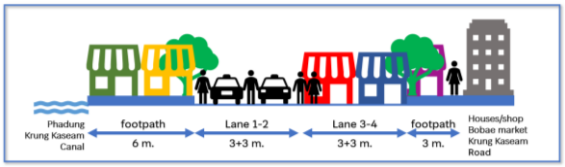


Figure 8 The current market layout in 2021 (cross section view) for comparison with the new layout of proposal

The advantages of the current Bobae night flea market layout (2021)

(1) It is the current flea market layout. No need to adjust the layout. No conflict between the district office/police and the stall vendors.

(2) The number of stalls is greater than the number of stalls that were in accordance with the plan of the market plan by the BMA in 2014.

Disadvantages of the current Bobae Night flea Market layout (2021)

(1) The market uses the space blocking the pavement. There are complained cases against the Bobae night flea market from many residents.

(2) The market layout (2021) causes traffic congestion especially during busy hours. It is difficult to enter - exit or pass through Krung Kaseam Road in Bobae area.

(3) People's walking paths and traffic mingle; accidents occur easily and often.

(4) The market condition is chaotic due to cars and people on the same road surface. This makes buyers to feel uncomfortable with shopping.

Finding the disadvantages of the current flea market layout (Year 2021), the researcher, therefore, came up with a new layout of the Bobae night flea market layout propose to experts and representatives from 4 sample groups for their comments.

Final conclusion on the selection of the flea market layout and development guidelines.

After the proposing the alternative layouts of Bobae night flea market to the panel of experts and representatives of the 4 sample groups, the researcher make the conclusion on the final design and development of the Bobae night flea market. The results are summarized as follows.

1) New market development guidelines proposes to improve the layout of the Bobae night flea market as follows:

In the first step: Using Scenario 1 which is more likely a walkway street market than the current layout (2021). Scenario 1 (Figures 9 and 10) will also have more advantages than Scenario 2 (Figures 11 and 12) in regard to the area where the stalls are set up, there are more stalls which promotes overall trade.

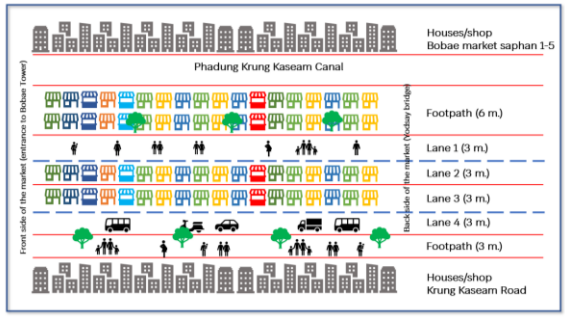


Figure 9 Scenario 1 for the development of a new layout of Bobae night flea market (top view)

Note: 1. Set a speed limit for cars traveling through Krung Kaseam Road near Bobae night market not more than 10 kilometres per hour.

2. Total stall area = 7,200 square meters (calculated)

3. Number of panels according to standard panel sizes (1.5 meters x 3 meters) can be arranged = 1,600 stalls (calculated).

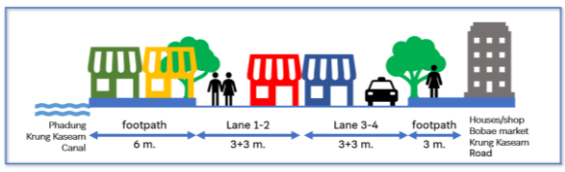


Figure 10 Scenario 1 for the development of Bobae night flea mark (cross section)

Advantages of Scenario1 for the new Bobae Night Flea Market Layout

(1) The market is similar to a walking street type. Pedestrian paths and driving paths do not mix on the road surface. The lanes for traffic surfaces are clearly divided.

(2) The market layout is separated from the traffic route by clearly dividing the area.

(3) The pavement in front of the buildings along the road is available to the residents of the district and general pedestrians. Reduce resistance from people in the neighbourhood.

(4) The stall that is moved from the pavement onto the road surface still has a stall length of approximately 2 lanes (6 meters) which is slightly less than the original (2021 layout).

Disadvantages of Scenario 1 for new Bobae night flea Market Layout

(1) Must rearrange the stalls from the footpath, in front of the houses, to be located on the road. There may be some opposition from stall sellers who do not want to change and might feel insecurity of the new stall area as it will be on the road instead of on a pavement, which is likely to be more stable.

(2) There may be a problem with stall rights that the district office has to settle a new agreement with the stall sellers.

(3) The traffic on Krung Kasem Road in front of Bobae is only one lane for vehicles to travel one-way. Because this kind of burial will focus on supporting the use of road space for flea market activities rather than focusing on the traffic of cars. The traffic will not run fully but it will flow through if there is no blocking or car accident.

(4) With layout of Scenario 1, a standard size of stall will be 1 meter x 3 meters which is smaller than the current market layout (2021).

In the second step: when Scenario 1 is used as a new market layout and traffic is getting heavier as many cars cannot easily travel in one lane and in one way, then use Scenario 2 (according to Figures 11 and 12). Scenario 2 is developed from Scenario 1 where the 2nd layout allows the car to run on 2 lanes of excess traffic and this market layout Plan 2 is still similar to the walking street market layout as well.

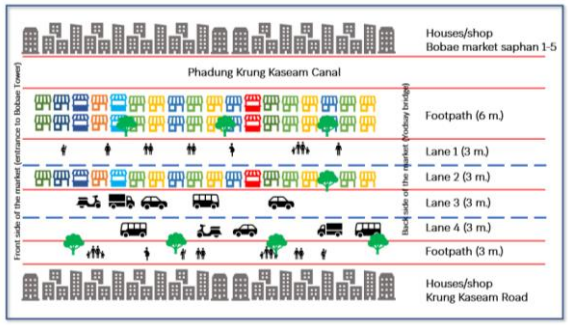


Figure 11 Scenario 2 for the development of new Bobae night flea market layout, finally proposed by the researcher. (Top view image)

Note: 1. Set a speed limit for cars traveling through Krung Kaseam Road near Bobae Night flea Market not more than 10 kilometres per hour.

2. Area used for setting up stalls Total = 5,400 square meters (calculated)

3. Number of panels according to standard panel sizes (1.5 meters x 3 meters) can be arranged = 1,200 stalls (calculated)

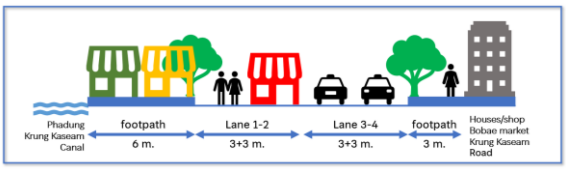


Figure 12 Scenario 2 for the development of new Bobae Night flea Market Layout, additional proposal finalized by the researchers (cross section)

2) Overall market development guidelines

(1) Renovate the layout of the Bobae night market as initially proposed.

(2) Improve facilities as shown in Figure 13.

This is consistent with the demand based on statistics from in-depth interviews in this research event and in accordance with the conditions of the area, including the regulations of the government.

(3) Improving the problems and conflicts between different groups of the population in the area related to Bobae night market.

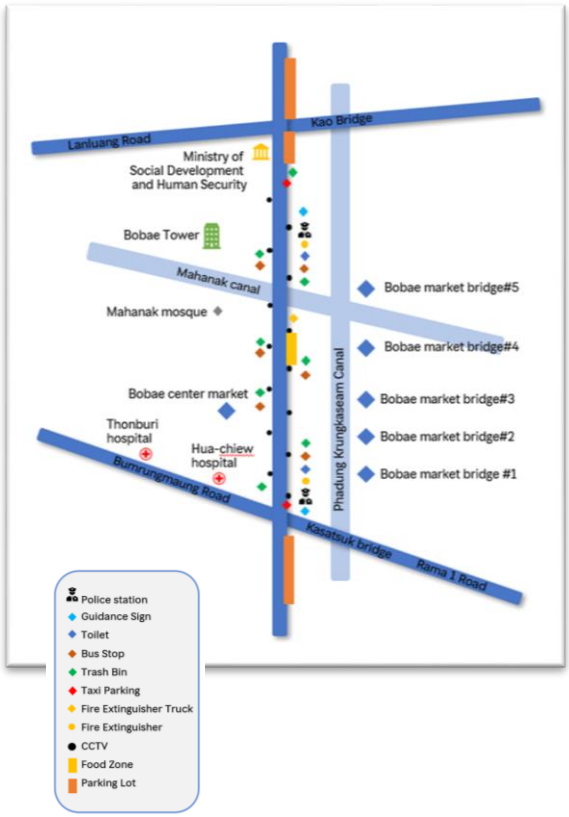


Figure 13 Proposal of facilities development

(4) Improve activities of sellers and service providers in the flea market to reduce the disturbance effect on residents in the district and the general public, regarding vehicle traffic and noise pollution or piled up garbage as well as promoting marketing and online trading activities to support community, therefore, aims to develop the area to be orderly, beautiful, clean, safe, with adequate facilities and aims for the relationship of "people, areas, activities" in the most profitable way by minimizing the negative impact on the various aspects arising from the provision of using public spaces, roads and footpaths to carry out economics activities in the style of the Bobae district's night market.

Conclusion, the study of problems and needs of all stakeholders for the market development before formulating a way to develop and solve existing problems by relying on academic knowledge, concepts and various tools which help organize a developmental approach is a better way for problems and condition solving in "people-activities-area" relation. This is a method that is probably more suitable than developing based on ignorance of basic problems. This research has guidelines and results consistent with many of the research examples cited, easy access and connection, there is a beautiful/safe condition and image and there are users, activities taking place in the area, and support people interaction.

References

[1] Thanachaisakul, J. 2002. The role of trade and production of Bobae area. [Master's thesis]. Chulalongkorn University, Bangkok.

[2] News Agency Online Manager. 2014. Interview with Dr. Wanlop Suwandee on the arrangement of Bobae Flea Market. Retrieved from http://www.js100.com/en/Site/news/view/7469

[3] Sereerat, S. 2003. Consumer behavior (pp. 192). Bangkok: SE-EDUCATION Publishing House.

[4] Laksitanon, P. 2001. Psychology and Consumer Behaviour (pp.54). Bangkok: Tipping Point Publishing.

[5] Pientam, C. 1999. Establishment of Political Institutions: Cities, Politics, Communities and Civil Society (Research report). Bangkok: Institute of Fundamental Development.

[6] Francis, M. 1989. "Control as a dimension apace quality", in Altman, I and zube, E. (Edited) public places and space (pp.144-172). New York: Plenum press.

[7] Jaiboon, K. 2011. Market and way of life: an introductory survey on markets in Thai society (Research report). Bangkok: Princess Maha Chakri Sirindhorn Anthropology Center (Public Organization).

[8] Wattanawanyu, K. 2011. Flea market management and community's creativity (Research report). Bangkok, King Mongkut's University of Technology Thonburi.

