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RESEARCH ARTICLE

EXPERIMENTATION OF EVAPORATION REDUCTION BY A USE OF PLASTIC BOTTLES COVERING

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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 eight simulated ponds. The testing aspects are the opacity of the floating bottles, the coverage area, and the floating pattern. Based on environmental impact concern, the deterioration of PET bottles due to hydrolysis reaction and ultraviolet rays in natural conditions is also investigated. The water samples from the testing ponds are collected and analyzed to be compared with the water quality standard. Initial result from the experiment showed that PET bottles containing laminated-aluminum-foiled (LAF) plastic bags have the greatest reduction in evaporation among different opaque materials. Cover flotation percentages of 75% and 100% were able to reduce evaporation the most and with little difference. The raft-floating pattern has a slightly lower evaporation rate compared to the free-floating. All this has the potential to reduce evaporation which are a very cost-effective alternative to the existing commercial materials and help support the reuse of plastic waste.

KEYWORDS

Degradation, Drought, Evaporation, Reservoir, PET bottle, Waste reuse.

1. INTRODUCTION

Evaporation is a major cause of water loss in reservoirs that result in the insufficient water supply to sustain life. The evaporation can vary by month and season. In Thailand, the average monthly evaporation is between 100 - 200 millimeters (Kongborriak and Suebsak 2010). 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, each of which targets controlling or eliminating the factors affecting evaporation (Settakhumpoo and Benjaoran 2021). For example, shade-cloth which was used to cover the water storages can reduce evaporation by approximately 90% for two years and maintain good quality of water (Hunter et al., 2007). However, it is only applicable to a portable size due to costly structural supports and maintenance.

Some chemicals in a kind of fatty alcohols can be used to self-create a thin film or 'monolayers' covering the water surface which resulting in evaporation reduction. A field test was conducted and reported with about 15% reduction and a benefit-cost ratio of 4.47 (Verlee and Zetland 2015). The following study varied the concentration of the covering chemicals and the results indicated that evaporation rates were reduced by 16% to 22%, corresponding to the concentration (Saggaï and Bachi 2018). The limitation of this chemical technique is a control on the proper concentration in the real site. Another study used palm-frond sheets as cover biomaterials which are environment friendly safe. They tested on water tanks with two different surface areas as square and rectangular shapes, and the tanks were covered with two patterns of palm-frond sheets (Elsebaie et al., 2017). The results indicated that the covering pattern and the shape of water tanks give different evaporation rates. The strips-covered pattern resulted in approximately 76% less evaporation depth compared to the uncovered reference tanks.

In addition, many recent studies attempt to use plastic as cover materials. Ball-shaped plastics so called 'shade balls' offers simple and reliable floating objects for evaporation reduction. A group researchers conducted the experiment to address the effect of immersion depth of the shade balls which induced by changing balls' density (Rezazadeh et al., 2020). They found that if the balls sink into the water more than a half, its surface coverage and thus suppression efficiency decreases. They also tried different balls' colors and found that the white ball is more effective than the black. Some researchers also conducted another study on shade balls (counterweighted spheres) and confirmed with a similar figure of evaporation reduction as around 70% (Han et al., 2020). They also reported that the water-surface temperatures of the covered reservoir are significantly higher than the uncovered. The water temperature near surface is about 0.2°C - 1.9°C higher than at the depth 0.7 meter. In other study, author tested on both plastic floating balls and plates (Li et al., 2021). They concluded the influence degree of the four factors on the evaporation rate of the floating balls are in descending orders as diameter, counterweight (filled-in the balls), density, type of floating balls. For the floating plates, their evaporation reduction is positively correlated with the surface area and thickness.

