

Seawater Evaporation Experiments: Determining Relative Evaporation Rates

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Introduction

Solar energy drives the hydrologic cycle. After evaporation from the oceans, fresh water is transported via the atmosphere to precipitate on land. The water then flows back to the oceans.

Evaporation is a critical parameter in the hydrologic cycle. Evaporation is defined as “the conversion of a liquid into vapor at temperatures below the boiling point” (About Physics Dictionary). The rate of evaporation is a function of the local meteorological conditions, the temperature and salinity of the solution as well as the ionic composition of the solution. As stated in Salhorta et al. (1985), “It is well known that evaporation from saline water is less than that from fresh water; however few comprehensive studies of evaporation from saline water bodies have been reported in the literature.”

The Laguna Beach evaporation pan experiments attempted to examine the relative contribution of additional energy required to evaporate seawater by conducting pair-wise evaporation pan experiments.

Empirical Ratio

In the literature, an empirically derived ratio comparing the evaporation rate of salt water to freshwater is used. The nomenclature for this ratio is alpha (α) such that

$$\alpha = E_{\text{sal}} / E_{\text{fresh}}$$

where α ($0 < \alpha < 1$) represents the reduction in evaporation due to salinity, E_{sal} is the rate of evaporation per unit area of saline water surface and E_{fresh} is the rate of evaporation per

unit area of fresh water surface. The ratio of salt water evaporation to freshwater evaporation is expressed as a function of the density (or salinity) of the solution. Studies involving primarily inland saline water bodies have reported these comparisons. The Laguna Beach results are compared with these previous studies.

Previous Studies

A handful of evaporation pan experiments have been reported using saline waters. Bonython (1956, 1965) used a pair of thermally-insulated evaporation pans over two consecutive summers to examine the effect of brine with density varying from 1.07 to 1.245 g/cm³.

Turk (1970) investigated the evaporation of brines on the Bonneville salt flats in Utah. He utilized eight pans installed over a one-month period installed within an enclosed evaporation pond. The solutions ranged in densities from 1.00 to 1.33 g/cm³. The densities were maintained by addition of freshwater to compensate for evaporative loss.

Janson (1959) examined four different salt solutions ranging in salinity from 30 ppt to 260 ppt (as reported in Salhotra et al. 1985).

Salhotra et al. (1985) used eight evaporation pans with different salinity and ionic compositions in a study of the mixing of Dead Sea and Mediterranean waters.

Authors in the above cited studies report the ratio of salt water evaporation to freshwater evaporation as a function of the density of the solution. This data is used in the comparison of the data reported below.

Methods

A series of evaporation pan experiments were performed to examine the relative difference in evaporation rate of salt water to distilled water. The salt water solution was adjusted to a salinity similar to seawater.

Salt was added to 3500 ml of distilled water to create a 35 ppt solution. A pair of evaporation pans made of glass cylinders, 18 cm in diameter and 25 cm in height was set out in Laguna Beach, California during the summer months of June through August. Experiments ran for 2 to 5 days. The final salinity, weight and water level were recorded before restarting the cycle.

The pair of evaporation pans was located on a flat cement area in either the southeast (SE) or northwest (NW) position (See Table 1).

Table 1. Experimental Design of Evaporation Pans[†]

Trial	SE location	NW location	Duration (hr)	Final Salinity (ppt)
1	SW	FW	96	40.0
2	FW	SW	72	37.5
3	FW	SW	96	40.7
4	SW	FW	72	44.8
5	SW	FW	72	38.7
6	FW	SW	120	37.9
7	FW	SW	48	37.2
8	SW	FW	72	37.8
9	SW	FW	72	39.3
10	FW	SW	72	38.5
11	FW	SW	144	40.9
12	SW	FW	120	40.2

[†]Note: SW is seawater and FW is freshwater.

Results

Results are presented in Table 2. The freshwater evaporation was on average 101 g/d (grams of evaporative loss per unit time, i.e. in units of grams/day) while the salt water evaporation was on the order of 97 g/d. The standard deviation, which is an indication of the variation in the experimental results, was very high on the order of 28%. In part, this variation is due to the variability in the experimental conditions. Initial water temperatures ranged from 19 to 32.5 °C and the initial salinity varied by 6 ppt. Additionally, the low number of experimental trials do not allow for conclusive testing of the hypothesis. Generally to draw a solid conclusion, narrower variability is required.

