precise work. These are based on a standard gravitational acceleration of 32.1740 ft per (sec) (sec) and are as follows:

1 Standard Atmosphere = 14.696 lb per sq. in. = 29.921 in. mercury at 32 F = 33.96 ft water column at 68 F

For most ordinary purposes, the following figures are of ample accuracy:

1 Atmosphere = 14.7 lb per sq in. = 29.9 in. mercury = 34.0 ft (408 in.) water column

Manometer tubes should be chemically clean. The bore is not important, except insofar as it affects the meniscus through wetting or surface tension. Bores of at least $^{3}/_{16}$ in. for rough, and $\frac{1}{2}$ in. for more precise, measurements are recommended. Liquids other than water are sometimes used for low-pressure measurement and, when this is done, the readings must be corrected for the density of the fluid.

For measuring pressure differences of a few inches of water, or less, U-gages are often set at an angle for scale amplification. In many gages of this type, commonly termed draft gages or inclined manometers, only one tube of small bore is used and the other leg is replaced by a reservoir. The scale is calibrated to read in inches of water, and it is necessary to use a fluid having the same gravity as that for which the gage was originally calibrated, or to apply a correction if another fluid is used. Such gages may be checked one against another. For more accurate calibration the gage may be checked against a micromanometer or a calibrating device known as a hook gage.[20] The accuracy of a draft gage is dependent on the slope of a tube, and consequently the base of the gage must be leveled carefully. It is not desirable to use a slope of less than 1 in 10. Where pressures are read under extreme conditions of temperature, and calibration is possible only at normal temperature, it is necessary to correct for the change in density of the liquid in the manometer.[21] For measuring low-pressure differences to within 0.001 in. of water, very sensitive micromanometers are available, such as the Illinois or Wahlen,[22] and the Emswiler.[23] Various instrument manufacturers are also prepared to furnish accurate micromanometers.

Pressure Gages

The Bourdon is the most common type of pressure gage, and its appearance probably is familiar to anyone having an acquaintance with power plants or laboratories. The essential element of such a gage is the Bourdon tube, a metal tube of oval cross-section curved along its length to form an almost complete circle. One end is closed and the other is connected to the vessel in which the pressure is to be measured. With an increase of pressure, the tube tends to straighten, and vice versa. The resulting motion of the closed end is communicated by suitable linkages to a needle moving over a graduated dial. If the range is above about 20 psi, such gages are usually calibrated by means of a *dead weight tester*, whereby known pressures are produced in a fluid by imposing known weights on a piston of known area. Suction gages and pressure gages with ranges below about 20 psi are ordinarily calibrated against mercury manometers. Gages are commonly set to read accurately at or near the pressure of probable use. Gages of several different types or qualities are available on the market.[14]

FLUID VELOCITY MEASUREMENTS

The theory of various means for measuring the flow of fluids is discussed in Chapter 6, Fluid Flow. Heating and air-conditioning engineers are called upon to measure the flow of air more often than that of other gases, and usually the air is measured at or near atmospheric pressure. Under this condition, the air can be treated substantially as an incompressible fluid which implies that simplified formulas can be used with sufficient precision for the solution of many problems.[15]

Instruments for measurement of fluid velocity are shown in Table 4, together with their range of application and precision.

Thermal Anemometers

Measurement of low air velocities (0–100 fpm) is particularly difficult. Frequently, the flow pattern is very unstable, causing the mass turbulence level to be of the same order of magnitude as the velocity. However, useful data can be obtained with any of several instruments now available, if they are maintained in calibration and the user understands their operation and limitations.[16] Several types of thermal anemometers, both directional and non-directional, are applicable to this range, but have questionable accuracy at the lower end. Virtually all of the non-directional instruments suffer the additional handicap of being unable to distinguish between large scale turbulence and the mass velocity of the air.

If a suitable sensing element is heated electrically at a fixed rate and exposed to an air stream, the temperature difference between the element and the stream becomes a measure of velocity by calibration. In the *hot-wire anemometer*, a very fine heated wire is employed as a resistance-thermometer element whose temperature may be determined accurately.[17,18,19] In the *heated-bulb thermometer* type, a heating wire is wound around the bulb of a mercury-in-glass thermometer, and the temperature difference between this thermometer and a similar unheated one serves as an index of air speed.[20] The *heated-thermocouple anemometer* is calibrated to give velocity in terms of the differential *emf* between heated and unheated thermo-junctions exposed to an air stream.[17,21] Combined measurements of air temperature and velocity are particularly useful for air distribution studies, and automatic recording potentiometers or resistance-thermometer devices facilitate spatial traverses. A correct calibration of thermal anemometers requires consideration of the effects of temperature, humidity, and pressure upon the air properties which influence convective heat transfer.[21] With sensing elements of simple shapes for which convection data are known, thermal anemometers may be designed, both thermally and electrically, for desired characteristics. Directional sensitivity is controllable. Thermal anemometers are convenient and practical for low velocities.

