Experimentation of Evaporation Suppression by Various Plastic Bottles Coverage Area

Laksamon Raksaksri*, Vacharapoom Benjaoran, and Jiradet Settakhumpoo

***Abstract*—Evaporation significantly affects the loss of water in reservoir. The effective use of water-surface covering materials for evaporation reduction purpose is commercially performed including plastic spherical and circular shapes. This study initiates to reuse very common polyethylene terephthalate (PET) drinking-water bottles to cover water surface instead. The bottle shape could have a covering percentage ratio as much as 91% equal to a commercial ball or circular disk. The experiment was designed and conducted to prove the reduction of water evaporation rate using five simulated ponds. The testing aspect is the percentage of the coverage area over the water surface. Based on environmental impact concern, the deterioration of PET bottles due to hydrolysis reaction and ultraviolet rays in natural conditions is also investigated. The initial result from the experiment shows that PET bottles have a potential for the evaporation reduction which are a very cost-effective alternative to the existing commercial materials and help support the reuse of plastic waste.**

***Index Terms*—Degradation, drought, evaporation, reservoir, polyethylene terephthalate (PET) bottles, waste reuse**

I. Introduction

Evaporation is a major cause of water loss in reservoirs that results in insufficient water supply to sustain life. The evaporation can vary by months and seasons. In Thailand, the average monthly evaporation is between 100–200 mm [1]. Since water is such an essential life resource, many studies are carried out to reduce evaporation in reservoirs. The existing techniques can be divided into three categories: biological, chemical, and physical [2], each of which targets to control or eliminate the factors affecting evaporation. For example, a use of chemicals to form a thin film covering the water surface [3], a use of canvas [4], or floating plastic materials, such as balls [5] or disks to cover the water surface. Most of these are commercialized and research-based innovative products; therefore, they are costly. The disks are claimed to reduce the evaporation rate by 70%–80% [6, 7]. Existing research proposed to replace the commercial floating plastic covering with an innovative reuse of Polyethylene Terephthalate (PET) drinking-water bottles that are post-consumer waste [8]. The result showed that 100% covering area by PET bottles has capability to reduce water evaporation 40%. Another study compared the cost effectiveness of many evaporation reduction methods including the proposed method of reusing PET bottles [2]. It was found that PET bottles would cost per square meter the cheapest.

Nowadays, PET plastic bottles are commonly used for single use drinking water container. Hence, large amount of waste is generated, and without efficient waste sorting to recycling it dumps into a landfill, it destroys landscapes. Moreover, mixed waste such as plastic containers contaminated with food exudes a foul smell as air pollution and is the source of the epidemic. They may leak into the sea that endangers marine plants and animals [9]. Waste recycling can reduce the use of natural resources, petroleum, and create a sustainable product life cycle by reverting to new substrates [10]. Factors that cause plastic deterioration include ultraviolet rays from sunlight (photolytic), water (hydrolytic), acids, alkalis, stress from the impact of raindrops. wind or by enzymes of microorganisms [11, 12]. Deterioration of plastic possible to detect by morphology, thermal analysis, mechanical properties, molecular weight determination, and the elements or compounds characterization.

A reuse of PET bottles as a substitute for evaporation reduction will simultaneously solve both drought and plastic waste management problems. This technique is proved to be economically feasible [2]. However, reliable experimental results are required to confirm its effectiveness. Therefore, this paper aims to present the experimental design of evaporation reduction using PET bottles and its ongoing results. The experiment was comprehensively designed to cover the efficiency of reducing the evaporation rate, and the deterioration of PET bottles. First, the efficiency of evaporation reduction involves comparing the conditions from various factors, collecting the relevant meteorological data, and measuring the evaporation rate. The optimum configurations of the use of PET bottles will be determined. The other, the deterioration of PET bottles that have been exposed for long periods of flotation will be monitored to assess their service life.

II. Literature Reviews

Basic knowledge and existing relevant research are reviewed here to lay fundamental understanding of three interrelated sections including the nature of evaporation process, PET, and the standard quality of water in reservoirs. They are as the following subsections.

