

DUAL IGNITION TEMPERATURES FOR DUST LAYERS

D.K. HENDERSON and B.J. TYLER

Department of Chemistry, UMIST, Manchester, M60 1QD (Great Britain)

(Received November 19, 1987; accepted in revised form April 25, 1988)

Summary

This note presents experimental results showing how differences of approach to the determination of the ignition temperature of a dust layer can lead to widely differing experimental values. For the material used, sodium dithionite, experiments starting at a high temperature and working down lead to an apparent ignition temperature of nearly 400°C compared to a value of about 190°C when experiments start at a low temperature and work up. The cause of this behaviour is a two stage decomposition characteristic of sodium dithionite; similar behaviour could be expected from many other materials.

Introduction

Many powders, particularly natural and synthetic organic chemicals as well as some inorganic materials, will ignite when present as a shallow layer on a hot surface. The minimum temperature for ignition depends on a number of factors [1], particularly the depth of the layer. Experimental tests have been devised [1,2] for measuring ignition temperatures, e.g. for use in defining safe surface temperatures of electrical equipment used in dusty conditions where layers might accumulate. Typically these tests involve the formation of a layer within a ring on a preheated, thermostatted plate. Heating up and reaction within the layer are followed over a period of minutes to hours by a thermocouple inserted within the layer. By repeated experiments over a range of plate temperatures the minimum ignition temperature is found, usually by bracketting to within a span of 5 or 10°C. Recommended layer depths range from 5 to 15 mm with diameters of several times the depth.

For practical purposes a dust layer can be considered to be inert if the plate temperature required for ignition is above that which might be found in actual plant units. Thus an upper limit, e.g. 450°C, can be specified as the highest temperature for testing. In determining an ignition temperature by a bracketting procedure this provides a convenient starting point since if no ignition is recorded at this upper limit then no further tests are necessary. The results

presented below show that this approach may, in some circumstances, lead to an erroneous conclusion as to the minimum ignition temperature for a layer.

Experimental

Experiments were carried out using sodium dithionite, sieved before use to 60–80 mesh size, in layers of 5 mm depth by 75 mm diameter. The layer temperature was measured at a point 2.5 mm above the plate using a 0.2 mm diameter Pt-Pt/13% Rh thermocouple. Details of the apparatus are described elsewhere [3]. The test layers were formed by hand, pouring a small excess of the powder into a ring on the preheated plate and levelling off the excess dust to a uniform 5 mm depth: it took between 45 and 75 s to prepare a layer in this way. The layer temperature was recorded both during layer preparation and for a period thereafter, to see whether it rose smoothly with little or no maximum to its final value or whether there was a considerable rise ($\leq 50^\circ\text{C}$) above the plate temperature. The former was classified as non-ignition, the latter as an ignition.

Results

Figures 1(a) and (b) show temperature-time traces for layers at plate temperatures of 360 and 400°C. They clearly suggest that the ignition temperature has been roughly bracketted since at the lower temperature there is only a small peak shown by the 2.5 mm thermocouple which does not reach the plate temperature, whilst at 400°C the plate temperature is overshoot by more than 100°C. Figures 2(a) and (b) show the outcome of similar experiments at plate

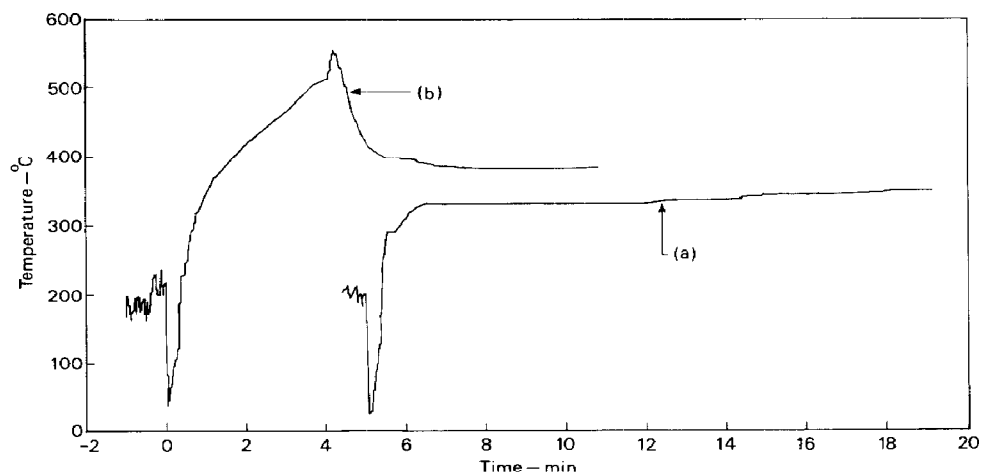


Fig. 1. Temperature vs time curves for 5 mm deep layer of sodium dithionite (a) hotplate at 360°C (time axis shifted by 5 min) and (b) at 400°C.

