Temperature Measurement with the Expendable Immersion Thermocouple

A SURVEY OF WORKS EXPERIENCE

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The expendable immersion thermocouple, developed by Leeds and Northrup to give greater accuracy, speed and convenience in the measurement of molten metal temperatures, has now been in use in a number of steelworks for some time. It has also begun to find a place in the melting of non-ferrous metals. This article surveys the results of experiences so far obtained in replacing the conventional platinum : rhodium-platinum immersion thermocouple with the expendable cartridge type.

For over twenty years the method of measuring molten steel temperatures has remained virtually unchanged. In 1937 Dr. F. H. Schofield of the National Physical Laboratory proposed a “quick immersion” method which allowed accurate noble metal thermocouples to be used to measure steel temperatures in excess of 1600°C. Robust and reliable pyrometer units were soon produced, and apart from minor modifications and improvements in instrumentation, the method is in use in most steelworks to this day.

Recently, expendable cartridge immersion thermocouples have been developed, principally by the Leeds and Northrup organisation, and it is claimed that they overcome a number of the disadvantages inherent in the older design. To appreciate the merit of these claims it is necessary to consider briefly the design of the conventional pyrometer, consisting essentially of platinum : rhodium-platinum thermocouple wires threaded through a long steel tube which normally has a right-angled bend some three feet from the hot end. The thermocouple is insulated with twin-bore alumina sleeves to within an inch of the hot junction. This hot junction, formed by welding or twisting the thermocouple wires together, is protected by a fused silica sheath which is cemented or plugged with asbestos cord into the end of the steel tube. In many cases the steel tube adjacent to the hot junction is further protected by an outer refractory or graphite sleeve or by a thick mild steel end-block. These prevent corrosive attack when the silica-sheathed hot junction is plunged through the slag layer into the molten steel.

At the cool end of the steel tube a reel-box houses reserve thermocouple wire so that when it is necessary to renew the hot junction fresh wire may be pulled from the reserve spools down through the insulators. Compensating wires complete the circuit back to the instrument.

Silica is not normally recommended for use in contact with platinum thermocouples at high temperature; it is chosen, however, as the sheathing material because of its outstanding thermal shock resistance but must be renewed after each measurement. The
Extensive trials with the expendable cartridge type of immersion thermocouple have proved successful at the Abbey Works of the Steel Company of Wales, and the system has been adopted in place of the conventional immersion pyrometer in both open hearth furnaces and Bessemer converters.

thermocouple hot junction, although untouched by molten slag or steel, has to be renewed frequently as it suffers a progressive deterioration with each dip, mainly due to contamination. This not only causes a reduction in the thermal e.m.f. output but also embrittles the wire. With care a junction may survive for thirty dips but in many steelworks the junction and a few inches of wire are cut off and the junction re-made much more frequently.

The response time is approximately 10 to 15 seconds owing to the relatively large thermal mass of the sheath and junction. The speed of response is also affected by the type of recorder used and by the rate of immersion chosen by the operator.

While this procedure has clearly established its reliability over a long period of years, it does have certain drawbacks. It does not present a new and hence an accurate thermocouple junction for every measurement; the replacement of the silica sheath after every dip means that there is an appreciable interval of time when a probe is out of circulation and emergency probes must be on hand in case temperature re-checks are required; the response time may be embarrassingly long especially with the new pneumatic steel-making processes, and skilled, or at least semi-skilled, labour is required to re-make the hot junctions.

The expendable cartridge type of pyrometer is claimed to overcome these difficulties. It uses exactly the same principle as the old system, but differs considerably in detail. It is essentially an assembly in which a new, uncontaminated noble metal thermocouple contained in a sealed plug-in unit is used for one measurement and is then discarded. The compensating leads and connectors form part of a permanent circuit back to the high-speed recorder and are so protected that the accuracy of the reading is unimpaired.

The device has three main components: the expendable thermocouple cartridge, the long
steel dipping tube and the expendable cardboard sleeve which slips over the cartridge and the hot end of the dipping tube.

The expendable cartridge has a fine gauge platinum : 13 per cent rhodium-platinum thermocouple wire enclosed in a small U-shaped quartz tube so that the junction is in the centre of the U. The ends of the tube are mounted in a special cement in a ceramic block so that about 1\(\frac{1}{2}\) inch of tube protrudes. At a point sufficiently far inside the cement not to be affected by excessive heat during the period of recording the thermocouple wires join leads of compensating material. These leads continue to the back face of the plug, where they form non-reversible contacts of the same material. Copper and a nickel-copper alloy, the normal compensating materials for noble metal thermocouples, are used for all leads and contacts.

The protruding quartz tube is covered by a steel cap which gives protection during handling and storage, and also absorbs the physical shock when the cartridge is plunged through the molten slag into the steel.

The long dipping tube is usually of 1 inch i.d. steel pipe, bent at one end if desired. Fitted into the hot end is a unit capable of accepting the plug-in cartridge. Leading from this unit a compensating cable runs the length of the tube and then back to the recorder.

The third component is the cardboard sleeve. This is slipped over the cartridge and the hot end of the dipping tube to prevent slag or metal coming into contact with the dipping tube.