A. Evaporation Measurement and Estimation

It is impractical to directly measure evaporation of a reservoir; hence, the estimation is generally acceptable and one of the widely used methods is a simulation of the evaporation pan. Standard evaporation pans are divided into 3 types: buried, floating, and on-ground pans. The last one is

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the most used and universally accepted. It complies with the standards of the U.S. Weather Bureau Class-A Pan. It is a cylindrical container fabricated of galvanized iron with a depth of 10 in. and a diameter of 48 in. It is accurately leveled at a site that is nearly flat, well sodded, and free from any shade. This type of pan is easy to install and use, and reasonable price. The dropping water level (E_m) in the pan is measured and recorded daily. It must be compensated for precipitation (P, mm/day) which is rainfall in the pan location. Therefore, the compensated dropping water level (E_p) in the pan is recorded daily according to Eq. (1).

$$E_p = E_m + P \quad (1)$$

Still, it needs to be further adjusted with a constant called the Pan Coefficient (C_p) which is unique for each individual pan. Therefore, the estimated evaporation rate (E, mm/day) is according to Eq. (2). This value represents the local evaporation and is used for the hydrological design and the water resources management.

$$E = C_p E_p \quad (2)$$

B. Factors Affecting Evaporation

Evaporation is the process by which liquid water molecules in a reservoir convert to a gaseous state and float out into the atmosphere. Evaporation depends on the physical characteristics of the reservoirs, water quality and meteorological factors, i.e., solar radiation (R_s), relative humidity (RH), wind speed (u), air temperature (T). These four meteorological factors are usually measured for the estimation of the evaporation rate.

Solar radiation (R_s) is a source of heat energy that affects air temperature (T) and water subsurface temperature (T_w). Water molecules near the water surface move more when the water surface temperature rises until it is enough to overcome the intermolecular bonding force, and escape from the water. thereby causing the evaporation of water [13].

Relative humidity (RH) is the ratio of the actual amount of water vapor in the air to the amount of water vapor that will saturate the air at the same temperature. If the relative humidity in the air is higher, the water will evaporate less. This is because there is less room for new coming water molecules to fill in that air.

Wind speed (u) above the water surface is another important factor. In a place with good ventilation or wind blowing will cause more evaporation. Due to the movement of air, the vapor molecules above the water surface move away and cause a lack. As a result, the liquid molecules near the water surface can vaporize more to fill in the room.

The physical characteristics of the reservoirs is also a factor affecting evaporation. Since all evaporation takes place at the area of water surface, the greater the surface area of the reservoir, the more evaporation it is. Shallower reservoirs are easier to increase the water surface temperature and cause more evaporation than deeper reservoirs. In addition, water reservoirs that are outdoor evaporate more than those that are shaded by trees, building, or wind breakers.

Last, the water quality is also a factor. Water with a less impurity and less dense solution has a higher evaporation rate. Pure water is less dense than sea water; therefore, more evaporates.

C. PET Bottles

Drinking water bottles consist of three parts which are bottle, cap, and label. The main body of the bottles is commonly made of polyethylene terephthalate (PET) while the opaque cap is made of high-density polyethylene (HDPE) and the label is made of either polypropylene (PP) or polyvinylchloride (PVC). The PET bottles are high toughness, transparency, and recyclability, but low gas permeability. Also, it can be easily molded into a variety of shapes. Therefore, it is very suitable for a lightweight liquid container. The American Plastics Council has confirmed that diethyl hydroxylamine (DEHA) is not used in the production of PET bottles. In addition, the Food and Drug Administration (FDA) has approved the use of PET bottles as food containers.

PET is a thermoplastic polyester that is polymerized through a condensing polymerization between terephthalic acid and ethylene-glycol monomers at 280–285 ℃. In general, pure PET grades for food packaging bottles have a molecular weight in the range of 20,000–37,000 g/mol and has an intrinsic viscosity equal to 0.80 dL/g. The production of PET bottles includes the injection molding of bottle preform, which is a small tube shape, and then hot air blowing stretch the preform into the mold cavity of the desired shape [14], [15].

