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ON THE DETERMINATION OF THE IGNITION TEMPERATURE OF SPONGE IRON

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ABSTRACT

Sponge iron or direct reduced iron (DRI) often shows a tendency to spontaneously combust in an oxygen-containing atmosphere. This property is very similar to that of coal. Several investigators have reported different methods of determination of the ignition temperature T_{ig}. In this paper the determination of T_{ig} using a thermal analyser is discussed and the technique is critically analysed. Typical values obtained for a few types of DRI are also reported.

INTRODUCTION

During the oxidation of sponge iron, above a certain temperature (generally above 300 °C) spontaneous combustion takes place. At this point the process becomes self-sustaining and the reaction continues as long as oxygen and unreacted iron are available. Ulrich [1] has reported some typical data on the ignition temperature of different categories of sponge iron. Recently, Vega et al. [2] have studied the sensitivity of this parameter to different experimental conditions. The data presented by Ulrich were obtained at a fixed experimental condition. The data of Vega et al. were obtained on a pure iron powder sample. It is apparent that a detailed study on the determination of the ignition temperature is not available in the literature. This paper presents the results of investigations carried out on different direct-reduced iron (DRI) samples using a thermal analyser.

EXPERIMENTAL

Non-isothermal studies on the oxidation of sponge iron were carried out in static air in order to determine the ignition temperature. A Netzsch STA-409 model simultaneous thermal analyser was used [3].

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Procedure

The experiments were carried out using −170 mesh size sponge iron powder obtained after pulverizing a DRI sample. In each case a sample mass of about 60 mg was taken. This fine grain was used so as to obtain a representative sample when conducting the experiment with small quantities of sample. Static air was used to eliminate any possibility of sample ejection by air and also because reoxidation of sponge iron in static air is more akin to the actual spontaneous combustion process. In the experiments alumina was used as the reference material. The maximum temperature was maintained at 1000 °C and various samples were tested at a heating rate of 5 °C min^{-1}. However, to observe the effect of the rate of heating on the kinetic parameters, one sponge iron sample was tested using four heating rates (5, 10, 15 and 20 °C min^{-1}). The ignition temperature of the sponge iron was determined from the DTA curve of the thermogram.

RESULTS AND DISCUSSION

The ignition temperature may be defined as the temperature at which the spontaneous combustion reaction takes place between sponge iron and atmospheric oxygen. However, it should be noted that it is not a fundamental property of a combustible substance because the temperature at which "spontaneous combustion" should occur will be influenced by the factors which control spontaneity. Strictly speaking it is the minimum temperature beyond which the combustion reaction sustains itself, i.e. beyond this temperature the rate of heat accumulation will exceed the rate of heat dissipation. While the former is essentially governed by the reaction temperature and, therefore, the reaction rate, the latter is governed not only by the reaction temperature but also by other factors which influence heat dissipation. Heat dissipation will also depend on the geometry and size of the combustion mixture and the container, the rate of gas flow, etc. Therefore, the ignition temperature must be measured under standardized conditions and it should be understood that the results obtained from different experimental units are likely to vary. However, the relative order of the ignition temperatures of the different combustibles should remain unaltered. Vega et al. [2] have found that the thermal runaway temperature for the oxidation of iron powder is a complex function of the system properties; it decreases with increasing sample size, increasing reactivity and poorer heat transfer, but increases with increasing extent of prior oxidation and decreasing heating rate.

It is shown in this paper that a thermal analysis apparatus can be used as a standard set-up for the determination of ignition temperature and for a

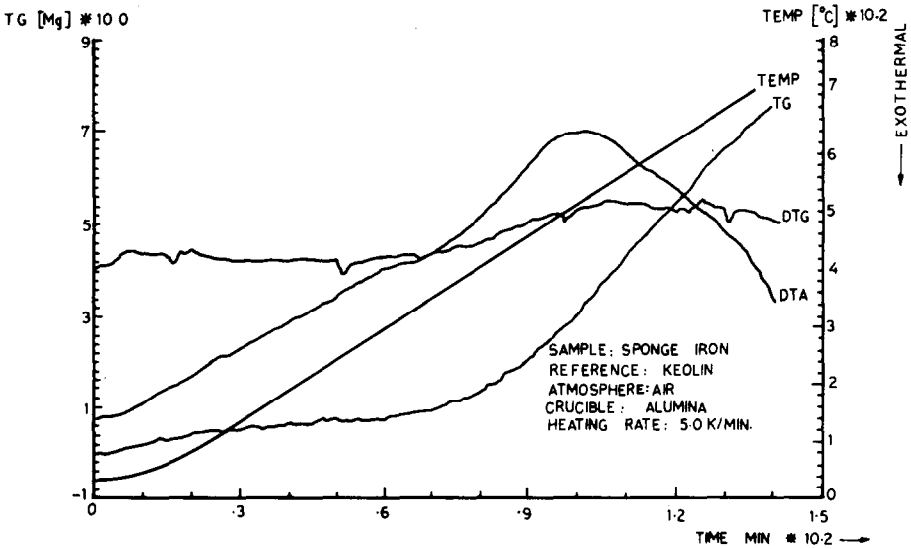

Fig. 1. Thermogram for oxidation of coal-based rotary kiln DRI.

comparison of the relative reactivity of DRI samples. The method proposed is based on the interpretation of TG and DTA plots.