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In other study also conducted experiments using floating spheres and disks of different colors, sizes, and materials for a range of external conditions (Lehmann et al., 2019). The results showed that at the maximum cover density of 91% surface cover, the evaporation reduction was 70% for spheres and 80% for disks. The material colors do not significantly affect the evaporation rate. Another study determined the water footprint of this water conservation using shade balls (Haghighi et al., 2018). They found that the 'water payback period', which determining by the 0.05 – 0.19 cubic meters of water used in the production of a kilogram of HDPE balls (water footprint) and the amount of water conservation of 1.15 million cubic meters per year, is approximately 0.2-2.5 years depending on the thickness of the ball. Some floating spheres and disks are commercial products such as E-VapCap, NetPro, AquaCap, and SuperSpan. They were tested and compared which resulted that these products are able to reduce the evaporation by around 70%-90% (Yao 2010; Youssef and Khodzinskaya, 2019). However, they are costly as US$6-US$30 per square meter of coverage area.

A wise alternative was proposed by (Simon et al., 2016). They used Polyethylene Terephthalate (PET) drinking-water bottles as a replacement for those commercial products and offered a much cheaper alternative. They tested the floating PET bottles in experimental pans and found that the average evaporation reduction is 40% with the 100% coverage area. They also suggested to fill the round bottles with soil to prevent their rotation, which could cause more evaporation, or used the square bottles instead. They reported that the addition of soil did not affect the degree of evaporation reduction. Settakhumpoo and Benjaoran conducted economic analysis and compared the PET bottles method with other reduction methods (Settakhumpoo and Benjaoran, 2021). They found that the PET bottles have the highest benefit-cost ratio as 2.24 and the cheapest cost as US$0.1 per square meter. Also, it promotes the reuse of PET bottles that will alleviate the plastic waste management in local communities.

Nowadays, PET plastic bottles are commonly used for single use drinking-water containers. Hence, a 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 (Watts et al., 2014). Waste recycling can reduce the use of natural resources, petroleum, and create a sustainable product life cycle by reverting to new substrates (Mendiburu-Valor et al., 2022). 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 (Arhant et al., 2019; Sang et al., 2020). Deterioration of plastic is possible to detect by morphology, thermal analysis, mechanical properties, molecular weight determination, and the elements or compounds characterization.

Past research has evidenced that physical flotation for water surface covering is a very effective method for evaporation reduction. Many studies have conducted experiments to discover influential factors of these floating materials related to the evaporation rate, such as type, shape, size, color, and immersion depth. Although a use of PET bottles was shown with an interesting efficacy and economic feasibility and has a potential to solve the problem of drought and plastic waste management at the same time, there is still a lack of experimentation on the configuration of the bottles and the environmental impact due to this floating cover. 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 three issues, namely the efficiency of reducing the evaporation rate, the deterioration of PET bottles, and the quality of stored water. 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. Second, the deterioration of PET bottles that have been exposed for long periods of flotation will be monitored to assess their service life. Third, the stored water will be regularly quality tested to compare with the national standard of surface water quality according to the Enhancement and Conservation of the National Environmental Quality Act B.E. 2535 (Pollution Control Department, 1994).

2. Evaporation and Water Quality

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

2.1 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 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 in the pan is recorded daily according to equation (1).

$$E_p = E_m + P \tag{1}$$

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 equation (2). This value represents the local evaporation and is used for the hydrological design and the water resources management.

$$E = C_p E_p \tag{2}$$

2.2 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 (Shalaby et al., 2021). If the heat flux over the reservoir is physically impeded by floating cover, evaporation can be reduced (Aminzadeh et al., 2018).

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.

2.3 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°C. 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 (Chen et al., 2019; Everall et al., 2002).

2.4 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 (Jung, 2021). 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 °C, 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.

2.5 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 (Pollution Control Department, 1994).

- 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 1 shows some selected quality indexes for the surface-water source class 2-4, which are standardized and controlled.

Table 1: Selected Standard Quality Indexes for Surface Water

		Water quality for the source class*		
Index	Unit	**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.

3. Experimental Design

The experimental design for the evaporation reduction with PET bottles was addressed on three aspects. The details are as follows.

3.1 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. Some issues are considered.

3.1.1 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 Figure 1.

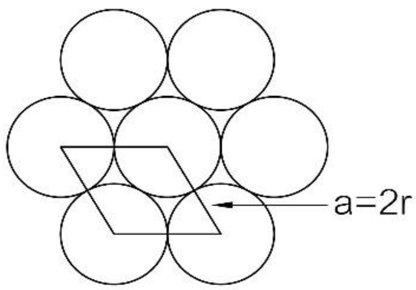

Figure 1: Coverage area of the densest packing of circles.