[9] Sakkomolphithak, J. 2015. Influence Factors on the selection of shopping in Night flea Markets, Bangkok area.

(Master's thesis). Thammasat University, Bangkok.
[10] Chapin, S.F. 1972. Urban Land Use Planning (pp 221-253). Illinois:Urbana University of Illinois Press.
[11] Udomsub, T. 2011. Renovation in Areas with Diverse Activities: A Case Study of Ratchadamnoen Klang Road Area. (Master's thesis). Thammasat University, Bangkok.
[12] Vance, J.E. 1970. The Merchant World: The Geography of whole selling. Eaglewood cliffs: Prentice-hall.
[13] Arunin, A. 2010. Theory and Practice for City Administrators (p.141-160). Chulalongkorn University, Bangkok.
[14] Charoenmuang A.D. 2002. Sustainable Cities: Western Concepts and Experiences (p.1-7). Chiang Mai University, Social Research Institute.
[15] Kanchanadul, P. 1980. Narration of Comparative Administrative Laws. Bangkok. Chulalongkorn University.
[16] Satyamongkol, S. 2008. Management of Srinakharinwirot University Flea Market by the Perspectives of Product Vendors and Consumers. [Master's thesis]. Srinakharinwirot University, Bangkok.
[17] Boonmeesri-sanga, M. 2013. Guidelines for Market development of Pranburi Bicentennial Walking Street to be a cultural attraction through community's participation. [Master's thesis]. Silpakorn University, Phetchaburi Campus.
[18] Smarter Machine. 2021. Statistics: covariance matrix and correlation matrix, Retrieved from smarter-machine.blogspot.com>2021/03
[19] The Wisdom Academy. 2021. What is SWOT Analysis. Retrieved from http:// The wisdom. com>content>what-is-swot-a…
[20] Content Shifu. Marketing Mix, Retrieved from http://content shifu.com>blog>4p-marketing-…]

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Organic Fertilizer Application using Leaf Waste According to Maejo Engineering Method 1

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Abstract

This study aimed to find a solution for leaf waste management in area of Valaya Alongkorn Rajabhat University which has a lot of perennials by applying Maejo Engineering Method 1. The experimental design of making organic fertilizer from leaf waste consisted of the proportion of leaves in 3 piles. This work used different ratios between leaf waste and cow dung by ratio 3:1, 4:1 and 5:1, respectively. We analyzed the results and checked the quality according to the organic fertilizer standard method using criteria of the Department of Agriculture. The result found that organic fertilizers from leaf waste in different ratios, can be decomposed into high quality organic fertilizer within 60 days. Using mixed cow dung that is 1 to 5% less than the Mae Jo Engineering method 1 can save a lot of cost of cattle. The results of the comparison of the t-test between the organic fertilizers obtained from the three experiments revealed that there was a statistically insignificant difference at the 0.05 level of significant. The results of the analysis of fertilizer quality standards found that the organic fertilizers from leaf waste in this study have been high quality more than the Department of Agriculture's organic fertilizer standards. The ratio between the carbon to nitrogen value is 14.25. This means very good degradation conditions. Furthermore, the organic fertilizers contain heavy metal impurities at a level not exceeding the standard value. The net present value valuation and payback period found that the resulting organic fertilizer has a net present value of 1,130 Baht/unit of production when 400 kg. of leaf waste, 100 kg of cow dung, yielded fertilizer in the study equal to 200 kg. The results of this study can be developed to determine concrete waste management guidelines in the study area and lead to the formulation of waste management policies to meet the needs of the organization towards becoming a green university.

Keywords : leaf waste; organic fertilizer; cost-effective

Introduction

The current situation of global resource use intensified in the management of waste pollution in various countries around the world, both in developed countries and developing countries. The problem of increasing amounts of solid waste from consumption, especially in large urban areas in various countries, reflects that there is still a large proportion of unmanaged organic waste in many countries, especially in countries where agriculture is the main income. For example, in Hanoi, where the proportion of organic waste is as high as 71%, it takes more than one technology to make organic fertilizer and it takes more than 6 weeks to get rid of Most of them come from educational institutions of different levels with a variety of activities [1]. In Thailand, there was 49% organic waste in Bangkok in 2014 [2]. Data on the amount of solid waste in Thailand by the Pollution Control Department in 2019 shows that the total amount of solid waste in the country is up to 28.71 million tons. The amount of solid waste that was disposed of properly was 9.81 million tons (34.20%), the amount of solid waste that could be used for 12.52 million tons (46.60%), and the amount of solid waste that was not properly disposed of was up to 6.38 million tons. (22.20%). The Master Plan under the National Strategy in 2019, issue, 18 addresses the actions to achieve the goal of effective waste management in the country according to international standards by reducing waste at source by campaigning to raise awareness for people and related sectors to jointly reduce the amount of waste from residential, schools or educational institutions, government offices Establishments, service establishments and hospitality activities. There often the source of large amounts of organic waste together with methods of supporting the use of products and services that promote production, including products that are environmentally friendly and can be reused many times [3]. In addition, there should be support and promotion of local groups or networks to manage the local solid waste with the capability and potential to manage waste in limited areas this corresponds to the concept of the circular economy system, which has the capacity and potential to manage waste problems in limited areas which is in line with the concept of the circular economy system. This research was conducted to create the value of leaf waste of Valaya Alongkorn Rajabhat University and economic valuation. The results of the study can be developed into the creation of the university's waste management policy in order to become a green university.

Methodology

Organic fertilizer production from leaf waste

1. The production of organic compost by Maejo 1, engineering method is a convenient method for the maintenance of the fertilizer pile and using a fast fertilizer production period. In this study, the conversion efficiency of digestion at different conditions was studied by dividing the experiment according to the ratio of fertilizers in different proportions. Design and define the area of the base frame of the manure pile, size 2 x 2 square meters, bring the pile of leaf waste together to a height of about 10 centimeters, alternating with cow dung from fattening cattle according to the ratio given in Table 1. Leave it for 60 days without turning over the fertilizer pile. Water and humidify daily and fertilize piles once a week to create an air circulation system. In this study, the name In tree Fertilizer derived from the use of leaf waste in the study area was used as VRU Fertilizer (Valaya Alongkorn Rajabhat University : VRU). The experiment was designed by specifying the ratio of 3 ratios as shown in Table 1. The experimental site was located in the university area for the convenience of conducting the study.

Table 1 Leaf waste cow dung ratio in experiment

experiment	Amount of leaf waste (kg)	Cow dung (kg.)	Total (kg)	Ratio
1	375	125	500	3:1
2	400	100	500	4:1
3	416	84	500	5:1

Figure 1 Three piles of experimental fertilizers

2. Preparing the Fertilizer Pile for the experiment (VRU Fertilizer). Determination of the moisture level of the fertilizer pile is carried out in accordance with the procedure in the fertilizer production manual with a non-reversible method of the fertilizer pile. Use the method of observing and recording the results of the experiment every 7 days, watering every day, once a day to keep the fertilizer pile always moist. From the study by observation method of watering each fertilizer pile, it was found that the outer layer of the fertilizer pile was moist but the inside was still dry. Therefore, the organic fertilizer pile must be stabbed to add water to humidify the organic fertilizer pile so that the fertilizer pile has sufficient moisture for the decomposition process of Mix Culture microorganisms that exist in nature and in the experimental material [4]. In this experiment, the moisture content was about 60-70% and the air circulation was combined with the humidity for the microorganisms to be used in the fermentation process of more than 50% or more [5] which is a diverse group of microorganisms that come from fattened cow dung and from leaf litter. It was found that the most common groups were Gammaproteo bacteria, Pseudomonas and Enterobacteria, Bacillales and Actinobacteria. These are the most common groups in the process of making organic fertilizers [6]. The process of making organic fertilizer VRU consists of 2 main steps, first Step is humidification in the experimental fertilizer pile and the second step is to create a ventilation system in the experimental fertilizer pile. By the method of stabbing the fertilizer pile every 7 days with a stick or iron bar into a small hole to have a depth of the base of the fertilizer pile. Measure the distance between the air inlets about 40 centimeters, then add water to increase the humidity inside the fertilizer pile [7].

3. Data analysis. Quality inspection of fertilizers produced in all 3 piles and compared according to the standards of the Department of Agriculture. Use the submission of samples for laboratory analysis and compare the results with the organic fertilizer standards of the Department of Agriculture which consists of the physical and chemical properties of the fertilizer as shown in Table 2.

Table 2 Physical properties and chemical properties according to organic fertilizer standards

Numb	Attribute	Criteria
1	Fertilizer size	Not more than 12.5x12.5 mm.
2	Moisture content and volatile matter	not more than 35% by weight
3	Stone and gravel quantity	Larger than 5 mm, not more than 5% by weight
4	Plastics, glass, sharp materials and other metals	Set to none
5	organic matter	Not less than 30% by weight
6	pH value (pH)	5.5 - 8.5
7	Carbon to Nitrogen Ratio (C-N)	Not more than 20:1
8	Conductivity (EC: Electrical Conductivity)	Not more than 6 dB/m
9	macronutrient content	- Nitrogen (Total N) not less than 1.0 percent by weight - Phosphorus (Total P_2O_5) not less than 0.5 percent by weight - Potassium (Total K_2O) not less than 0.5 percent by weight
10	complete degradation	more than 80 percent
11	heavy metal	- Arsenic, not more than 50 mg/kg - Cadmium not more than 5 mg/kg - Chromium not more than 300 mg/kg - Copper not more than 500 mg/kg - Lead not more than 500 mg/kg - Mercury not more than 2 mg/kg

Reference source: Government Gazette (2007)

Economic cost analysis

1. Cost. For this study refers to the cost of various activities, including the cost of experimental materials in a production activity, divided into two categories: fixed costs and variable costs. Fixed costs are costs with constant behavior, meaning total costs that do not change according to the level of production during a certain stage of production but the fixed cost per unit will change in a decreasing way if the production volume increases. In addition, fixed costs can be divided into 2 types: Committed fixed cost, which is fixed cost that cannot be changed in the short term, such as long-term lease depreciation and short-term fixed costs. Discretionary fixed costs are fixed costs that arise from time to time from meetings or decisions of the management such as public relations or research expenses. (2) Variable costs are costs that will have a total cost that changes in proportion to the change in activity level or production volume while the cost per unit will remain the same for every unit. Generally, variable costs can be controlled by the department or entity that caused the variable cost. In this study, referring to an agency affiliated with the university that conducts experimental activities.

2. Net present value (NPV). It is the sum of the adjusted net returns for the project time taking into account ongoing projects or starting to work, will it be worth it or not. That is, if the resulting NPV is greater than zero or positive. Shows that it is worth the investment, and in case the NPV value is negative or below zero, it means that the investment under the project is not worth it. It can be written as a formula for calculating as follows:

$$NPV = \sum_{t=1}^{n} \frac{B_t - C_t}{(1+i)^t}$$

NPV is Net present value of the project
B_t is The return as of the year of computation
C_t is The cost as of the year of computation
i is The discount rate
t is The age of the project

3. Payback Period (PBP). The duration of the investment in which the net cash inflows from the project are exactly the same as the net cash outflows or the investment has no profit and no loss, it is based on the cumulative net present value that changes from negative to positive [8].

