Mausam, (1980), **31**, 1, 169-174

551.508.71

Infrared hygrometer

(MRS.) L. C. MANOHARAN and S. NAGABHUSHANA
National Aeronautical Laboratory, Bangalore
(*Received 24 January 1978*)

ABSTRACT. This paper describes in detail the design and construction of an infrared hygrometer to measure absolute humidity in the atmosphere. The hygrometer has good dynamic response compared to other methods and the speed of response is essentially limited by the electronic filters. The hygrometer can be readily modified to measure the humidity for atmospheric research also. Use of two infra-red filters for differential measurement which chop the measuring light beam, eliminates completely the errors due to aging of infrared source, atmospheric light scattering and other extraneous disturbances. The calibration procedure is also outlined.

1. Introduction

Quite a few methods are available for measurement of the different parameters of atmospheric humidity like relative humidity, dew point etc. The hair hygrometer in which the length of a strand of hair is dependent on the relative humidity, the dew cell, which gives the dew point, the wet and dry bulb hygrometer are a few examples of the instruments used for measurement of humidity. All these instruments are rather slow in their response and hence could be used only for the determination of time averaged humidity.

In the infra-red (IR) hygrometer the method of measurement by absorption spectra analysis is employed and it uses a beam of light as the sensing element (Wood 1958), and hence this instrument is inherently several orders of magnitude faster (Middleton and Spilhavs 1953), limited only by the speed of IR radiation (*i.e.*, speed of light), response time of the IR detector and the electronic circuit time constant.

2. Principle of working

2.1. The IR region of the electro magnetic spectrum is divided into three sections (*viz.*, near, middle and far) IR (Hackforth 1960). Approximately: 0.72 to 1μm is near IR, 1 to 10 μm is middle IR, 10 to 1000 μm far IR.

2.2. The selective absorption at certain wavelengths (1.3, 1.89, 2.6, 2.7 and 6.3 μm) in the middle IR region by water vapour is made use of in the development of the IR hygrometer (Hudson 1969). The 1.3 and 1.89 μm bands are weak absorption bands and are useful in measuring high absolute humidities and the 2.7 and 6.3 μm bands are fairly strong absorption bands and are useful in measuring low humidities such as those in dry places and in clouds from —20°C to 10°C as well as high humidities.

When an IR beam with a wavelength in the absorption band of water vapour is passed through a certain path length l cm of the atmosphere and is received by a detector, the signal obtained at the detector is a function of the total amount of water vapour in the path length. The output at the detector is less when the water vapour content is more causing more absorption and *vice versa*.

If the signal at the detector is I_0 when there is no water vapour and I when the density of the water vapour in the IR path is ρ_w gm/m^3, then:

$$\frac{I}{I_0} = \left[\exp\left(-\ a\rho_w\right)\right] \tag{1}$$

(Hyson and Hicks 1975) where a is constant for a given λ and l. $I/I_0 = \tau =$ transmittance of the sample of air.

2.3. Eqn. (1) could be used for determining ρ_w if the IR beam is monochromatic, but in practice the IR beam though narrow has a certain bandwidth, and within this narrow band also water vapour has selective absorption and hence Eqn. (1) is not applicable.

Considering the selective absorption by water vapour within the narrow finite bandwidth of the IR beam, an equivalent bandwidth (B.W.) (Hudson 1969) is reckoned which is a fraction of the actual bandwidth of the beam. This equivalent bandwidth serves as a measure of reckoning the absorptance $A = 1 - \tau$, if it is in a weak band or a strong band according as $A \times$ (B.W.) is less than or greater than a given No./cm