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 1.43×10^{-2} sq.m. The densest packing of them (horizontally laid) is shown in Figure 2. The CP of the PET bottles is equal to 91.2% which is slightly more than that of the balls or circular disks. A used PET bottle costs about US$0.005 or about US$0.30/sq.m. which is much cheaper than that of the commercial ones. Therefore, it is worthwhile to be used as an alternative material.

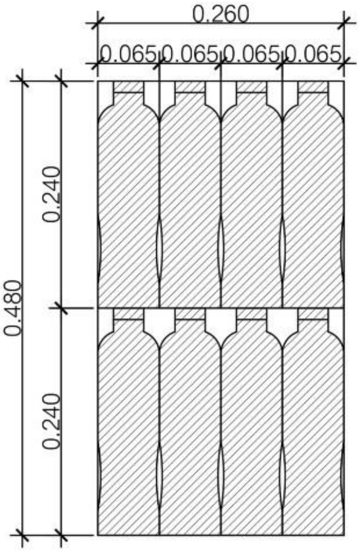

Figure 2: Coverage area of a bottle shape versus the containing area.

3.1.2 Bottles Configurations

It is hypothesized that the configurations of floating PET bottles may affect the performance of evaporation reduction rate. The experiment was designed to cover three characteristics: the opacity of the bottles, coverage area, and floating patterns. The opacity of the bottles: 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. They are put in and firmly filled up the bottles. The experiment is designed to compare the efficiency of the three floating materials, i.e., empty bottle, bottle with LAF, and the one with assorted plastic. Figure 3 shows examples of the three bottles.

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

The coverage area: 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. They are chosen because it is expected to be the best opacifying materials. 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 floating pattern: the experiment is designed to arrange two different floating patterns as a free-floating and a raft floating. The free-floating pattern is a flotation of bottles that are not attached to each other. On the other hand, the raft-floating pattern is a pack of bottles that are attached together by silicone glue to form a raft-like flotation. A raft is composed of 16 bottles, of which is 8 bottles each row for 2 rows. This bottle raft is built with an appropriate size strong enough to maintain its form throughout the experimentation. Figure 4. shows the two floating patterns. The experiment is designed to use all bottles which are filled up with LAF and to set both floating patterns at the 50% coverage area which is hypothesized to be the optimum percentage. Also, it is hypothesized that the free-floating pattern creates intermittent cover or fragmented shades and should be less effective than the raft-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.

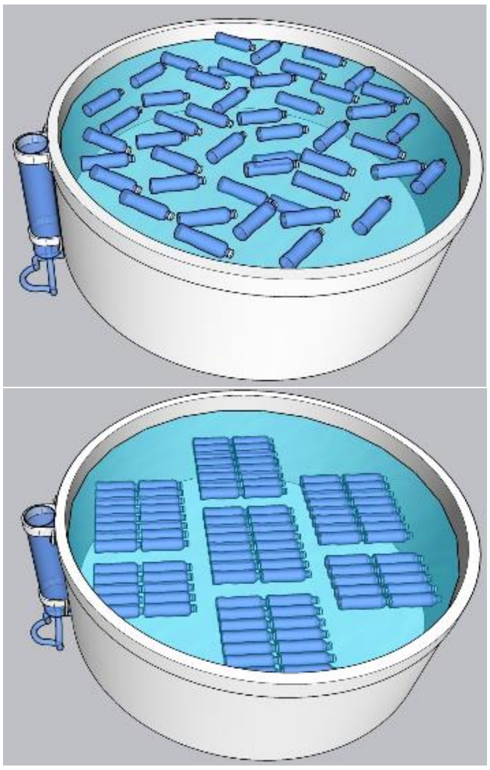

Figure 4: Free-floating pattern (left) and raft-floating pattern (right).

3.1.3 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 sq.m. 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 meters above sea level. From the experimental configurations, a total of eight ponds is required as shown in Table 2. 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.

