

COMPUTER SYSTEMS FOR MEASUREMENTS OF THERMAL PARAMETERS OF MATERIALS AND FUELS USED IN HEAVY INDUSTRY

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Abstract – *This article describes the computer systems employed in heavy industry for the measurements of parameters of materials and fuels, when the tubular electric furnaces are used in the measurement process. The computers control the scheduled temperature changes of examined samples and the reactor atmosphere composition. They also supervise the measurements and conduct data processing and acquisition.*

Keywords – thermal measurements, temperature control.

1. INTRODUCTION

The examination of various parameters of the materials and fuels used in heavy industry needs appropriate measurement conditions. The measurements discussed here can be divided into the following groups:

- Dependence parameters on temperature
- Parameters after a specific thermal processing
- Determination of composition by means of a specific thermal treatment

The above-suggested classification concerns a variety of problems. They may be much different in many aspects, but will have one issue in common. It is the problem of design and control of the devices dedicated to such a kind of measurements – as an integral part of such a device is a specialised furnace.

This work concerns the automatic measurements done with the application of such furnaces. The temperature and the atmosphere composition inside are computer controlled during measurements. The computer also handles all data processing and acquisition pertaining to the measurements.

We shall concentrate here on a particular class of specialised electrothermal devices that make use of furnaces with tubular reactors of the working temperature up to 1800°C. Such furnaces have been worked out and are manufactured in The Industrial Institute of Electronics (Przemyslowy Instytut Elektroniki - PIE) in Warsaw, Poland.

These devices are intended for automatic thermal measurements of materials and fuels, mainly for the needs of heavy industry, mining, metallurgical industry and power engineering. Below we describe some exemplary applications.

As the environment preservation becomes increasingly important, the devices in question are used in the power engineering industry for the determination of sulphur contents in the coal. Another devices are used for finding the

temperature of ash fusibility, exceeding of which can lead to the destruction of boiler grates.

It is important, particularly in the power and mining industry, the determination of the self-ignition index, whose value influences the level of safety when the coal is stored in heaps and excavations. Examination of the blast furnace coke reactivity index enables to keep the appropriate conditions for crude iron melting. In foundry the examination of sandmix fusibility temperature and the contents of bright coal allows to obtain the required surface of castings.

We present both the equipment and the methods that enable us to perform the above examinations. The devices worked out in PIE enable the automation of analyses that were up to now performed manually. Moreover, they often employ measurements based on quite new methods, whose implementation is possible thanks to the application of computers.

2. FEATURES OF MEASUREMENTS

This paper deals with the measurements of parameters that depend on the phenomena of diverse nature. Usually these parameters can be associated with thermophysical or thermochemical phenomena, but it should not be ignored that the examined specimens of material or fuel can be contaminated, or they can be non-uniform by their nature. The investigations can concern for instance such parameters as the temperature of sandmix sintering point [1,2], or the melting temperature [3] of the ash from small coal. It must be taken into account that normally the speed of the temperature change is different for various components of the examined samples. That is why, to obtain good repeatability of the measurements, it is often necessary not only to keep good accuracy of the measurements, but also the repeatability of the temperature to time profile during the processing preceding the measurement, or even during the measurement itself. In many cases the procedure and the parameters of this stage are strictly stipulated by standards.

Taking into account a variety of definitions for temperature parameters of materials and fuels and sundry methods that can be used to determine those parameters, we can only generally classify the problems pertinent to the subject in question. It concerns in particular the methods and the conditions of measurement. The methods can be divided into the following groups:

- Direct measurement methods
- Indirect measurement methods

For example, the determination of the global contents of sulphur dioxide resulting from the burning of a carbon specimen belongs to the first group. On the other hand, the determination of the ash melting temperature with the method worked out at PIE belongs to the second group. This measurement is performed on the basis of the pattern recognition methods, and the changes of the specimen's shape is analysed during the process of heating with a controlled rate of temperature change [1,2,3].

Measurements of thermal parameters are conducted in various thermal conditions that can be classified according to miscellaneous aspects. Considering the moment the measurement is taken out, we can form the following groups:

- Measurements in steady-state thermal conditions
- Measurements in dynamically changing conditions
- Measurements after a specific thermal processing

Although the last category concerns the measurements in static conditions, it is strictly linked up to a former pre-programmed specific processing that is an indispensable part of the measurement.

