of quadratic vector functions. Analysis is represented by a contribution from G. A. Bliss on functions of lines and one from A. Dresden upon the calculus of variations.

EDWIN BIDWELL WILSON

SPECIAL ARTICLES

A MODIFICATION OF THE BELLANI POROUS PLATE ATMOMETER

A RECENTLY renewed and increased interest in the direct measurement of the evaporating power of the air[1] has brought the atmometer (incorrectly called evaporimeter, etc.) into greater prominence than has heretofore been enjoyed by that instrument. Atmometers are now being used more than ever before, especially in plant physiology, plant and animal ecology, and the agricultural aspect of climatology.[2] This newer development of atmometry has emphasized the employment of water-impregnated solids to furnish the evaporating surface from which the rate of evaporation is studied, and has discouraged the use, for many purposes at least, of the open pan or tank of water so commonly met with in meteorological and general climatological literature. It has thus come about that considerable misunderstanding has arisen as to what atmometry is really aiming at and as to the relative desirability of studying evaporation from one or another kind of evaporating surface.

Of all the different forms of water-impregnated surfaces employed in the study of atmospheric evaporating power, the cylindrical porous clay cup of Babinet[3] has met with the most favor among biological and agricultural workers, and the standardized porous cups now in general use follow the principle of Babinet's device. This type of atmometer possesses a number of pronounced advantages over the free water surface, when atmospheric evaporating power is to be studied as an environmental condition affecting animals and plants. Among these advantages may be mentioned the fact that the evaporating surface of the cup projects up into the air like most animal and plant surfaces. Thus it does not so readily become clogged, as it were, by its own vapor blanket, as does a horizontal surface. Furthermore, the porous cup instrument is much more readily and precisely read than is the open tank, and very short time intervals may consequently be employed. I have frequently constructed graphs showing the march of evaporating power by minute or 5-minute rates, a procedure hardly possible with any form of pan atmometer. More important than any other of the advantages here in question, however, is the one depending upon comparative variability of the evaporating surface with

[1] The evaporating power of the air may be thought of as the reciprocal of the resistance offered by the air to evaporation from exposed liquid water. The term is a misnomer to a degree, for evaporation proceeds from a water surface *in spite* of the conditions obtaining in the surrounding air. Ceteris paribus, the greater is the air pressure, the less rapid is evaporation; the less water is contained in the air the more rapid is evaporation, etc. The term has come into rather general use, however, and may as well stand till a better is suggested; it is logically no worse than the word suction, and, like it, is readily understood by everybody. *Condensing* power or *water supplying* power can not here be used in place of *resistance,* because air without water-vapor offers resistance to evaporation but has no condensing power; it can not deposit water upon a surface, no matter what its pressure may be. The resistance offered by such dry air can be expressed in terms of an equivalent condensing power, however.

[2] Livingston, B. E., "The Relation of Desert Plants to Soil Moisture and to Evaporation," Carnegie Inst. Wash. Pub. 50, 1906. Shelford, V. E., "Animal Communities in Temperate America," Geog. Soc. Chicago Bull. 5, 1913, pages 162–65. Livingston, B. E., and L. A. Hawkins, "The Water Relation between Plant and Soil," Carnegie Inst. Wash. Pub. 204, 1915 (the first paper of that publication). Shive, J. W., "An Improved Non-absorbing Porous Cup Atmometer," *Plant World,* 18: 7–10, 1915. Livingston, B. E., "Atmometry and the Porous Cup Atmometer," *Plant World,* 18: 21–30, 51–74, 95–111, 143–149, 1915. Livingston, B. E., "Atmospheric Influence upon Evaporation and Its Direct Measurement," *Mo. Weather Rev.,* 1915. McLean, F. T., "Relation of Climate to Plant Growth in Maryland," *Mo. Weather Rev.,* 1915.

[3] Babinet, J., "Note sur un atmidoscope," *Compt. Rend. Paris,* 27: 529–30, 1848.

reference to wind action. When ripples or waves are formed on a free water surface the surface is very markedly altered, and this kind of alteration occurs so generally and so uncontrollably with pan or tank atmometers exposed in the open, that it renders futile any detailed study of evaporating power carried out with such instruments. Properly cared for and properly operated, the porous cup surface does not appreciably alter, at any rate it is never altered by wind action. Other advantages of the porous cup over the free water surface are related to errors in reading the latter type of atmometer arising from splashing and spray, the removal of water by animals and the capture of animals, wind-blown leaves, etc., in the tank; none of these errors are encountered in the operation of the Babinet atmometer. Also, the porous cup may be so mounted as not to absorb rain, which always plays havoc with readings from open pans.

For certain purposes, however, such as the study of atmospheric evaporating power at or near the soil surface or the surfaces of reservoirs, etc., the porous cylinder is not well suited; here a plane evaporating surface is frequently requisite. The well-known Piche atmometer, or Cantoni's[4] or Houdaille's[5] modification of the latter, all three employing blotting-paper disks, may be used in such cases, but these instruments are less convenient in operation than is the porous cup, in various ways. It therefore seemed desirable to bring into use what amounts to a porous clay cup with a plane evaporating surface. Just such an instrument was devised and described very long ago by Bellani,[6] who appears to deserve credit for first employing a water-impregnated solid connected by a simple water column with a reservoir at a lower level. The principle here involved forms the basis of the Piche-Cantoni and Babinet instruments as afterwards constructed.

