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Evaporation Reduction from Open Water Tanks Using Palm-Frond Covers: Effects of Tank Shape and Coverage Pattern

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Abstract

The limited fresh water resources and increasing future demand for water necessitate the importance of optimum use of water; especially in arid/semi-arid regions. The purpose of this study is to examine reducing evaporation losses from open water bodies using palm-frond sheets as cover material. Four open constant-depth water tanks with two different surface areas have been used in the study. The tanks had square and rectangular surface areas. The tanks were covered with two patterns of palm-frond sheets: a) staggered strips-no strips covering half of the surface area (strips-covered), and b) single sheet covering half of the surface area (½-covered). Data of cumulative evaporation depths were recorded daily continuously from the covered tanks, as well as from the uncovered tanks, to assess the relative efficiency of evaporation reduction. The results indicated that the strips-covered pattern outperformed the ½-covered; it reduced the evaporation depth by approximately 20% and 24% for the square and rectangular surface tanks; respectively, when compared to the ½-covered pattern. Moreover, the strips-covered pattern resulted in approximately 76% less evaporation depth compared to the uncovered reference tanks. Additionally, water quality analyses showed that such palm-based cover materials have insignificant effect on the water quality. These results confirmed that evaporation can be reduced and controlled using environment friendly safe techniques.

Keywords: *arid zones, evaporation losses, palm fronds, water conservation*

1. Introduction

Water is one of the most precious natural resources in the world, especially in arid and semi-arid zones such as the Kingdom of Saudi Arabia (KSA). The renewable water resources of KSA are significantly less than its non–renewable water resources, due to its fairly low average annual precipitation ranging from 100 mm to 150 mm. KSA experiences, as well, high evaporation rates with average annual rate ranging between 2500 mm and 3000 mm. This shows the need for water conservation techniques; such as reducing evaporation from impounding reservoirs, and puts greater attention to long-term water use for development and sustainability management (Al-Hassoun *et al.*, 2011; Alam and AlShaikh, 2013).

Considering the importance of optimal utilization of renewable water resources, the Government of KSA has been constructing dams on many wadis to harvest rainwater. However, one of the water management challenges in arid regions is the large amount of water loss from the reservoirs of such dams, due to the extremely high evaporation rates. Evaporation losses from dam reservoirs affect their water storage efficiency. Evaporation from open water bodies such as wetlands and lakes often represents the largest loss in their local hydrological budget, yet its quantification still continues to be a theoretical and practical challenge. Thus, there has been an increased focus on evaporation control techniques that can be applied to water storage, due to severe drought conditions in many parts of the world (Anonymous, 2003). Management of water by reducing the evaporation rates will conserve water that can be used to support the ever-growing domestic, agricultural and industrial demands.

One way of reducing evaporation rates from open water bodies; for example, lakes and dam reservoirs, is to partially cover their exposed surface areas to lessen evaporation losses while not affecting water quality. Cooley (1983) tested the effect of long-term exposure of different floating chemicals and physical cover materials on the evaporation reduction efficiency. He showed that evaporation reduction efficiencies ranged from 36% to about 84% depending on the cover type. Craig *et al.* (2005) and Martinez-Alvarez *et al.* (2006) investigated the effect of installing suspended shade-cloth covers and reported they are

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considered one of the most promising options for reducing evaporation. Alvarez *et al.* (2006) examined different types of shading meshes and reported that the shading of pan induced significant decrease of the daily evaporation rate, ranging from 50% for the aluminized screen to near 80% for the colored-polyethylene meshes. Craig *et al.* (2007) observed that the use of physical covers enabled evaporation reduction substantially. They suggested that these types of covers would be more effective for small reservoirs; less than 10 ha in area. Although physical covers can also be used for large reservoirs, they would be uneconomical. One way to reduce the cost and to make it economical is using the local material as the cover. In a more recent relevant study by Xi Yao *et al.* (2010), they employed a 2D-model to estimate evaporation rates on Wivenhoe Dam and tested the effectiveness of suspended and floating covers for evaporation reduction. They concluded that suspended and floating covers have great potential in reducing evaporation through the reduction of energy input. Their results show that if Wivenhoe Dam was fully covered, the annual efficiency of evaporation reduction would reach 76% for suspended covers and 68% for floating covers.