Another aspect of classification is the energy process that can go on inside the examined specimen or object under the influence of temperature. We can make this classification like this:

- When the internal reactions take place without a heat absorption or emission of the intensity significant for the measurement results,
- When the internal endothermic or exothermic reactions exert a significant influence upon the measurement results

The already mentioned determination of the melting temperature of ashes performed at changing temperature may serve as an example belonging to the first group.

The second group can be exemplified by the determination of parameters of the iron blast furnace coke obtained from various grades of coal. The parameters of this type of coke must meet specific requirements in order to be used in the blast furnace. For this reason the measurement requires that the specimen be treated with carbon dioxide in the conditions corresponding to those of melting the ore in the blast furnace at the standard conditions. Depending on the grade of the coke obtained, it is in various degree liable to the reaction with carbon dioxide, during which it is reduced to carbon monoxide and a considerable amount of energy is absorbed.

A special kind of the specimen temperature control is necessary to compensate for the effects of endothermic reaction. In the result of this reaction that is conducted at a constant temperature for a defined period of time, the mass of the material and its mechanical endurance to the pressure of the blast furnace load change. The relative loss of the coke mass determined after the processing, and the coke granulation (obtained after the additional process of

drumming that is performed afterwards) form the wanted parameters (CRI/CSR) that describe the immunity of the examined lot of coke to interaction with carbon dioxide [4].

A different situation occurs at the determination of the coal self ignition point, which is an example of exothermic process. The temperature of the specimen kept in a stream of air of a controlled flow is raised at a controlled rate. When a certain threshold is exceeded, the coal self-ignites and it results in some rise of the specimen temperature above that of the reactor's [5]. In contrast to the former case, any temperature control is in this case not only needless, but also unacceptable, because of the measuring method principle.

The application of an appropriate gas atmosphere is another important factor associated with the discussed measurements. In many cases the measurement can be carried out in normal atmosphere, but in the case of the controlled specimen burning, often a stream of oxygen of a defined flow should be supplied.

In the case of composition analysis (for instance for the sulphur contents) the all post-reaction gas is to be provided to a gas analyser, while for determination of the coal reactivity, a controlled inflow of carbon dioxide is required and the resulting post-reaction gas must be disposed of in a safe way, because it contains poisonous carbon monoxide.

As illustrated above, the conditions of measurement of thermal parameters of objects or materials can be much diverse. In many cases the standard laboratory furnaces will do, but in numerous instances dedicated equipment is indispensable to effectively perform measurements.

Several dedicated laboratory devices intended for the automatic thermal measurements concerning materials and fuels have been worked out in PIE for the needs of mining, power engineering and heavy industries. An essential part of each of these devices is an electric furnace equipped with a horizontal or vertical tubular reactor having a single or multisectional heater. Usually the tubular ceramic, quartz or metal reactors are used in such furnaces for the following reasons:

- They allow to obtain much uniform temperature in the cross section of the reactor,
- They facilitate the separation of the heater assembly from the reactor atmosphere, which can be harmful to the furnace, heater or personnel,
- They offer a possibility to achieve a laminar, controlled gas flow along the reactor,
- The post-reaction gas can be easily submitted to quantitative analysis,
- It is easy to inspect the object visually during the processing by means of a TV camera placed at the end of the reactor tube.

Table 1 gives the most essential data of chosen devices.

Tab. 1. Thermal measuring apparatus manufactured by PIE in Warsaw, Poland

No.	Description	Type	Range	Gas	Remarks
1	Analyser of the total contents of coal and sulphur in the solid-state fuels.	ACS-70/1300	up to 1500°C	O ₂	NDIR probes
2	Analyser of the hard coal self ignition point	PR-30/250	up to 250°C	air	
3	Tester of the coke reactivity index	PR-90/1300-V	up to 1300°C	N ₂ , CO ₂	Cascade control
4	Analyser of the contents of bright coal in the foundry sandmix	AWB-50/1000	up to 1000°C	N ₂ , O ₂	NDIR probe
5	Tester of the ash fusibility temperature	PR-37/1600	800°C÷1600°C		CCD camera, pattern recognition
6	Testers of the characteristic temperatures of phase transitions and the angle of wettability.	PR-45/1300 PR-37-1600 PR-25/1750	100°C÷1300°C 800°C÷1600°C 800°C÷1750°C		CCD camera, pattern recognition

3. COMPUTER CONTROLLED MEASURING PROCESSES

An appropriate temperature control is necessary to ensure suitable conditions for measurements. In many cases it is possible to obtain sufficient control with a simple PID controllers used to control the heater temperature only. In other instances, as it is with the already mentioned tester of the blast furnace coke reactivity it is not sufficient because of the discussed endothermic reaction of carbon dioxide with the coke. A layout of the furnace used in such a tester [4] is shown in Fig.1.

