The Development of a Small Scale Class A Fire Test

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1. Introduction

Recently there has been a drive to test fire suppressants on a small, convenient laboratory scale. Gaseous suppressants have been relatively easy in this respect, as they are conveniently tested against heptane fires floated on water. Flammable liquid fires are well understood and predictable. The rate of burning is a function of surface area, temperature and other well defined parameters, allowing easy scaling [1].

Aqueous agents, on the other hand are normally tested against Class **A** fire threats (carbonaceous material, *e.g.* wood, paper) and at the moment no suitable laboratory scale fire threat exists. There is a need to develop such a fire threat, for screening novel suppressants. This paper describes the apparatus and procedure used in developing a small scale Class **A** fire threat.

2 Experimental

2.1 The Mini-crib

Standard Class **A** fire threats usually take the form of a wood crib, whose dimensions depend on the fire rating used and the standard being followed. UL 711 cribs are square, whereas BSI standard uses cribs of uniform width, whose length is varied according to the desired rating. **A** UL 1A crib is quite large, which means it is not only expensive (in terms of wood cost) but it is also time consuming to build, ignite and extinguish. Also, the use of large, standard cribs precludes screening tests with novel, expensive suppressants. Contrast this with work carried out on exotic suppression agents on Class B fires [2].

The mini-crib is compared with the two smallest standard sizes of cribs in Table 1 below:

Table 1: Comparison of UL & BS5423 Cribs

	UL 711	**BS 5423**	**Mini-crib**
Rating:	1A	3A	1/8A
Wood dimensions (mm):	38 × 38 × 505	39 × 39 × 300	10 × 12 × 65
Number of layers:	10	14	5
Members per layer:	5	3	3
Total wood volume (cm^3):	36,461	19,165	117

A small, square crib was chosen for ease of construction. Previously, the smallest non-standard crib which had been reported in the literature used members which were 1" x 1" x 6" (25 x 25 x 150 mm) [3]. **A** crib made from wood of these dimensions equates to approximately ½A (UL standard). Although this is significantly smaller than a standard wood crib, it is still too large to used conveniently and easily with a laboratory.

After some initial burning tests, the size of wood decided upon was 10×12×65 mm (0.4 x 0.5 x 2.5 inches). The wood was arranged in a square crib comprising of 5 layers of **3** members, shown diagrammatically in **Figure 1.**

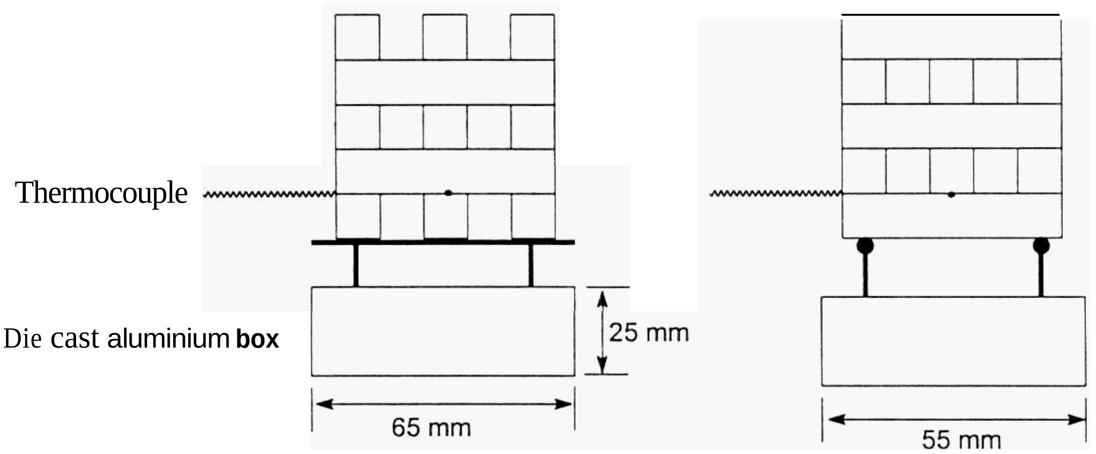


Figure 1

The wood was dried in an oven at 110 "C for a minimum of 2 weeks. If the wood was not dried sufficiently, it was found that the crib did not burn reproducibly. Similarly, any attempt to reduce the total amount of wood led to fires which were not reproducible. The total volume of wood used for each of these cribs was 117 cm^3.