D. Plastic Deterioration

Disposed of mixed plastic waste by landfilling in open spaces can cause many serious problems. Some may be broken or gnawed by animals into small pieces and become microplastics. Microplastics means plastics that deteriorate from the environment and break into pieces as small as 20-300 micrometers, which are very difficult to manage [16]. Therefore, to reduce large amount of waste, a reuse is a primary method of plastic waste management. Although PET bottles exhibit a high chemical resistance under normal operating conditions, deterioration by neutral hydrolysis cannot be avoided in the presence of accelerated degradation variables: water, temperature at 200–280 ℃, pressure 10–40 atm.

Deterioration of plastic can be analyzed qualitatively and/or quantitatively through many techniques such as Attenuated Total Reflectance-Fourier Transform Infrared Spectrometry (ATR-FTIR), Differential Scanning Calorimetry (DSC), Thermogravimetric analysis (TGA) and Scanning Electron Microscopy (SEM). For some advanced characterizations are Gel Permeation Chromatography (GPC), H-Nuclear Magnetic Resonance Spectroscopy (H-NMR), etc.

E. Water Quality

Water quality refers to the condition of water that contains physical, chemical, and biological impurities. Water that is subjected to evaporation is surface water, or water that located on the top of the Earth's surface. Surface-water sources are such as rivers, canals, swamps, marshes, lakes, reservoirs, and other public water bodies within the land. The National Environment Board has categorized surface-water sources into five classes to be suitable for different purposes according to the quality of water found in those sources. It has set the quality standard of water for those sources to control and maintain their water quality [17].

Class 1 is a water source where the water quality is natural without any effluent from all kinds of activities.

Class 2 is a water source where receives some wastewater from certain activities, its water can be consumed after common treatment, and suitable for aquatic animals, fisheries, and water sports.

Class 3 is a source where water has poorer quality than Class 2, its water can be consumed after common treatment, and suitable for agriculture.

Class 4 is a source where water has poorer quality than Class 3, its water can be consumed after special treatment, and suitable for industry.

Class 5 is a source where water has the worst quality, its water is not suitable for consumption but only for transportation.

This standard is considered of the safety and health of people and environmental conservation of natural resources. The standard of surface water quality includes physical, chemical, and biological indexes. The physical indicators are such as the number of suspended solids, color, smell, taste, conductivity, turbidity, temperature, and hardness. The chemical indicators are related to dissolved hazardous chemicals, such as acidity-alkalinity, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), nitrates, ammonia, and heavy metals. The biological indicators are related to contamination with organisms, such as fungi, viruses, and bacteria. Particularly, the quantity of coliform bacteria is of concern by indicators which are Total Coliform Bacteria (TCB) and Fecal Coliform Bacteria (FCB). These indexes are criteria for indicating the quality of surface water suitable for any of those classes. Table I shows the selected quality indexes for the surface-water source class 2-4, which are standardized and controlled.

TABLE I: SELECTED STANDARD QUALITY INDEXES FOR SURFACE WATER

Index	Unit	Water quality for the source class*		
		2	3	4
Acidity	PH	5.0–9.0	5.0 – 9.0	5.0–9.0
DO	mg/L	6.0	4.0	2.0
BOD	mg/L	1.5	2.0	4.0
TCB	MPN/100 mL	5,000	20,000	n.a.
FCB	MPN/100 mL	1,000	4,000	n.a.
NO_3	mg/L	5.0	5.0	5.0
NH_3	mg/L	0.5	0.5	0.5
Zinc	mg/L	1.0	1.0	1.0
Lead	mg/L	0.05	0.05	0.05

*All figures are an upper bound, except for DO is a lower bound

III. EXPERIMENTAL DESIGN

The experimental design for the evaporation reduction with PET bottles was addressed on the efficiency of the technique. The details are as follows.

A. *Efficiency of Evaporation Reduction*

This experiment aims to determine the optimum configurations of PET bottles flotation for the evaporation reduction and to measure the efficiency of this new technique.

1) *Coverage area of the floating materials*

Water surface area is a crucial factor on evaporation. It is an air-water contacting place where the evaporation occurs. Many studies attempt to use various floating materials to cover the water surface area of reservoirs. The commercial Shade Balls (spherical balls) shade the coverage area as circles, and so do the commercial Aquacap (circular disks). Besides, PET bottles shade the coverage area differently, depends on their submerging level. It is assumed that the bottles are floating horizontally and sinking exactly halfway. These floating materials reduce the water surface area exposed to open-air or the area of evaporation. The coverage area by different shaped floating materials, i.e., spherical balls, circular disks and PET bottles are calculated and compared. Coverage percentage (CP) refers to a percentage ratio of the coverage area in case of the densest pattern to the containing area. The CP of circles is equal to 90.8% as shown in Fig. 1.