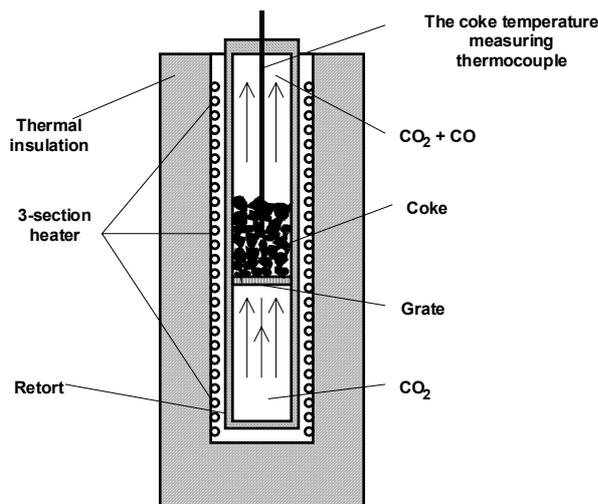


Fig. 1. Layout of a furnace for the coke reactivity examination

The heater temperature in this device is controlled with two ordinary PID controllers coupled with a computer, which controls the set value for each of the PID controller. This way the temperature changes are kept in accordance with the

schedule entered into the computer, which also controls the measurement of actual coke temperature in the retort. When the retort reaches the appropriate temperature, the flow of carbon dioxide is turned on. At this moment the endothermic reaction starts, which, in the case when only the heater temperature control is used, makes the heater temperature drop down by a few, or even up to a few tens of centigrades. And again to compensate for this effect a computer programme was used. At the moment the carbon dioxide flow is turned on, the computer closes a supervisory loop of cascade control [6,7] and, making use of the measured actual reactor temperature, modifies the setpoints of the heater controllers to stabilise the reactor temperature. Figure 2 shows the results of such a control.

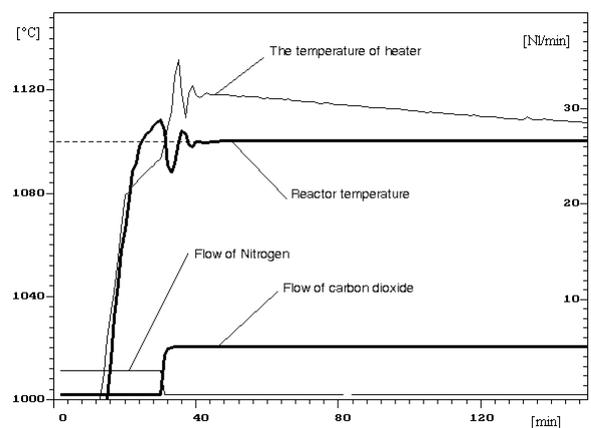


Fig. 2. Heater and the reactor temperatures in the presence of carbon dioxide reaction with coke, with the cascade control of the reactor temperature active

A computer control of temperature rise takes also place during the examination of the coke self ignition point. In a defined time interval, when the temperature is rising, the computer registers the actual temperature of the specimen that at a certain point lights up in the oxygen atmosphere and then its temperature additionally rises. Afterwards by means of data processing the temperature build up is analysed and the ignition point found [5].



Fig. 3. Test stand of PR-45/1300 model for the examination of the phase transition characteristic temperature points by means of the pattern recognition methods

Programmable furnace temperature changes are also utilized in the tester shown in fig. 3 designed for the examination of the phase transition characteristic temperatures.

As the material phase transitions can occur in a very wide range of temperatures (see: Table 1), the computer controls not only the temperature, but also the illumination of the specimen in the lower range, and switches over the camera optical filters in the higher temperature range.