Ignition of the crib was by the conventional means of a heptane pan fire underneath the wood members. Construction of the wood crib on a die cast aluminium box allowed the box to be used as the pan for the heptane. The crib was supported on two brass rails 15 mm above the top of the aluminium box. This allowed good airflow through the crib during pre-bum, ensuring the fire was reproducible. By adopting this arrangement, it also meant that the small crib mimics larger full scale cribs in terms of ignition characteristics and airflow.

2.2 Test Chamber

The crib was set up in an enclosed, ventilated box fitted with two nozzles. The test chamber is shown diagrammatically in **Figure 2.** The suppressant under test was stored in a 1 L reservoir and pressurised with nitrogen to 1 bar(g). The two nozzles (type: BLM 9-90) protruded into the chamber by 40 mm as the throw of these nozzles was not sufficient to reach the crib with enough force to penetrate the flame plume. In order to simulate a real fire threat the right hand side fan was left running throughout the experiment, This ensured that extinction was not aided by oxygen depletion, thus making the fire considerably harder to extinguish. These conditions were arrived at after many preliminary tests, such that one litre of water was just sufficient to extinguish flaming combustion, but not to give any significant cooling. Thus any improvement due to additives to the water would manifest itself readily.

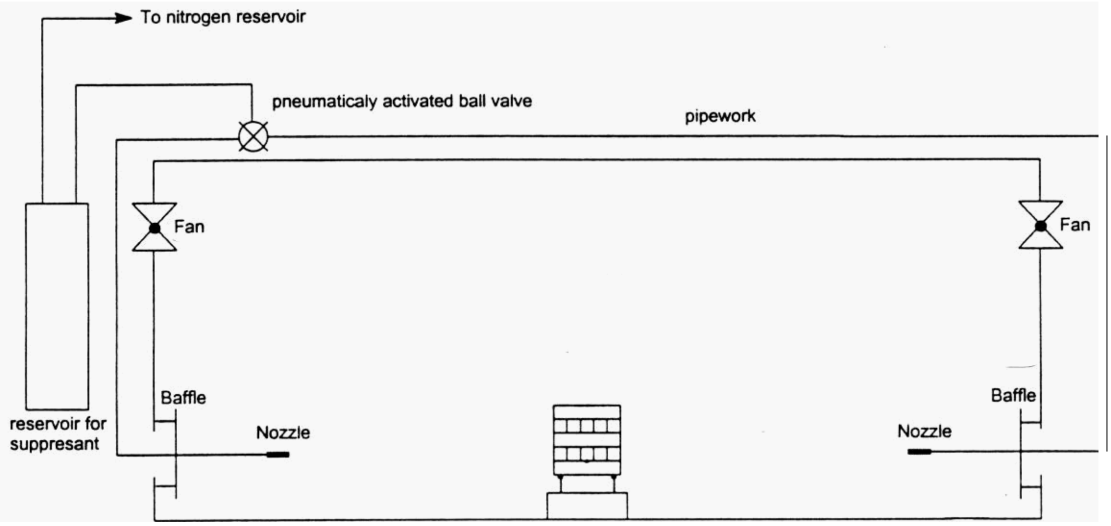


Figure 2

The chamber itself had dimensions of 1000 x 550 x 650 mm, giving a nominal volume of 358 L. Timed weight-loss experiments allowed the heat output of the crib to be estimated as 3.5 - 4 kW. This makes the fire threat equivalent to *ca.* 10.5 kWm^{-3}, which for Class **A** fire threats is “large” **[4]** and, when compared to many Class B threats, is not dissimilar to a marine or naval fire threat [5].

One of the features of class **A** combustion is the ability of the fire to re-strike if insufficient suppressant is used. The mini-crib exhibits this phenomenon, but not necessarily every **time.** On some occasions during initial experiments the centre of the crib was observed to be glowing bright orange, but no re-strike occurred. It was presumed that there were insufficient volatile species remaining in those particular wood members to cause re-ignition.

A thermocouple was placed between the first and second layers of the crib in order to measure the temperature between the two wood surfaces. **A** record of temperature with respect to time allows the comparative performance of suppression agents to be determined. A value for the temperature of the crib one minute after the fire had been extinguished was set at 200 °C. Once the crib temperature has dropped below 200 °C, the crib does not possess enough energy for re-ignition, and the fire was said to have been extinguished. The temperature was recorded for a further three minutes and agents compared to each other in their ability to remove heat from the wood embers.