Table 2: Different Configurations of Experimental Ponds

	Experimental Pond Number							
Configurations	1	2	3	4	5	6	7	8
Opacity								
Empty							●	
LAF filled		●	●	●	●	●		
AP filled								●
Coverage area								
25%		●						
50%			●			●	●	●
75%				●				
100%					●			
Floating pattern								
Free		●	●	●	●		●	●
Raft						●		

3.1.4 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 eight 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 confirmed that the floating materials covering the water surface can lower T_w, and consequently reduce the evaporation (Shalaby et al., 2021).

3.1.5 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, %) is calculated as shown in equation (3) (Assouline et al., 2011).

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

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.

3.1.6 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 Nonlinear Regression (NLR).

3.2 Deterioration Inspection of PET Bottles

The deterioration of PET bottles is an important issue 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.

3.3 Water Quality Inspection

The quality of stored water is crucial to the success of this new evaporation reduction technique. The floating materials reduce the water surface area of the reservoirs. Consequently, they reduce the contacting surface where oxygen in the air is dissolved in the water and reduce the amount of sunlight entering the water. These changes can ruin the water quality. It is hypothesized that the floating materials will worsen the water quality over time. This experiment is designed to include the water quality inspection so that the result will be compared to the standard quality of water in the source class 3.

Also, the reuse of waste materials such as drinking water bottles, LAF and plastic bags can also cause both microplastic and coliform bacteria contaminations. It is necessary to include the design of water-quality monitoring methods into this experiment. 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 chosen i.e., PH, DO, BOD, TCB and FCB bacterial counts.

The experiment is designed to initially use the agricultural quality-class 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 cu.m.) and the water samples are immediately collected from all ponds. After that, the water samples will be collected continuously every month. 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. The water samples are collected in the same manner as the first round and continue until the end of the experiment.

For microplastic contamination, the test results of the deterioration of PET bottles will be used for an indirect analysis. If the PET bottle deteriorates severely, it can be interpreted that there is a lot of microplastics contaminating the stored water in that pond. It is assumed that all degraded plastic and tiny fragments will not be lost but will accumulate in the pond.

4. Results

This study requires a lengthy and continuous experimentation, and it is now ongoing. The initial result regarding the efficiency of the evaporation reduction is reported in this article. The evaporation rates from all eight 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 figures. An overview result is that all eight 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.

The control (untreated) pond has a clearly and significantly higher evaporation rate than the other ponds (its graph is all above the others). However, a comparison between some ponds is grouped according to the three testing aspects, to clearly see the effects of the different configurations.

Figure 5 illustrates a comparison between four different experimental ponds in the aspect of the opaque materials. Their evaporation rates are different in an ascending order as LAF-filled, assorted plastic-filled, empty bottles and the control (no float). It proves that the filled-up materials in the bottles influence the evaporation and the LAF is the most efficient materials. While the assorted plastic-filled one surprisingly has a slightly lower rate than the empty one, it is not efficient.

Figure 6 illustrates a comparison between five different experimental ponds in the aspect of the coverage area as 25%, 50%, 75%, 100%, and the control (no float). 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.

Finally, Figure 7 shows a comparison between three different experimental ponds in the aspect of the floating pattern. The free-floating and the raft-floating has performed almost the same. The raft-floating has just a slightly lower evaporation rate than the free-floating. It is suspected that the controlling condition of the 50% coverage area of both ponds is not much enough to magnify the effect of these two different floating patterns. The redesign for this experiment is needed and further experiment must be conducted before reaching a conclusion. However, if the floating pattern is later proved and reconfirmed that it has just a little effect, the free-floating will be the optimum pattern. It is a lot more convenient and cheaper to prepare. Also, the free-floating pattern allows or maintains water activities and boating in the reservoirs as their usual.

