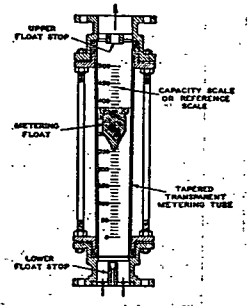

Fig. 15 .... Schematic Diagram of Variable Area Flow Meter

linkage, causes a pointer to move across an indicating dial, moving a pen across a recording chart, or actuating a pneumatic or electric control mechanism.

Common organic materials employed are human hair, animal membrane, animal horn, wood, and paper. Unfortunately, although the field has been well explored, no organic material has been found which can be relied upon to consistently reproduce its action over an extended period of time. Such devices require initial calibration and frequent recalibration or setting, especially if they are exposed to extremes of either high or low humidity. In spite of this they are highly useful because they read directly in terms of humidity, they are simple and inexpensive by comparison with most other types, and the inconvenience of recalibration is often less than that of providing distilled water and servicing the wicks of wet- and dry-bulb psychrometers.

Electrolytic Hygrometers

The dampness, and therefore the electrical resistance of a salt film, varies with the humidity of the atmosphere to which the film is exposed, and at least two types of instruments based on this fact have been developed. The Dunmore hygrometer was originally designed for use in radiosondes or small balloons, and means were devised whereby the device transmits humidity data back to earth in the form of a radio signal. In the more usual form, this hygrometer consists of a dual winding of small wire on a nonconducting tube. The whole is coated with an electrolytic film, usually containing a salt such as lithium chloride, which forms an electric connection between the windings. Means are provided for determining the electrical resistance of the film, which is an indication of the humidity. In the radiosonde, variations in the resistance of the film affect the frequency of an oscillating circuit. These hygrometers are usually calibrated by comparison with a wet- and dry-bulb psychrometer. For calibration for some purposes, particularly for use at subzero temperatures, means have been provided for producing atmospheres of known humidity.[40] Advantages of instruments of this type for some scientific and industrial purposes are becoming apparent, and some forms of them are on the market.

The Weaver-type hygrometer is particularly useful for determining the humidity of air or other gas in pipes or closed vessels at various pressures and temperatures. It consists of a threaded plug carrying a central electrode insulated from the plug, except for a gelatinous electrolytic film. The film is exposed to the air or gas from the pipe or vessel, and provision is made for determining its electrical resistance. The hygrometer, or detector, is mounted in a manifold equipped with valves whereby the film can be alternately exposed to the test gas, and to a standard gas having a known absolute humidity. The pressure of the standard gas is varied until contact with it establishes the same resistance in the film as the test gas, and the humidity of the test gas is then determined by computation based on the gas laws.

Chemical Hygrometry

The humidity of an atmosphere can be measured directly by extracting and weighing the water vapor from a known sample. For precise laboratory work, powerful desiccants such as a sulfuric acid and phosphorus pentoxide are used for the extraction process; while for some purposes, calcium chloride, lithium chloride, or silica gel are satisfactory. Freezing the water vapor out of a measured stream of air or gas with solid carbon dioxide, and weighing the resulting ice, is a similar operation. A thermal conductivity method for gas analysis can be used for temperatures above 212 F, or for very low humidities.[41]

MEASUREMENT OF MEAN RADIANT TEMPERATURE

Because of its effect on human comfort, it is sometimes desirable to measure the radiation exchange between a person and his surroundings. The radiant environment of a space is usually expressed in terms of its mean radiant temperature (MRT), which is defined in Chapter 67.

The Vernon globe thermometer[42,43] is commonly used to measure mean radiant temperature. This instrument consists of a 6-in. diameter hollow copper sphere coated with flat black paint and having a thermocouple or thermometer bulb at its center. The temperature assumed by the globe at equilibrium is the result of a balance between the heat gained or lost by radiation and the loss or gain by convection. In terms of heat-transfer relationships:

$$T_r^4 = T_g^4 + 0.103 \times 10^8 \sqrt{V}\,(t_g - t_a) \qquad (15)$$

where

T_r = mean radiant temperature, Fahrenheit absolute (black-body equivalent),
T_g = globe temperature, Fahrenheit absolute,
V = air velocity, feet per minute,
t_g, t_a = globe ambient air temperature, Fahrenheit.

It will be noted from the above equation that the air temperature and the air velocity around the globe must also be determined. It is the velocity measurement which presents the greatest problem in the use of the globe thermometer.

