

ON MEASUREMENT OF TEMPERATURE IN GASES.*

SVEN STROMGREN.

The mercury thermometer is one of the simplest instruments ever designed. It is used extensively for industrial and scientific purposes, and despite its simplicity is comparatively accurate. Naturally, there is a variation in the degree of accuracy between different types of thermometers; nevertheless, even the ordinary thermometer, such as is used in tea factories, must be termed an accurate instrument.

When speaking of accuracy in connection with instruments, one must differentiate between the instrument itself, and the actual measurement obtained with it. In the latter case, a number of errors may be engendered by extraneous conditions over which the instrument itself is powerless. This is more particularly the case, when it becomes necessary to interpret readings and draw conclusions with regard to phenomena not directly registered by the instrument.

A concrete example is the measurement of the temperature of the air entering a tea dryer. This is usually measured by means of a single thermometer, when it is taken for granted that the temperature registered applies to the entire volume of air entering the dryer. Although the thermometer used may, as an instrument, possess a very high degree of accuracy, the interpretation of the reading may be radically incorrect for the following reason. The thermometer only registers the temperature of its own bulb, with possibly that of

*The Institute does not necessarily endorse the views expressed in papers contributed by persons not members of the staff.

the air immediately adjacent to it, without, however, giving any information with regard to the temperature of the air at other positions in the current.

This way of looking upon temperature measurements may, at first sight, appear to border on the academical and savour of the unpractical, but when one considers the significance of drying temperatures, for instance, whose permissible latitudes it is so important to determine, reasonably accurate measurements become essential.

Before dealing with the question of methods of measurement, it may be of interest to discuss briefly the instrument itself, and the errors from which it suffers. The mercury thermometer — and this applies to most instruments for measuring temperatures, — is designed to record the temperature at a certain point. The inaccuracy of the instrument *per se*, therefore, is the discrepancy between the temperature read on the scale, and the temperature impulse received by the bulb. As far as the mercury thermometer is concerned, an error in this respect may be due to any of the following reasons: inaccurate manufacture, glass with uneven co-efficient of expansion, air or other gases inside the thermometer which causes the mercury column to split, and heat conductions from the bulb through the glass or through the mercury column to points with a lower temperature.

In speaking of thermometers it is usual to classify them in accordance with their inherent errors. Thus, class A would usually refer to the most accurate thermometers by means of which temperatures may be recorded within $\pm 0.01^{\circ}\text{C}$ or even less. The thermometer used in tea factories is found further down the scale, and should normally not suffer from a larger error than $\pm 0.25^{\circ}\text{C}$ or 0.5°F , which quite amply satisfies requirements. Bearing in mind other errors which may be encountered during the taking of measurements, this must be considered to be a very high degree of accuracy.

Thermometers are usually tested in boiling water which is sufficient for practical purposes. Two points to be remembered are that boiling point varies with altitude, and that the thermometer must remain in the steam just above the boiling water level for a reasonable period so as to ensure that it actually attains the temperature of the surrounding steam. It must be realised that the temperature of the water may be higher or lower than that of the steam, owing to the varying conditions of pressure inside the liquid itself.

The following table gives the relationship between temperature and barometric pressure. For altitudes below 10,000 feet, it can be assumed that 1 inch of mercury column corresponds to 1,000 feet.

Approx. Altitude	10000	9000	8000	7000	6000	5000	4000	3000	2000	1000	sea level
Barometric pressure inches.	20	21	22	23	24	25	26	27	28	29	30
Temp. F.	193	195	197	199	201	203	205	207	209	211	212

The above data makes no claim to have been arrived at with absolute scientific accuracy but from a practical point of view should prove to be satisfactory enough. Should it be necessary to calibrate a thermometer accurately a mercury barometer should be used to measure the atmospheric pressure.

