Volumetric Water Drop Evaporation Measurement

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ABSTRACT

A volumetric method was used to measure the evaporation loss of water drops larger than 0.3 mm diameter. This method, which uses microliter syringes, yields more accurate results than photographic measurement of changes in drop diameter. Evaporation data is presented for a range of drop sizes, air temperature, humidity and air velocity conditions.

INTRODUCTION

Losses from sprinkler irrigation include spray evaporation and drift losses which are difficult to measure separately and are usually reported as a combined loss. A wide range of losses has been reported in the literature due to the many physical parameters and environmental factors involved. The most promising method of separating these components and evaluating the true efficiency of sprinkler irrigation is by using mathematical models. Measurement of water drop evaporation is important for evaluating these models. Sprinkler irrigation nozzles produce drop sizes generally in the range of 0.3 to 3 mm in diameter.

Most previous evaporation measurements (Kinzer and Gunn, 1951; Roth and Porterfield, 1965; Williamson and Threadgill, 1974; and Longley, 1984) were made by photographing drops that were either suspended in an airstream or caught in an oil bath, and then measuring the change in diameter due to evaporation for a known time perid. Ranz and Marshall (1952a,b) estimated evaporation by measuring the water flow through a microburet that was required to maintain a suspended drop on a capillary tube at a constant diameter. Drop diameter was measured optically.

Evaporation measurement by drop diameter measurement has two specific problems. First, drops suspended from a tube in a moving airstream tend to become distorted and may vibrate, which makes accurate diameter measurements difficult. Second, since drop volume is proportional to diameter to the third power, measuring volume directly is likely to be more accurate than estimates of volume made from diameter measurements. For example, a 1% change in diameter is equivalent to 3% change in volume.

Kincaid and Longley 1989 (In process) developed a water drop evaporation model. In order to verify their model, it was necessary to measure the evaporation rates of individual drops subjected to different flight conditions (temperatures, humidity and air velocity). The photographic drop evaporation data of Longley (1984) gave reasonable agreement with the model but had a high degree of variability. A more accurate measurement method was needed. The technique described here involves suspending a drop from the needle of a microliter syringe for a known time period and measuring the net loss volumetrically.

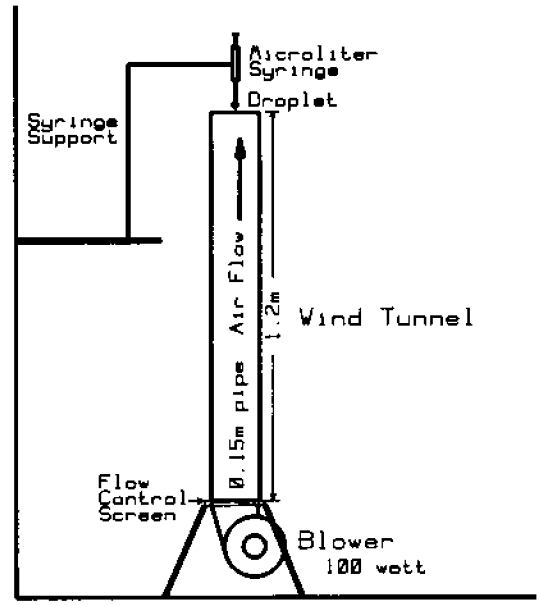

Fig. 1—Laboratory setup showing the position of the microliter syringe at the outlet of the wind tunnel.

Drops are usually emitted from sprinkler nozzles at high velocity (17 m/s at 138 kpa (20 psi) nozzle pressure) and rapidly approach terminal fall velocity. Terminal velocity is about 1 m/s for a 0.3 mm drop and about 8 m/s for a 3 mm drop. The objective was to measure drop evaporation using as wide a range of drop sizes and velocities as possible with the technique and equipment described herein.

EQUIPMENT

A small wind tunnel was constructed (Fig. 1) which provided air flow at velocities up to 10 m/s, comparable to the initial (and maximum) velocities of droplets leaving spray type sprinkler heads. A flow-restricting screen was placed at the wind tunnel inlet to adjust the air velocity at the outlet to the desired level. Tests were conducted in a small room in which the air temperature and humidity could be controlled.