A two-sphere radiometer[44] has recently been developed which may be used for the measurement of MRT. This instrument utilizes two spheres approximately 2 in. in diameter, one of which is gold-plated, and the other black. The two spheres are heated electrically to the same temperature, thus eliminating differences in convection. The difference in energy required by the two spheres to maintain temperature equilibrium is measured, and from this difference, the MRT of the space may be calculated.

Several instruments have been developed to evaluate the combined effect of radiation and convection on human comfort. Among these are the eupatheoscope[45] and the thermal integrator.[46,47]

Table 6 .... Measurement of Humidity

No.	Measurement Means	Application	Range, F	Precision, F	Limitations
1	Wet-bulb thermometer with dry-bulb thermometer	Room of building, outside air, air moving in ducts; standard method	0 to 500	0.1 to 1	Should be used in air stream moving 1,000 to 1,500 fpm or correction made. Unsuitable for recording at sub-freezing sub-zero temp
2	Dew point apparatus				
	Condensation type	Occasional laboratory work; not widely used	−180 to 200	2	Cumbersome, expensive, difficult to use with precision; unsuitable for remote use
	Fog type	Simple wide range method	−100 to +100	2	Series of readings necessary for determination
	Electrical conductivity type	Accurate measurement of dew point; suitable for remote use	0 to 200	1	Unusable below −20 F and below 15% rh or for any moderate humidity at temp. under 0 F
3	Hygrometer (for relative humidity)				
	Hair gyrometer	For direct rh in air where motion is slight	0 to 100% rh −40 to 150 F	3% rh	Considerable lag; low sensitivity; adversely affected by temp above 125 F and rh below 20%; frequent calibration required when used at extremes of range
	Hygroscopic material other than hair	Same as above—also for high sensitivity	0 to 100% rh −40 to 150 F	2 to 5% rh	Frequent calibration required when used at extremes of range
	Electrical conductivity type	For remote use			Requires frequent calibration
4	Infra-red radiation	While usable at all temperatures it is uniquely applicable to extremely low temp			Requires the use of very costly equipment
5	Standard salt	For standards			
6	Chemical analysis				
7	Absorption and weighing				Cumbersome process

HEAT TRANSFER THROUGH BUILDING MATERIALS

Thermal Conductivity

The thermal conductivity (k value) of an insulation, as defined in Chapter 22, is a unit heat-transfer factor. Practically universally accepted for the conductivity determination of flat insulation is the guarded hot plate, which is described in ASTM test method C-177.[48] In its simplest form it consists of an electrically heated plate and two water-cooled plates. Two identical specimens or slabs of a material are required for a test, and one is mounted on each side of the hot plate. A cold plate is then pressed against the outside of each specimen by a clamp screw. The heated plate is divided into two portions: the central or measuring section, and the outer or guard section. During tests the two sections are maintained as nearly as possible at the same temperature. The purpose of the guard section is to minimize errors due to edge effects. The electric energy required to heat the measuring section is carefully observed and converted to Btu per hour. From this heat quantity, the area of the test section, the temperature gradient, and the specimen thickness, the thermal conductivity of the material can be calculated. Hot plate apparatus accommodating specimens on the order of one foot square and an inch or more thick is common. The apparatus at the National Bureau of Standards takes specimens 8-in. square, while plates as large as 3-ft square have been used. The thermal conductivity of cylindrical or pipe insulation (Chapter 22) is determined in a similar manner except that an equivalent thickness must be calculated to account for the cylindrical shape.[49]

Recently there has been considerable development of transient state conductivity apparatus utilizing a slender probe.[50-53] These instruments are commercially available and have the advantages of rapidity and requiring a small test specimen. While useful as research and development tools, the probe has not been generally accepted as have the guarded hot plate and pipe insulation apparatus.

Wall Conductances

The thermal conductances (C values) of many walls can be satisfactorily estimated from the conductivities of their components and their dimensions, but some walls are complicated by the inclusion of metal, for instance, and tests for conductance are required. The apparatus is required to accommodate large specimens representing actual construction. The guarded hot box apparatus was developed for this purpose. Test specimens for the apparatus at the National Bureau of Standards are 5 ft long and 8 ft high, while others require different sizes, some larger, others smaller.

The guarded hot box is described in the *ASTM Standard Test Code for Built-up Sections* C-236-54T.[54] The apparatus consists essentially of three boxes: a cold box, cooled by a refrigerating machine; a hot box, heated electrically; and