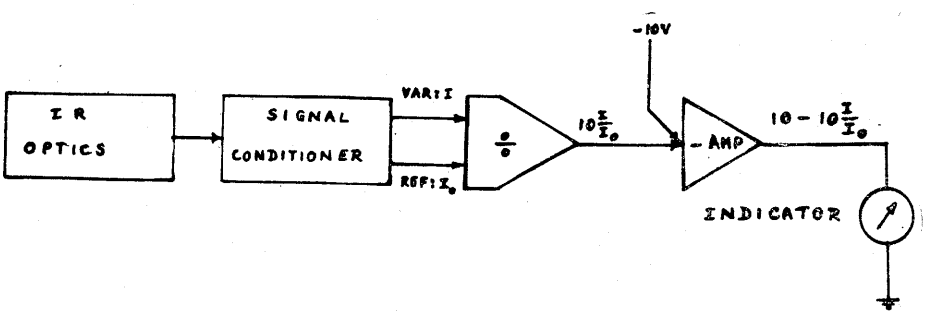

Fig. 1

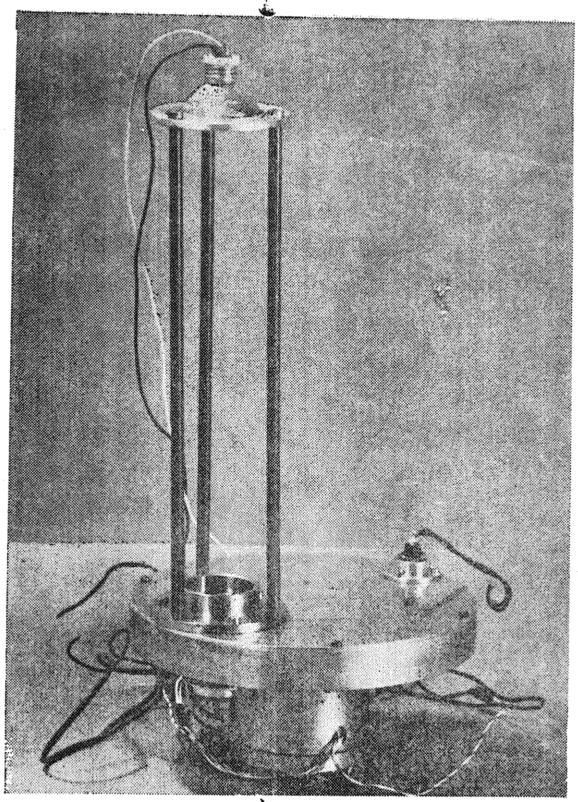

Fig. 2

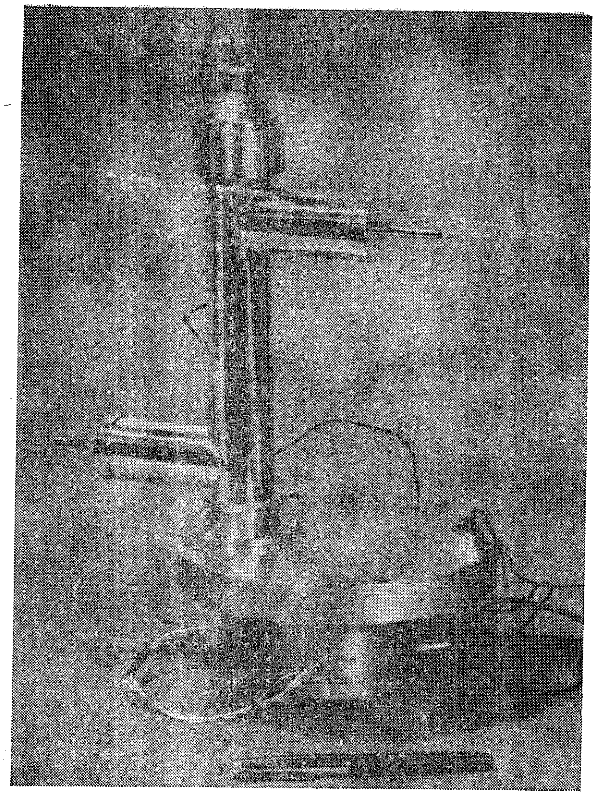

Fig. 3

(which is different for different centre wavelengths).

In the weak band region which is of interest to us :

$$A\times(\text{B.W.}) = C.\ W.\ \tfrac{1}{2}P^{b} \qquad (2)$$

where, C=constant for a given centre wavelength

=316 at 2.7 μm (Hudson 1969)

$W = 10^{-4}\ \rho_{w} l =$ the precipitable water vapour in cm. (3)

P = atmospheric pressure in mm of Hg.

b = constant for a given band (0.32)

It A could be experimentally determined for a known ρ_w (controlled humidity), knowing P, l and b, the equivalent band width (B.W.) for the IR filter used may be calculated. Usually the mean value of the B.W. is obtained after repeating the experiment for various known values of ρ_w. Thus the equipment may be calibrated and used for determining unknown values of ρ_w in any sample of air. If the specific humidity q is required, it may be obtained from:

$$\frac{\rho_w}{\rho_a} \simeq q \qquad (4)$$

where, ρ_a = density of air (gm/litre)

and q is expressed in gm/kg.