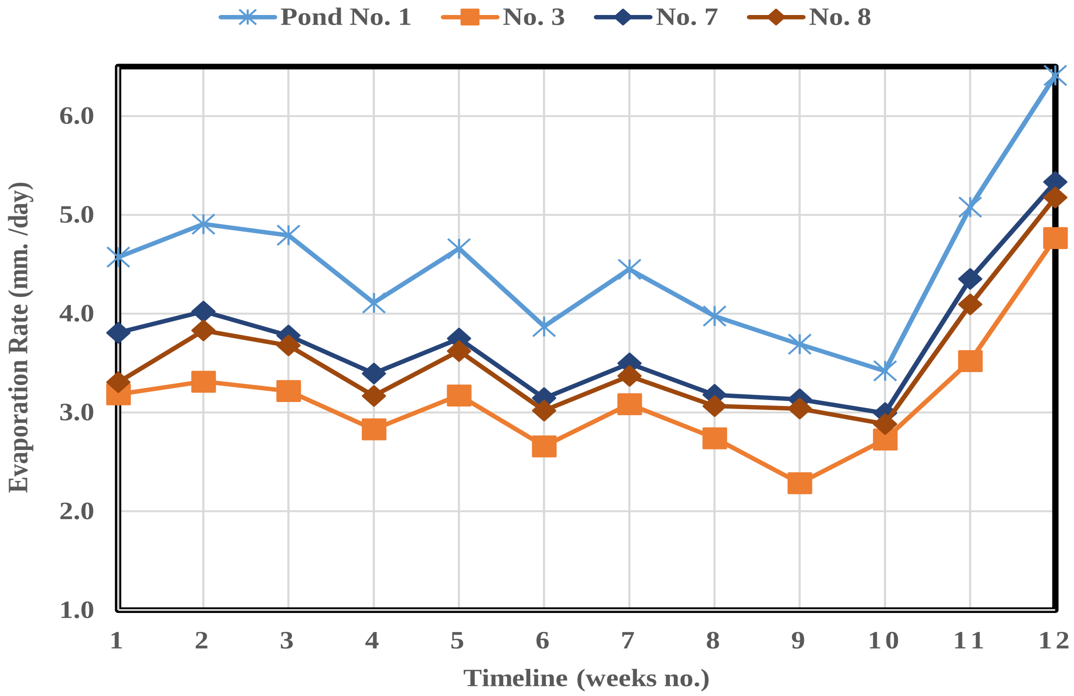

Figure 5: A comparison of the ponds for the various opaque materials.