Statistics used for testing

In this study Descriptive statistic was used which consisted of frequency, mean, percentage and standard deviation. Analyze and compare the results of the study with the quality level of fertilizers determined from various chemical properties according to the criteria with t-test independent for economic calculations [9].

The experimental and analysis process can be summarized as follows, as shown in Figure 2.

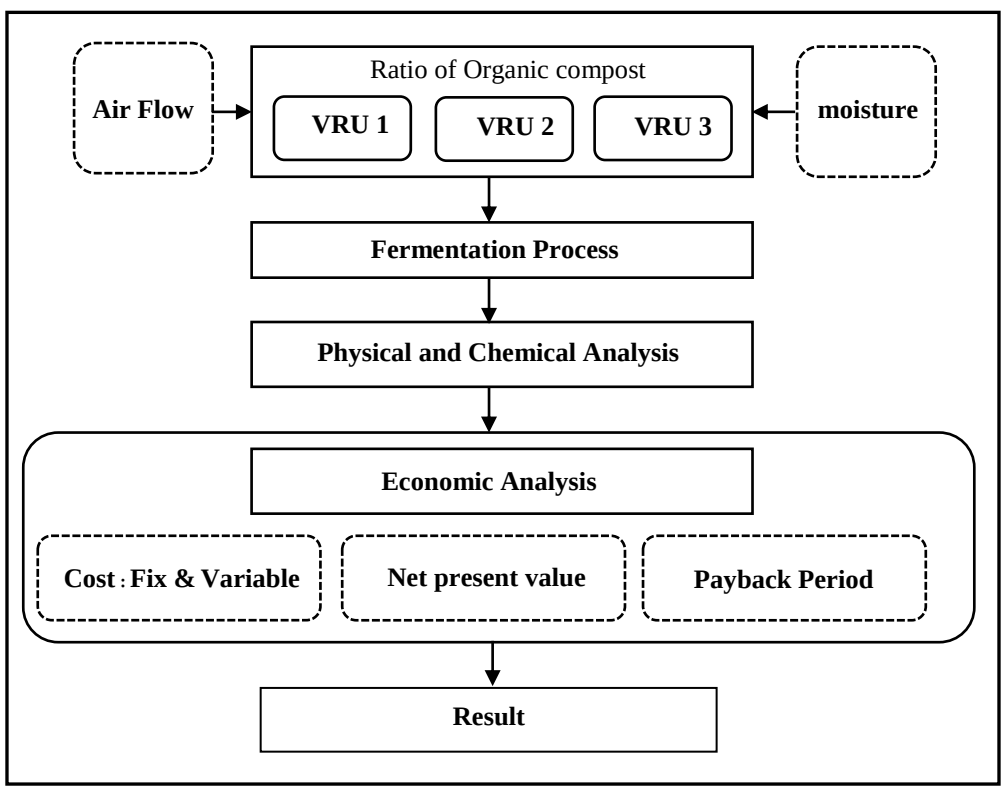

Figure 2 Educational procedures and method

Results and Discussion

Quality Analysis of Organic Fertilizer (VRU Fertilizer)

Fertilizer analysis was based on formulas or ratios designed for each experiment. After 60 days of microbial decomposition process, stop watering, humidify the compost pile and reduce humidity by drying the organic fertilizer in sunlight and in a well-ventilated area for microorganisms to enter the resting process. Spread the fertilizer layer to a thickness of about 20-30 cm. After that, leave the time for the organic fertilizer to dry for 3-4 days. Then reduce the size to make it easier and more convenient to use by using a coarse grinder. Fertilizer samples were analyzed in the laboratory by standard methods to compare the quality of the 3 piles with the standard criteria and the method of analyzing organic fertilizer according to the standards of the Department of Agriculture [10]. The results of the analysis are shown in Table 3.

Table 3 The results of organic fertilizer analysis were compared with organic fertilizer standards

Analytical parameters	VRU 1	VRU 2	VRU 3	Organic fertilizer standard
total nitrogen content (%)	1.61	1.56	1.12	not less than 1
Phosphorus content (%)	2.13	1.88	1.47	not less than 0.5
potassium content (%)	1.02	0.89	0.71	not less than 0.5
Carbon to Nitrogen Ratio (C/N Ratio)	13.24	14.25	15.77	no more than 20
Certified organic material (%)	36.72	38.4	30.47	no more than 30
(pH)	8.01	7.8	7.93	5.5 - 8.5
Conductivity (dS/m)	4.235	4.62	2.315	no more than 6
Arsenic (mg/kg)	2.05	2.51	3.7	not more than 50 mg/kg
Cadmium (mg/kg)	0.59	0.71	0.92	not more than 5 mg/kg.
Chromium (mg/kg)	9.17	9.46	14.84	not more than 300 mg/kg
Copper (mg/kg)	50.32	46.99	32.81	not more than 500 mg/kg
Lead (mg/kg)	7.99	8.3	12.06	not more than 500 mg/kg
Mercury (mg/kg)	ND	ND	ND	not more than 2 mg/kg

From Table 3, the results of organic fertilizer analysis were compared with the 13 parameters of organic fertilizer standards. The results showed that the quality of VRU fertilizer passed the standards of the Department of Agriculture and there is also a trend of high quality especially in the three main nutrient groups, including the total amount of nitrogen, phosphorus content and potassium content. From the experiment, it was found that the nutrient content was very high, indicating that VRU organic fertilizer can be used in agriculture as efficiently as organic fertilizer or bio-fertilizer that has passed the same standard test. In addition, the results of other comparative analyzes also indicated that It is higher than the specified organic fertilizer standards as well. The results of the percentage analysis of macronutrients Shown in Figure 3.

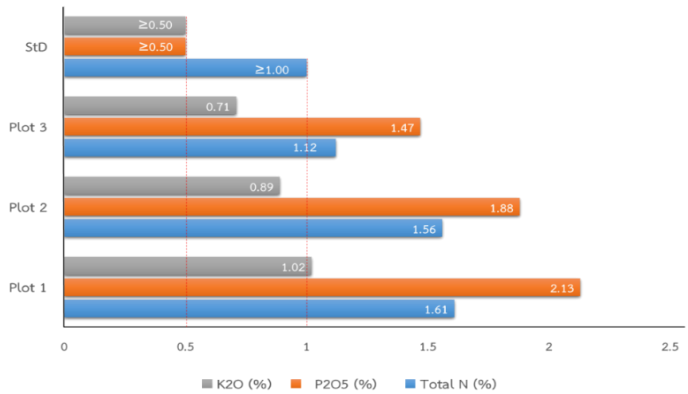

Figure 3 Comparison of macronutrients of VRU organic fertilizers and organic fertilizer standards

Note : The red dotted line shows Reference point for organic fertilizer standards of the Department of Agriculture (2007)

From Figure 2, all 3 stacks of VRU organic fertilizers meet the standards of the Department of Agriculture according to the Government Gazette Fertilizer Act (No. 2 B.E. 2550). The results of checking the relationship by independent t-test to compare the differences of the three fertilizer piles found that the three fertilizer piles. It was found that the three fertilizer stacks were related in terms of chemical and physical properties for all 13 parameters. The significance level of 0.05 is shown in Table 4.

Economic evaluation and presentation as a policy

The economic valuation in this study was calculated in two parts: Payback Period (PBP) and Net Present Value (NPV). The results of the payback period calculation revealed that the payback period of biofertilizer production is very short. The payback period is only 1 month and 11 days to produce 600 kg of organic fertilizer (which comes from 300 kilograms of leaf waste and 300 kilograms of fattening cow dung). Total cost of VRU organic fertilizer production is 1,410 baht (It is the cost that comes from fattening cow dung and packaging only). In the production of organic fertilizer VRU from 3 piles of experiments, each experimental pile will yield a quantity of 600 kg of fertilizer per pile, a total of 1800 kg which can be packed in bags of 120 bags, size 15 kg per bag. When selling all fertilizers at a price of 40 baht per bag, a total return of 4,800 baht will be obtained.

Table 4 Statistical correlation test of all 13 parameters analyzed per fertilizer pile

The relationship of the 3 piles of VRU fertilizer	t	Sig.
VRU 1 – VRU 2	0.0037	0.9970
VRU 1 – VRU 3	0.1987	0.8490
VRU 2 – VRU 3	0.2009	0.8426

Conclusion

In this study, there were 3 preliminary experiments in the test fertilizer piles to find the average to determine the most suitable ratio of fertilizer pile representatives. Starting from a total of 5 ratio to only 3 ratios are left for use as a representative study. Although the results showed consistent with the study report on composting piles by Maejo Engineering

Method 1 but the results of this study show that the amount of cow dung used did not show a statistically significant difference. Therefore, if conducting studies or composting in this way in areas where there is a shortage of cow manure or the need to reduce production costs as much as possible. Using cow manure at a lower rate than the Maejo Engineering Method 1 stipulates, it is possible to shred twigs and leaves without affecting the quality of organic fertilizers were also statistically significant. When considering the Carbon to Nitrogen Ratio (C/N Ratio), which represents the degradation rate of tree and leaf litter, it was found that VRU Organic Fertilizer Stacks 1, 2 and 3 had these values at 13.24, 14.25 and 15.77, respectively. It can be seen that when the amount of cow manure is different the degradation rates are similar and are still within acceptable levels according to the Department of Agriculture's organic fertilizer standard, which states that the C/N Ratio must not exceed 20. Economic value analysis shows great value for money in action. It also encourages the cost-effective utilization of leaf waste in line with the circular economy concept to focusing on Circular Supplies, which is the use of recycled materials and bio-based materials. The materials that can be reused entirely to be used as the main raw material in production to reduce the use of resources in production reduce waste. And more importantly, it is the use of renewable energy in the production process to the maximum benefit.

References

[1] Thanh, H. T., Yabar, H. and Higano, Y. 2015. Analysis of the environmental benefits of introducing municipal organic waste recovery in Hanoi city, Vietnam. Procedia Environmental Sciences, 28, 185-194.

[2] Sukholthaman, P. and Sharp, A. 2016. A system dynamics model to evaluate effects of source separation of municipal solid waste management: A case of Bangkok, Thailand. Waste Management, 52, 50-61.

[3] Filimonau, V. and Delysia, A. 2019. Food waste management in hospitality operations: A critical review. Tourism management, 71, 234-245.

[4] Iqbal, M. K., Shafiq, T. and Ahmed, K. 2010. Characterization of bulking agents and its effects on physical properties of compost. Bioresource Technology, 101(6), 1913-1919.

[5] Liang, C., Das, K. C. and McClendon, R. W. 2003. The influence of temperature and moisture contents regimes on the aerobic microbial activity of a biosolids composting blend. Bioresource technology, 86(2): 131-137.

