# Modelling and Experimental Investigation of the Evaporation Suppression Using Floating Covers in the Presence of Surface Flows

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**ABSTRACT:** The increase in fresh-water demand due to the rapid population growth and climate changes with severe droughts highlights the protection of limited fresh-water resources. In arid regions, evaporation accounts for a significant fraction of losses from water reservoirs. Among different methods for suppressing evaporative loss, the use of modular floating elements offers a simple and reliable technique. Despite numerous studies on application of floating elements, performance of this method in the presence of surface flows is not yet addressed comprehensively. Hence, the present study aims to investigate the effect of surface flows on evaporation from covered reservoirs. For this purpose, a 500-liter water reservoir was covered with white and black balls and a water-pump provided surface flows at different rates. The results show that evaporation decreases monotonically with increasing surface flow rate until a specific flow rate, called optimal flow rate.  The increase in surface flow more than this optimal rate results in increase in evaporative loss. Regardless of surface flow condition, the results indicate that the lowest water evaporation occurs for the coverage with white balls while coverage using a mixture of black and white balls and only with black balls showed higher evaporation rates, respectively (the highest evaporation is of course for the uncovered surface). The experimental findings demonstrate that surface flows with appropriate rates can effectively enhance evaporation suppression efficiency of floating elements. Comparison of the modeling results with experimental outputs highlights application of the physically-based energy balance model in estimating surface evaporation for covered and uncovered water surfaces with and without surface flow conditions.

## 1. INTRODUCTION

Freshwater supply is one of the major concerns in many parts of the world due to increasing droughts, reducing rainfall, population growth and development of industries highlighting the need for optimizing consumptions and suppressing losses. Evaporation is the reason of significant losses in open water reservoirs thereby suppressing it with different techniques such as the use of physical covers [1], windbreaks [2], and chemical coatings [3] have been among the common practices. Investigations show that modular floating elements provide a rather simple and efficient solution for suppressing evaporative losses [4]. While most studies have often focused on the effect of covers with different geometrical, physical and thermal properties on suppression of evaporation rate from water bodies, surface flows and their impact on thermal mixing of water layers and energy exchange with covers could potentially alternate evaporation suppression efficiency of floating elements [5]. Therefore, the main objective of the present study is modelling and experimental investigation of the evaporation suppression using floating covers in the presence of surface flows.

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## 2. METHODOLOGY

Figure 1 shows the schematic drawing of the equipment and the experimental set up. A Polyethylene basin of $106 \times 107 \times 50$ cm3 and 6 mm wall thickness was filled with water. Surface flows were generated with a pump. A pressure transmitter in the bottom of the Marriott bottle recorded the hydrostatic pressure changes. In order to measure air temperature, relative humidity, and wind speed, a psychrometer-anemometer device (C310, KIMO: ±0.1℃ & ±1.5% FS-RH & ±3.05% FS-Vel accuracy) was utilized. The water temperature was monitored by four thermocouples (KTT320, KIMO: ±0.1℃ accuracy) at depths of 0, 12, 24 and 36 cm from the water surface. Humidity and velocity sensors were also installed 30 cm above the water surface. Six 500 watts tungsten-halogen lamps, with uniform radiation of 600 to 700 W/m2 , mimicked radiative flux on the surface of the reservoir (the spectrum is similar to the sunlight with a peak of 0.9 μm at 3200 K). A Pyranometer (SL100 KIMO: 0~1300 W/m2, ±0.5 W/m2 accuracy) was used to measure radiation intensity on the surface of the reservoir.
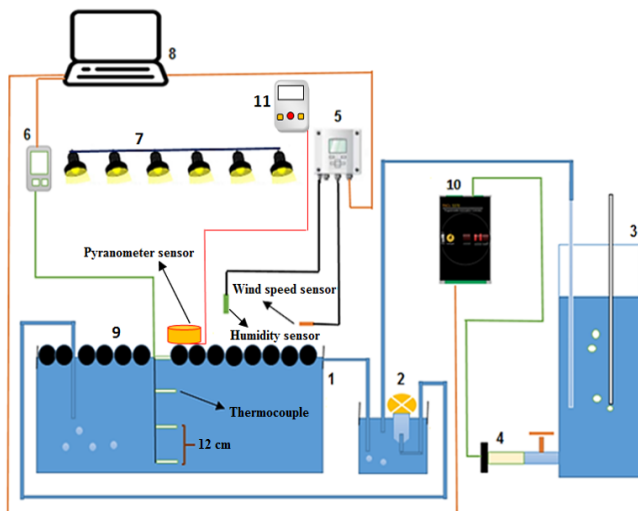
**Fig. 1. Schematic drawing of the equipment and the experimental set up: (1) Polyethylene reservoir, (2) Pump, (3) Marriott bottle, (4) Pressure transmitter, (5) Psychrometer and Anemometer device, (6) Thermometer, (7) Lamps, (8) Monitor for displaying and storing measured values, (9) Floating covers, (10) Pressure recording and processing device, (11) Pyranometer.**