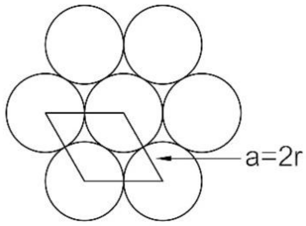

Fig. 1. Coverage area of the densest packing of circles.

For PET bottles, a typical drinking-water PET bottle with a packing size of 600 ml. is 0.240 m. high, 0.065 m. wide, and has a coverage area of $1.43\text{x}10^{-2}$ sq.m. The densest packing of them (horizontally laid) is shown in Fig. 2. The CP of the PET bottles are equal to 91.2% which is slightly more than that of the balls or circular disks. A used PET bottle costs about 0.005 US Dollar or about 0.30 US Dollar/sq.m. which is much cheaper than that of the commercial ones. Therefore, it is worthwhile to be used as an alternative material.

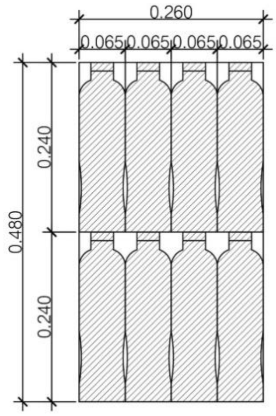

Fig. 2. Coverage area of a bottle shape versus the containing area.

2) *Bottles configurations*

It is hypothesized that the configurations of floating PET bottles may affect the performance of evaporation reduction rate. The solar radiation is a factor that promotes evaporation, but a PET bottle is a transparent material that allows radiation to penetrate the water. Therefore, it was hypothesized that the PET bottles must be opacified to reduce evaporation. Two different opaque materials, laminated aluminum foiled (LAF) and assorted plastic bags. LAF are commonly used as food or snack packaging bags. Assorted plastic bags come from many different uses in daily life. Both are also single-use plastic and garbage and can opacify the bottles, but LAF can reflect sunlight. The experiment is designed to put in LAF plastic bags and firmly filled up the bottles. Fig. 3 shows examples of the three bottles.

Fig. 3. Empty PET bottle (left), bottle filled with LAFs (middle), and bottle filled with assorted plastic bags (right).

The experiment is designed to vary the amount of flotation area covered with PET bottles into four sets as 25%, 50%, 75%, and 100% of the whole water surface area. All of those is bottles filled up with LAF. Their different efficiencies of evaporation reduction will be compared and a relationship between the percentage of the coverage area and the evaporation rate can be determined.

The experiment is designed to arrange the floating pattern as a free-floating. The free-floating pattern is a flotation of bottles that are not attached to each other. Fig. 4 shows the free-floating pattern. It is hypothesized that the free-floating pattern creates intermittent cover or fragmented shades and should be less effective than a continuous floating pattern. However, in practice the free-floating pattern will allow any water activities such as boating in the reservoirs and is cheaper to construct.

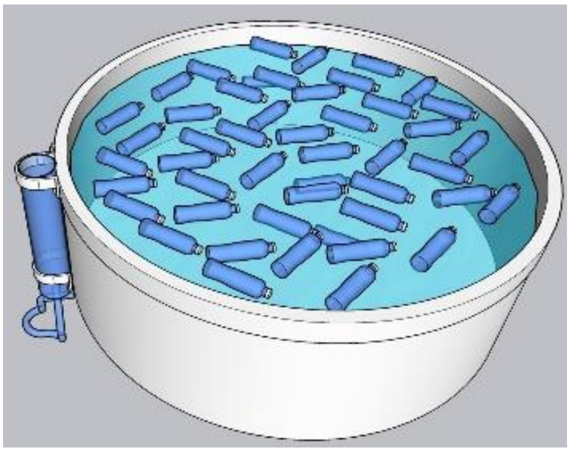

Fig. 4. The free-floating pattern.