[6] Sundberg, C., Franke-Whittle, I. H., Kauppi, S., Yu, D., Romantschuk, M., Insam, H. and Jönsson, H. 2011. Characterisation of source-separated household waste intended for composting. Bioresource technology, 102(3): 2859-2867.

[7] Mattanaporn Maikami, Phanwipa Pangsri, Watthana Atchariyaphotha, Treeranut Srisunont, Phimnara Nilrit, Narumol Thanananta. 2019. A survey of tree in Valaya Alongkorn university under the royal Pratronage, Pathum Thani. Research and Development, Valaya Alongkorn Journal. 14(2): 1-11.

[8] Teeraphong Sawangpanyangkun. 2558. Non-reversible bulk organic fertilizer production Maejo Engineering Method 1. Chiang Mai : Faculty of Engineering and Agro-Industry, Maejo University.

[9] Putro, G. M. and Prijoto, P. (2021, November). Study of Investment in the Organic Fertilizer Industry to Improve Community Economists. In RSF Conference Series: Engineering and Technology (Vol. 1, No. 1, pp. 652-660).

[10] Standard, T. A. National Bureau of Agricultural Commodity and Food Standards. 2018, Ministry of Agriculture and Cooperatives.

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Selection of the Non-methanogenic Microorganism for Biogas Production from Napier Grass Extract

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Abstract

This study selected outward methanotrophic bacteria for biogas potential experiments in Napier at the age of 60 and over 90 days using the Biochemical Methane Potential method (BMP) until steady state at mesophilic temperature. In this experiment, Clostridium beijerinckii and Cutibacterium acnes were chosen because they both have biogas potential in extracted Napier at the age of 60 and over 90 days of 59.98% maximal methane production. The accumulation of methane production was 4.84, 1.02, and 0.53 ml, respectively, as a result of Napier extract of 60 days with *Clostridium beijerinckii* ($N_{60}G$), 90 days with *Clostridium beijerinckii* ($N_{90}G$), and 90 days with *Cutibacterium acnes* ($N_{90}K$), and 0.28, 2.26, and 0.33 ml/TSadded of BMP.

Keywords : Biogas; Non-methanogenic; DNA sequence; Methane production; Napier grass extract

Introduction

Energy is the main instrument for driving economic growth, reducing poverty, and livelihood opportunities. Intense research has been conducted into new technological techniques for generating clean and sustainable energy from renewable sources [1] of energy because of the constantly rising global energy demand, the depletion of fossil fuels [2, 3], rising prices for oil, and the growing worries about environmental issues. However, there is a problem with energy sufficiency because there are not enough fossil resources. Consequently, there has been an increase in the utilization of various forms of renewable energy in recent years [4, 5].

The treatment and stabilization of organic component wastes using anaerobic technology are well recognized as being effective, and it also produces methane in the process [6] and anaerobic digestion is a popular approach for converting biomass into energy [7, 8]. Organic wastes and a variety of lignocellulose materials can be used in anaerobic treatment [9] and also used to prevent wastewater pollution [10], industrial waste [11], and municipal waste [12] and has proven to be a potential method of producing hydrogen and biogas, two renewable energy sources [13]. Moreover, A huge and diverse array of agricultural feedstocks are useable in Thailand for the manufacture of biogas. Numerous energy crops can be used to produce biogas, such as sugarcane, sorghum, and Napier grass. The net yield per hectare, high nutrient content, and cultivation ease are all key considerations when selecting energy crops for biogas production [14]. Feedstocks should be easy to cultivate, harvest, and store, drought-tolerant, and able to grow in low-nutrient soil. With a high organic content, including protein and carbohydrates, Napier grass (*Pennisetum purpureum*) is a substance that is used for energy crops (livestock) [15], Napier grass gives

the highest methane production rate of approximately 11.46 ml/day compared with other feedstock in Thailand [16]. The harvest age of Napier grass was affecting the biogas and methane production because the composition in each harvesting age was different cellulose decomposition [17]. With the ability of Napier grass was easy to plant and grow [18] making it popular to be a feedstock for animals, and the unharvested Napier grass turn into agricultural waste. Thus, the researcher sees an opportunity to change Napier grass to alternative livestock into methane production for reducing gricultural waste by non-methanogenesis microbe. Many non-methanogenesis that can produce methane in oxygen-saturated aquatic and terrestrial ecosystems such as cyanobacteria, algae, fungi, purple non-sulfur bacteria, and cryptogamic covers, produce methane in oxygen-saturated aquatic and terrestrial ecosystems [19].

The potential of biogas production from the extraction of Napier grass that was harvested in 60 and over 90 days inoculated with the outward microbe group from various sites was described in this study.

Materials and Methods

Selection of methane-producing anaerobic microbe

Microbe selection and methane production ability

Samples were collected from two different locations. 3 samples from Klong Ha, Klong Luang, Pathum Thani province and 4 samples from an organic goat farm, which is located in Bang Sai, Phra Nakhon Si Ayutthaya province (Table 1). The inoculation was done by using an anaerobic jar. Anaero pack™ was incubated in 37ºC for 12-18 hrs and suspended solids at dilution 10^{-6} cell/ml, later were evacuated into RCM (Reinforce Clostridium Medium). Determination of colony was carried out by simple streak method, [20] then analysis of methane production by gas chromatography (Agilent Technologies GC 6890, USA).

Table 1 Sites and types of soil samples

Site	Samples
Klong Ha, Klong Luang, Pathum Thani	1. Soil at 10 cm deep 2. Soil under the garbage dump 3. Water-well sediment
Organic goat farm Bang Sai, Phra Nakhon Si Ayutthaya	4. Soil at 10 cm deep 5. Soil under the garbage dump 6. Water-well sediment point-1 7. Water-well sediment point-2

Biomolecular approach for morphological characterization and classification of microbe species

All samples were DNA extraction following by Zhou et al (1996) [21]. Pair primers of 27F (5'- GAGTTTGATCMTGGCTCAG-3') and 1492R (5'CGGTTACCTTGTTACGACTT-3') were used for Polymerase Chain Reaction (PCR). Mixture PCR solution contained 5 pmol/µl each primer, 10 mM dNTP, 10X PCR buffer+$MgCl_2$ 5U/µl Taq DNA poly-merase, and adjusted DI water to total volume at 50 µl. The PCR condition with the thermal profile of denaturation step by 1 cycle, 94°C for 3 min, annealing step followed by 35 cycles at 94°C for 30 sec, 55°C for 30 sec, and 72°C for 1.1 mins, and final extension step at 72°C for 10 min. PCR products were kept under 4°C and then were checked targeting size by 1% agarose gel with 1X TBE buffer under electrode at 100 volts for 40 min and fragment DNA base was sent tosequencing and blasted result by NCBI's GenBank.

Napier grass extract preparation and Characteristic Analysis

Napier grass was obtained from the Faculty of Agricultural, Kasetsart University, Kamphaeng Sean campus, Nakorn Prathom province, Thailand. The Napier grass (*Pennisetum purpureum*) was harvested at 60 (Pak Chong 1 stain) and >90 days (mixed Pak Chong 1 stain at the age of 90 days with Taiwan stain at the age of 110 days), and, extracted by cold screw press shown in Figure 1(A). Napier grass of 60 days and over 90 days were extracted approximately 100 ml/kg and 50 ml/kg (Figure 1B), respectively.

(A) **(B)**

Figure 1 Cold screw press for produce extract Napier grass (A) and Napier grass extract age >90 days in serum vials (B)

The physical and chemical characteristics of Napier extract were determined in COD, SCOD, TKN, ammonia, TS, VS, alkalinity, VFA, and pH in triplicate according to the procedures in the APHA Standard Method [22] and analyzed in 3 replicates shown in Table 2.

Biochemical methane potential assay

The BMP method (biochemical methane potential) was used to determine the optimum day of Napier grass and hydraulic retention time (HRT) with the highest biogas yield in lab-scale [23], and the studies were carried out in serum vials in replicate, as shown in Table 2.

Table 2 Conditions of the experiments

Age (days)	Sample	Napier Grass extract (ml)	Microbe (mg)	
			G	K
60	$N_{60}G$	60	600	-
	$N_{60}K$	60	-	600
	$N_{60}KG$	60	300	300
	$N_{60}C$	60	-	-
>90	$N_{90}G$	60	600	-
	$N_{90}K$	60	-	600
	$N_{90}KG$	60	300	300
	$N_{90}C$	60	-	-

Remark: G: *Clostridium beijerinckii*, K: *Cutibacterium acnes*, C: without inoculation

All sample-experiment tests were incubated at 35°C with 120 RMP for 24 hrs, and the samples were collected on an alternate day until the reaction ended.

Analysis

COD, SCOD, TKN, ammonia, TS, VS, alkalinity, VFA, and pH were determined before and after the experiments. Gas samples were analyzed with gas chromatography in three replicates, and the biochemical methane potential (BMP) was calculated as follows:

$$\text{BMP} = \frac{(ml\ Methane)}{gTS\ removal} = \frac{Biogas\ (l) \times Methane\ (\%)}{(TS\ influence - TS\ effluence)(mg/l)}$$

Results and Discussion

The result of anaerobic microbe selection and biogas production

Anaerobic microbes from nine samples produced methane, including soil under garbage dumps (Isolates 3 and 5), water-well sediment (Isolates 6 and 7), and the organic goat farm Bang Sai in Phra Nakhon Si Ayutthaya. These samples included soil 10 cm deep (Isolate No. 9), soil under garbage dumps (Isolate No. 13), and water-well sediment (Point 1). However, Ananou et al. [24] found that 10 cm of the soil sample had the ability to produce biogas from fermented paper. 3,000 and 4,000 ml produced 6 and 9 ml/g of paper, which was consistent with this study (Figure 2).

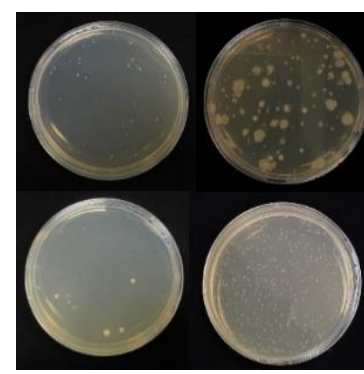

Figure 2 Colony characteristics of microorganisms at dilution 10^{-2}-10^{-8}

Result of methane production

The K5-1, G-5, and G-2 samples had the highest methane contents of 87.32%, 81.46%, and 48.13%, respectively (Table 3). The K5-1 and G-5 showed the highest methane content. And the production of methane in the extraction process was at Napier's age of 60, and over 90 days were tested in the experiments.

Morphology

Methane-producing microbes from nine isolates were gram-stained to determine their arrangement and staining. According to Table 4, nine isolates were gram-positive, seven isolates were bacilli, and group arrangement Cocci and group A were the other two isolates.

