

Short Communication

EFFECT OF HUMIDITY ON THE IGNITION BEHAVIOUR OF A LIQUID SODIUM POOL

F.C. PARIDA, S.R. MUKUNDA RAO and D.S. MITRAGOTRI*

Safety Research Laboratory, Reactor Research Centre, Kalpakkam-603 102 (India)

(Received February 20, 1985; accepted February 25, 1985)

Introduction

Liquid sodium is used as a circulating coolant in the heat transport circuits (primary and secondary) of nuclear fast-breeder reactors. The inventories involved are large and the coolant temperatures reach 500–600°C at the reactor core. Behaviour of a sodium pool resulting from any accidental spillage is of interest from the point of view of accident analysis. In this context, the ignition behaviour of an unstirred liquid sodium pool, consequent to its exposure to ambient atmosphere, needs to be characterised as a function of atmospheric humidity.

Reactions of sodium with oxygen and water are both highly exothermic and rapid, and consequently the exposures are associated with a high degree of fire hazard. Studies have been conducted earlier on the ignition behaviour of sodium by various workers and these have been summarised by Newman [1]. The reported values of ignition temperatures (Table 1 of Ref. [1]) range from 118 to 425°C and the large spread shown by these values was attributed by Newman to the varying ignition conditions employed by the workers. Differences in conditions arise due to varying uses by these workers of: pool/spray, agitated/non-agitated pool, pool–dry O₂/dry air/wet air, etc. In an earlier work, Newman [2] heated small, shallow pools of sodium in an atmosphere of normal wet air and associated the observed ignition temperature with the melting of the protective hydroxide/carbonate layer formed on the metal surface during heating. In the present work, heating of small, fixed-size sodium pools is carried out under an atmosphere of ambient oxygen content. Relative humidities of the atmospheres are maintained constant at selected values in the range 20–90% R.H. Experimental details of measurements on ignition temperatures are indicated below.

Experimental

The experimental set up is shown schematically in Fig. 1(a). Heating of sodium (~20 g) is carried out in a mild steel crucible (25 mm diameter × 50 mm height) held in an experimental chamber.

*To whom correspondence should be addressed.

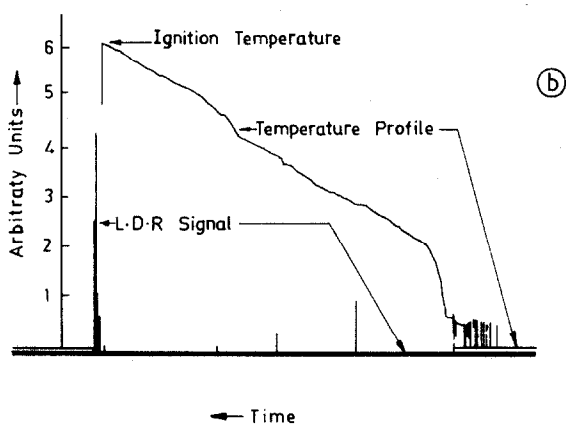
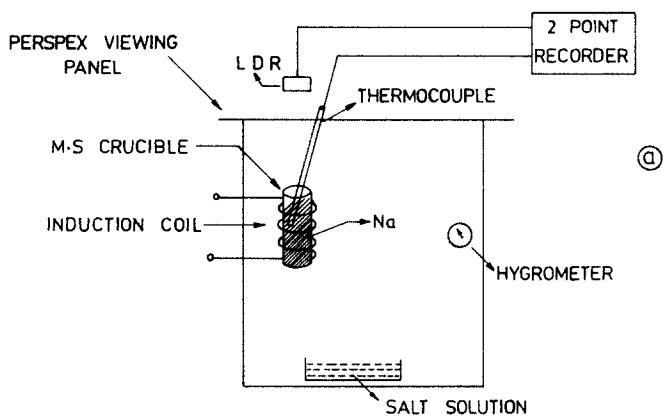


Fig. 1. (a) Schematic of experimental set up. (b) Record of signals from thermocouple and LDR.