3) Experimental ponds

The experiment is designed to use a plastic pond as a simulation of reservoirs. The experimental pond is made of durable food-graded, white-colored polyethylene (PE) plastic with a diameter of 1.90 m. and a height of 0.60 m. The water surface area is 2.84 m^2. On the side of each pond, a vertical clear acrylic pipe is installed for measuring the water level of the pond. The experimentation site is located at GPS coordinates 14.899851N, 102.009102E and at the elevation 183 m above sea level. From the experimental configurations, a total of five ponds is required as shown in Table II. Pond No. 1 is only filled up with water and has no float nor treatment. It is used as a control. They are accurately leveled on the sodded ground and free from any shade. At the same site, a standard Class-A Pan and a rain gauge are installed beside the ponds.

The experiment is designed to initially use the agricultural quality-class (Class 3) water of the same source in all experimental ponds. At the start of the experiment, all ponds are filled up to the water depth of 0.50 m (about 1.40 m^3). When the water level in the pond is less than 0.20 m., the water will be refilled until the level reaches 0.50 m. again as the first round and continue until the end of the experiment.

TABLE II: DIFFERENT COVERAGE AREA OF EXPERIMENTAL PONDS

	Experimental Pond Number				
Coverage area	1	2	3	4	5
0%	●				
25%		●			
50%			●		
75%				●	
100%					●

4) Data collection

A preliminary experiment (before the real one) was carried out to verify the applicability of the experimental ponds. All of them were filled up with only water and so was the standard Class-A Pan. The dropping water levels of all ponds and the pan were recorded every day for 15 days. After the analysis, the result confirmed that these ponds can be used to observe evaporation like the standard Class-A Pan.

The real experiment is scheduled in a dry season, from November to May, to avoid precipitation that could cause any inaccurate results. The experimental data are collected daily during 8:00-9:00 a.m. over the course of the experiment via digital measuring instruments. The collected data are the evaporation variables and meteorological variables. The meteorological variables are air temperature (T), wind speed (u), relative humidity (RH), solar radiation (R_s), and precipitation (P). These data will be used to estimate the evaporation rate. Besides, the evaporation variables are the water levels of all five experimental ponds and the Class-A Pan. The water levels are measured via a vernier.

The water subsurface temperature (T_w) of all experimental ponds will be also collected. T_w is defined as the water temperature at a level of 2 cm. lower from the water surface. In this experiment, T_w is measured using a waterproof digital thermometer with a submerging probe, which is installed on the float at the middle of the pond. It is hypothesized that T_w is an important affecting factor of the evaporation because it indicates the heat energy of water molecules near the surface which is prompt to escape from the liquid to the air. Previous study [13] confirmed that the floating materials covering the water surface can lower T_w, and consequently reduce the evaporation.

5) Efficiency calculation

The data collected from the experiment will be analyzed and compare to determine the optimum configurations of the

PET bottles. The Evaporation Suppression Efficiency (ESE, %) [18] is calculated as shown in equation (3).

$$ESE = (1 - E_i)/E_c \times 100 \quad (3)$$

where: E_i is the evaporation rate (a dropping water level) of Pond No. *i* in a unit of mm/day.

E_c is the evaporation rate (a dropping water level) of the control pond (Pond No. 1) in a unit of mm/day.

6) Relationships analysis

In addition, data analysis was to determine an equation for estimating the evaporation rate based on meteorological variables such as *T*, *u*, *RH*, R_s, *P*, and T_w. This is combined with data from the different percentages of coverage area at 25%, 50%, 75%, and 100%. The statistical methods for the analysis are Multiple Linear Regression (MLR) and Non-linear Regression (NLR).

B. Deterioration Inspection of PET Bottles

The deterioration of PET bottles is proposed to be examined in this experiment because the residuals from the deterioration are fragments or small particles of plastic (or microplastic) detaching and mixing with the stored water. These plastic particles are a concern about the impact on health and the environment. Moreover, the deterioration rate of the floating bottles by time is used to estimate the useful life of PET bottles. This experiment, therefore, is designed to investigate the deterioration of PET bottles over time to make an inference of the contamination of the stored water.