Results of biomolecular analysis

Classification of microbe species by biomolecular method. Furthermore, the DNA base content was compared to the NCBI's GenBank program. The identified microbe species resulting from K5-1 and G-5 were Clostridium beijerinckii (MN733990.1) and Cutibacterium acnes (MT613579.1), respectively, and were more similar than 99%.

Table 3 Characteristics of the growth, gas production, and methane content of microbe

Sample	Isolate (label)	Colony	Biogas Production	Methane content (%)
1. soil at 10 cm deep	1	circular, milky white, small	-	/
	2	circular, milky white, small	-	/
2. soil under the garbage dump	3 (K5-1)*	smooth-edged, cream	+	87.32
	4	circular, milky white, small	-	/
	5 (K5-4)	circular, milky white, small	+	19.78
3. Water-well sediment	6 (K5-2)	jagged-edge, clear white, small	+	/
	7 (K5-3)	smooth-edged, cream	+	/
4. soil at 10 cm deep	8	circular, white, smooth-edged	-	/
	9 (G-1)	circular, white, smooth-edged	+	21.74
	10	jagged edge, milky white	-	/
5. soil under the garbage dump	11	circular, cream, smooth-edged	-	/
	12	circular, clear, smooth-edged	undeveloped	/
	13 (G-2)	circular, milky white, small	+	48.13
6. Water-well sediment point1	14	smooth edge, milky white, small	-	/
	15 (G-3)	jagged-edge, milky white, jagged surface	+	21.13
	16 (G-4)	jagged-edge, milky white, jagged surface	+	9.09
	17	circular, milky white, small	-	/
7. Water-well sediment point2.	18	cocci, clear, small	undeveloped	/
	19 (G-5)**	cocci, white, smooth-edged	+	81.46

Remark * : *Clostridium beijerinckii*, ** : *Cutibacterium acnes*, - : No gas production, + : Generate gas, / : No methane content

Table 4 Morphology by gram's straining method

Isolate	Appearance	Arrangement
3 (K5-1)	bacilli	single
6 (K5-2)	bacilli	single
7 (K5-3)	cocci	group
5 (K5-4)	bacilli	single
9 (G-1)	cocci	group
13 (G-2)	bacilli	single
15 (G-3)	bacilli	single
16 (G-4)	bacilli	single
19 (G-5)	cocci	group

Biochemical methane potential (BMP)

Biogas producing potential

Table 5 shows the physical and chemical properties of the Napier extract at 60 and 90 days. The high organic content of Napier extract makes it suitable for anaerobic treatment, with methane produced as a byproduct of selected microbe activity. The C/N ratio was 286.40 and 262.34 after inoculating selected microbes into Napier extract age 60 and over 90 days [25] A high C/N ratio reduces nitrogen production and reduces biogas production. A C/N ratio of 20 to 30 is appropriate for anaerobic digestion, and biogas produces the highest yield [26]. However, if the C/N ratio is low, it will cause the system to accumulate a lot of ammonia as a result of the breakdown of nitrogen, which will result in alkalinity and the formation of biogas [27]. According to J. Dioha et al. [26], who studied the effect of the C/N ratio of the substrate on biogas methane inoculated with cow dung, poultry droppings, rice husks, neem tree leaves, and sugar cane bagasse, the C/N ratios of neem tree leaves and sugar cane bagasse were 82:1 and 47:1, respectively. While digesting, those substrates have little or no odor. However, the

biogas yield of neem tree leaves and sugar cane bagasse was low (0.65 and 0.20 m^3/kgVS). Napier's extract VFA/Alkalinity Ratios at 60 and over 90 days were 1.64 and 3.50, respectively: a VFA/Alkalinity Ratio greater than 0.3-0.4 reduced stability in anaerobic digestion [28]. by accumulating in the system volatile fatty acids, causing the pH to become acidic [29].

Table 5 Characteristic of Napier grass extract at 60 and >90 days (mean±standard deviation)

Parameter	unit	Days	
		60	>90
COD	mg/l	133,653.33± 1,293.33	134,666.67± 4,664.99
sCOD	mg/l	123,946.67± 466.93	60,131.20± 4528.27
TKN	mg/l	466.67±80.83	513.33±80.83
NH4	mg/l	5.13±0.81	4.20±1.40
Alk	mg/l as $CaCO_3$	305.33±18.04	166.67±28.87
TS	mg/l	104.2083± 1.2925	103.9064± 28.9751
VS	%	52.37±23.69	77.20±30.00
VFA	mg/l as $CaCO_3$	500.00±0.00	583.33.00±72.17
pH	-	5.00±0.00	5.43±0.20

Complex molecules were broken down into simple molecules by the enzyme of hydrolytic bacteria, and those molecules were transformed into other organic substances such as organic acids and alcohol. process of anaerobic acetic acid, carbon dioxide, hydrogen, and methane Thus, methane production can indicate hydrolytic activity [30].

Archaea, a methanogenic microbe, produces methane as a metabolic byproduct in anoxic environments. It has an unusual metabolic system because bacteria use H_2, CO_2, methylated C_1 compounds, or acetic acid as a carbon energy source to grow [31]. Methane production occurs by two methods: splitting the acetic acid molecule to create carbon dioxide and methane or reducing carbon dioxide with hydrogen [32]. It was observed that during the first 24 hr. no lag phase occurred in all experiments, like the research of Amornpan et al. [33], who studied the activity relationships in anaerobic sludge anaerobic digestion systems from various commercial digesters, such as pig farms, palm oil mills, and concentrated rubber latex factories, and found that no lag phase appeared from any inoculate sets over the first 24 hr.

The biogas potential of anaerobic digestion systems of microbes selected for fermentation in Napier extract at 60 and over 90 days is shown in Figures 3 and 4, respectively, for Clostridium beijerinckii at 60 and 90 days. Napier extract had biogas accumulations of 86.07 and 134.40 ml, respectively. 59.98% and 1.22% of maximal methane, methane accumulation was 0.16 and 0.11 ml, respectively, and 0.28 and 0.26 ml/gTS_{added} of BMP, respectively.

Cutibacterium acnes accumulated 99.70 and 108.80 ml of biogas in Napier extract ages 60 and over 90 days, respectively. Methane accumulation was 0.10 and 0.15 ml, respectively. Maximal methane was 22.65 and 21.07%, respectively and 0.44 and 0.17 ml/gTD of BMP, respectively.

Clostridium beijerinckii mixed with *Cutibacterium acnes* in equal proportions has methane accumulations of 54.27 and 107.63 ml, respectively. 59.98% of maximal methane, 0.02 and 0.08 ml of accumulated methane, respectively, and 2.29 and 0.33 ml/gTS_{added} of BMP, respectively. *Clostridium beijerinckii* and *Cutibacterium acnes* were anaerobic bacteria, and when they were in the right condition, they would generate biogas. However, research on the biogas potential and methane production of *Clostridium beijerinckii* and *Cutibacterium acnes* is limited.

The control experiment at 60 (N60C) and 90 (N90C) days had biogas accumulation at 20.80 and 16.16 ml, respectively; maximal methane at 0.18 and 0.15%, respectively; and methane accumulation at 0.65 and 0.03 ml, respectively. The BMP concentrations were 0.06 and 0.03 ml/g T added, respectively. The experiment with the control (N60C and N90C) produced biogas with the microbe that could be contaminated by the microbes on the Napier grass extract without sterilized and under anaerobic conditions.

In all experiments with 60 and 90 days of extracted Napier grass, Napier had HRT at 11 and 21. The methanogen bacteria are pH-sensitive and do not cause degradation activity at pH below 6.2, causing less production of methane [34]. Most anaerobic bacteria, including methanogen bacteria, have an optimal pH in the range of 6.8-7.2 [35]. The generation of biogas is influenced by a variety of variables, including temperature, concentration, material characteristics, and the carbon-nitrogen ratio. The production of biogas depends on mixing, acidity, and material type [36].

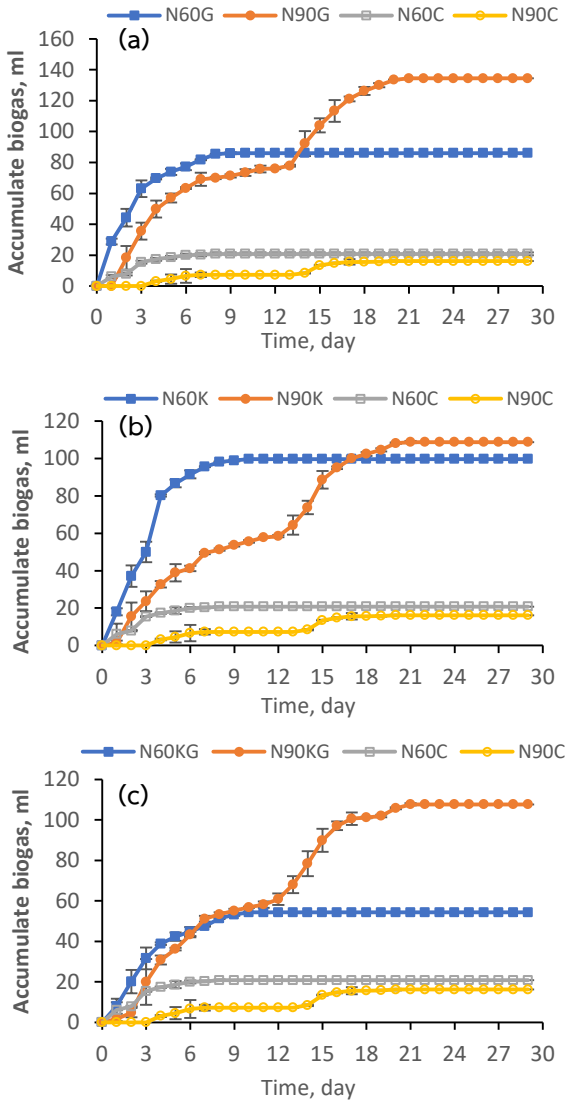

Figure 3 Biogas accumulation of extraction Napier age 60 days and >90 days inoculated with microbe (a) *Clostridium beijerinckii*, (b) *Cutibacterium acnes*, (c) *Clostridium beijerinckii* mix with *Cutibacterium acnes*