It is hard to understand why Bellani's device should have remained unmentioned during nearly a century of climatological and meteorological advance. Especially surprising is this lack of recognition when it is appreciated that this horizontal plate of Bellani is exactly the form of instrument that should have replaced the open pan in the vain struggles of meteorological students to obtain the long-sought "evaporation formula"; thus might have been avoided, perhaps, some of the wasted effort expended in attempts to express by a single term the influence of wind upon evaporation, when the latter was measured from the variously rippled surface of free water.

In Bellani's atmometer, a horizontal porous clay disk closed the top of a vessel completely filled with distilled water, so that the lower surface of the disk was in contact with the liquid, while the upper surface was exposed to the air. A horizontal, graduated glass tube, of small bore, open at its distal end, projected laterally from the vessel, and the air-water meniscus in the tube progressed toward the vessel as evaporation occurred, the tube thus becoming more or less rapidly emptied of water. A suitable reservoir and cock allowed the meniscus to be pushed back over the scale, by admitting more water into the vessel. As water evaporates from the porous surface of such an instrument more is imbibed from below, and air pressure drives the meniscus inward along the scale, keeping the vessel completely filled and the plate continuously in contact with the water below. The instrument may be mounted with a burette reservoir, as is frequent with the porous cups now in use, instead of the horizontal graduated tube.

After some preliminary discouragement I have at length been able to obtain circular

4 Cantoni, G., "Sulle condizioni di forma e di esposizione piu opportune per gli evaporimetri," *Rend. R. Ist. Lomb.*, II., 12: 941–46, 1879.

5 Houdaille, F., "Mesure de l'évaporation diurne; description d'un évaporimètre enregistreur," *Bul. Mét. Hérault*, 1890. (This is the instrument catalogued by Richard Frères, Paris. For further references to Houdaille's work, as well as that of others, see: Livingston, Grace J., "An Annotated Bibliography of Evaporation," *Mo. Weather Rev.*, 36: 181–86, 301–06, 375–81, 1908; 37: 68–72, 103–09, 157–60, 193–99, 248–52, 1909. Reprinted, repaged, Washington, 1909. This includes most of the papers appearing before 1908.)

6 Bellani, A., "Descrizione di un nuovo atmidometro, etc.," *Gior. Fis. Chim.*, 3II: 166–77, 1820. (Reprinted, Pavia, 1820.)

porous clay plates (77 mm.—3 in.—in diameter) mounted across the large end of a glazed porcelain funnel. The apparatus is made as a single piece, the funnel wall and the disk being continuous, and the lateral surface is afterwards heavily glazed externally. The funnel part is nearly hemispherical, with the cylindrical neck projecting outward from the spherical surface, opposite the center of the porous disk which closes the hemisphere at the top. A vertical section of such a piece is shown in Fig. 1. In operation, the opening

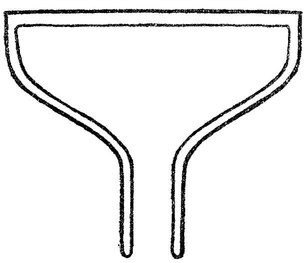

Fig. 1.

is closed by a rubber stopper bearing a tube reaching to the water reservoir below, just as in the case of the ordinary porous cup atmometer. Of course it is not at all essential that the plate be horizontal; it may be exposed in any direction, even downward. All that is necessary is that the water level in the reservoir be at a lower level. It may be mounted on a bottle or a burette, or any convenient form of reservoir, and the non-absorbing mounting may be employed to prevent the absorption of rain. In general, these Bellani plates are to be operated just as are the ordinary porous cups. Where a plane evaporating surface is required, they possess all the advantages of the free water surface and none of its disadvantages. They also possess all the general advantages of the porous cup instrument.

Burton E. Livingston

THE EFFECT OF TEMPERATURE ON THE LIFE CYCLE OF MUSCA DOMESTICA AND CULEX PIPIENS

Owing to a scarcity of data necessary to illustrate the relation of the temperature to the rate of breeding of flies and mosquitoes, a set of experiments was undertaken at the suggestion of Professor C.-E. A. Winslow, to determine (approximately) this relation.

These experiments were made possible through the courtesy of the department of natural history of the College of the City of New York in loaning us three incubators for the purpose.

The experiments began late in July, 1914, and ran through to the middle of September.

An effort was made to eliminate all factors but that of temperature.

Individual variations among different batches of eggs were eliminated by dividing the same batch into three portions to be incubated at the three temperatures.

Larvæ reared from the batches of eggs compared were fed on the same food.

The light, throughout, was either diffused or absent, and the same condition obtained in the batches compared with each other.

By exposing several tumblers of water in each incubator, the atmosphere was kept in a high state of saturation.

All vials containing the breeding fly larvæ were of the same cross section and the height of manure was about the same in each, *i. e.*, from 1½ to 2 inches; the mosquito-larvæ vials and infusions were also uniform.

From the above it will be seen, that although the results may not indicate a breeding rate generally true for each temperature, they nevertheless offer a fair comparative study of the rate at the three temperatures.

Experiments with Flies

Experiments with the life cycle of flies will be treated first.

Egg batches were obtained in the following way: Flies were caught by net and females with gorged abdomens selected. These were first placed together in large fruit jars containing rotten fruit (plums), and the jar was

TABLE I

Average Duration of Each Stage—Flies

Temp.	Egg Stage	Larva	Pupa	Total
20°	1.2 da.	12.3 da.	8.8 da.	22.3 da.
30°	1 da.	5.1 da.	4.2 da.	10.3 da.
35°	1 da.	4.3 da.	4.0 da.	9.3 da.