Not only the cover material, but also the number of layers of the cover influences the evaporation rates. Barnes (1993) found that monolayer is potentially most effective in conditions where the rate of evaporation is high. The study by Ikweiri *et al.* (2008) on the Omar Muktar Reservoir tested the effect of the monolayer technique to reduce evaporation in comparison to the cost of the local lost water by evaporation. More recently, Alam and AlShaikh (2013) studied the layer effects of palm-frond sheets that were used to cover standard evaporation pans. They observed that the average reduction in evaporation from a single-layer fully-covered pan was about 47%; whereas it reached about 58% in a double-layer fully-covered pan, when compared to the evaporation from an open uncovered reference pan.

Covering water bodies by chemicals or physical covers has its concerns on water quality of the water bodies. Maestre-Valeroa *et al.* (2011) evaluated the effects of suspended shade-cloth cover on the quality of agricultural water stored on farm. They concluded that the installation of the suspended shade-cloth cover induced positive balance between rainfall and evaporation; hence, conserving water and improving water quality by reducing the electrical conductivity of the water by 8.2%. Their study also showed that the lack of turbulence under the cover and the reduction in photosynthesis reduced the concentration of Dissolved Oxygen (DO) from 16 mg L^{-1} to 1.5 mg L^{-1} and turbidity from 40 NTU at installation to less than 1 NTU eventually. Maestre-Valero *et al.* (2013) further reported that the suspended shade-cloth cover limited the water oxygenation produced by the wind dragging effect on the water surface and the photosynthesis processes. They also reported that the Total Dissolved Solids (TDS) did not seem to be affected by the presence of the cover; neither did the cover have any consequences on the chemical water quality parameters. Accordingly, they concluded that applying such cover material would not involve any modification in the fertirrigation practices. Moreover, the cover greatly reduced the concentration of fecal coliforms and E. coli that might have negative effects on health if statutory thresholds are exceeded.

For the particular application of palm-based products in reducing evaporation from open water bodies, experiments performed by Al-Hassoun *et al.* (2009) over a period of five weeks indicated reduction in evaporation using floating palm-leaves cover of approximately 63% for fully covered pool; whereas for half covered identical pool, it was 26%. In a similar study by Al-Hassoun *et al.* (2011), they observed evaporation reduction from the fully covered pool of about 55%, while from the half covered pool, it was 26%; their measurements lasted for eight months. In their second study, water quality analysis showed that fronds have insignificant effect on water quality. This eliminated concerns on the negative environmental impacts of cover materials. Palm tree is considered to be one of the most important commercial crops widely distributed across KSA that is capable of withstanding extremely hot weather conditions of the arid region (Al-Juruf *et al*., 1988). The number of palm trees in the Kingdom is estimated to be over 21 million, yielding about 210,000 tons of fronds (Alam and AlShaikh, 2013). Palm-based products have also proven successful in reducing peak water temperatures during summer and for saving energy during winter when used as natural insulators for overhead storage water tanks (Fouli, 2013; Fouli *et al*., 2014).

In the present study, the use of two different patterns of palm-frond sheets as physical cover for the reduction of evaporation from different-shape and different-area open water tanks is tested. The two patterns are: a) staggered strips-no strips covering half of the surface area (strips-covered), and b) single sheet covering half of the surface area (½-covered). Four constant-depth tanks of square and rectangular surface area were used. In the same time, water quality parameters; namely DO and electrical conductivity, were also quantitatively evaluated and the effect of evaporation on such parameters were assessed. Shaded covers reduce the energy available for evaporation, reduce wind action over the water surface and trap humid air under the cover; all these factors contribute to evaporation reduction.

This work is considered extension to the work previously done by Al-Hassoun *et al.* (2009, 2011) where their storage reservoirs were of fixed shape. In our present study, the effect of tank shape, surface area and coverage pattern are being newly considered. Our findings have also increased the understanding of the correlation between the climatological parameters and evaporation.

2. Materials and Methods

2.1 Experimental Setup

In this study the effect of the tank surface area, its shape and the coverage pattern on evaporation reduction was investigated. Four tanks having vertical sides and constant depth of 0.50 m were used in the study. Two of the tanks had square surface area, whereas the other two had rectangular surface area. Two surface