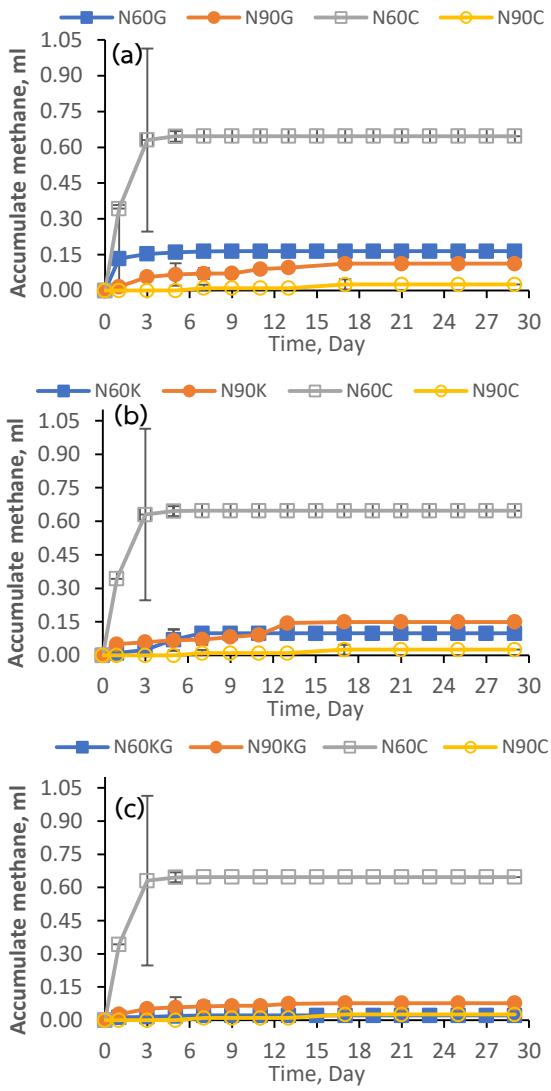

Figure 4 Methane accumulation of Napier extract age 60 days and >90 days inoculated with microbe (a) *Cutibacterium acnes*, (b) *Clostridium beijerinckii*, (c) *Clostridium* beijerinckii mix with *Cutibacterium acnes*

Conclusions

The study of biogas production potential from water Napier extract aged 60 and over 90 days by outward microbes found that N60G, N60GK, and N90GK had maximal methane of 59.98%, total methane accumulation of 4.84, 1.02, and 0.53 ml, respectively, and BMP of 0.28, 2.26, and 0.33 ml/TS_{added}, respectively.

The results showed that Clostridium beijerinckii and Cutibacterium acnes were the outward group of biogas-producing microbes that had the potential for biogas production by anaerobic digestion from extraction Napier at age 60 and over 90 days, with 11 days of HRT. Therefore, anaerobic digestion depends on the C/N ratio and the VFA/alkalinity ratio. The microbe will be encouraged to perform more

effectively if it is in the optimal range, including in terms of producing methane and biogas.

The goal of this study was to experiment with outwardly visible microbes that are easily found and natural at those sites. This result demonstrated that the visible microbes have the potential to produce methane, but at a lower yield than the methanotroph. Because they are a carbon source for methanotrophs and have a low tolerance and slow rate of production in the anaerobic digestion system, these visible microbes can also produce CO_2. However, we expect the outwardly facing microbes would help to actuate the activity of methanotrophs in the sense of producing more carbon sources to improve methane production.

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References

[1] Gurung, A., Ginke, S.W.V., Kang, W. and Qambrani, N.A. 2012. Evaluation of marine biomass as a source of methane in batch tests: a lab-scale study. Energy, 43(1): 396-401.

[2] Deymi-Dashtebayaz, M., D. Dadpour and J. Khadem. 2021. Using the potential of energy losses in gas pressure reduction stations for producing power and fresh water. Desalination, 497: 114763.

[3] Hekmatshoar, M., Deymi-Dashtebayaz, M., Gholizadeh, M., Dadpour, D. and Delpishen, M. 2022. Thermoeconomic analysis and optimization of a geothermal-driven multi-generation system producing power, freshwater, and hydrogen. Energy, 247: 123434.

[4] Deymi-Dashtebayaz, M., M. Rezapour, and M. Farahnak. 2022. Modeling of a novel nanofluid-based concentrated photovoltaic thermal system coupled with a heat pump cycle (CPVT-HP). Applied Thermal Engineering, 201: 117765.

[5] Tayyeban, E., M. Deymi-Dashtebayaz, and D. Dadpour. 2022. Multi objective optimization of MSF and MSF-TVC desalination systems with using the surplus low-pressure steam (an energy, exergy and economic analysis). Computers & Chemical Engineering, 160: 107708.

[6] Verstraete, W., Sagastume, M., Aiyuk, S., Wawery, M., Rabaey, K. and Lissens G. 2005. Anaerobic digestion as a core technology in sustainable management of organic matter. Water Science and Technology, 52(1-2): 59-66.

[7] Emebu, S., J. Pecha, and D. Janáčová. 2022. Review on anaerobic digestion models: Model classification & elaboration of process phenomena. Renewable and Sustainable Energy Reviews, 160: 112288.

[8] Ali, S., Shafique, O., Mahmood, S. and Mahmood, T. 2020. Biofuels production from weed biomass using nanocatalyst technology. Biomass and bioenergy, 139: 105595.

[9] Cruz, I.A.,Melo, L.D., Leite, A.N., Sátiro, J.V.M., Andrade, L.R.S., Torres, N.H.T., Padilla, R.Y.C., Bharagava, R.N., Tavares, R.F. and Ferreria, L.F.R. 2019. A new approach using an open-source low cost system for monitoring and controlling biogas production from dairy wastewater. Journal of Cleaner Production, 241: 118284.

[10] Kusmayadi, A., Lu, P.H., Huang, C.Y. and Kit, L.Y. 2022. Integrating anaerobic digestion and microalgae cultivation for dairy wastewater treatment and potential biochemicals production from the harvested microalgal biomass. Chemosphere, 291: 133057.

[11] Tayyeban, E., M. Deymi-Dashtebayaz, and M. Gholizadeh. 2021. Investigation of a new heat recovery system for simultaneously producing power, cooling and distillate water. Energy, 229: 120775.

[12] Saratale, G.D., Saratale, R.G., Banu, J.R. and Chang, J.S. 2019. Biohydrogen production from renewable biomass resources, in Biohydrogen, Elsevier. 247-277.

[13] Gholizadeh, M., Dashtebayaz, M.D., Mehri, A., Zameli, A. and Dadpour, D. 2022. Experimental evaluation and optimization of the anaerobic digestibility of two new desert weeds for biogas

production. Biomass Conversion and Biorefinery, 1-11.
[14] Lehtomäki, A. 2006. Biogas production from energy crops and crop residues. University of Jyväskylä.
[15] Okaraonye, C. and J. Ikewuchi. 2009. Nutritional and antinutritional components of Pennisetum purpureum (Schumach). Pakistan Journal of nutrition, 8(1): 32-34.
[16] Lerdlattaporn, R., C. Phalakornkule and W. Songkasiri. 2021. LIGNOCELLULOSIC BIOMASS TO BIOGAS: BIOCHEMICAL METHANE POTENTIAL FROM FIELD GRASSES IN THAILAND. SEATUC journal of science and engineering, 2(1): 8-14.
[17] Mayuree, C. and C. Orathai. 2016. Study of Napier Grass Harvesting Age Influencing on Biogas Production. Thai Environmental Engineering Journal, 30: 39-47.
[18] Mullai, P., Vishali, S., Yogeswart, M.K., Lopez, M.E. and Rene, E.R. 2020. Methane production and recovery from wastewater, in Current Developments in Biotechnology and Bioengineering. Elsevier. 17-36.
[19] Liu, L.-Y., Xie, G.J., Ding, J., Liu, B.F., Xing, D.F., Ren, N.Q. and Wang, Q. 2022. Microbial methane emissions from the non-methanogenesis processes: A critical review. Science of The Total Environment, 806: 151362.
[20] Katz, D.S. 2008. The streak plate protocol. Microbe Library.
[21] Zhou, J., M.A. Bruns, and J.M. Tiedje. 1996. DNA recovery from soils of diverse composition. Applied and environmental microbiology, 62(2): 316-322.
[22] AWWA-WEF, A.-. 2005. Standard methods for the examination of water and wastewater. Edición, 21: 5-10.
[23] Owens, J. and D. Chynoweth. 1993. Biochemical methane potential of municipal solid waste (MSW) components. Water Science and Technology, 27(2): 1-14.
[24] Ananou, S., ZINEB, B., LAILA, M., AND GHACHTOULI, N.E. 2021. Production of biogas and ethanol from stationery wastes using a microbial consortium isolated from soil as starter culture. Universitas Scientiarum, 26(3): 318-335.
[25] Weerayutsil, P., U. Khoyun, and K. Khuanmar. 2016. Optimum ratio of chicken manure and napier grass in single stage anaerobic co-digestion. Energy Procedia, 100: 22-25.
[26] Dioha, I., Ikeme, C.H., Nafi'u, T., Soba, N.I. and Uusuf, M.B.S. 2013. Effect of carbon to nitrogen ratio on biogas production. International Research Journal of Natural Sciences, 1(3): 1-10.
[27] Kigozi, R., A. Aboyade, and E. Muzenda. 2013. Biogas production using the organic fraction of municipal solid waste as feedstock. World, 5: 6.
[28] Sambusiti, C., Ficara, E., Malpri, F., Steyer, J.P. and Carrere, H. 2013. Benefit of sodium hydroxide pretreatment of ensiled sorghum forage on the anaerobic reactor stability and methane production. Bioresource technology, 144: 149-155.
[29] Mézes, L., Biro, G., Sulyok, E. and Petis, M. 2011. Novel approach of the basis of FOS/TAC method in Proceedings. International Symposia "Risk Factors for Environment and Food Safety" and "Natural Resources and Sustainable Development".
[30] Phuttaro, C., Reungsang, A., Boonsawang, P. and Chiaiprapat, S. 2019. Integrative effects of sonication and particle size on biomethanation of tropical grass Pennisetum purpureum using superior diverse inocula cultures. Energies, 12(22): 4226.
[31] Christy, P.M., L. Gopinath, and D. Divya. 2014. A review on anaerobic decomposition and enhancement of biogas production through enzymes and microorganisms. Renewable and Sustainable Energy Reviews, 34: 167-173.
[32] Mosey, F. and X. Fernandes. 1988. Patterns of hydrogen in biogas from the anaerobic digestion of milk-sugars, in Water Pollution Research and Control Brighton, Elsevier. 187-196.
[33] Thaemngoen, A., Phuttaro, C., Saritpongteeraka, K. and Leu, S.Y. 2020. Biochemical methane potential assay

using single versus dual sludge inocula and gap in energy recovery from napier grass digestion. BioEnergy Research, 13(4): 1321-1329.

[34] Samani Majd, S., Abdoli, M.A., Karbassi, A., Pourzamani, H.R. and Rezaee, M. 2017. Effect of physical and chemical operating parameters on anaerobic digestion of manure and biogas production: A review. Journal of Environmental Health and Sustainable Development, 2(1): 235-247.

[35] Horiuchi, J.-I., Shimizu, T., Tada, T., Kanno, T. and Kobayashi, M. 2002. Selective production of organic acids in anaerobic acid reactor by pH control. Bioresource technology, 82(3): 209-213.

[36] Qiao, W., Yan, X., Ye, J., Sun, Y., Wang, W. and Zhang, Z. 2011. Evaluation of biogas production from different biomass wastes with/without hydrothermal pretreatment. Renewable energy, 36(12): 3313-3318.