There are a variety of methods for inspecting the deterioration of plastics. This experiment is designed to employ the ATR-FTIR, DSC, and SEM methods. The ATR-FTIR analysis can determine the vibration of functional group on the polymer surface. When analyzing the deteriorated PET bottles, spectrum changes are significantly reduced at the following positions: for C=O bond at 1715 cm^{-1}, aromatic-ether C-O bond at 1245 cm^{-1}, aliphatic ether C-O bond at 1100 cm^{-1}, aromatic C-H bond at 870 cm^{-1}, and aliphatic ether C-H bond at 730 cm^{-1}. While the other positions would find increasing intensity at the following spectra: for -CH bond at 620 cm^{-1}, and the CH_2 bond at 1435 cm^{-1}, these are often detected due to ultraviolet deterioration. Moreover, if the end of the chain of molecules transforms into a hydroxyl group from the hydrolysis reaction, the spectral analysis will find at the position of 3200–3400 cm^{-1}. In addition, the DSC analysis is performed to detect if the melting temperature is changed from the control specimen. The change of melting temperature due to a decay into smaller molecules might occur. If the regenerative melting temperature is shown at 110 °C, it is possible that those small molecules are a BHET monomer. An observation of morphology by SEM at the surface of PET bottle specimens can be used as additional evidence to confirm the deterioration of PET bottles.

Sampling of PET bottles to determine their deterioration can be conducted by collecting two separate sets of samples: bottle parts that are submerged in water and not exposed to direct ultraviolet light. The other set are bottle parts that are above the water and exposed to direct ultraviolet light. The collected samples include the empty bottles, LAF-filled PET bottles, and assorted plastic-filled PET bottles. In the experiment, samples are collected at different time interval as 6, 12, and 18 months.

IV. Results

This study requires a lengthy and continuous experimentation, and it is now ongoing. The results of the experiment design are mainly reported in this article. They described the rationales, assumptions, details and sampling of the experiment. Also, this article only reports on the initial testing result of the coverage area factor, which is regarding the efficiency of the evaporation reduction. The evaporation rates from all five experimental ponds have been daily collected for 12 weeks from the start. The daily data are averaged into weekly values. Their resulting graphs are shown in the following figure. An overview result is that all five experimental ponds have a fluctuating evaporation rate, and their graphs have the similar pattern. It is anticipated that some meteorological factors must be daily fluctuating and similarly affecting all ponds' daily evaporation rates because all ponds are located at the same site with the same environment conditions.

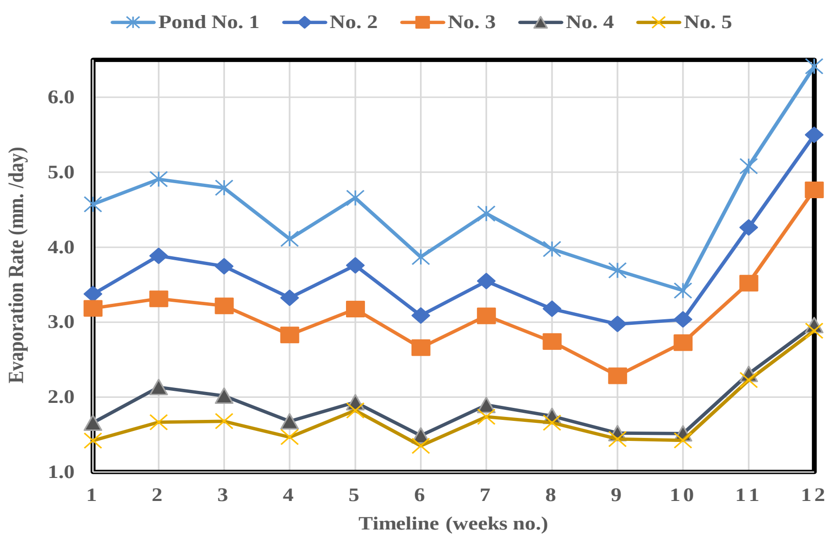

Fig. 5. A comparison of the ponds for the various coverage areas.

Fig. 5 illustrates a comparison between five different experimental ponds in the aspect of the coverage area as the control (no float), 25%, 50%, 75%, and 100%. The control (untreated) pond has a clearly and significantly higher evaporation rate than the other ponds (its graph is all above the others).