The graphical procedures for the determination of ignition temperature T_{ig} shown in Fig. 1 are self explanatory. Essentially T_{ig} can also be determined from an α–T plot (Fig. 2). The ignition temperature T_{ig} is defined as the temperature at which the DTA plot baseline begins to show a shift towards an exothermic oxidation reaction. In the TG plot it is obtained by the intersection of the tangent as shown. Figure 1 shows an ignition

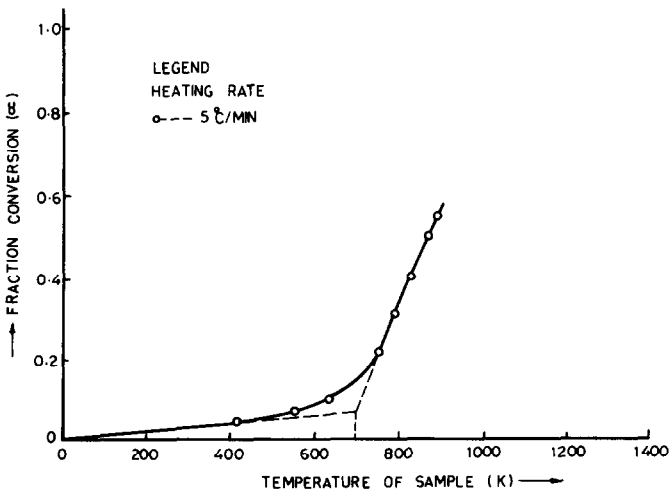

Fig. 2. Fraction of conversion vs. temperature plot.

TABLE 1

Ignition temperature of sponge iron samples

Sample	Heating rate (°C min^{-1})	Ignition temperature (°C)
Coal-based kiln DRI	5	475
Coal-based kiln DRI	10	490
Coal-based kiln DRI	15	515
HyL DRI	15	425
Hot briquetted iron HBI	15	490
Charcoal-reduced DRI	10	510

temperature of 475 °C and Fig. 2 shows an ignition temperature of 430 °C. These two temperatures are reasonably similar. However, it should be noted that the onset of the increase in weight cannot be identified as the onset of ignition. The ignition temperature must be defined in terms of the spontaneous rise in temperature—a tendency for the temperature of the system to exceed that of the environment. Therefore, the DTA plot is considered to be a better guide.

The ignition temperatures of various samples as determined by thermal analysis are summarized in Table 1. Some T_{ig} values presented by Ulrich [1] are summarized in Table 2. In the experimental work reported by Ulrich [1] a cage containing 500 g of the sponge iron was, in each case, fastened to a thermal balance and heated in a dry air flow. The rate of temperature increase of the sample was approximately 2.5 °C min^{-1}. The change in weight was registered and the temperature inside the samples was measured using a thermocouple. It should be noted that our T_{ig} values are about 100 °C higher for the same type of sample. This difference may be attributed to the difference in the experimental conditions. In Ulrich's case, where the sample size is larger and the heat dissipation is expected to be lower, T_{ig} can also be expected to be lower.

The heating rate is also expected to have some effect. Table 1 shows, for a particular sample, the values of T_{ig} obtained for three different heating rates. The apparent T_{ig} value increases with an increase in heating rate.

Although the values in Table 1 are higher than those in Table 2 the relative order remains unaltered. In both cases the HyL sample, which is a

TABLE 2

Summary of ignition temperature data reported by Ulrich [1]

Number	Sample	Ignition temperature (°C)
1	Coal-based DRI	400
2	DRI from shaft furnace	300
3	Briquettes from shaft furnace	380

gas-based DRI, shows the lowest ignition temperature. Thus it may be concluded that the thermal analysis technique can be used as a reliable method for the determination of ignition temperature.

CONCLUSIONS

It has been shown that a thermal analyser can be used to measure the ignition temperature of sponge iron. The ignition temperature varies with the experimental conditions employed. The ignition temperature increases with an increase in heating rate. Under identical conditions a gas-based DRI sample (HyL sample) shows a lower ignition temperature than a coal-based DRI sample; the difference is about 100 °C. Comparison of T_{ig} data obtained here with published data shows that the values are expected to be lower for larger-sized bulk samples. This indicates that bulk DRI is more prone to reoxidation than small powdered samples, obviously because of inferior heat dissipation properties in the former.

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