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Variation of Moisture Accumulation of Ancient Remains in the Early Ayutthaya Period, The Residence of the Patriarch of Wat Bhudthaisawan, Pranakorn Sri Ayutthaya Province, Thailand

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Abstract

This study measured moisture accumulation variation in the walls of ancient remains and compared it to results from the same measurement site over the last 13 years. It has the potential to reveal significant changes in moisture accumulation. Important murals inside buildings can deteriorate over time if they are not properly cared for. The purpose of this research is to determine the accumulated moisture content on the surface of an ancient wall from the Late Ayutthaya Period. The study was conducted in the patriarch's residence at Wat Bhudthaisawan, Pranakorn Sri Ayutthaya, by measuring the accumulated moisture contents on the surface of the wall at systematically selected locations with a Moisture Meter. The analysis discovered a statistically significant difference between measuring accumulated moisture in the wall at different heights. Moisture accumulation in the wall at the highest level adjacent to the roof had the highest value in all directions and the moisture accumulation in the walls was statistically significantly higher when compared to the results of the study 13 years ago.

Keywords : Moisture; Ancient remains

Introduction

Thailand is in a tropical zone, with relatively high air temperatures and relative humidity all year. High humidity is a leading cause of damage to priceless national art. Moisture in the air, moisture from rain, moisture from the soil, groundwater quantity, and building material are all factors that contribute to moisture accumulation in buildings [1].

Previous research on the relationship between the volume of human activity in buildings and air temperature and relative humidity discovered that they were significantly low within the various styles of buildings and their ventilation. They demonstrated that the air temperature and relative humidity changed over time, with a significant difference each day [1]. The variation of moisture content data in the walls will be an important factor in the materials used in the building's moisture restoration. Measuring the variation of humidity accumulation in the walls of ancient remains and comparing it to results obtained at the same measurement site over the previous 13 years may allow us to detect significant changes in moisture accumulation. Important murals inside buildings can deteriorate over time if not properly cared for. This study may point to the primary causes of the mural's destruction and may also be used as a guide to the restoration of this ancient site using environmental science principles as a guide.

Study area

The study area is located in the ancient remains of the early Ayutthaya Period, the residence of the patriarch of Wat Bhudthaisawan one of the so call temples in the province of Phra Nakhon Si Ayutthaya on the south side of the Chao Phraya River, it is situated across from the city island (Figure 1). This structure was erected where King Ramathibodi I tabernacle once stood

before he moved his capital from Ayutthaya to Ayutthaya. Wat Bhutthaisawan was built as a royal monument during the founding of Ayutthaya in 1353 AD. by decree of King Ramathibodi I. The Important historical structures, including the main pagoda and the residence of Somdej Phra Buddhakosachan, can be found inside the temple.

A historical illustration of Somdej Phra Buddhakosachan's journey to Lanka can be found on the wall. The paintings that decorate the residence are dated to the late Ayutthaya period (1788–2245 B.E.), which corresponds to the rule of Somdet Phra Pet Raja. The painting is made with powdered paint. The way the image is put together tells a tale by placing photographs of various events on each wall [2].

The residence of the patriarch of Somdej Phra Buddhakosachan is an ancient site of great religious and historical value (Figure 2). Currently, it has deteriorated over time. Due to being located on the banks of the Chao Phraya River, it is affected by flooding in the flooding season, causing the walls of the building to have a high level of humidity. This results in the deterioration of the murals over time.

Data collection

In this study, data was collected from July - December 2021 by monthly measurement of the variation of moisture inside the wall. The accumulated moisture contents on the wall's surface were measured at the systematically selected locations using a Moisture Meter. Each point is separated by a distance of about one meter but excludes door and window regions. The east and west walls have a height of about 6 meters and a length of about 5 meters, so the humidity measurement positions can be set to 6 positions in a row, a total of 30 (5Row-6column) (Figures 3). The north and south walls have 4 meters high and about 18 meters long, so there can be 4 humidity measurement positions in each row, a total of 60 positions (4Row-15column) (Figure 4).

Data analysis

This study will analyze the data in different ways by using descriptive statistical analysis, and two-sample tests, and statistical significance was determined with the Pearson correlation coefficient ($p < 0.05$).

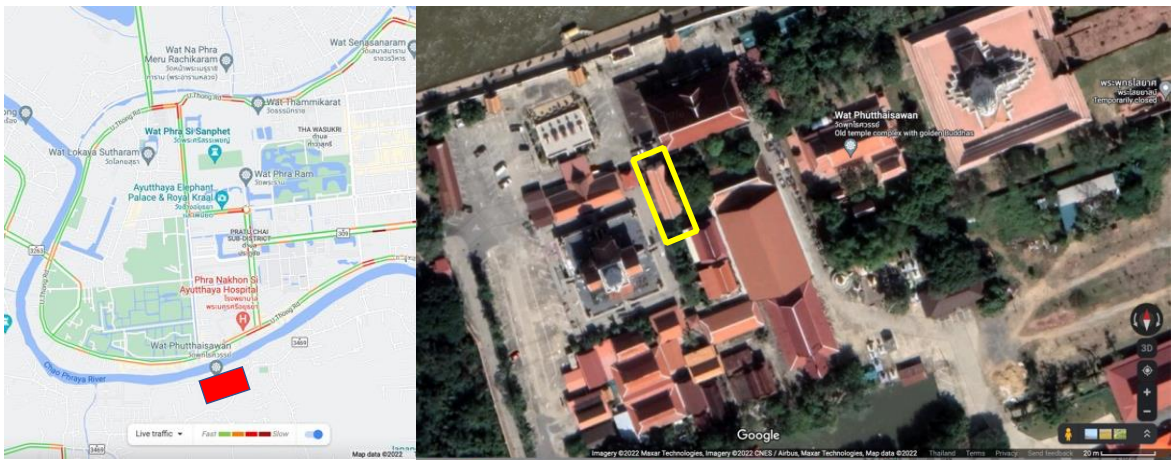

Figure 1 Map of Phra Nakhon Si Ayutthaya (upper) and the area of Wat Bhudthaisawan which locate on the south side of the Chao Phraya River (yellow mark)
Source: www.google.com/maps, 2022

Figure 2 The area of residence of the patriarch of Somdej Phra Buddhakosachan

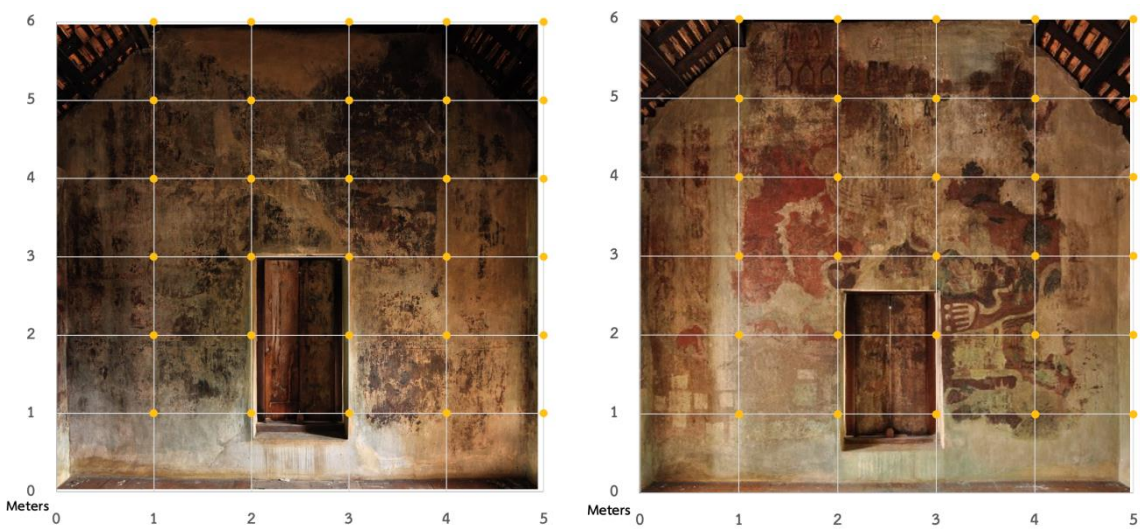

Figure 3 Positions of moisture accumulation measurement in the east wall (left) and the west wall (right)

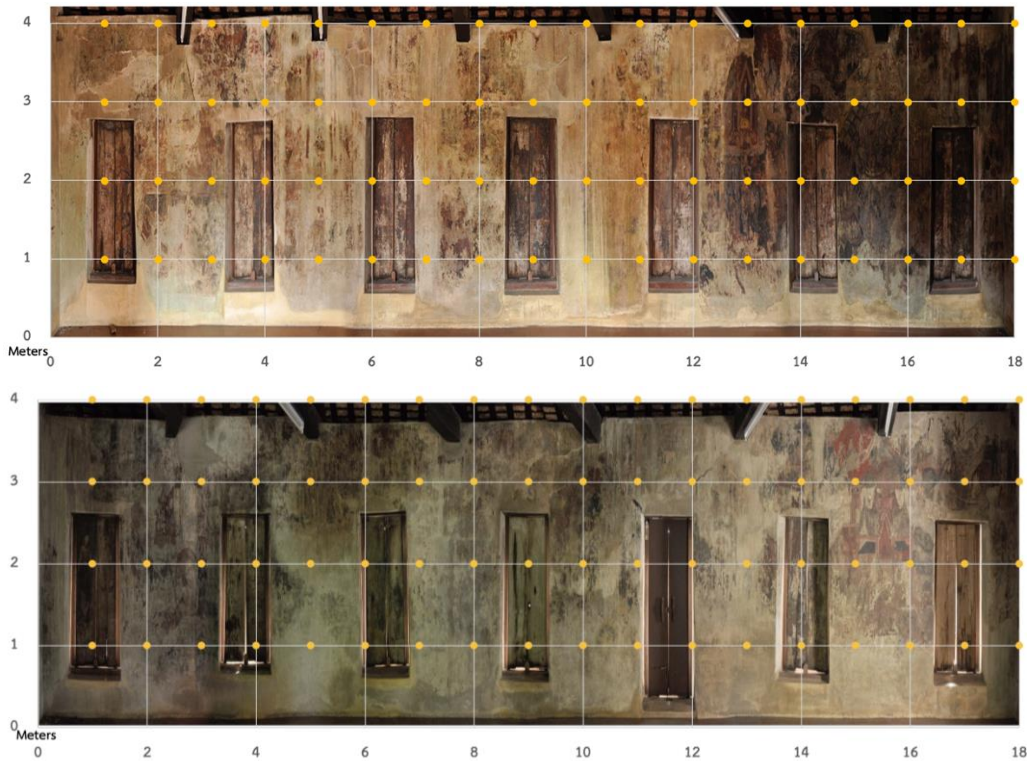

Figure 4 Positions of moisture accumulation measurement in the north wall (upper) and the south (lower)

Results

The variation of moisture accumulation (MC) in the wall

The analysis of variance for moisture accumulation in the walls on all four sides of the line (from the ground) is the main factor, and the order of the set as a factor in segmenting (Blocking factor) revealed that the variation between the rows is significantly ($p < 0.05$) different in three directions of the building, except for the west wall (Table 1), while the variation between columns is not significantly different. Furthermore, upon examining the relationship between MC and an average elevation above ground, a relationship between MC 2021 and height off the ground has been found: It should be noted that moisture at the highest level adjacent to the roof had the highest value in all directions, while moisture at the middle level had the lowest value. This is why the mural in the middle of the wall is still relatively intact. It's worth noting that the most intact part of the mural is located 2-3 meters above the ground level. The MC in this area is relatively low. Because this is a two-story structure, the influx of groundwater effects, as well as the pores of the walls, which can penetrate approximately one meter upwards and then evaporate from the wall, have less influence than rainwater [3].

