



EVAPORATION OF WATER FROM OTTAWA SAND USING AIR FLOWS ABOVE AND BELOW THE SAND LAYER

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ABSTRACT

The primary source of water for crops and livestock in the United States Central High Plains is irrigation from the Ogallala Aquifer. Due to the semi-arid climate of this region, little rainfall contributes to watering crops, thereby resulting in water scarcity. Reducing the evaporation from soil is one approach to conserve the water. In this study, a soil evaporation chamber was designed and constructed to study the impacts of environmental conditions on evaporation from Ottawa sand. Prior to entering the sand test section, compressed air flow was dried in a desiccator then split in two flows before entering the 57mmx228mmx838mm test section, with one airflow flowing above the 57mm thick sand layer and the other below and, subsequently, flowing through the moist sand layer. The percent relative humidity (RH) was measured at the entrance and exit to record the change in relative humidity and, therefore, water content removed from the sand. Using inlet air mass flow rates of air of approximately 1E-4kg/s–2E-4kg/s, temperatures of 28–31°C, and dry air (i.e. 0–1%RH), exit flows of 19–20°C and 80–85%RH were measured. Measured evaporation rates ranging from 3.0E-6kg/s to 5.0E-6kg/s for soil saturation levels of 55–80.5%.

KEY WORDS: Evaporation, porous media, diffusivity, relative humidity.

1. INTRODUCTION

Western Kansas has excellent soil for crop production but receives less rainfall than what is required for crop production [1]. Therefore, irrigation from the underground Ogallala Aquifer is the primary source of water for crops and livestock as well as factories and residential use. This aquifer provides one-fourth of the total water supply used for agricultural production across the United States [2]. The aquifer has declined by more than 150 feet in parts of western Kansas from 1950 to 2013 [3]. To reduce the amount of depletion of the aquifer and benefit agriculture in other semi-arid climates, research is necessary to optimize irrigation and reduce water losses. Water evaporated from soil and not absorbed by plants is a source of water loss.

Evaporation from porous media, such as soil, depends on temperature, relative humidity, pressure, and the physical properties of the media, such as pore size and density. Studies have been conducted on diffusivity from porous media and predict the vapor flux from various media and noted the importance of thermal gradients in the media [4,5]; thermal gradients may be more important than soil water content for determining evaporation rates [6]. Soil properties, such as pore size and particle density, are primary factors which affect evaporation rates [7]. Evaporation has also been shown to occur in three stages, with the first stage being nearly constant (i.e., constant rate of evaporation), -followed by a falling rate of evaporation stage, and, subsequently, a lower rate period [8]. The research objectives of this study are to investigate the stages of evaporation with different soil saturations and compare the impact of convection.

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2. EXPERIMENTAL APPARATUS

2.1 Experimental Apparatus: The experimental apparatus was constructed from 6.35 mm thick aluminum plates welded and bolted together to form an airtight chamber. The top and side of the apparatus comprise of transparent, polycarbonate windows sealed with adhesive to allow visualization and permit light from a solar simulator. Swagelok stainless steel tubing and connectors were used to construct air lines. The air was dried with a desiccator (Sharpe 6760 Dryaire Desiccant System) and then sent through a constant temperature water-bath (Neslab RTE-211 Temperature Bath) to heat the dry air to a specified temperature. Multiple valves were added for proper flow control. The volumetric flow rate was measured (Omega FMA-1609A) as well as temperature (Omega TMQSS-0125U-6), pressure (Omega PX309-100G5V), and relative humidity (Omega HX200HR) of both flows before entering the chamber for flow above and below the layer. The temperature, pressure, and relative humidity were recorded at the exit. Sand temperature was measured (Omega TMQSS-062U-6) at .0762m, .4191m, and .762m from the inlets in 3 columns and monitored during experiments. The entire apparatus sits atop a table that is itself on top of a very sensitive scale (McMaster 1852T85, ± 0.01 kg) to allow for mass measurements of the sample. A nylon membrane (EMD Millipore NY6000010) was placed in the chamber to hold the sand layer but allow water and air to pass through.