Air temperature at the wind tunnel outlet was

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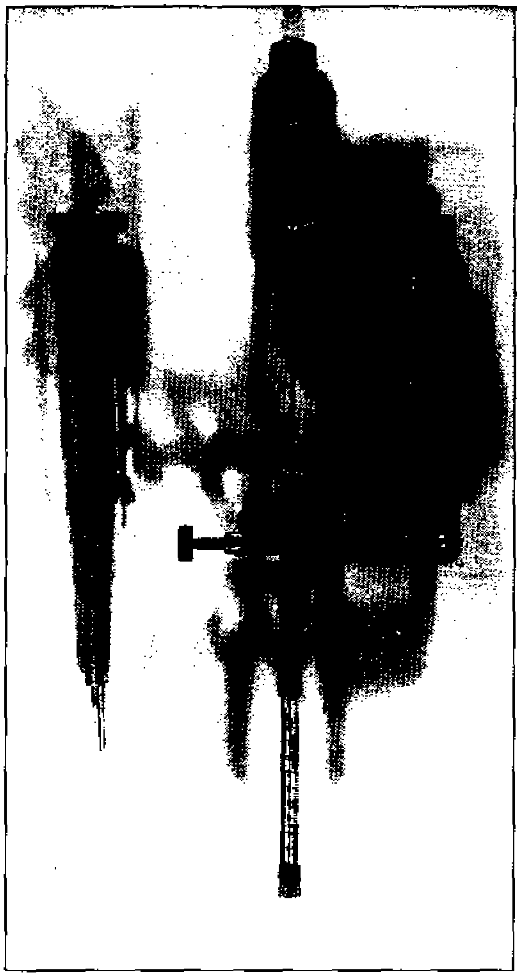

Fig. 2—Microliter syringes used for droplet evaporation measurement. The 2 microliter syringe is on the left and the 5 microliter syringe on the right is fitted with a micrometer displacement measuring device.

measured with thermocouples and dry bulb thermometers. Wet bulb temperature was measured with an aspirated electric psychrometer. Air velocity was measured with a thermal anemometer (Kurz Instrument Company Model 441)*, with a small probe for making point velocity measurements.

Microliter syringes are precision devices for injecting and sampling small quantities of liquids or gases and are available from laboratory equipment suppliers. Capacities of these syringes are as low as 1 ml, which is (at 70 mm full scale displacement) equivalent to a 1.2 mm drop diameter. Figure 2 shows two of the microliter syringes used in the study. The scales on these syringes can be read to a precision of about 1%.

In order to increase the precision when only part of the scale was used (i.e. for small drop sizes), a screw type micrometer (reading to .025 mm (.001 in.)) was mounted on a 5 ml syringe (Hamilton No. 95) as shown on the right in Fig. 2. This syringe had a silica needle with 0.18 mm outside diameter, the smallest diameter needle available. The addition of the micrometer enabled the 5 ml syringe to be used for smaller drops. Also shown is a 2 ml syringe with a stainless steel needle of 0.5 mm outside diameter which was used for larger drops (1.5 to 3 mm). The 2 ml syringe was also used for smaller drops by inserting a short length of the silica needle into the stainless steel needle, and cementing it with silicone.

*The use of trade names is for information only and does not constitute endorsement of a manufacturer's product by the author or the USDA.

PROCEDURES

Air velocity was measured near the water drop position prior to placing the syringe in its mount. The syringe was mounted with the needle pointed downward into the airstream at the outlet of the wind tunnel. The water surface was positioned at the tip of the needle, and then a drop of known initial volume was extruded through the needle. After allowing the drop to evaporate for a predetermined time period of 10 to 120 s, the drop was then drawn back into the syringe, and the water surface again adjusted to the tip of the needle. The net loss was measured by the net plunger displacement change required to bring the water surface back to its initial position. The silica needle was semitransparent, which aided in positioning the water surface at the tip of the needle. A magnifying lens also aided in this process.