In use the assembly is similar to the traditional probe, no preheat is required, and the tip can be plunged directly into the steel. The cap immediately melts and allows molten steel to surround the thin quartz tube. The excellent thermal contact and the low thermal mass allow the maximum temperature to be recorded within four or five seconds and the probe can then be withdrawn. The thermocouple cartridge together with the charred cardboard sleeve must be stripped off immediately before excessive heat is transferred to the contacts. A new assembly of cardboard sleeve and cartridge can then be fitted.

Normally no attempt is made to recover the scrap thermocouple wires although in a large works it may be found to be worth while.

To deal with the rapid response a high-speed recorder is desirable. One model incorporates special signal lights and an
audible warning device, the sequence being a green signal light when the cartridge is plugged in, indicating a closed circuit; a timing device which operates as soon as a certain temperature is achieved, say 1300°C, and then after four or five seconds have elapsed a red light and warning horn are operated.

Clearly the expendable cartridge system offers the great advantage of presenting a new and uncontaminated thermocouple on each immersion. Provided that this does not increase the cost of temperature measurement, and that the introduction of additional components into the circuit does not affect accuracy and reliability, there is much to commend the method. It is not to be expected, of course, that it will entirely replace the conventional system, which will retain its usefulness in a number of applications, but where rapid response is essential and automatic recording is installed an appreciable improvement can be secured. The economy achieved by the use of fine diameter platinum and rhodium-platinum alloy wires is to a considerable extent offset by the very much lower—if any—recovery of scrap platinum and rhodium from the spent cartridges, and the net cost per immersion is comparable with the older method.

**Experience at the Steel Company of Wales**

At the Abbey Works of the Steel Company of Wales extensive trials have been carried out with expendable cartridge thermocouples in open hearth furnaces, in Bessemer converters and in ladles. Mr J. T. Davies, Chief Fuel Technologist to the company, reports that they are now convinced of the superior accuracy and reliability of the new method, and would not wish to revert to the previous system of immersion pyrometry.

During check immersions using both procedures readings with the expendable cartridge were almost invariably higher than those obtained with the older method but the differences in temperature were in general agreement with the fall normally experienced in the e.m.f. of the conventional type of couple. When cross-checks were made using a second expendable cartridge or a new and uncontaminated couple of the old type the readings were all in close agreement. Failures from all causes are now running at about 55 per cent of those experienced before the adoption of this method.

Maintenance on the dipping rods is also only a fraction of that previously required. There have in fact been periods of several weeks during which thousands of immersions have been made without any repair to the dipping rods being necessary. The life of a connecting receptacle has been found to be about 500 immersions, while only a few minutes are required for a replacement to be fitted. The steel tube has been found to last for over 1500 immersions.

Experience at the Steel Company of Wales also goes to show that the design of the contacts in the cartridge and the connecting receptacle can play a particularly important part in the accuracy and reliability of the system, since any temperature difference existing across the faces of the contacts can cause errors in measurement. The disintegration of the cardboard tube during immersion is also rather active and can cause some oscillation of the dipping rod, with the possibility of causing contact chatter. On the other hand the ease of assembly of a cartridge into a dipping rod does enable a temperature to be taken within seconds of its fitting, and although this may not be standard practice it can and does happen, particularly when a quick check is required. The use of the cardboard tube was found to prevent excessive temperature rise very effectively, but a cartridge can be fitted into a dipping rod that has a receptacle temperature considerably above that of the tip and it is in these conditions that good heat transfer between the contacts is required. Fitting a cartridge into a well-used receptacle at a temperature higher than that experienced in normal working indicated, however, that
In addition to its applications in the steel industry, the expendable immersion thermocouple has begun to find a place in the melting of non-ferrous metals. Here it is being used to check temperature before casting in a copper-alloy foundry.

the maximum error from this source would not exceed 3° at 1600°C.

The consistency of response of the cartridges, coupled with the very short immersion period necessary to obtain a reading, makes possible—and requires if the maximum life is to be obtained from the dipping rods—the automatic timing of immersion as described earlier.

Use in Arc Furnaces at Samuel Fox

In the Stocksbridge works of Samuel Fox & Co Limited, the expendable cartridge thermocouple has also been under extensive tests and has now been adopted as a regular procedure on two 60-ton arc furnaces. Dr R. H. Baulk, Instrumentation Officer to the company, reports that this system of immersion pyrometry appears to have several advantages over the conventional method. It is more accurate and always gives a reading either identical with or higher than the older method; it is more reliable, and very few dips have to be repeated because of defective readings, while the instrument is more readily handled since it is much lighter. The cost per dip at Stocksbridge was found to be less with the newer system when all labour charges are included.

Initial difficulties experienced by Dr Baulk were of two types; the design of the supporting arm and of the contacts made it possible for some overheating to occur, while the re-

A High Temperature Cartridge

A further development of considerable interest in connection with the use of oxygen in steelmaking is the substitution of an iridium : 40 per cent iridium-rhodium couple for the normal platinum : rhodium-platinum combination. This is capable of measuring temperatures up to 2000°C, and an expendable cartridge designed by the Amalgams Co Limited, of Sheffield, incorporating this thermocouple has been used successfully during the oxygen blowing period in an arc furnace to record 1960°C. This is a significant advance in instrumentation, as there has hitherto been no method of measuring such temperatures under industrial conditions.