# THE OPTICAL HYGROMETER AND ITS WORKING

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*(Received for publication, June 15, 1941)*

**ABSTRACT.** In this paper, the description of the construction of the optical hygrometer is given. It works on the principle of a balance in the form of a rod supported by two loose screws and at right angles to it there is another rod having two pans on its ends, rigidly attached with it. One pan contains the substance having high power of absorption and desorption of moisture and the other pan balancing weights. The rotation of the rod which is proportional to the change in humidity is measured by the lamp and scale arrangement.

The theory, its sensitiveness and working are discussed in detail. A few observations recorded with this instrument are compared with those of the other kinds of hygrometers.

## INTRODUCTION

Various kinds of hygrometers are being used in these days for determination of the relative humidity of the air. Some of the common forms are the wet and dry bulb hygrometer, hair hygrometer, and the paper hygrometer. But all of them are such that they take a long time to adopt the conditions of the air and do not show high degree of accuracy. Moreover, the hair and the paper hygrometers do not give correct readings at very high and very low relative humidities. The small changes in the humidities of the air cannot be detected easily and correctly by any one of them.

In view of the above difficulties, a new type of hygrometer[1] has been invented in this Laboratory which works on the principle of optical instruments. By its use many practical difficulties, which one has to face for the accurate work, will be overcome.

A short note regarding it has already been published in the Current Science in its February number, 1941. But now in this paper, a detailed study of its construction, theory, sensitiveness, and use has been made. A short note regarding the selection of a suitable substance having high power of absorption and desorption of moisture is given. Besides a few observations recorded with it are compared with those of the other kinds of hygrometers commonly used in the laboratories.

## CONSTRUCTION

Its construction is very simple and its line sketch is given in Fig. 1. To a zinc rod *a* (balance beam) of about 1 mm. thickness, 2 mm. depth, and 6 cm.

length, a cup of zinc of about 1 cm. square and about 2 mm. deep, is regidly attached on its each end. Another cylindrical revolving rod of copper, *b*, about 1 mm. thick and 4 cm. long passing through the middle of the beam *a* is regidly attached at right angles to it. A small galvanometer mirror *m* of about 2 metres focal length is fixed to the revolving rod, just on one side of the junction of the revolving rod and the balance beam.

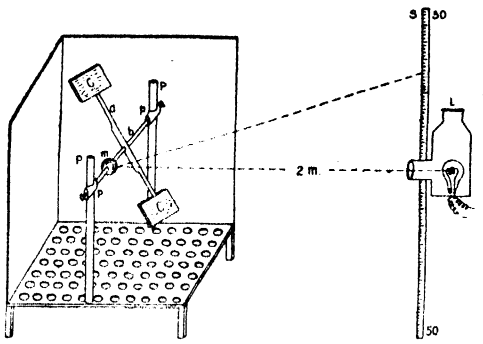


FIG. 1

The two ends of the revolving rod are made to rest on two fine well-polished and equally levelled glass plates *p*, *p* fitted on stands or they are very loosely fitted in the grooves of two hollow adjustable screws fixed in the two vertical supports P and P. The former method is more sensitive than the latter one but the latter is stabler than the former. Any one of them can be used according to the nature of the experiment and the accuracy needed.

One of the cups (*c* and *c*) is filled with the Plaster of Paris containing about two percent calcium chloride or the black cotton-soil of Poona. Both have fairly high power of absorption and desorption of moisture, being available easily and at cheaper rate and also having slightly higher power of absorption and desorption of moisture than that of the former. Suitable weights are added into the other pan till the balance beam (zinc rod *a*) becomes horizontal. Instead of the fractional weights, pure thick sand or quartz powder can be used and may prove better than the weights which sometimes move in the pan and disturb equilibrium.

The whole instrument is enclosed inside a rectangular glass cover. It fits well on its base which is perforated with holes. They help in free circulation of the external air inside it. The cover avoids any disturbance to the revolving arrangement due to any direct and strong current of air.