The time period allowed for evaporation was determined by model prediction or successive trials so that volumetric losses were between 10 and 30%. With this loss range, the actual change in drop diameter was usually less than 3%. For purposes of comparison with instantaneous loss rates predicted by the model, the loss rate was computed for the average drop size during the test. Alternatively, larger changes in drop size can be allowed, and the model used to predict the time required for the drop diameter to change by the measured amount.

RESULTS

Data is presented in a form usable by researchers and model developers. Table 1 lists measured drop evaporation data grouped by constant dry bulb (DB) and wet bulb (WB) air temperature, and velocity conditions. The initial (V1) and final (V2) volumes (microliters), average drop diameter d (mm), and time (s) are given.

DISCUSSION

Some error is introduced because of the time required to form the drop and to draw the drop back into the syringe, usually less than 1 s. The error increases as the drop size decreases since shorter time periods are necessary.

The needle/drop size ratio was about 0.1 to 0.3 except for the 0.3 mm drops where this ratio was 0.6. The needle reduces the effective droplet surface area. The needle diameter should be kept small relative to the drop size in order to minimize heat conduction to the drop through the needle. The thermal conductivity of silica is about 10% that of stainless steel. Approximate calculations by Longley (1984) showed that heat conduction through the needle can be neglected. The upward air velocity counteracts gravity and allowed measurements to be made with velocities up to about twice the estimated terminal fall velocities of the drops. At higher velocities the drops were blown of the needle. A method needs to be found to enable measurements at

TABLE 1. Water Drop Evaporation Measurements at 1200 m Elevation

Vel m/s	DB C	WB C	V1 ml	V2 ml	d mm	Time s
0.0	22.0	12.0	0.05	0.037	0.44	40
			0.10	0.077	0.55	40
			0.10	0.084	0.56	30
			0.20	0.175	0.71	40
			0.30	0.277	0.82	40
			0.40	0.364	0.90	40
			0.50	0.462	0.97	40
			0.60	0.547	1.03	60
			0.59	0.552	1.03	40
			0.70	0.658	1.09	40
			0.79	0.725	1.13	60
			0.89	0.838	1.18	40
			0.99	0.912	1.22	60
			1.10	1.049	1.27	40
			1.19	1.111	1.30	60
			1.29	1.237	1.34	40
			1.39	1.308	1.37	60
			1.38	1.317	1.37	40
			1.47	1.408	1.40	40
			1.58	1.487	1.43	60
			1.57	1.498	1.43	40
			1.78	1.688	1.49	60
0.1	26.0	13.0	0.99	0.665	1.16	120
			0.99	0.826	1.20	60
			0.60	0.457	1.00	60
			0.59	0.384	0.97	90
			0.53	0.401	0.96	60
			0.55	0.339	0.94	90
			0.54	0.396	0.96	60
3.0	10.9	5.5	1.50	1.324	1.39	60
			1.01	0.857	1.21	60
			0.79	0.649	1.11	60
			0.60	0.485	1.01	60
			0.39	0.301	0.87	60
			0.30	0.221	0.79	60
			0.25	0.179	0.74	60
			0.20	0.137	0.68	60
			0.10	0.052	0.52	60
3.0	10.3	8.2	1.51	1.374	1.40	120
			1.00	0.860	1.21	120
			0.85	0.710	1.14	120
			0.65	0.533	1.04	120
			0.54	0.454	0.98	120
			0.50	0.401	0.95	120
			0.44	0.357	0.91	120