3. Description of the equipment developed

The equipment developed for the measurement of absolute humidity consists of the basic blocks shown in Fig. 1.

3.1. *I.R. optics (Figs. 2, 3 and 5)*

This consists of an incandescent tungsten filament lamp (about 2W) as the IR source and a PbS photo-conductive cell 61 SV with a spectral response in the region 0.3 to 3.0 μm, as the detector. These are separated from each other through a column of air whose humidity content is to be determined. The light beam is collimated by a parabolic reflector, which is protected from the humid air by a plane glass plate. The beam of light after passing through the air is converged on the detector, by a biconvex lens. The detector is not mounted at the exact focus of the lens but slightly in front, so that the entire area (which is finite—Phillips 1969) of the detector may be illuminated. The light beam incident on the detector is alternately chopped by two IR narrow band interference filters of centre wavelengths 2.4 μm and 2.7 μm mounted on a disc rotated by a servomotor at a speed of 3000 r.p.m.

The signal obtained as the output of the detector, through the 2.4 μm filter serves as the reference, since water vapour does not have an absorption band in this region and the IR beam in this region is incident unattenuated on the detector, while the signal obtained through the 2·7 μm filter is the variable which is a function of absolute humidity. The use of two filters one in the absorption band and the other one outside it, is to minimise the effect of aging of the lamp and collection of dust on the optics when the hygrometer is left unattended for days.

The space between the IR source and detector may be open for free flow air (Fig. 2) or enclosed-using a brass tube of about 1½″ diameter with inlet and out let tubes for flow of air (Fig. 3).

3.2. *Signal conditioner, divider and indicator (Fig. 4)*

The PbS detector is biased at 50 V through a load resistor of 1MΩ and the A. C. component of the signal obtained across the 1 M Ω resistor is amplified suitability, by a monolithic precision operational amplifier with a high input impedance and ultra low drift. This A. C. component is in the form of pulses of alternately high and low amplitude (Fig. 6). The high amplitude pulses (reference) are separated from the low amplitude pulses (variable) by CMOS transmission gates, gated by square waves, one of which is 180° out of phase with the other. These square waves are synchronised with the light chopper frequency, by having a slot cut in the chopper disc (Fig. 5) and having a lamp and phototransistor arrangement on either side of the disc.

3.2.1. The reference and variable signals thus separated are available as two independent outputs of the transmission gate and further conditioning of the signals is made simple. These signals are temporarily separated (oscillogram) and are individually averaged by operational amplifier circuits and their ratio obtained by an analog divider. $10I/I_0$ is thus obtained. The overall gain of the electronics is adjusted such that $10\ I/I_0 = 10$ volts in the absence of any water vapour in the light path.

The analog divider output is always less than 10 V in the presence of water vapour and is subtracted from 10 V and amplified by a summing amplifier set to a gain of ten in order to boost the signal level to operate a D'Arsomoval type meter. The output of the amplifier is then calibrated in terms of absolute or specific humidity.

4. Calibration of the instrument (Fig. 3)

4.1. Fig. 3 shows the set up for calibration purposes. The open space between the IR source and detector system is replaced by a brass tube with inlet and outlet for controlling the amount of water vapour in the path. The brass tube has the same height as the path length in the system.

At first the tube is evacuated so that the absolute humidity is almost zero (*i.e.*, less than 0.1 gm/m^3). The overall gain of the electronic system is then adjusted such that the divider output $10I/I_0 = 10$ volts using a D.V.M. With a very accurate wet and dry bulb hygrometer the relative humidity (R.H.) of the ambient is determined, and for the ambient temperature the

