THE MEASUREMENT AND CONTROL OF TEMPERATURES IN INDUSTRY

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PREFACE

SOME important developments have taken place in the standardisation, measurement and control of temperatures in industry since this book was first introduced under the title of *The Measurement of Steady and Fluctuating Temperatures.* These developments have necessitated much revision of the earlier volume, and it was felt that the new title more adequately describes the scope of the present book. The different methods and arrangements which are available for measuring temperatures are each best suited to a particular range and purpose, and are here described and discussed in turn. Greater attention is now directed to standardisation and to the automatic control of temperatures in industry. The thermometer or pyrometer is the sensitive element in all temperature controllers, and besides measuring the temperatures, the elements used may have to be adapted to operate in conjunction with the controllers. The signals received by the sensitive elements are usually too feeble to move the controlled medium effectively without being first mechanically or electrically magnified by the controller to give power enough for the purpose of control.

Special acknowledgments are due to The Institution of Civil Engineers and to The Institution of Mechanical Engineers for much technical information and for a variety of illustrations from their *Proceedings* ; to the National Physical Laboratory, of Teddington, and the National Bureau of Standards, of Washington, and to the several firms and other sources of information mentioned in the text, as well as to the many further particulars gleaned from sources too numerous to mention separately.

R. ROYDS.

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INTRODUCTION

When heat has to be used in modern industry, one of the most important factors governing the effective control of the heating processes is the measurement of the temperatures with a reasonable degree of accuracy. Thermometers or pyrometers are used in many industries, as in the furnaces of steel, iron and other metal works, to assist in the production of the metals in the desired form and condition ; in the cracking and distillation of oils ; in the production of chemicals ; in the manufacture of glass and refractories ; in cement, pottery and brick kilns, varnish and enamel stoves, rubber preparation and vulcanisation ; in breweries and distilleries ; in power plant and in cold storage plant, various textile processes, and in numerous other industries. The automatic control or regulation of temperatures is also receiving increased application for the purposes of improving the quality and reliability of the product, of increasing the rate of production and the saving of heat and of labour. In important power plant, measurements of temperatures are undertaken for effective control of the operation and efficiency and reliability of the plant, usually under continuous working conditions. Important developments are likely to take place in power stations and on board ship because of the introduction of gas turbines ; in the utilisation of low temperature heat for the heating of works and buildings ; and in the manufacture of chemical and other products requiring low temperature heating or evaporation. Such plant needs to have effective temperature control. The converse problem of the internal cooling of works or buildings in hot climates, or during the summer season, is likely to receive more attention than formerly. An abnormal rise in the exhaust temperature from any cylinder of an internal combustion engine may be one of the first indications of an excessive consumption of fuel in that cylinder, either due to the cylinder taking too large a share of the load, or to a decrease in the thermal efficiency. The effective maintenance of thermal efficiency not only has an influence on the economy of fuel, but may have an effect on the reliability of the plant, because a reduction of efficiency at a given load usually means that more heat has to be dissipated externally.

Temperature measurements are usually required when ordinary performance or acceptance tests are made on heating or cooling plant, or on heat engine installations, and it may be legitimate in some cases to include the measurement of losses of heat. Therefore the installation of thermometers and pyrometers in laboratories or in research stations often forms an important part of the equipment. In recent years most large firms or industrial and service establishments have devoted increased attention to the value of research work and in the formation of research associations. The various methods of measuring temperatures are being applied, with perhaps special designs or arrangements suitable for the problems in hand, such as are dealt with in Chapters VII and VIII.

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CHAPTER I

STANDARD SCALES OF TEMPERATURE

THE word temperature signifies the degree of hotness or the intensity of the heat in a body, measured according to some chosen scale. The most suitable method of measuring temperature usually depends upon a multitude of circumstances, but it is evident that, whatever method is adopted, it is desirable to have a common scale of measurement, or at any rate, if more than one scale is used there should be a definite relationship between them. Experience has shown that the melting point of ice and the boiling point of water can be reproduced with great exactitude under definite conditions, and the ease with which "pure" water can be obtained has led to the range between these two points being adopted as the Fundamental Interval to which all measurements of temperature are referred.