Then the beam of light is thrown from an electric lamp and the scale arrangement L on the galvanometer mirror and the reflected beam is thrown somewhere in the middle of a vertical scale S at a distance of about 200 cms. from the mirror. With a small change in the humidity of the air the spot of light moves through a great distance on the vertical scale.

SELECTION OF THE SUBSTANCE

In view of selecting a suitable substance having high power of absorption of moisture from the moist air and desorption of moisture to the dry air, for the pan of the balancing beam, powders of various substances were tried. Some of them which need a mention are the following :—

Plaster of Paris, calcium hydroxide, aluminium hydroxide, lycopodium powder, sodium bicarbonate, sodium nitrate, calcium chloride, black cotton-soil of Poona; Patiala soil, and various mixtures of Plaster of Paris and calcium chloride, in quantities varying from 1% to 50% of calcium chloride in Plaster of Paris.

It was observed that the calcium chloride, calcium hydroxide, and sodium bicarbonate have high power of absorption of moisture from the air and little power of desorption of moisture to the dry air. While aluminium hydroxide, stearic acid, sodium nitrate, and lycopodium powder have very little power of absorption and desorption of moisture. But it was observed that the fine powdered soil of Patiala, the black cotton-soil of Poona, and Plaster of Paris containing 2% calcium chloride work quite satisfactory for they cause a good shift of the spot of light on the scale for a small change in the humidity of the air, and the rates of absorption of moisture from the moist air and desorption of moisture to the comparatively dry air are almost the same. But the last two are far better than the first, and the black cotton-soil of Poona is undoubtedly the best.

It is a better arrangement, if a paste be made by mixing the black cotton-soil with a suitable quantity of water and one of the cups is filled with it. On drying up the paste, it works well. This process avoids the blowing away of the fine particles of the soil from the cup.

THEORY

Let the weight of the substance in one of the cups be $m$ gms. and the standard weights in the other pans be also $m$ gms., so that the balance beam be horizontal. When the relative humidity of the air increases, the substance in the cup absorbs some more moisture from the air and by this let the increase in weight of the substance be $\mu$ gms. This will bend the balance beam on the soil side through an angle $\theta$ and raise the other side by the same angle. The revolv-

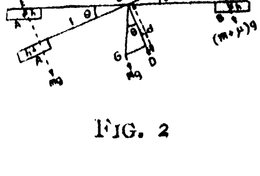

FIG. 2

ing rod which is rigidly attached to the balancing beam rotates through the same angle. The galvanometer mirror attached with the revolving rod also rotates through the same angle. But the reflected ray of light deviates through double that angle, *i.e.*, $2\theta$.

Now in the above fig. 2, let the weight of the balancing beam be M gms. When the beam is horizontal in the position ABC, the weight $mg$ is acting at A, $mg$ at B, and $Mg$ at C. But after the adsorption of moisture, the beam takes the inclined position ECF. By imagining the vertical section taken through the centre of the beam that it cuts the beam at E, G, F. Thus the weight $mg$ acts at E, $(m+\mu)g$ at F and $Mg$ at G. In this case the three points where the weights of the central beam and the pans are acting are not coplanar, *i.e.*, A, B and C are not coplanar but C is slightly higher than the other two points A and B.

Let $l$ be the length of each arm, *i.e.*, horizontal distance, $CB=CA=l$ and $d$ the depth of centre of gravity D below C. Let $h$ be the depth of A and B below C when the balance beam is horizontal. It is approximately the same in both cases.

When the beam is inclined :—

The horizontal distance of A from C $= l\cos\theta + h\sin\theta$.

" " B " $= l\cos\theta - h\sin\theta$.

" " G " $= d\sin\theta$.