The Kata Thermometer

Another instrument useful for studying air currents in free spaces is the Kata thermometer. This is essentially an alcohol thermometer with a very large bulb, and with only two scale divisions etched on its stem. On the *Low Kata* these divisions are 95 and 100 F; on the *High Kata* they are 125 and 130 F. In use, the instrument is heated, usually in a water bath, until the alcohol has risen sufficiently above the upper calibration on the stem. It is then thoroughly dried, and placed at the point at which the air velocity is to be measured. The time in seconds required for the temperature to drop from the upper to the lower scale division is observed. From this cooling time and the calibration factor inscribed on each Kata thermometer, the air velocity can be calculated or determined from a chart. The Kata thermometer is also used in determining the cooling power of the atmosphere, since it loses heat by radiation and convection when dry, and by radiation, convection, and evaporation when the bulb is equipped with a wetted cloth covering.[22] To minimize the effect of radiation, the Kata thermometer is also made with a silvered bulb.

Table 4 .... Measurement of Velocity

No.	Measurement Means	Application	Range fpm	Precision	Limitations
1	Hot-wire anemometer	(a) Low air velocities; directional and nondirectional available	5–1,000	1–20%	Accuracy of some types not good at lower end of range
		(b) High air velocities	up to 60,000	1–0.01%	
2	Kata thermometer	Low air velocities in rooms; non-directional	5–300	5–15%	Awkward to use; affected by radiation
3	Smoke puff or air-borne solid	Low air velocities in rooms; highly directional	5–50	10–20%	Awkward to use but valuable in tracing air movement
4	Swinging-vane type anemometer	Air velocities in rooms, at outlets, etc; directional	30–24,000	5%	Not well suited for duct readings; needs periodic check calibration
5	Venturi-type multiplying pitot tube	Low air velocities in rooms and ducts; directional	100–2,000 with micromanometer; 180–2,000 with draft gages	1–5%	Accuracy falls off at low end of range; requires calibration
6	Revolving-vane type anemometer	Moderate air velocities in ducts and rooms; somewhat directional	100–2,000	5–20%	Extremely subject to error with variations in velocities with space or time; easily damaged; needs periodic calibration
7	Pitot tube	Std instrument for measurement of duct velocities and pressures	180–10,000 with micromanometer; 600–10,000 with draft gages; 10,000 up with manometer	1–5%	Accuracy falls off at low end of range
8	Impact tube and side-wall or other static tap	High velocities, small tubes and where air direction may be variable	120–10,000 with micromanometer; 600–10,000 with draft gages; 10,000 up with manometer	1–5%	Accuracy depends upon constancy of static pressure across stream section

Airborne Solid Tracer Techniques

Another useful device for very low velocities is to time the rate of movement of a smoke puff, feather or piece of lint. This technique, like the Kata thermometer, is well suited to velocity measurement in an open space, but not particularly adaptable to measurements in ductwork.

Smoke is a qualitative tool which is very useful in studying air movements. Satisfactory smoke can be obtained from titanium tetrachloride (which, however, is very irritating to nasal membranes) or by mixing potassium chlorate and powdered sugar (a nonirritating smoke) and firing the mixture with a match. This latter process evolves considerable heat, and it should be confined in a pan away from flammable materials. The titanium tetrachloride smoke lends itself to spot determinations, particularly for leakage through casings and ducts, as it can be easily handled in a small pistol-like ejector. The fumes of aqua ammonia and of sulfuric acid, if permitted to mix, form a white precipitate which is useful for some purposes. Two bottles, one containing ammonia water and the other acid, are connected to a common nozzle by means of rubber tubing. Air is forced over the surfaces of the liquids in the bottles by means of a syringe, and the two streams, upon mixing at the nozzle, form a white cloud.

A satisfactory test smoke may also be made by bubbling an air stream through ammonium hydroxide and then through muriatic acid.[23] Smoke tubes, smoke candles, and smoke bombs are available for studying airflow patterns.

Deflecting Vane Anemometer

The deflecting vane anemometer consists of a pivoted vane enclosed in a case. Air exerts a pressure on the vane as it passes through the instrument from an upstream to a downstream opening. The movement of the vane is resisted by a hair spring and a damping magnet. The instrument gives instantaneous readings of directional velocities on an indicating scale. With fluctuating velocities, it is necessary to average visually the swings of the needle to obtain average velocities. This instrument is very useful for studying motion of the air in a room,[24] and in locating objectionable drafts. Various attachments are available, such as the double tube arrangement for determining velocities in ducts, and a device for measuring static pressures. Each instrument, and the attachments for it, must receive individual calibration. For determining average velocity in a duct, it is necessary to *traverse* the duct as is done when using the Pitot tube.

Propeller or Revolving Vane Anemometer

The propeller or revolving vane anemometer consists of a light revolving wind-driven wheel connected through a gear train to a set of recording dials that read the linear feet of air passing in a measured length of time. It is made in various sizes, 3 in., 4 in., and 6 in. being most common. Each instrument requires individual calibration. At low velocities the friction drag of the mechanism is considerable. In order to compensate for this, a gear train that overspeeds is commonly used. For this reason the correction is often additive at the lower range and subtractive at the upper range, with the least correction in the middle range of velocities. Most of these are not sensitive enough for use below 200 fpm.