The "freezing point," as the lower fixed point is called, is usually determined by placing the instrument or "thermometer" in a vessel surrounded by finely broken pure ice from which the water is dripping, as represented in Fig. 2. The boiling point is determined by placing the thermometer in the saturated steam coming from "pure" boiling water with the pressure at one standard atmosphere * in the manner shown in Fig. 3, p. 12.

The most common scale of measurement used by English-speaking engineers is the Fahrenheit scale, where the freezing point is called 32 degrees (32° F.) and the boiling point 212

* Refer to p. 244 for definition.

degrees (212° F.). Thus the range from the freezing to the boiling point is 180°. The Centigrade or Celsius scale is often used by English-speaking engineers, but more generally by physicists and chemists, and also by engineers and industrialists on the Continent of Europe. The freezing point is called 0 degrees (0° C.) and the boiling point 100 degrees (100° C.). Thus a change of temperature of 1° F. is equivalent to a change of $\frac{100}{180}=\frac{5}{9}°$ on the Centigrade scale. Thus, temperature in degrees Cent. $=$ (deg. Fahr. $-32) \times \frac{100}{180}$. An easily remembered rule to convert from deg. Fahr. to deg. Cent., or vice versa, is to add 40 to the temperature reading, multiply by $\frac{5}{9}$ or by $\frac{9}{5}$ as the case may be, and then subtract 40. A convenient table for conversion of these scales is given on p. 252.

For practical use a thermometer needs to be graduated in degrees of temperature, and whatever may be the type of thermometer the reading should be definite and invariable if true temperatures are to be recorded. It is known, for instance, that mercury does not expand at quite a uniform rate with increase of temperature, although a mercury thermometer usually has the degree divisions equally spaced along the stem. Most other substances have similar defects and involve similar discrepancies. Thus, even though the freezing and boiling points might be correctly recorded by different types of thermometers, it does not follow that the intermediate readings would agree, and it becomes necessary therefore to have some definite standard of comparison.

The zero points on the ordinary scales of temperature referred to previously were originally fixed because of their general convenience and without considering their relationship to what is called " the absolute zero " of temperature. Although the absolute zero of temperature has never been actually reached, its value in relation to the ordinary scales of temperature has been accurately determined by indirect means.

Standard Thermodynamic Scale of Temperature.—The necessity for some standard scale led Lord Kelvin in 1848 to propose the thermodynamic scale, based upon the Carnot cycle * for heat engines. On this theoretical cycle a quantity

* For a detailed description of this cycle, reference may be made to any standard textbook on " Heat " or " Heat Engines."

of heat Q_1 is supposed to be taken in by the working substance at the absolute temperature τ_1, and the quantity of heat Q_2 rejected at the absolute temperature τ_2. It can be shown that, no matter what the working substance may be,

$$\frac{Q_1}{Q_2}=\frac{\tau_1}{\tau_2}$$

or,

$$\frac{Q_1}{\tau_1}=\frac{Q_2}{\tau_2} \quad . \quad . \quad . \quad . \quad (1)$$

It will be noted that if Q_2 were zero the value of τ_2 would also be zero, that is, the "absolute zero of temperature." Temperatures on the absolute scale in deg. Cent. are sometimes distinguished by the letter K.

It can also be shown that if a Carnot cycle engine works between the temperature limits of 100° C. and 0° C., then for every 373 units of heat put in at 100° C. it will turn 100 units into work theoretically and reject 273 units at 0° C. The ratio of these temperatures on the thermodynamic scale is therefore 373 : 273, and thus the freezing point would be 273 degrees on this absolute scale.

Experience has shown that it is practically impossible to carry out the Carnot cycle completely, and thus, while the idea of the cycle is a useful conception, no practical thermometer can be constructed to use the Carnot cycle directly. It can be proved, however, that an equivalent measure of temperature is given by the expansion of a perfect gas with increase of temperature,* and as there are the gases, hydrogen, nitrogen, oxygen, etc., which nearly obey the laws of perfect gases, such can be used to give a standard measure of absolute temperature. The characteristic equation expressing the fundamental law of a perfect gas is

$$PV=RT \quad . \quad . \quad . \quad . \quad (2)$$

where P=absolute pressure ; V=absolute volume ; T=absolute temperature, and R is a constant depending only upon the units adopted and the mass of perfect gas under consideration. Although the previously mentioned "permanent" gases follow this law fairly closely under ordinary conditions,

* See Preston's *Theory of Heat.*

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