Table 1 The p-value from the analysis of variance of the moisture accumulation in the walls in the row and column of each wall

Wall Direction	p-value	
	Row	Column
East	0.01	0.44
West	0.08	0.70
North	0.05	0.64
South	0.00	0.87

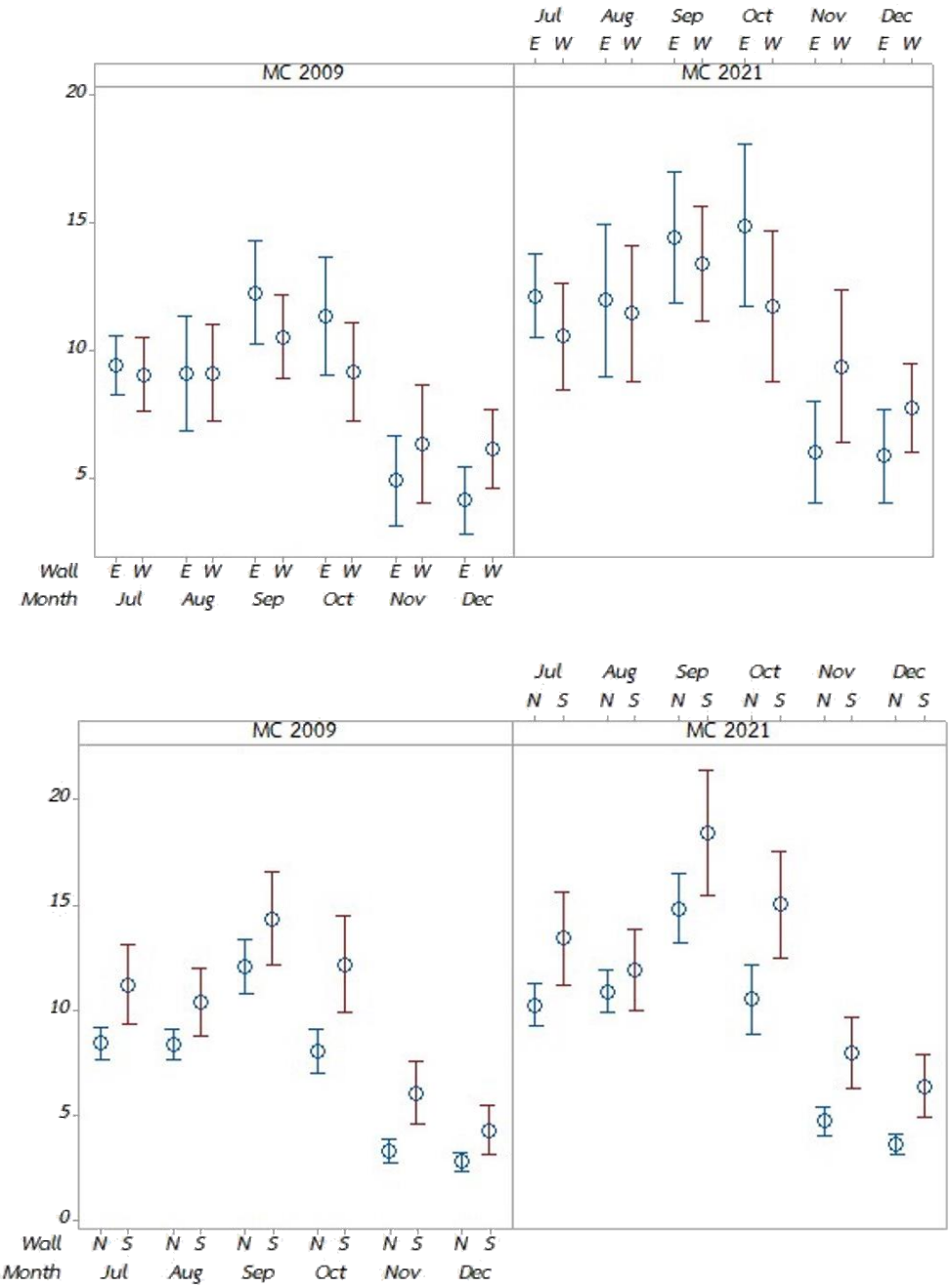

Figure 5 The interval graph compares MC2009 and MC 2021 over a 6-month period (Jul-Dec). Comparisons of building wall sizes are shown in pairs

A comparison study of moisture accumulation in walls between 2009 and 2022 using the T-Value of Paired-samples T-test. MC 2021 was discovered to have increased statistically significantly (Table 2 and Figure 5). The maximum increase trend may be influenced by rain, which is influenced by the southwest monsoon in Thailand during the rainy season.

Table 2 T-Value of Paired-samples T-test between moisture accumulation in the walls of 2009 and 2022

	East 2021	West 2021	North 2021	South 2021
East 2009	-12.88**			
West 2009		-12.48**		
North 2009			-15.63**	
South 2009				-16.68**

(**P<0.01, *P<0.05)

Conclusion

Due to rain, the humidity in the walls of this building varies significantly and peaks at about 1.00 meters below the roof. When the amount of moisture accumulated in the wall is compared to the previous 13-year study, it is discovered that the amount of moisture accumulated in the walls of this ancient building has increased. This could be because the material has deteriorated. A single-story building built close to the ground is distinguished by this phenomenon. The amount of groundwater absorbed by capillaries action is effective at 1 - 2 m above ground level [4]. Moisture is one of the most important factors influencing building performance and durability, particularly in humid climates. Moisture-related problems in the building include chemical deterioration and dissolution of materials such as gypsum sheathing and glued wood products [5].

The MC problem must be addressed at its source. The primary causes are water leaks and moisture condensation. The initial cause must pinpoint the location of the leak. It could be a perforated ceiling or a wall-to-roof joint. These joints are being repaired. Walls exposed to direct rain and moisture seeping through old plaster Care must be taken, especially during storms, to avoid splashing rain and to allow the building to dry completely before closing [6].

Moisture is a major factor in the degradation of porous masonry materials such as stones, bricks, mortar, and plaster. The open pores in the plaster and brick/stone masonry supports, as well as their contact with the microclimate and external factors, cause problems for wall paintings in particular [7]. Salt solutions that easily transfer to the plaster beneath the painting may find their way through the porous mortar backing and onto the wall. The volumetric expansion caused by the crystallization of these salts may have a negative impact on the adhesion of the pictorial film to the plaster as well as the adhesion between the plaster layers, resulting in the surface disintegrating [8]. The study of theology for the preservation of ancient sites is still limited at the moment. For these reasons, the pursuit of appropriate methods for preserving valuable ancient sites should be given careful consideration [9].

Because the monthly and annual rainfall in central Thailand is expected to be higher than average in 2022. In order to preserve cultural heritage, relevant authorities must take this damage into account. As a result, ancient buildings with roof leaks or that are exposed to rain may accumulate more moisture (1991-2020). In order to preserve cultural heritage, relevant authorities must consider this damage. The paintings inside this historic structure are very old and susceptible to moisture damage. The traditional short roof style is vulnerable to the effects of rainwater. During the rainy season, opening the building for ventilation and using fans to help ventilate may be an option.

The findings of this study can be viewed as a case study on the impact of moisture on buildings in general and historical sites in particular, implicating future construction and restoration considerations. Moisture level measurement and management in historical sites should be viewed as an ongoing process that will guide future cultural heritage conservation planning.

References

[1] Popradit, A. and Khun-Anek, R. 2019. Influences of the number of tourists on

the alteration of temperature and relative humidity in ancient buildings. Journal of Research and Development Valaya Alongkorn Rajabhat University under Royal Patronage, 14(1), 33-44.

[2] Brereton, B. P. 2013. Mediums, Monks, and Amulets: Thai Popular Buddhism Today by Pattana Kitiarsa. The Journal of the Siam Society, 101, 291-294.

[3] Oxley, T. A. and Gobert, E. G. 1983. Dampness in Buildings: Diagnosis, Treatment, Instruments. England: Butterworths.

[4] Busser, T., Berger, J., Piot, A., Pailha, M. and Woloszyn, M. 2018. Comparison of model numerical predictions of heat and moisture transfer in porous media with experimental observations at material and wall scales: An analysis of recent trends. Drying Technology.

[5] Straube, J. F. 1999. Moisture control and enclosure wall systems (pp. 4983-4983). The University of Waterloo.

[6] Hoła, A., Zygmunt, M. and Jerzy. 2017. Analysis of the moisture content of masonry walls in historical buildings using the basement of a medieval town hall as an example. Procedia Engineering, 172, 363-368.

[7] Capitani, D., Proietti, N., Gobbino, M., Soroldoni, L., Casellato, U., Valentini, M., and Rosina, E. 2009. An integrated study for mapping the moisture distribution in an ancient damaged wall painting. Analytical and bioanalytical chemistry, 395(7), 2245-2253.

[8] Liu, B.D., Wen, J., Lin, L. and Peng, F. 2014. Effect of moisture content on static compressive elasticity modulus of concrete." Construction and building materials, 69, 133-142.

[9] Hola, A. 2017. Measuring of the moisture content in brick walls of historical buildings–the overview of methods. In IOP Conference Series: Materials Science and Engineering, 251(1), 012067.

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[1] Inthorn, D., Sidtitoon, N., Silapanuntakul, S. and Incharoensakdi, A. 2002. Sorption of mercury, cadmium and lead in aqueous solution by the use of microalgae. Science Asia. 28(3): 253-261.

Reference to article or abstract in a conference proceedings:

[1] Inthorn, D., Singhakarn, C. and Khan, E. Decolorization of reactive dyes by pre-treated Flute reed (phargmites karka (Retz)). At 34th Mid-Atlantic Industrial & Hazardous Conference, Annual Mid Atlantic Industrial and Hazardous Waste Conference at Rugers University, New Jersey, USA on September 20-21, 2002.

Reference to a book:

[1] Polprasert, C. 1996. Organic Waste Recycles. John Wiley & Sons Inc., New York.

Reference to article in a conference proceedings:

[1] Inthorn, D. Heavy metal removal. In: Kojima, H. and Lee, Y.K. Photosynthetic Microorganisms in Environmental Biotechnology, Springer-Verlag, 2001; 111-135.

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