When the beam is in the equilibrium position, the moments acting on both the sides are equal. Therefore,

$$(m+\mu)g\ (l\cos\theta - h\sin\theta) = Mg.d\sin\theta + (l\cos\theta + h\sin\theta)mg$$

since the angle $\theta$ is very small, so $\cos\theta = 1$ and $\sin\theta=\theta$ very approximately and the above equation can be put down in the following form :

$$(m+\mu)g\ (l-h\theta) = Mg.d\theta + (l+h\theta)mg$$

$$-\mu h\theta + ml - mh\theta + \mu l = Md\theta + ml + hm\theta.$$

By neglecting the product $\mu\theta$ which is very small and negligible, we get :

$$\theta = \frac{\mu l}{Md+2mh} \qquad \dots (1)$$

or

$$\frac{\theta}{\mu} = \frac{l}{Md+2mh} \qquad \dots (2)$$

and

$$\mu = \left(\frac{Md+2mh}{l}\right)\theta \qquad \dots (3)$$

$$= k\theta \qquad \dots (4)$$

where $k$ is a constant equal to $\frac{Md+2mh}{l}$.

The equation (2) gives the ratio of the deflection $\theta$ to the difference $\mu$ in the loads on the two cups. This ratio is the sensitiveness of this instrument.

The equation (4) gives the value of $\mu$, the increase in weight of the soil by adsorption of moisture from the moist air in terms of a constant $k$ and deflection $\theta$ where $k$ is equal to $\frac{Md+2mh}{l}$ which remains constant for any instrument and depends merely on its construction. Therefore, the increase in weight $\mu$ is proportional to $\theta$ which is the rotation of the revolving beam.

$$\mu \propto \theta.$$

But the increase in weight is proportional to the increase of the relative humidity of the air,[1] therefore

$$(H_2 - H_1) \propto \theta \qquad \ldots \quad (5)$$

where $H_1$ and $H_2$ are the initial and final relative humidities of the air. When $H_1$ is zero, we get

$$H_2 \propto \theta \qquad \ldots \quad 6)$$

The angle $\theta$ of rotation of the revolving rod is measured by means of a lamp and scale arrangement. If the distance of the scale be $y$ cms. from the galvanometer mirror and the spot of light shifts through the distance $x$ cms. on the vertical scale, then we get :

$$2\theta = \frac{x}{y} \text{ (angle } \theta \text{ being very small)}$$

or

$$\theta = \tfrac{1}{2}\left(\frac{x}{y}\right) \qquad \ldots \quad (7)$$

therefore, by substituting this value in equation (4), we obtain :

$$\mu = k.\tfrac{1}{2}\left(\frac{x}{y}\right)$$

$$= Gx \qquad \ldots \quad (8)$$

where G is another constant equal to $\frac{1}{2}.\frac{k}{y}$ which remains constant as long as the arrangement of the apparatus, *i.e.*, the distance of the scale from the mirror remains the same.

Let $\mu_1$ be the increase in weight when the humidity increases from $H_0$ to $H_1$ and $\mu_2$ be the increase in weight when the humidity increases from $H_0$ to $H_2$, and let the shifts of the spot of light in both cases on the vertical scales be $x_1$ and $x_2$ respectively, then

$$\frac{H_1 - H_0}{H_2 - H_0} = \frac{\mu_1}{\mu_2}$$

$$\therefore \quad \frac{H_1 - H_0}{H_2 - H_0} = \frac{Gx_1}{Gx_2} = \frac{x_1}{x_2}. \qquad \ldots \quad (9)$$

If $H_0$ and $H_1$ are known, $H_2$ can be calculated. If the arrangement is so made that $H_2$ represents zero, relative humidity and the corresponding reading on the scale be zero cm. and $R_1$ and $R_2$ are the readings taken on the scale for the relative humidities $H_1$ and $H_2$, then

$$\frac{H_1}{H_2} = \frac{R_1}{R_2}. \qquad \ldots \quad (10)$$

If $H_1$ is known, we can calibrate the scale in terms of the relative humidities. Then the readings on the scale will represent directly the relative humidity of the air or any chamber where the instrument is kept for record of observation.