2.3 *Procedure*

The suppressant under test was placed in the reservoir, and the pipework filled with suppressant by opening the ball valve for 5 s. The crib was assembled in the centre of the test chamber, trapping the thermocouple between the middle members of the first and second layers. The right hand fan only was switched on. The heptane (8 mL) was placed in the bottom of the aluminium die cast box and ignited. The front doors of the chamber were closed, and both data logging of temperature and timing were started. The pre-burn time was set at 2 min 45 s, or 20 s longer than the heptane fire took to burn out, whichever was the longer. After the pre-burn period had elapsed, the crib temperature was recorded, and the pneumatic valve actuated in order to apply the suppressant. Once the flames had been extinguished, the application of suppressant was stopped and the crib temperature and the time required for flame extinction were recorded. Temperature data was recorded for a further three minutes, after extinction of the fire.

It was felt that the procedure of stopping the flow of suppressant at the moment of extinction **as** described above was not a good model of how aqueous suppressants (either from hand extinguishers or fixed sprinkler or water mist systems) are used in reality. Therefore a modified procedure was adopted whereby the suppressant was continuously applied even after flame extinction had occurred. This is referred to **as** **Procedure 2** and the above method as **Procedure 1.**

3 Results

3.1 *Ammonium Dihydrogen Phosphate (ADP, $NH_4H_2PO_4$)*

For a given agent, a range of concentrations were used and a bar chart of extinction time *vs.* crib temperature was plotted. **As** way of **an** example, a plot of crib temperature for ammonium dihydrogen phosphate at varying concentrations (using Procedure 1) **is** given in **Figure** 3 below.

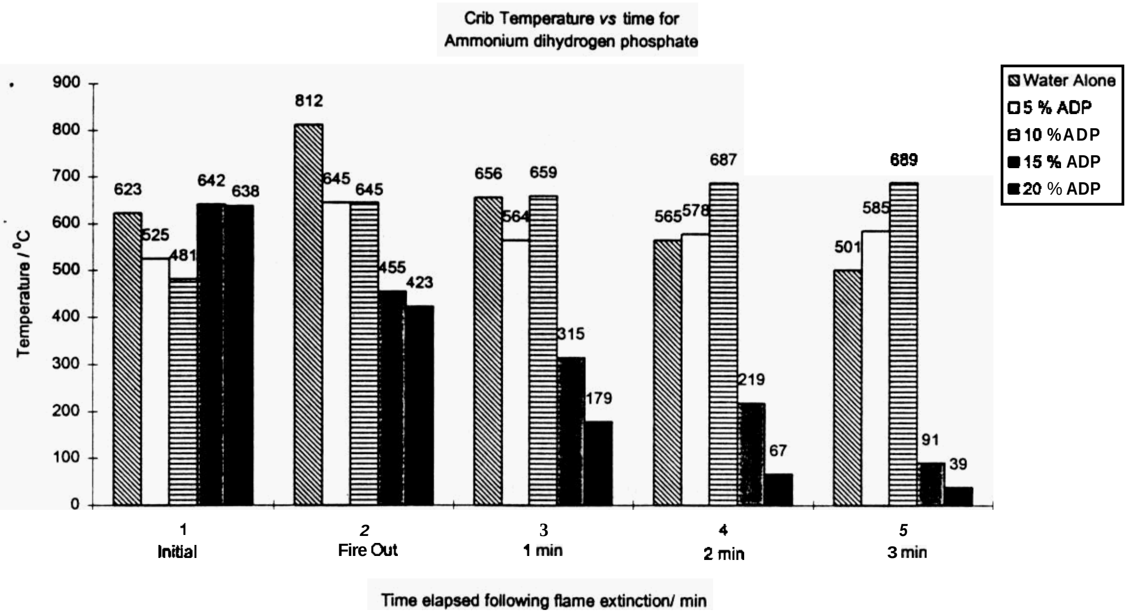


Figure 3

Figure 3 shows quite clearly how the use of a more concentrated solution is effective in extinguishing the wood crib. The first three entries (water alone, 5 % ADP, 10 % ADP) had temperatures which continued to rise throughout the duration of the test. For higher concentrations of ADP (15 % and 20 %), the crib has been extinguished more effectively, and cools rapidly, preventing the fire from re-striking. Indeed, the use of **20** weight% ADP resulted in the ***core*** of the crib cooling to virtually ambient in just **3** minutes.