A simple arrangement for checking mercury thermometers can be made from a vessel of chemical glass, with a narrow cylindrical opening through which the steam is able to escape, and inside which the thermometer bulb is placed. The whole glass container in which the water is to be boiled, should, be lagged, preferably by placing it inside a sheet metal cylinder, with the space between the glass and the sides of the cylinder packed with asbestos fluff. By this arrangement one does not risk vapour condensating inside the glass container, and on the walls of the outlet, which might upset the calibration. Before the actual reading is taken, the thermometer to be calibrated should have been in position for at least 20 minutes from the time the water started boiling. Should the thermometer bulb be covered with a perforated brass tube, the latter should be removed before calibration.

However, one seldom finds anything wrong with a mercury thermometer unless the mercury column has split. In such a case the obvious remedy is to return the thermometer to the makers. As a rule therefore one may assume that erroneous measurements of temperatures are not due to defective thermometers but can usually be otherwise accounted for.

Temperature measurements are often made to ascertain the behaviour and condition of heat. By the uninitiated, temperature and heat are often taken to be synonymous, naturally, a quite incorrect assumption. However, as quantities and condition of heat cannot be measured directly, the temperature therefore is our only guide in this respect. From the temperature inferences are drawn as to the heat content, or condition, of a certain medium as there exists a practical, as well as theoretical, relationship between temperature and heat.

In tea manufacture it is sometimes found necessary both to ascertain the upper limit of the temperature, and to find an average temperature. In practically every instance this refers to temperatures of air or combustion gases. I shall deal therefore with this particular problem, limiting the discussion to temperatures at boiling point and thereabout, as distinct from measurement of temperatures below freezing point, and temperatures connected with visual heat.

One often hears emphatic statements with regard to the most suitable temperature for drying tea. With a view therefore to finding out the influence of the temperature of the air entering the dryer upon the tea, careful measurements were taken on several dryers in different factories. In the course of these tests it was observed that the individual thermometer hardly ever registered even the average temperature. Owing to the drying chambers not being lagged, a low temperature prevailed close to the sides, while, normally, a high temperature was registered in the middle. In a suction dryer this difference might amount to 30°F or more. This unevenness of temperature in suction dryers probably accounts for some of the difficulties experienced with this type of dryer. The defect unfortunately cannot be entirely eliminated without a complicated system of baffles and air seals. The situation is much more satisfactory in a pressure dryer, although even there, variations amounting to 10°F may be found.

It is not a simple task to ascertain the average temperature, or the temperature variations in a dryer. To begin with, a great number of thermometers of special design to allow readings to be taken from outside the dryer would be required, and such thermometers are expensive. A simpler method is to use thermometers based on the variation in electrical resistance of nickel wire. Such instruments may be fitted with a large number of bulbs, each of which can be switched on to a central instrument registering the temperature. From a measurement of this description, one may then compute the average temperature. Furthermore, for each individual dryer one could arrive at an approximate relationship between the maximum temperature and the average. Having done this, an ordinary mercury thermometer may be placed in the position most suitable for registering the mean temperature. This procedure is possible because in any dryer with a given system of baffling, the temperature gradient across the air current is very nearly constant, particularly as the tea in the dryer has little influence upon the baffling, a fact which is contrary to the belief of many practical men. If therefore one investigates a dryer in accordance with the suggested method, placing the thermometer in a suitable position, one may expect a

reading which is accurate enough for practical purposes. Work of this nature could be quite easily carried out at small cost.

There is however another phenomenon which might upset these measurements. It is a well known fact that when sitting in front of an open fire, one feels warm despite the fact that, on the whole, the room is comparatively cool. The same phenomenon may be registered by a thermometer when placed in front of the fire. If however a metal shield is placed between the thermometer and the source of heat, the thermometer shows a lower temperature which more closely approximates that of the air in the room. In some types of tea dryers it often happens that radiant heat, either direct or reflected, reaches the thermometer bulb. Such heat need not be visual, but might be carried by ultra red light invisible to the eye. Under those conditions, the bulb registers a higher temperature than the surrounding air and to prevent errors of this nature, particularly in suction dryers, it is advisable to shield the bulb with three or four curved metal screens $\frac{1}{8}$ -inch apart. This will prevent radiant heat reaching the bulb, but, at the same time, will have no influence upon the registration of the true air temperature.