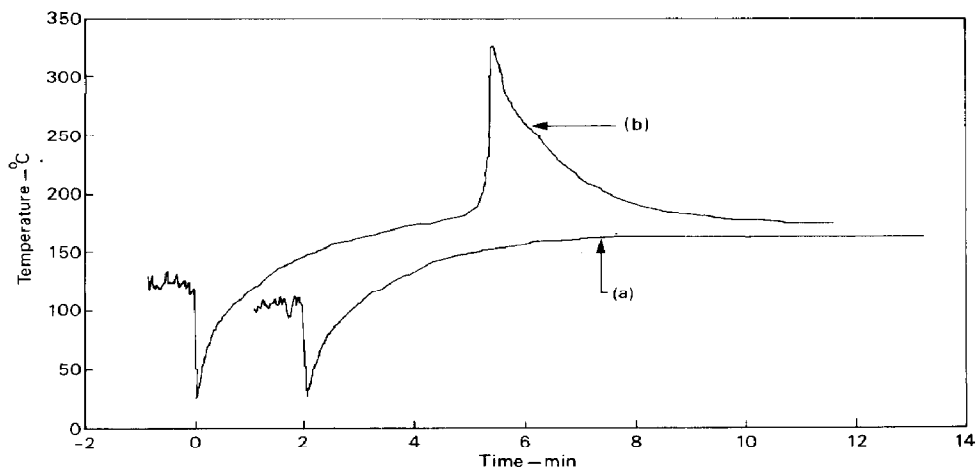


Fig. 2. Temperature vs time curves for 5 mm deep layer of sodium dithionite (a) hotplate at 185°C (time axis shifted by 2 min) and (b) at 192°C.

temperatures of 185 and 192°C. Again they can be interpreted as bracketting an ignition temperature.

Thus for sodium dithionite different experimental procedures can give widely divergent values for the “minimum” ignition temperature of a 5 mm layer. In a short investigation aimed only at determining the self-ignition temperature the one that would be identified will depend on the experimental approach, in particular whether a “top-down” or a “bottom-up” method is used. The results from the different methods will show a startling difference.

Discussion

Sodium dithionite is unusual, but not unique, in decomposing in a multistage process, in this case forming an initial product which can itself decompose exothermically; this is illustrated in Fig. 3 which shows that at a plate temperature of 300°C there are two exotherms. The second one occurs several minutes after the first, an indication that kinetic factors are important in determining the onset temperature of the second stage of the decomposition. Several combinations of the two peaks could occur depending on the kinetics of decomposition and the plate temperature and the dynamics of heating of the powder when placed onto the hot plate. Likely outcomes are:

- only the first peak is seen,
- the two peaks appear quite separately,
- the two peaks are contiguous,
- only the second peak is seen.

Our results show that the extreme cases of single peaks are seen as in Figs.