Table 2. Evaporation Rates for Fresh and Salt Water.

Trial	Date	Evaporation Rate		α
		Seawater (g/d)	Freshwater (g/d)	
1	30-Jun-02	101	105	0.9596
2	4-Jul-02	91	92	0.9856
3	7-Jul-02	65	65	0.9962
4	11-Jul-02	94	98	0.9626
5	14-Jul-02	115	122	0.9425
6	17-Jul-02	59	60	0.9702
7	22-Jul-02	115	117	0.9787
8	24-Jul-02	135	140	0.9643
9	28-Jul-02	139	142	0.9789
10	31-Jul-02	54	60	0.8994
11	3-Aug-02	82	85	0.9630
12	11-Aug-02	116	122	0.9525
Average		97	101	
Standard Devia		28	29	

In order to compare the Laguna Beach results with previous works, we assume that the solution density is equal to the final density based on water temperature and salinity (see Cox et al. 1970 for seawater conversion). The Laguna Beach results are plotted along with previous published results in Figure 1. The graph indicates that the Laguna Beach results fall within the range of expected results. Only Salhotra et al (1985) specified their error bars.

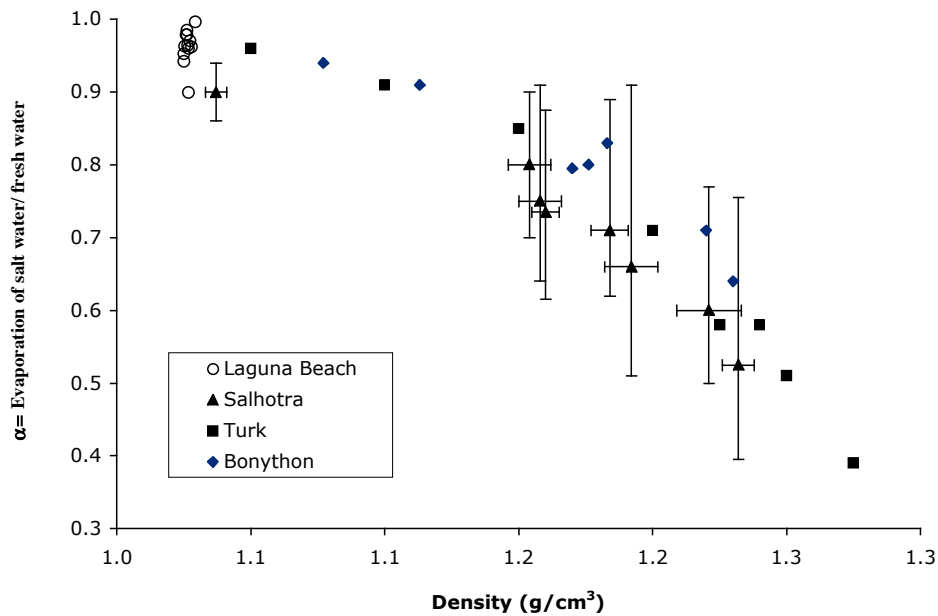


Figure 1. Results of the Laguna Beach Experiment. The ratio of evaporation rate of salt water to freshwater, α , is plotted versus the solution density.

To convert liquid water into a gaseous state requires large amounts of energy. For example, at 100° C, 540 calories of heat energy are used to vaporize 1 g of fresh water. For 20° C, the required energy is 620 cal/g.

If we assume the water temperature is 20° C for the Laguna Beach experiments, the approximately 4 g/d difference in seawater to freshwater evaporation is equivalent to an extra energy input of 9791 Joules (= 2340 calories) daily.

Discussion

Salhotra et al. (1985) noted that the common practice of correcting freshwater evaporation by an empirical ratio (α) of salt water to fresh water evaporation rates is only approximate. They suggest that a more accurate approach based on measuring the saturation vapor pressure.

There is an extra component of solar energy required for oceans to produce the same amount of water vapor as that of freshwater. It may be on the order of 2%. Large scale inequities in the distribution of solar input make resolving the exact value of this minor adjustment to evaporation water extremely difficult.

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