The average Evaporation Suppression Efficiency (ESE, %) according to Equation (3) of all five ponds (pond no. 1 to 5) are as 0%, 21.8%, 32.7%, 59.2%, 63.3%, respectively. The less coverage area, the more evaporation rates. This proves that PET bottles work, however, this is not a constant proportional relation. While the control, 25%, 50% and 75% ponds are clearly different, the 75% and 100% ponds are slightly different. It seems that the 75% coverage area is an optimum, since the 100% coverage area gives a little lesser evaporation rate.

Based on the most recent results (the experiment is still on-going), it is positively evidenced that the LAF-filled PET bottles have more ESE than the assorted plastic-filled PET bottles and the least ESE goes to the empty bottles. It is initially proven that LAF filled-in materials can be more protective against solar radiation, which is one of the affecting factors of the evaporation, than the assorted plastics. Both filled-in materials are used to opacify the PET bottles.

For the aspect of the water quality of the experimental ponds, water from all the five ponds has been collected every month since the start of the experiment. The first three times of the water quality testing results shows that all five indices i.e., PH, DO, BOD, TCB, and FCB values are consistently within the quality standard of the Class 3 water. Also, these values are quite constant or a little change throughout the three times of the tests. Therefore, the floating PET bottles do not affect PH value, dissolved oxygen content, organic matter content, and bacteria content. On the other hand, they can effectively and efficiently reduce evaporation in the experimental ponds, making them a viable innovation and an economical alternative solution to drought and waste management.

V. Conclusion

This article reports an experiment design for investigating the efficiency of the evaporation reduction of PET bottles. The evaporation and the configurations of PET bottles involves many factors and are constrained by time and seasonality. The experiment must be carefully scoped, designed and planned accordingly. The reliable and accurate results are needed to prove the applicability of this new technique, which has a high potential even higher than the existing commercial techniques. The expected benefits of this technique are a promotion of waste reuse and a low investment required solution for the drought. This experiment will result in the best configurations of PET bottles that give the optimum evaporation reduction. These include the type of materials should be filled up PET bottles, the amount of floating area, and the floating patterns. In addition, the results of the deterioration inspection of PET bottles will help design their suitable service life for the healthily and environmentally safe use. The dismantled bottles can still be collected and go to the plastic recycle process. This salvage value can raise the fund to trade in for new replacing bottles.

This article intends to report the initial results proved that the floating of PET bottles can potentially reduce the evaporation of the experimental ponds. The testing result of the coverage area factor is reported. These reused PET bottles should be filled up with laminated aluminum foiled (LAF) plastic bags to gain an additional effect of reduction and reuse even more plastic wastes. The coverage area at 75% with the free-floating pattern will give an optimum reduction and should be used.

The further experiment is needed and must be conducted before reaching a comprehensive conclusion. Some other opaque materials are potentially filled up the bottles and compared their efficiency against the empty bottles. Also, the other floating patterns such as a continuous or a raft-like float can be arranged to determine the different efficiency. However, if the continuous floating pattern has just a little effect, the free-floating will be the optimum pattern because it is a lot more convenient and allows or maintains water activities and boating in the reservoirs as their usual. It is necessary to include the design of water-quality monitoring methods into this experiment. The water samples from the testing ponds should be regularly collected and analyzed to be compared with the water quality standard of the targeted Class 3. The quality of stored water is targeted for the class of an agriculture use, of which natural reservoirs are a typical supply. Five indexes for water quality are such as, PH, DO, BOD, TCB and FCB bacterial counts.

This experiment is wisely and comprehensively designed to cover not only the efficiency aspect, but also the effectiveness which reflects on the longevity of the PET bottles and the quality of the stored water. This new evaporation reduction technique is anticipated to be applied broadly as an alternative cost-effective solution to the drought problem, together with the plastic waste management.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Raksaksri designed and wrote the experiment related to the deterioration of PET plastic. Benjaoran supervised this research and wrote the article. Settakhumpoo designed and wrote the experiment related to the evaporation. All authors had proofread and approved the final version of the manuscript.