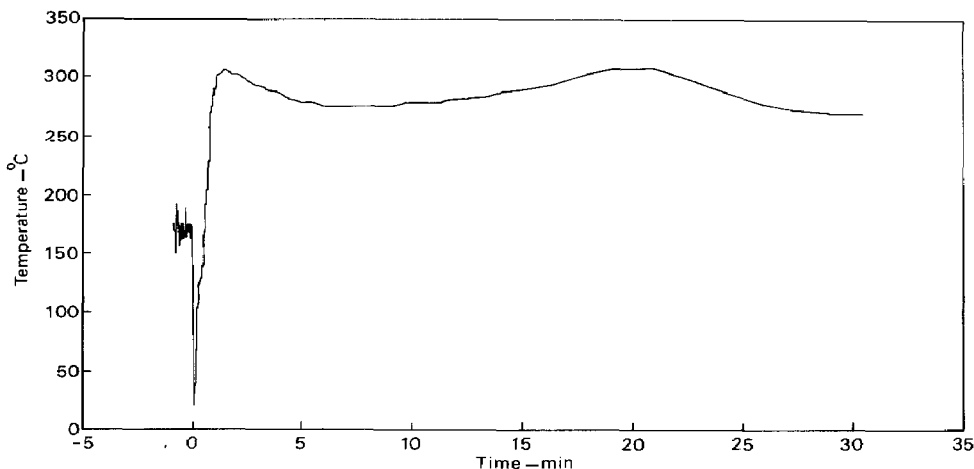


Fig. 3. Temperature vs time curve for 5 mm deep layer of sodium dithionite with hotplate at 300°C.

1 (b) and 2 (b). Figure 3 illustrates the second of the four possibilities. A merging of the two peaks was not found within the conditions investigated.

Perhaps the most important question is how a single peak can be seen when operating at a high plate temperature since it is this event that could lead to the assignment of a high value to the minimum ignition temperature. The temperature-time traces in Figs. 1 (a) and (b), when examined closely, clearly show a different heating characteristic compared to those at plate temperatures of $\leq 200^\circ\text{C}$. With all the traces there is initially a varying temperature from the exposed thermocouple before the layer is made up. Then the temperature drops as the powder, at ambient temperature, contacts the thermocouple junction. The drop is quickly followed by an increase due to heating of the powder by thermal conduction from the hot plate. For an inert material this gives a smooth curve up to the final equilibrium temperature, very similar to that shown in Fig. 2(a) and in the approach to the temperature peak in Fig. 2(b). In contrast, the warming up period shown in Figs. 1(a), 1(b) and 3 are irregular clearly indicating, in retrospect, that some exothermic process was occurring. The difficulty in observing this is that it occurs within the period of preparation of the layer, i.e. the initial 45–75 s of the event. In this period physical changes such as gas evolution from the layer are easily missed and the indications on the temperature–time trace can be overlooked unless this type of behaviour is known and anticipated. It is reasonable to conclude that an experimental study of sodium dithionite which started with measurements at plate temperatures of 400°C would have resulted in the assignment of a “minimum” ignition temperature close to that and would not have identified the ignitions at much lower temperatures.

This phenomenon is unlikely to be confined to sodium dithionite. There are

well known examples of two component systems with a minor, exhaustible component which reacts at a lower temperature than the bulk component. The rate of heat release from the minor component determines whether a runaway reaction is initiated in the main component. Practical examples encountered [4] include oilseed meal and fishmeal and these cases were of sufficient importance for a model of ignition of two component mixtures to be developed [5]. It is very likely that these materials would show the characteristics reported for sodium dithionite with, at a high plate temperature, the minor component being exhausted during the make-up period and a high ignition temperature being determined based upon the properties of the major component. Another possible material is cellulose, where it is reported [6] that two exothermic processes are observed.

Three approaches could be used to ensure that a misleading high ignition temperature is not assigned:

1. Start experiments at a low temperature and work up.
2. Prepare layers as quickly as possible and check the warming up curve for any irregularities indicating early exotherms.
3. Use thick layers. In this case the warming up period is longer (compared to the making up time) and so it is less likely that early exotherms will affect the outcome or be overlooked by the operator.

Of these three, the first is to be preferred.

Acknowledgement

The work described was done under contract to the Fire Research Station and so this paper forms part of the work of the Fire Research Station, Building Research Establishment, Department of the Environment. It is contributed by permission of the Director, BRE on behalf of the Controller, Her Majesty's Stationery Office.

References

- 1 P.C. Bowes, *Self heating: evaluating and controlling the hazards*, HMSO, London, 1984.
- 2 N. Gibson, D.J. Harper and R.L. Rogers, *Plant/Operations Progr.*, 4 (1985) 181.
- 3 D.K. Henderson, Ph.D. thesis, University of Manchester, 1986; B.J. Tyler and D.K. Henderson, *Ind. Chem. Eng. Symp. Ser.*, 102 (1987) 45.
- 4 P.C. Bowes, *op. cit.* p. 255.
- 5 P.C. Bowes, *op. cit.* p. 251.
- 6 P.C. Bowes, *op. cit.* p. 362.