Fire extinction time, although an easy parameter to measure (defined as the time to extinguish flames only) is not necessarily the best indication of fire suppression ability, particularly for Class **A** fires, and, (in this series of tests at least) does not wholly correlate with increases in the suppressant concentration as shown in Table **2.**

Table 2

Concentration of ADP	Extinction Time (s)
0 % (water alone)	81
5 %	90
10 %	51
15 %	67
20 %	51

The value recorded for 15 % ADP is high and typifies the variation in results common with fire testing natural materials, such as wood. Flame extinction times for wood fires are misleading if measured in isolation.

The measurement of the temperature of the crib centre *vs.* time for continuous application of suppression agent (Procedure 2) should give an indication of the ability of the agent to effectively suppress glowing combustion. **A** series of tests with ADP were repeated, and the times taken for flame extinction and, post-extinction, for the temperature of the crib to fall to 400, 300 and 200 "C were measured. This data is given in **Table 3.**

Table 3

ADP Conc.	Extinction Time / s	Initial / °C	Time to Reach Temperature / s 400 °C	300 °C	200 °C
10 %	-*	692	68	76	84
15 %	42	603	39	56	78
20 %	62	589	51	60	77

* Flames were extinguished instantaneously, this particular sample of **wood was** probably not sufficiently *dry.* **This** emphasises *the* difficulty experienced **using** flame extinction time **as** a test parameter.

It can clearly be seen from the **Table** that both **15** and 20 % solutions of ADP were more effective than a 10 % solution of ADP at extinguishing glowing combustion, although little difference was seen between the performance of 15 or 20 % solutions. This should be compared to the data presented in **Figure 3,** which implied that a solution of 20 % ADP was more effective at removing heat from the glowing embers of a fire ***once** extinguished.* Combined, the data suggests that the use of 20 % ADP is preferable as a fire-fighting agent, not for increased flame knock-down efficiency, but for its ability to render the embers safe, once the flaming combustion **has** been extinguished. ADP is, of course, well known both as a Class **A** fire suppressant *[6]* and a fire retardant for cellulosic material [7]. The chemical mechanism for the inhibition of the glowing combustion is the same in both cases (see below).

3.2 Potassium Hydrogen Carbonate

The use of potassium hydrogen carbonate at varying concentrations is shown in the **Figure 4** below. Basically, there is a critical concentration (15 weight%) below which no significant chemical activity occurs, and the dilute $KHCO_3$ solutions behave more or less as water, since the flame extinction time does not vary significantly. However, with these rapid extinction times, the crib has a tendency to re-strike, probably because of the reduced quantity of agent applied.