### SENSITIVENESS OF THE INSTRUMENT

The equation (2) $\frac{\theta}{\mu} = \frac{l}{Md + 2mh}$ which has already been derived above represents the ratio of the deflection $\theta$ to the difference $\mu$ in the loads on the two cups and is the sensitiveness of the instrument. But if the cups are so made that they are above the horizontal, that is, C is below A and B, then the sensitiveness of the instrument becomes :

$$\frac{\theta}{\mu} = \frac{l}{Md - 2mh}. \qquad \ldots \quad (2.a)$$

Thus the sensitiveness can be increased in both the cases by increasing $l$ the length of the arms of the balancing beam and by decreasing M the mass of the beam and $d$ the depth of the centre of gravity of the beam from the point of suspension.

In the former case, the sensitiveness will also increase by decreasing $m$ the load in either pan, and $h$ the depths of the points A and B below the horizontal. But in the latter case the sensitiveness will increase by increasing $m$ and $h$ for C is below the external points.

In both the cases, the quantity $(Md \pm 2mh)$ is very small and $l$ is fairly large for the balancing beam is made of zinc and has small dimensions and the beam is almost horizontal. The quantity $2mh$ is very small. Therefore the sensitiveness is very high.

## OBSERVATIONS

The results obtained with this instrument are satisfactory. It works to a high accuracy. The small changes in humidity of the air can easily be detected with it. A few of the observations recorded with it and other kinds of hygrometers are given below in table I and indicate the comparison of results.

TABLE I

| No. | Kind of Hygrometer | Change in % Humidity recorded by it | Shift of the spot of light on the vertical scale or of the needle on the dial of the instrument |
|---|---|---|---|
| 1 | Wet and dry bulb Hygrometer | 1.2% increase | A fraction of a degree on the thermometers |
| 2 | Paper Hygrometer | 1.5% ,, | 1 mm. approximately on the dial |
| 3 | Hair Hygrometer | 1.1% ,, | 1.5 mm. approximately on its dial |
| 4 | Optical Hygrometer | 1.0% ,, | 2.5 cms. approximately on the vertical scale |
| 1 | Wet and dry bulb Hogrometer | 1.1% decrease | A fraction of a degree on the thermometers |
| 2 | Paper Hygrometer | 1.3% ,, | 1.1 mm. approximately on its dial |
| 3 | Hair Hygrometer | 1.0% ,, | 1 4 mm. approximately on its dial |
| 4 | Optical Hygrometer | 1.0% ,, | 2.4 cms. approximately on the vertical scale |

The above observations lead us to the conclusion that even one percent. increase or decrease of humidity of the air cannot be easily detected and accurately read from the wet and dry bulb, the hair and the paper hygrometers, as in the first instrument the size of the degree of the thermometer is very small, and in the case of the second and third instruments the shift of the pointer on the dial is hardly of the order of one millimetre. But the same change in the humidity causes a shift of the spot of light on the vertical scale of the optical hygrometer through 2.5 cms. which can be read quite easily and accurately. Thus small variations in the relative humidity of the air, even of the order of 1% or less than 1% can easily and accurately be detected by this instrument.

The sensitiveness of this instrument may be compared with that of the hair hygrometer by comparing their shifts on their corresponding scales. Thus,

$$\frac{\text{Sensitiveness of the Optical Hygrometer}}{\text{Sensitiveness of the Hair Hygrometer}} = \frac{\text{Shift of the spot of light on the vertical scale}}{\text{Shift of the pointer on the dial}}$$

$$= \frac{2.5}{0.15}$$

$$= 17 \text{ times approximately.}$$

## CONCLUSIONS

Further work is being done in this laboratory to find a better substance having still higher power of absorption of moisture from the moist air and desorption of moisture to the comparatively dry air, than that of the present ones used in it. Attempts are also being made now to make it more sensitive, accurate and practicable for everyday use in the laboratories and the meteorological observatories.

The author is greatly indebted to the Government of Patiala, for having provided facilities to carry out the above work in the Research Laboratory of the Mahendra College, Patiala. The author also expresses his heartfelt thanks to Dr. L. A. Ramdas, Agricultural meteorologist of the India Meteorological Department, Poona, for having provided me with a sample of black cotton soil of Poona for the above work.

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