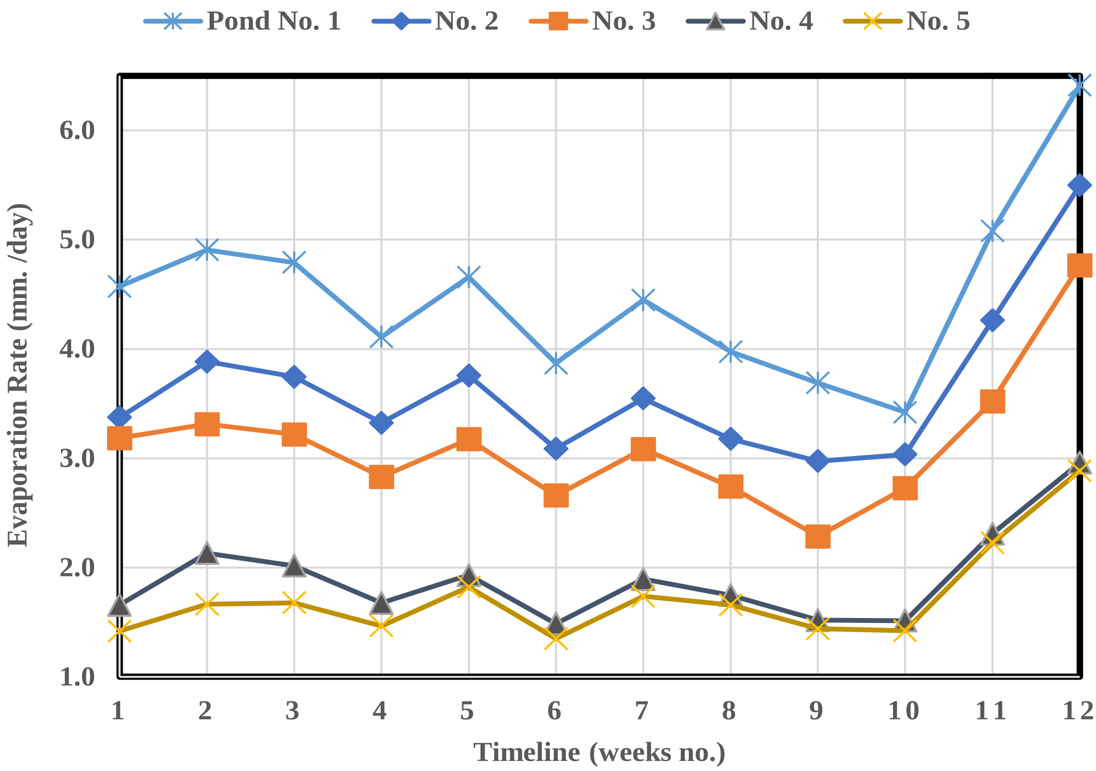

Figure 6: A comparison of the ponds for the various coverage areas.

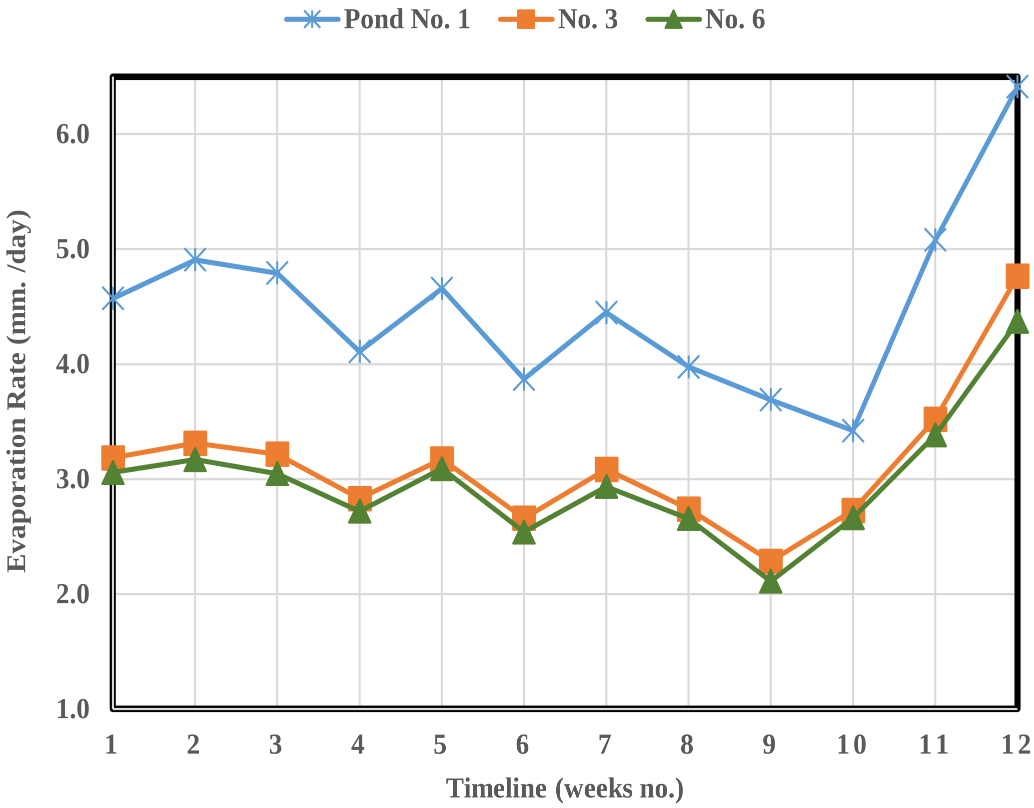

Figure 7: A comparison of the ponds for the different floating patterns.

5. Conclusion

This experiment is designed to investigate 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. The initial results proved that the floating of PET bottles can potentially reduce the evaporation of the experimental ponds. 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% will give an optimum reduction. Moreover, the free-floating pattern gives a reasonable result and should be used.

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.

Data Availability Statement

The datasets generated or analyzed during the current study are available from the corresponding author on reasonable request.

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