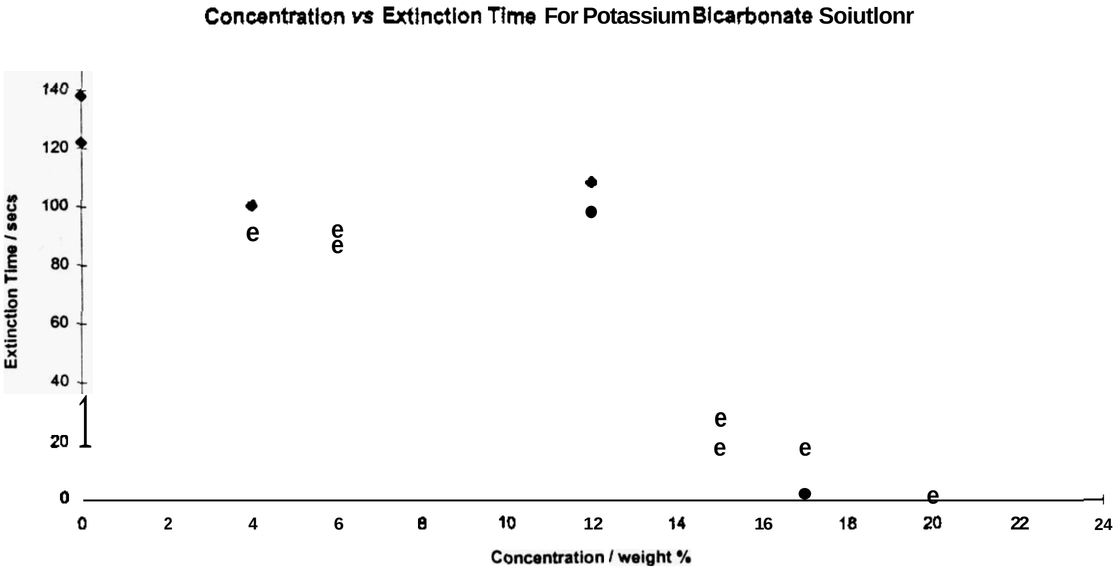

Concentration vs Extinction Time For Potassium Bicarbonate Soiutlonr

Figure 4

4. Discussion

4.1 Class A Combustion

Most of the heat generated by a wood fire stems from the flames burning volatile components which evaporate from the hot wood surface. Bryan has discussed the factors which determine the degree of difficulty a wood fire is to extinguish. The most important single factor is the total thermal content of the crib, and Bryan concluded that flames were both the greatest source of heat from a wood fire and the easiest component to extinguish [8,9]. Once the gas phase combustion is suppressed a second combustion mechanism takes over if the heat content/ temperature of the crib is sufficient. This is the glowing combustion of the remaining cellulosic char. This is actually a slow heterogeneous reaction involving the oxidation of carbon **[7]** which is nevertheless sufficiently exothermic to bring the temperature of the char up to red heat. If unchecked, this glowing combustion will propagate, and the conducted and radiated heat may be sufficient to cause ignition of unpyrolysed wood, *i.e.* a re-strike will occur.

This then leads on to the question of how long the pre-bum should **be,** to ensure the crib is fully alight. However, a balance has to be drawn between a pre-bum period long enough to establish true deep-seated combustion, and one which consumes all of the volatile species, rendering flame extinction too easy. This criterion appears to be satisfied by the time selected (2 minutes 45 seconds).

4.2 Suppression of Class A Fires

Water is used extensively as a Class A suppressant, due to its high cooling capability. However, *this* test has been deliberately set up so the water application rate is not sufficient to give sufficient cooling, so any improvements over pure water can be easily detected.

A true Class A suppressant, such as ADP, even in aqueous solution, can suppress fire by two separate mechanisms. Firstly, the heat absorption capability, via its endothermic decomposition reactions of the salt helps reduce gas phase combustion, and also cools the wood. Secondly, on the surface of the wood, the endothermic reactions produce polymeric phosphoric acid, which seals the surface of the hot char from the oxygen in the air, thus inhibiting the glowing combustion reaction mentioned above.

$$NH_4H_2PO_4 \rightarrow NH_3 + H_3PO_4$$
$$nH_3PO_4 \rightarrow [HPO_3]_n + nH_2O$$

In the realm of the real world however, rapid extinction of flames by chemical means would be very advantageous to the fire-fighter ***(vide supra),*** allowing access to the root of the fire and therefore more rapid and complete extinction would be possible. This is one of the current goals of the project; to identify an agent that combines the rapid flame knockdown of a chemically acting agent with the true Class A suppression exhibited by the ADP solutions.