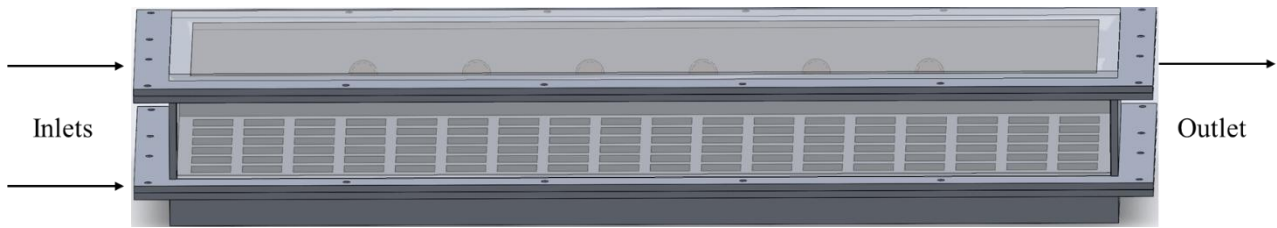


Fig. 1 A schematic of the experimental apparatus, shown without the sand layer for clarity. This figure shows the metal mesh that supports the sand layer, the bolt holes for compression seal of the chamber, and the air inlets and outlets to the chamber.

2.2 Sample Preparation: Ottawa Sand has a known specific gravity of 2.65 (Humboldt H-3820BX) and porosity of .34-.37 [9]. The mass of Ottawa Sand to fill the chamber was measured and water was added to it to achieve a known soil saturation.

$$S_r = 100 \left(\frac{wG_s}{1-n} \right) \quad (1)$$

where S_r is the saturation percentage of the sand, w is the water content, G_s is the specific gravity of the sand, and n is the porosity.

Water and sand were thoroughly mixed for over one minute and then added to the chamber in 3 layers. Each layer was tamped down to fill the chamber space and prevent large air pockets. The excess sand was then removed and the mass of what remained was measured. Since the saturation of the mixture was known, the total mass of the mixture in the chamber allowed for the calculation of the mass of the sand and water in the chamber. Changes in mass inside the chamber correlate to the decrease of the amount of water through evaporation, thereby reducing soil saturation.

2.3 Experimental procedure: To measure the evaporation from the soil, inlet air was completely dried using a desiccator. This was verified by relative humidity sensors before the air entered the chamber. The humidity at the outlet to the chamber is due to water evaporated from the soil. Using the flow rates and the relative humidity, the evaporation rate was calculated for each trial.

Inlet mass flows were 1.0E-4kg/s or 2.0E-4kg/s. Three experiments were conducted: 1) flow above the sand set to 2.0E-4kg/s and the flow through the soil set to 1.0E-4kg/s, 2) flow above the sand set to 1.0E-4kg/s and through set to 2.0E-4kg/s, and 3) both flows set to 2.0E-4kg/s. Reported data are averaged over five minutes to ensure steady state and were recorded by using National Instruments LabView software and processed in Engineering Equation Solver (EES) and Excel. The value for the saturation rate was found using the initial mass of the sample placed into the chamber and the current mass of the sample. After data were collected, the apparatus was run with higher flow rates of around 3.0E-4kg/s for each inlet to increase evaporation and lower the saturation level so more evaporation rates could be found.

3. RESULTS AND DISCUSSION

3.1 Results: Using a geometric profile of a rectangular duct and hydraulic diameter of .0457m, the Reynold's number was found to range from 140 to 300 in the space about the sand layer, depending on the flow rate, resulting in laminar flow above the sand layer. An uncertainty analysis was also completed using the uncertainties of each sensor used. For the constant rate period, evaporation rates ranged from 3.55E-6kg/s to 4.06E-6kg/s of water with either the top or bottom flow lower than the other. With both flows being the same flow rate, evaporation rates ranged from 4.6E-6kg/s to 5.26E-6kg/s.