## 3. RESULTS AND DISCUSSION

Seven different surface water flow rates including 1, 3, 4.5, 6.5, 8, 10, and 12 l/min created by the pump were tested. In each flow rate, evaporation of uncovered, covered with white balls, covered with black balls, and combined coverings (in the form of an equal mixture of black and white balls) conditions were measured for a period of six hours. As seen in Figure 2, floating balls have a significant effect on reducing evaporation. In addition, by increasing the flow rate and consequently increasing the mixing of the stratified water layers, evaporation decreases until an optimum flow rate. For example, for uncovered condition, the rate of evaporation decreases from 0.915 mm/hr (when there is no flow) to about 0.685 mm/hr when the flow rate is about 6.5 l/min (as the optimum flow rate). Then the evaporation increases by passing the flow rate from the optimum value. To analyze this phenomenon, it is necessary to provide further explanations for the boundary layer of air created on the surface of basin. In the presence of surface flow, the stagnant air layer above the water is forced to move due to the no-slip condition forming an aerodynamic boundary layer with thickness of $\delta_v$. Since the value of $\delta_v$ is proportional to the inverse of the air velocity near the surface [6], increasing the surface flow rate results in decreasing of $\delta_v$ and the thickness of the mass boundary layer (i.e., $\delta_m = Sc^{-1/3}\delta_v$, where $Sc$ is Schmidt number) [6-7]. Accordingly, the gradient of vapor concentration increases between the surface and air flow, and eventually the evaporation rate increases. Also, according to the results of Aminzadeh and Or [7] and Haghighi and Or [8], the sensible heat flux coefficient is inversely proportional to the thickness of the air boundary layer. Thus, by increasing the surface flow-rate, the heat transfer from the air flow to water surface increases for a condition where the surface temperature is
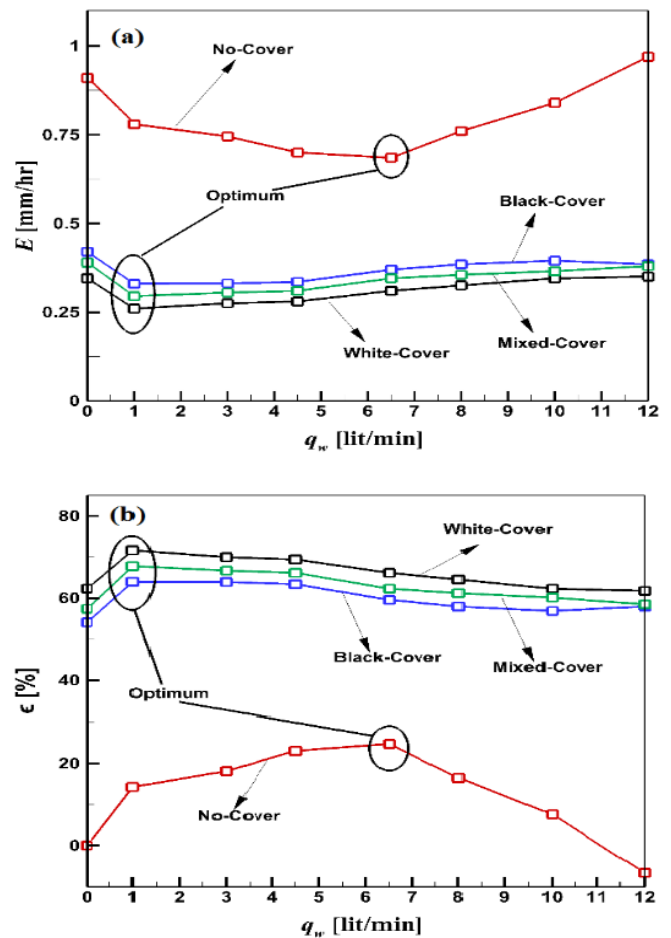


**Fig. 2. Results obtained by the surface evaporation test for various surface flow-rates. (a) Surface evaporation for the last two hours from total of six hours of experiment (b) Evaporation reduction efficiency. Here the evaporation from covered surfaces in no-flow condition (i.e., $E_0 = 0.915 [mm/hr]$ ) is used as the reference evaporation to calculate the efficiency.**

lower than the air temperature (often in summers). In this way, the energy needed to increase the evaporation rate is provided. Therefore, by passing the optimal flow-rate, the role of increasing the evaporation rate due to the reduction of the thickness of the air boundary layer exceeds from the role of the mixing of the water layers in suppressing the evaporation rate and it decreases the evaporation efficiency.

## 4. CONCLUSION

The present study focuses experimentally on the effect of surface flows on evaporation from covered reservoirs. For this purpose, a water reservoir was covered with white and black balls and a water-pump provided surface flows at different rates (i.e. 1, 3, 4.5, 6.5, 8, 10, and 12 l/min). The results show that in the presence of surface flows evaporation decreases to a specified rate, called optimal-flow-rate, and then increases with increasing the flow rate from the optimal case. Regardless of surface flow condition, the results indicate that the lowest water evaporation occurs for the coverage with

white balls while coverage using a mixture of black and white balls and only with black balls showed higher evaporation rates, respectively (the highest evaporation is also for the uncovered surface).

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