Vel m/s	DB C	WB C	V1 ml	V2 ml	d mm	Time s
3.0	22.4	19.9	1.99	1.772	1.53	120
			1.38	1.202	1.35	120
			1.30	1.117	1.32	120
			1.19	1.012	1.28	120
			0.79	0.720	1.13	60
			0.61	0.542	1.03	60
			0.40	0.344	0.89	60
			0.20	0.162	0.70	60
5.0	26.0	13.0	0.99	0.562	1.13	60
			0.99	0.748	1.18	30
			0.98	0.749	1.18	30
			0.98	0.755	1.18	30
1.0	23.0	12.0	0.10	0.083	0.56	20
			0.20	0.175	0.71	20
			0.40	0.343	0.89	30
			0.59	0.524	1.02	30
			0.79	0.722	1.13	30
			0.99	0.912	1.22	30
			1.20	1.105	1.30	30
			1.43	1.330	1.38	30
			1.59	1.480	1.43	30
			1.79	1.679	1.49	30
2.0	23.0	12.0	0.20	0.162	0.70	20
			0.39	0.349	0.89	20
			0.60	0.547	1.03	20
			0.79	0.724	1.13	20
			0.99	0.920	1.22	20
			1.20	1.108	1.30	20
			1.40	1.302	1.37	20
			1.58	1.486	1.43	20
			1.79	1.684	1.49	20
2.5	30.2	18.0	1.70	1.500	1.45	30
			1.48	1.283	1.38	30
			1.30	1.118	1.32	30
			0.90	0.743	1.16	30
			0.69	0.565	1.06	30
			0.49	0.387	0.94	30
			0.30	0.221	0.79	30
			0.20	0.134	0.68	30
3.0	22.4	13.0	1.99	1.631	1.51	60
			1.78	1.430	1.45	60
			1.40	1.238	1.36	30
			1.17	1.031	1.28	30
			1.00	0.863	1.21	30

Vel m/s	DB C	WB C	V1 ml	V2 ml	d mm	Time s
3.0	22.4	13.0	0.79	0.682	1.12	30
			0.70	0.589	1.07	30
			0.59	0.493	1.01	30
			0.39	0.306	0.87	30
			0.29	0.226	0.79	30
			0.20	0.150	0.69	30
3.0	23.0	13.0	0.20	0.162	0.70	20
			0.40	0.363	0.90	20
			0.59	0.525	1.02	20
			0.79	0.724	1.13	20
			0.99	0.919	1.22	20
			1.20	1.110	1.30	20
			1.40	1.301	1.37	20
			1.58	1.487	1.43	20
			1.79	1.684	1.49	20
1.0	31.0	16.4	0.05	0.035	0.43	10
			0.10	0.075	0.55	10
			0.10	0.076	0.55	10
			0.29	0.263	0.81	10
			0.40	0.365	0.90	10
1.0	31.4	16.8	0.02	0.012	0.32	10
			0.02	0.011	0.32	10
			0.02	0.010	0.31	10
			0.02	0.011	0.32	10
2.5	31.2	16.5	0.20	0.162	0.70	10
			0.10	0.075	0.55	10
			0.08	0.055	0.50	10
			0.05	0.033	0.43	10
			0.02	0.014	0.33	10
			0.02	0.012	0.32	10
			0.05	0.025	0.41	10
			0.02	0.009	0.31	10
4.0	23.0	13.0	0.10	0.069	0.54	10
			0.20	0.162	0.70	10
			0.30	0.261	0.81	10
			0.40	0.363	0.90	10
			0.50	0.455	0.97	10
			0.60	0.550	1.03	10
			0.70	0.655	1.09	10
			0.79	0.729	1.13	10
			0.99	0.918	1.22	10

higher velocities since drops are ejected from sprinkler nozzles at higher velocities.

The accuracy of the method can be shown by example. Using the 5 ml syringe with attached mm (.001 in. precision), a 0.99 ml drop was extruded (Table 1, line 13). After 40 s, the volume was 0.912 ml. The volume loss was 8%. The scale factor of this syringe is 0.427 in. (plunger displacement) per ml. The loss of 0.078 ml would be 33 units on the micrometer, so the loss was measured to about 3% precision. For the smallest drop measured (0.31 mm average diameter) using this syringe, the volume changed from 0.020 to 0.010 ml in 10 s, resulting in a precision of about 25% (4 micrometer units) in loss measurement. Thus, the accuracy is dependent on the syringe capacity and drop size. The measurements were highly repeatable within the precision of the equipment.

SUMMARY AND CONCLUSIONS

A volumetric microliter syringe method was used to measure evaporation loss from water drops suspended in a moving air stream. Data was presented for drop sizes between 0.3 and 1.5 mm diameter, the size range produced by typical irrigation sprinklers. In conclusion, the volumetric syringe method is an accurate and reliable method of measuring evaporation loss from drops of a particular size range which can be suspended on the syringe needle.

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