Due to evaporative cooling in the sand, sand temperature can affect the evaporation rates. For this reason, a sand temperature range of 18 to 20 °C was used for all trials. Air inlet temperatures ranged from 27.5 to 31 °C and air outlet temperatures ranged from 19.5 to 21.5 °C. The inlet temperature did not seem to have a significant impact on the evaporation rates; however, outlet temperatures outside of this range did alter the evaporation rates and generally corresponded to the temperature of the sand sample.

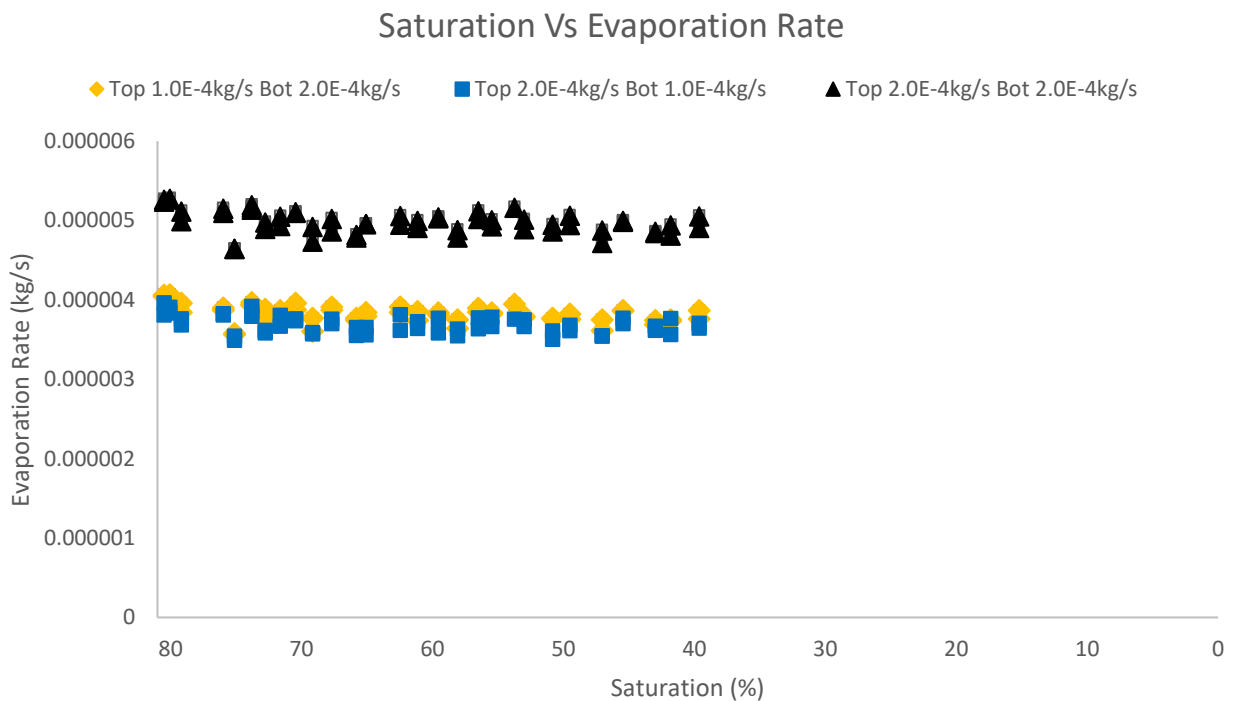


Fig. 2 Graph of the saturation percentage against the evaporation rate from the Ottawa Sand layer.

4. CONCLUSIONS

Convective effects were studied for evaporation from Ottawa sand. For the same flow rates, lowering the top flow did not cause significant changes in evaporation compared to the bottom flow being lower. Further studies are being considered involving a solar simulator to investigate the impacts of a temperature gradient applied to the sand layer.

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