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References

[1] P. Kongborriak, and K. Suebsak, "Evaporation in Thailand period 10 year (2001–2010)," in *Proc. Meteorology*, Ministry of Information and Communication Technology, pp. 30–38, 2010.

[2] J. Settakhumpoo and V. Benjaoran, "Comparing the cost efficiencies of traditional evaporation reduction with PET bottles containing plastic waste," *Engineering Journal of Chiang Mai University*, vol. 28, pp. 42–54, 2021.

[3] D. Verlee and D. Zetland, “Extending water supply by reducing reservoir evaporation: A case study from Wichita Falls, Texas,” in *Proc. Mine Water Solutions in Extreme Environments*, Vancouver, Canada, pp. 1–10, 2015.
[4] K. Hunter, N. Finn and S. Barnes, “The benefits of shade-cloth covers for potable water storages,” in *Proc. 70th Annual Water Industry Engineers and Operators Conference*, Melbourne. Australia, pp. 86–92, 2007.
[5] E. Haghighi, K. Madani, and A.Y. Hoekstra, “The water footprint of water conservation using shade balls in California,” *Nature Sustainability*, vol. 1, pp. 358–360, 2018.
[6] X. Yao, H. Zhang, C. Lemckert, A. Brook and P. Schouten, “Evaporation reduction by suspended and floating covers: overview, modelling and efficiency,” *Urban Water Security Research Alliance Technical Report No.28*, 2010.
[7] Y. W. Youssef and A. Khodzinskaya, “A review of evaporation reduction methods from water surfaces,” presented at the E3S Web of Conferences, Moscow, Russia, vol. 97, 2019.
[8] K. Simon, R. Shanbhag and A. Slocum, “Reducing evaporative water losses from irrigation ponds through the reuse of polyethylene terephthalate bottles,” *Journal of Irrigation and Drainage Engineering*, vol. 142, 2016.
[9] A. J. Watts, C. Lewis, R. M. Goodhead, C. J. Beckett, J. Moger, C. R. Tyler and T. S. Galloway, “Uptake and retention of microplastics by the shore crab Carcinus maenas,” *Environmental science & technology*, vol. 48, pp. 8823-8830, 2014.
[10] E. Mendiburu-Valor *et al.* “Valorization of urban and marine PET waste by optimized chemical recycling,” *Resources, Conservation and Recycling*, vol. 184, 2022.
[11] M. Arhant, M. L. Gall, P. Y. L. Gall and P. Davies, “Impact of hydrolytic degradation on mechanical properties of PET—Towards an understanding of microplastics formation,” *Polymer Degradation and Stability*, vol. 161, pp. 175–182, 2019.
[12] T. Sang, C. J. Wallis, G. Hill, and G. J. P. Britovsek, “Polyethylene terephthalate degradation under natural and accelerated weathering conditions,” *European Polymer Journal*, vol. 136, 2020.
[13] M. M. Shalaby, I. N. Nassar, and A. M. Abdallah, “Evaporation suppression from open water surface using various floating covers with consideration of water ecology,” *Journal of Hydrology*, vol. 598, 2021.
[14] M. H. Chen *et al*., “Preparation of long-chain branched polyethylene terephthalates (PETs), and crystallization behaviors, thermal characteristics, and hydrolysis resistance of their biaxially stretching films,” *Journal of Physics and Chemistry of Solids*, vol. 129, pp. 354–367, 2019.
[15] N. Everall, D. MacKerron, and D. Winter, “Characterization of biaxial orientation gradients in poly (ethylene terephthalate) films and bottles using polarised attenuated total reflection FTIR spectroscopy,” *Polymer*, vol. 43, pp. 4217–4223, 2002.
[16] J. W. Jung *et al*., “Ecological risk assessment of microplastics in coastal, shelf, and deep-sea waters with a consideration of environmentally relevant size and shape,” *Environmental Pollution*, vol. 270, 2021.
[17] Pollution Control Department, *Enhancement and Conservation of National Environmental Quality Act. (1994)*, 2022.
[18] S. Assouline, K. Narkis, and D. Or, “Evaporation suppression from water reservoirs: Efficiency considerations of partial covers,” *Water Resources Research*, vol. 47, pp. 1–8, 2011.