ber is a stainless steel (s.s.) vessel (260 mm diameter \times 520 mm height) with a volume of about 28 litres. The top of the s.s. vessel is closed with a perspex viewing panel. The s.s. vessel is also provided with a port on its side for penetration of an induction heater coil. The crucible is held in the coil and is separated from it by asbestos packing. A stainless steel thermowell carrying a chromel-alumel thermocouple dips into the sodium mass in the crucible and is used to monitor the temperature of sodium continuously during the heating. Relative humidity of the vessel atmosphere is controlled by exposure of the vessel atmosphere to a selected aqueous solution of salt placed in a container on the bottom of the vessel. Suitable compositions of salt solutions for obtaining various equilibrium relative humidity values are tabulated by Nelson [3]. Salts selected in the present

study are shown in Table 1. Actual relative humidity values obtained are monitored with a hair hygrometer (range 20–100% R.H.) located inside the vessel. To obtain equilibrium in relative humidity rapidly, the vessel atmosphere is recirculated (3 l/m) with an external pump and tubings (not shown in figure) and the flow is directed through the aqueous solution. A light dependent resistor (LDR), fixed on the outside of the transparent viewing panel, monitors emission of light on ignition. The outputs of the thermocouple and the LDR are fed to a two-pen recorder for simultaneous recording.

In each experimental run sodium is cut from a dry-packed, oil-free sodium brick and is sliced in an argon atmosphere glovebag to remove the hydroxide/carbonate crust. Three trials are conducted at each relative humidity value.

Results and discussion

Figure 1(b) shows a typical record of signals received from the LDR and the thermocouple during an experimental run. As the temperature of the sodium in the crucible is raised (average rate: 15°C/min) transient signals from the LDR are also recorded and correspond to isolated particulate ignitions. A persistent signal from the LDR is taken to represent the stable ignition temperature. Results of measurements of these ignition temperatures at the relative humidity values selected are shown in Table 1 and are plotted in Fig. 2(a). Spreads in measured values are also indicated in the figure. Using the ambient temperature value of 32°C, the results are re-plotted in Fig. 2(b) as $\log P_{\text{H}_2\text{O}}$ vs. $1000/T_k$. The latter plot is seen to be a straight line. This may indicate that the oxidised layer (necessarily present on the sodium pool surface) allows the reaction rate to be influenced by the partial pressure of water vapour in the atmosphere right up to the event of ignition. Thus, under the conditions of the experiments, the oxidised

TABLE 1

Ignition temperature of sodium pool vs. ambient relative humidity

| S | Measured R.H. (%) | Ignition temperatures (°C) | Mean I.T. (°C) |
|---|-------------------|----------------------------|----------------|
| 1 | 90 | 168, 181, 197 | 182 |
| 2 | 76 | 182, 198, 196 | 192 |
| 3 | 60 | 219, 223, 236 | 226 |
| 4 | 40 | 240, 251, 259 | 250 |
| 5 | 32 | 293, 296, 305 | 298 |
| 6 | 21 | 337, 368, 348 | 351 |

Equilibrium relative humidities were obtained using saturated solutions respectively as follows: (1) $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$, (2) NaCl , (3) NaNO_2 , (4) $\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$, (5) $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$, and (6) NaOH (40% w/w).