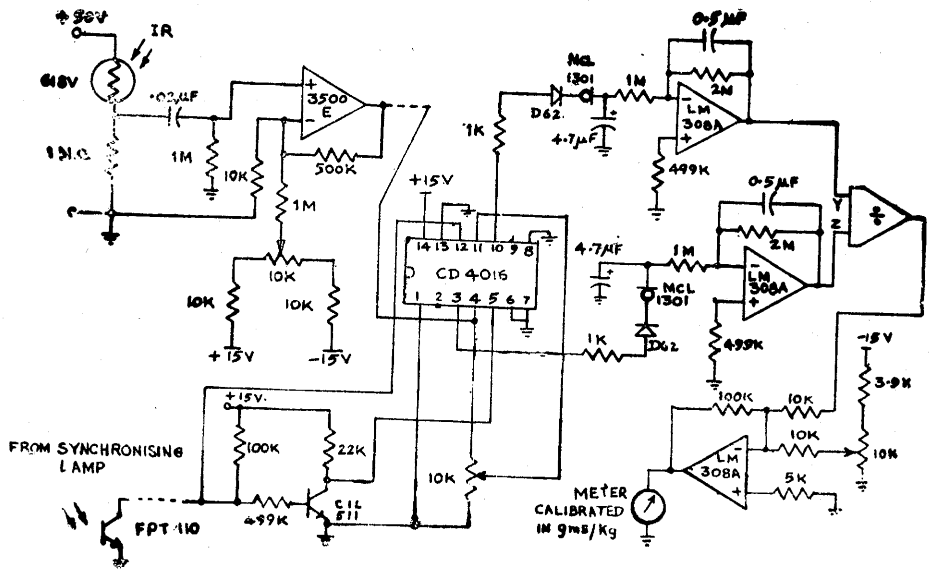

Fig. 4. Hygrometer circuit diagram

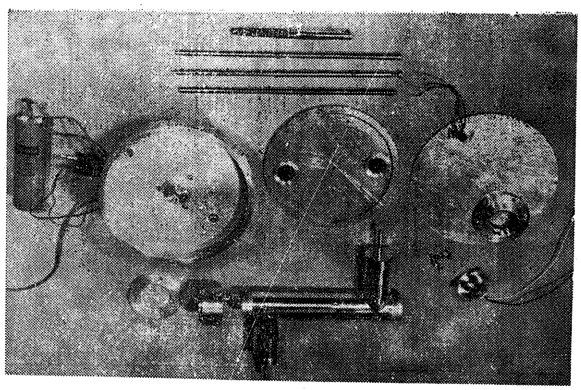

Fig. 5

Component sources in Fig. 4 :

61 SV	PbS detector	Philips, Holland
3500 E	Op. Amp.	Burr Brown, USA
CD 4016	C/Mos gate	RCA, USA
MCL 1301	Constant current diode	Motorola, USA
Model 107C	Multiplier/divider	Hybrid Systems Corporation, USA
LM 308A	Op. Amp.	Semiconductors Ltd., Pune
CIL 511	NPN transistor	Continental Devices, India
FPT 110	Photo transstor	Fairchild, USA
IR Source	Any torch bulb	Any shop in India
IR Filters	V-24 V-27	Valtec Corpn., USA

saturation vapour density ρ_w (sat.) is obtained from the *Smithsonian Meteorological Tables* (List 1958) ρ_w of the ambient is then given by :

$$\rho_w = \rho_w \text{ (sat)} \times \text{R. H.}\%/100 \qquad \text{(List 1958)}$$

The ambient air is then let through the brass tube and the divider output is noted.

The absolute humidity ρ_w is related to the divider output $10\, I/I_0$ by the equation:

$$10 - 10\, I/I_0 = 10\, K \sqrt{\rho_w} \tag{5}$$

from Eqn. (5) the constant K is calculated.

TABLE 1

ρ_w (gm/m³)	Reading (μA)
0	0
5	32
10	46
15	57
20	65
25	72
30	79

4.2. The constant K is also determined at various known humidities. Saturated solutions of LiCl, $MgCl_2$, NaCl and KNO_3 are prepared and kept in wash bottles and also distilled water. The R.H. of the air over saturated LiC1 solution at 25 °C is 11 per cent, $MgCl_2$ solution is 33 per cent, NaCl solution is 75 per cent, KNO_3 solution is 93 per cent and distilled water is 100 per cent (Middleton and Spilhavs 1953). From this the expected value of ρ_w at any given temperature may be obtained with the help of *Smithsonian Meteorological Tables* and Eqn. (5).

The brass tube is evacuated and air from over one of the salt solution or distilled water is allowed to occupy the tube, and the reading 10 I/I_0 is obtained and K is calculated. This is repeated for all the salt solutions and distilled water and the mean value of K is calculated, which is a constant for a given altitude and atmospheric pressure, for various values of ρ_w ranging from 1 to 30 gm/m³ the value of 10—10 I/I_0 is calculated and a table is drawn up for ρ_w *vs* $[10 - 10\ I/I_0] \times 10$ and the output of the IR hygrometer system is calibrated with this table.