As it was mentioned earlier, the determination of the phase transition points is based on the pattern recognition methods – as the specimen shape changes with temperature. During the measuring process, the shape of the specimen changes in successive phases. At the beginning, the specimen has a shape of a regular cylinder. Then it warps and its edges and walls round out, and in the final phase it takes on a shape of a creeping drop. During this process the computer, by means of a camera, records the successive frames of the specimen image for the pattern analysis that follows afterwards. In the result of this analysis the temperatures: of sintering, of softening, of melting and flowing are obtained. The analysis is based upon many parameters describing the contour of the examined specimen [3]. As it is carried out after the real process (offline), the analysis can filter out many unfavourable phenomena of the physical process, as image jitter caused by rising hot air, etc. In a similar way it is possible to find the angle of wettability of a material, whose specimen takes on the drop shape during melting [8, 9].

There are many processes, during which the computer controls a flow of gas, as it was in the case of the coke reactivity tester. In some cases it also performs the post-reaction gas quantitative analysis, which is used, for

example, for the determination of sulphur contents in the coal. In this case the specimen is burnt up in the oxygen atmosphere and the exhausts are passed on to an NDIR (Non-dispersive Infrared) probe that works on the principle of infrared absorption. The probe output signal is proportional to the contents of sulphur dioxide [10], and the integral of that signal gives the total sulphur contents. The recorded signals additionally tell about the contents of organic sulphur and that of non-organic in the examined specimen.

PC computers with the Windows operational system were used in all described cases. It was justified by a reasonable cost of such computers, as well as the abundance of software available. Considering the speed of temperature change that takes place in the described devices, the sample interval was chosen of an order of a few seconds. For this reason serial interfaces were used to couple the system with other digital devices, as temperature controllers, etc.

4. EFFECTS OF APPLICATION OF COMPUTERS

The application of computer technology allowed for the automation of several measurement procedures that were so far conducted manually. It allowed the staff of lower qualifications to do the job of measurements. The automatic analysis of sulphur contents in the coal is an example of the measurement that replaced the older alkalimetric method that was performed by a manual titration. Another profit brought in by automation is the impartiality of measurements. It can be illustrated, for instance, by the tester of the characteristic points of phase transitions, which up to now required that the operator visually compared the shape of specimen to the classified reference patterns. A similar method is still used in the glass-making and ceramic industries. In the devices described here the pattern recognition methods are used. It brought on a considerable improvement of measurement accuracy and repeatability.

In many cases quite new methods have been invented thanks to the computer capabilities. It concerns, among the others, the measurement of sandmix sintering temperature that is conducted according to the directives of Comité International des Association Technique de Fonderie by heating up the samples to various temperatures and then by sifting them through sieves and weighting the obtained fractions. The method worked out in PIE allows of using the automatic pattern recognition, in some respects similar to the earlier developed one used in the glassmaking and ceramic industries for the analysis of the phase transition characteristic points.

We also obtained good results with a method developed by PIE in co-operation with The Technical University of Łódź, worked out for the determination of sandmix sintering temperature. It utilises the analysis of the sandmix specimen surface radiation parameters. The analysis is based upon the computer comparison of the temperature measured by means of a thermocouple that is in touch with the specimen – to that measured with a pyrometric probe directed at the specimen surface [11].

A still different example presents the automatic method of evaluation of the bright coal and pyrolytic products contents in the sandmix, worked out in a joint venture of PIE and The Technical University of Ostrava (Czechs Republic) [12].

It is possible, making use of the computer technology, to control thermal processes by means of special sophisticated and highly accurate algorithms of temperature control [6,7]. Such algorithms can be adjusted not only to a given object, but also to the kind of the process used [7]. Thanks to that it is possible to achieve a considerable improvement of accuracy and repeatability of thermal processes, comparing to what we can obtain with the traditional (for instance PID) control [6,7].

An important advantage of the computer technology application is an availability of data storage in databases, which allows of the post-processing for the statistic and research purposes, etc.

5. SUMMARY

This paper presents numerous applications of computers for the thermal measurements of materials and fuels used in heavy industry.

In many cases the computer control replaces the manual methods used so far. The automatic testers and analysers eliminate the operator errors, and enable the data storage in databases and creation of automatic reports.

One of the important features is that the automatic measurement enables coupling the measuring devices to the computer aided manufacturing systems and to the company management system.

These solutions increase the efficiency of industrial processes and the lifetime of technical equipment.

The computer data processing and acquisition also facilitates the work of the sanitary inspection, or that of industrial safety or environment preservation.

The computer-aided devices also stimulate the application of new measuring methods.

The general proliferation of new methods much depends not only on the design and research development in the field of measuring devices, but also on the development in the legislative field of standards and regulation.

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