While dealing with this problem, there is another error of exactly the opposite kind, which occurs when measuring temperature in chimneys. There, the bulb is placed in a gas of a comparatively high temperature, inside a chimney, consisting of a thin metal casing surrounded on the outside by cold air. The walls of the chimney are therefore comparatively cold, while the thermometer bulb might attain a temperature several hundred degrees Fahrenheit above that of the chimney. Under those circumstances, heat may be lost by radiation from the bulb to the walls, and the thermometer will then register too low a temperature. To remedy this defect, the bulb must be shielded as described above, and to ensure that the measurement is accurate, the shield should be heated by means, say, of a small electric coil, to a temperature a little below the gas temperature. This latter modification is not necessary when measuring gases below 500°F, but without a shield at all, the error may still be appreciable at 250°F.

There is finally the question of registering temperature variations as related to time. This is a considerably more difficult task as it depends upon the mass of the bulb. For example, the temperature recorded by the bulb of a thermograph, which is comparatively heavy, considerably lags behind the temperature variations of the air, and accordingly the graph registers a smaller variation of temperature than has actually taken place. The method to adopt in that case is to use instruments with very small bulbs, preferably

thermo-couples, the bulbs of which are only slightly larger than a pin's head. In actual practice, however, it is not necessary, in a tea dryer, for instance, to register these variations with any high degree of accuracy, because the point of interest is not the temperature variations in the air, but the temperature variations of the tea itself. The latter has a certain mass, in addition to which it is resting on metal trays, so its temperature will not fluctuate more than is shown, even on the thermograph itself. Whilst fluctuations of short durations are of little importance, one must guard against any fluctuations over an appreciable period of time.

I mentioned above that a definite relation exists between the temperature and the heat content, the link between the two being called the specific heat. If temperature measurements on a dryer aim at determining its thermal efficiency this relationship will have to be taken into account, because there is then no longer the question of merely registering temperatures, but also that of computing from these temperatures the heat quantities in calories, or B.Th.Us passing through the dryer. If, for example, the temperature distribution across the air current entering a dryer is known, it is not possible, without further investigations, to calculate the quantity of heat this current carries. To arrive at this quantity, the air distribution must also be measured, and it is the difficulty of ascertaining the latter, which makes calculations on thermal efficiency of dryers, or drying chambers, so uncertain.

The following example will illustrate this fact. In a circular duct carrying warm air to a dryer the temperature was measured at different radii. The duct was lagged, was 3 feet in diameter, and each measurement was the mean of a number of readings taken on the corresponding circle. Similarly the air velocity was measured, and a mean calculated from several readings on the same circle.

If the amount of heat, in this case, was calculated from the average temperature reading, taken over the whole area, which was 225°F (variation 232-208), and the velocity in the centre (15 feet a second), the heat current would have been approximately, 60 B.Th.Us per second, whereas if calculated correctly, with the due consideration for the air distribution, it would have been only about 50 B.Th.Us per second, and error of at least 20 per cent.

The original problem set was to discover what latitudes one may permit in the variation of temperatures in tea manufacture, without endangering the quality of the tea. This paper does not pretend to have given an answer to that question as so much work still remains to be done, but it does show how difficult it is to draw a

conclusion from temperature measurements in general, unless they are carefully done and a great number of observations are available. Although the drying process mainly has been used as an example, the same problem exists with regard to withering, where it is even more difficult to arrive at exact results owing to the far larger dimensions of the withering lofts.

It is probable that drying temperatures can be varied within wide limits without any definite effect upon the tea, in which case, of course, the highest temperature should be chosen for best thermal efficiency.