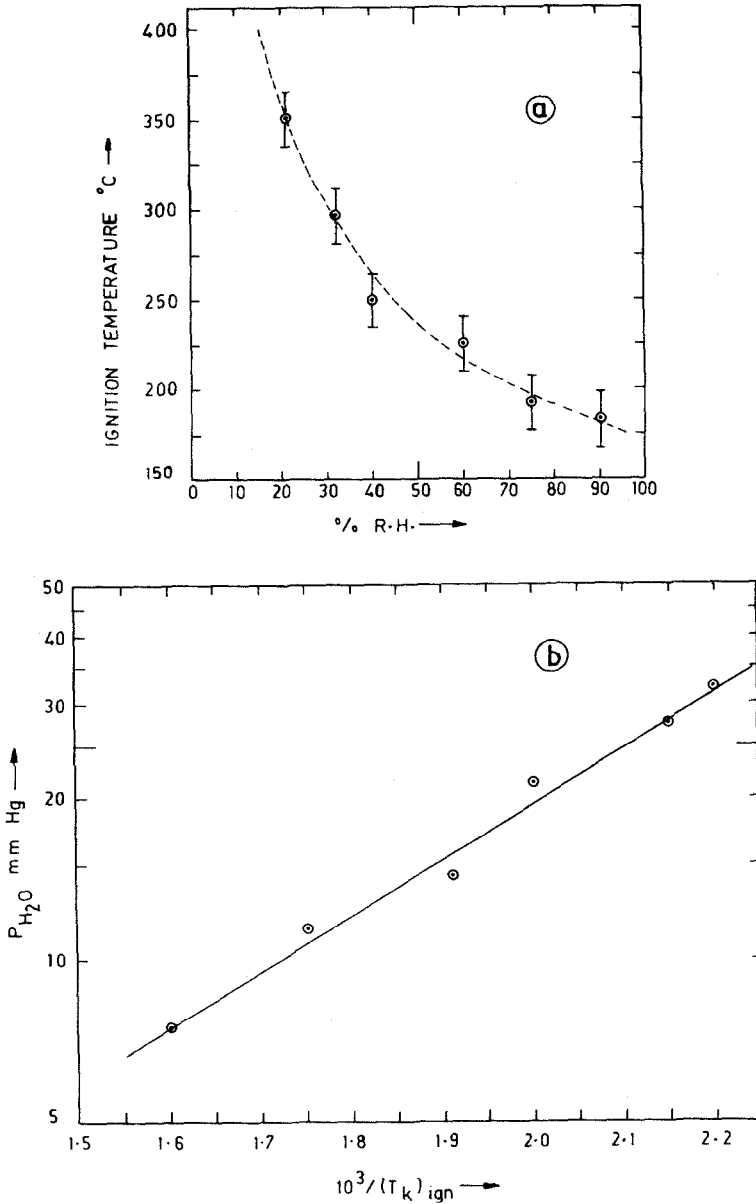


Fig. 2. (a) Plot of ignition temperature of sodium pool vs. % R.H. (b) Re-plot $\log P_{H_2O}$ vs. $10^3 \times$ reciprocal absolute ignition temperature.

layer is seen to be sufficiently thin to be effectively permeable to water vapour, and ignition is facilitated with increasing humidity.

Deviations from the observed pattern of ignition temperatures might, however, occur (i) when cold-trapped (high purity) liquid sodium is sudden-

ly exposed, leading to an effectively lower thickness of oxidised layer, and (ii) when the rate of external heating of sodium pool is too low, causing growth of larger and effectively impermeable thicknesses of the oxidised layer. In the field trials (wind velocity, 10–30 km/h) conducted by Raju and Kale [4], the ignition temperature appeared to rise from 220°C to about 320°C with a rise in R.H. from 53% to 69%. However, in view of the short range of relative humidities covered in their work the role possibly played by impermeable thicknesses of oxidised layers cannot be unambiguously characterised. In the present study, however, the ignition temperatures are seen to be steadily decreasing with rise in R.H. and there is no evidence of any turning point.

Acknowledgements

The authors express their sincere thanks to Dr. D.V. Gopinath for his keen interest and encouragement and to Shri A.R. Sundararajan for useful discussions.

References

- 1 R.N. Newman, *Prog. Nucl. Energy*, 12(2) (1983) 124.
- 2 R.N. Newman, CEGB Note RD/B/N/2412, 1973.
- 3 G.O. Nelson, *Controlled Test Atmospheres*, Ann Arbor Science Publishers, 1973, p. 184.
- 4 C. Raju and R.D. Kale, *Indian Atomic Energy Commission Report RRC-34*, 1979.