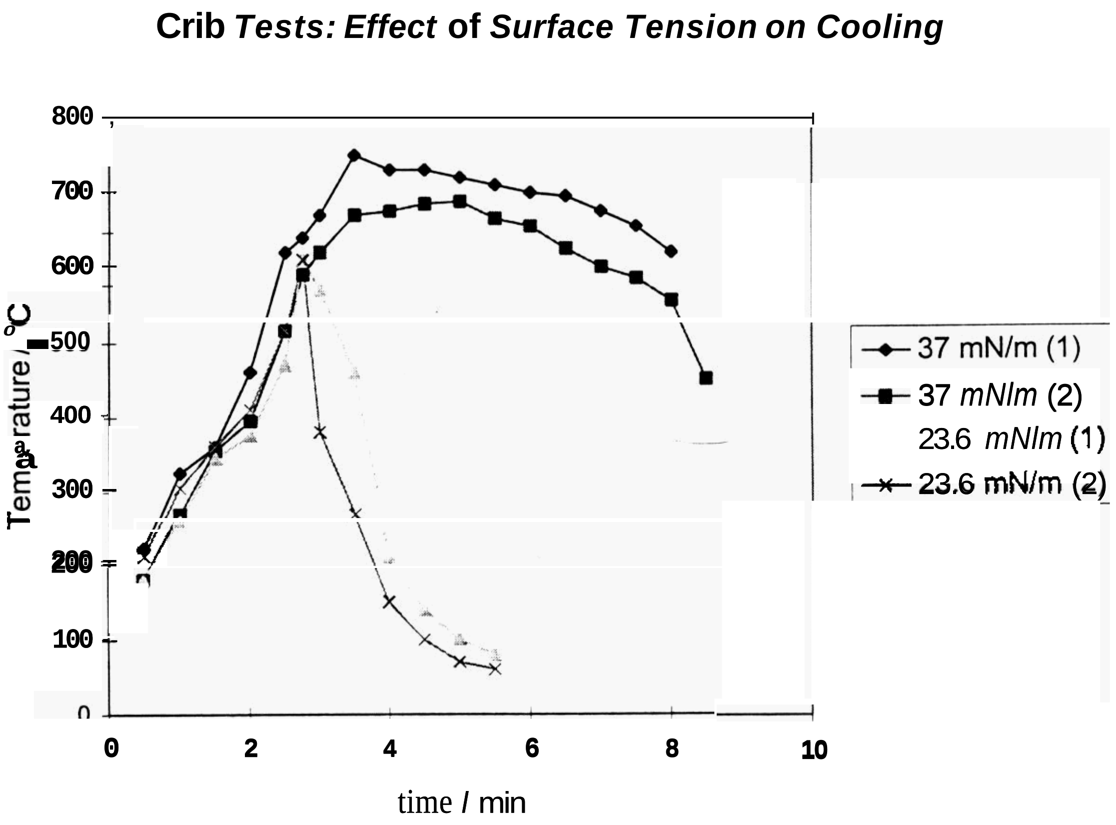
Agents such as potassium bicarbonate, which have excellent heat absorption and chemical suppression effects on Class B fires [10] are similarly able to rapidly extinguish the flaming combustion of the wood, if used at a concentration of 15 weight% or greater. However, they have no effect on the heterogeneous glowing combustion reaction, because their endothermic decomposition products do not form a barrier layer as with ADP. Consequently re-strike is a serious problem with this type of agent, and therefore it is not usually considered as a Class A fire suppressant.

5. Further Work

5.1 *Water Wetting Agents*

Water is not generally considered a good wetting agent due to its high surface tension (72.9 mN m^{-1} at 20°C). This surface tension could be reduced to as low as 15 mN m^{-1} by addition of an appropriate surface active agent (surfactant), thereby improving the wetting properties of water. This could be of benefit in suppressing Class A fires, as "wet" water would spread more effectively over burning wood or paper, allowing more cooling to take place via the high heat capacity/latent heat of vaporisation of water.

Figure 5 below shows four temperature-time plots for water to which a surfactant has been added at two concentrations. The surface tension reduction, and subsequent improved cooling of the mini-crib is clearly evident. These are preliminary results, but are nevertheless very encouraging.



Crib *Tests: Effect* of *Surface Tension on Cooling*

Figure *5*

5.2 *Gelling Agents*

Addition of gelling agents to water could allow improved cooling of Class A fires by the increased viscosity of the resulting gel giving an enhanced water contact time with the fire. The higher the water content of the gel, the more effective the cooling should be.

6. Conclusions

1. A convenient and small laboratory scale Class A fire threat has been developed. The mini-crib exhibits true Class A combustion characteristics (glowing embers, propensity to re-strike etc.) In addition, it can differentiate between a recognised Class A suppressant (ADP) and an agent not normally associated with Class A fires (potassium bicarbonate). New agents can be tested quickly and with relative low cost in materials.

2. Class A fires (of any size) can never be identical due to the natural variation present in the wood members. This includes not only the variation in moisture content, but grain and even cellular structure. In the case of the mini-crib, this is minimised by drying the wood for at least two weeks at 110 °C

3. Either the time taken for full extinction of *the* crib to occur with continuous application of suppressant or flame extinction and subsequent loss of thermal energy was measured. For suppression agents which have a mechanism available for the suppression of glowing combustion, measurement of the time for full extinction was possible and useful. A comparison of flame knockdown, heat removal capability and complete extinction times, may well be the best way to accurately gauge a suppressant agent's performance.

4. The use of solely chemically acting agents for the extinction of wood cribs was not useful and this test was not able to show or offer any advantages - other than the expected flame knockdown times over ammonium dihydrogen phosphate.

5. Other approaches to improve the performance of pure water are either to lower its surface tension, thus improving its wetting capabilities, or the use of a gel to improve contact time, also improving cooling.

7 References

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