If instead of ρ_w, q the specific humidity is required, then:

$$\frac{\rho_w}{\rho_a} = q \qquad (6)$$

where ρ_a=density of air in gm/litre. The instrument is now ready for use. If the instrument is to be used at a different altitude and hence at a different pressure K is modified according to:

$$K' = K\,(P_1/P)^{0.32}$$

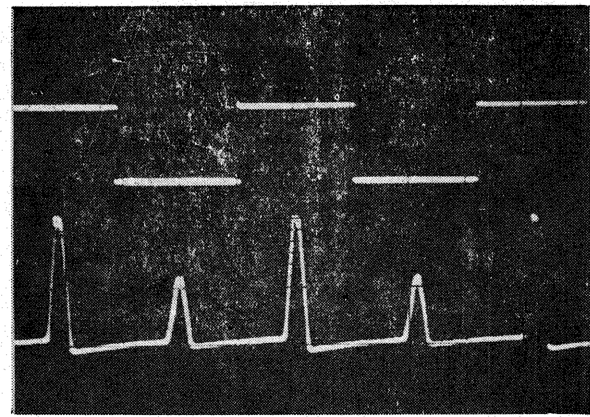

Fig. 6. Oscillogram

where P is the atmospheric pressure at the place of calculation and P_1 the pressure at the place of use and K' the new value of K.

5. Summary

The absolute humidity is directly obtained from the IR hygrometer whereas in other conventional types the relative humidity or the dew point is first obtained, from which the absolute humidity is calculated. Most of the instruments give R.H. or dew point which is dependent on the ambient temperature. For example an R. H. of 100 per cent at 25 ° C corresponds to a ρ_w of 23.05 gm/m³ and that at 30 ° C to 30.38 gm/m³ and therefore they do not give an idea of the actual water vapour content in the air.

The wet and dry bulb hygrometer depends on the rate of evaporation of water to determine the wet bulb reading, and the dew cell absorbs moisture from air in order to determine the dew point and hence in both these cases there is modification of the water vapour content of the air, whereas, in the IR hygrometer no such modification takes place as the instrument depends only on the selective IR radiation by the water vapour (Bemis 1951). The calibration depends only on the optical filter characteristics, which does not vary with time and hence calibration changes are eliminated (Hyson 1975).

The instrument is especially useful in determining quick fluctuations in humidity as its response time is low (less than a second) while the other hygrometers have response times of one to several minutes. By virtue of this property, this instrument finds applications in measuring humidity in the clouds from an aircraft for cloud seeding operations for artificial rain making and for cloud physics studies, and also in measuring humidity fluxes over the seas, oceans and land.

A simple design of the IR hygrometer for field use may be made by eliminating the servomotor and using two detectors with the two filters and a single IR source with a beam splitter (partially reflecting mirror) or it is possible to use a single source and a single detector with a small low power (2 or 3W) D.C. motor which could be operated from 3 V cell for light chopping.

Acknowledgement

The authors wish to thank Dr. S. R. Valluri, Director, National Aeronautical Laboratory for his interest and encouragement in this work. The authors are also thankful to Prof. R. Narasimha and Dr. A. Prabhu of Indian Institute of Science and Dr. S. Balakrishna of National Aeronautical Laboratory, Bangalore for helpful discussions.

References

Bemis, Alan C., 1951, Aircraft Meteorological Instruments, *Compendium of Meteorology*, pp. 1223-1234.

Hackforth, Henry L., 1960, *Infrared Radiation*, p. 4.

Hudson Jr, Richard R., 1969, *Infrared system Engineering*, pp. 114-166.

Hyson, P., and Hicks, B.B., 1975, A single-Beam Infrared Hygrometer for evaporation measurements, *J. appl. Met.*, **14**, 3, pp. 301-307.

List, Robert. J., 1958, *Smithsonian Meteorological Tables*, pp. 348, 383,

Middleton and Spilhavs, 1953, *Meteorological Instruments*, pp. 116, 117, 197-216.

Philips, Holland, 1969, *Semiconductor and IC data Handbook*.

Wood, Rex. C., 1958, Improved IR absorption spectra hygrometer, *Rev. Sci. Instr.*, **29**, 1, pp. 36-42.