Central Fire Brigades Advisory Council
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The Use of Foam Against Large-Scale Petroleum Fires Involving Lead-Free Petrol Summary Report

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In September 1991, a series of foam trials was carried out on a 56m² circular tray using 3000 litres of petrol as fuel for each test, to establish whether the introduction of lead-free petrol conforming with current standards would present any new problems to the fire service when using their standard low expansion foam equipment and techniques. The conclusions were that, providing brigades followed the application rate guidance given in the Manual of Firemanship as amended by the DCO Letter 10/91, no problems would be expected when using good quality AFFF or FFFP against petrol formulations permitted by current and likely future standards.

INTRODUCTION

As a result of public concern, the Fire Experimental Unit was asked to evaluate the performance of portable foam extinguishers on fires of various traditional and unleaded petrol formulations. The tests, carried out in 1989, revealed that the foams tested suffered no significant loss of fire extinguishing capability when used on small scale unleaded petrol fires. The report concluded that there appeared to be no need to change fire extinguisher requirements for garage forecourts or comparable situations.

The report also suggested, however, that the stability of the foam blanket could be reduced at large scale incidents involving petrol formulations containing high levels of oxygenates, and that further research might be required in this area. When the report was presented to the Joint Committee on Fire Brigade Operations, the members concluded that this should be the subject of further work.

The objective of the tests described in this report was to establish whether lead-free petrol, conforming with current standards, would present any problems to the fire service using their standard low expansion foam equipment and techniques. The tests were designed to represent an incident that would be tackled using one main delivery foam branchpipe.

Discussions were held between the Home Office and the petroleum industry during the planning of the trials. The industry co-operated fully and assisted with the specification, mixing and delivery of fuel. The fuel for the main tests was donated by the Industry with the Home Office paying the duty and VAT charges.

FACTORS AFFECTING TRIALS DESIGN

Application Rate

Successful use of foam is dependent on the rate of application. Application rates are generally defined in terms of the amount of foam solution in litres per minute expended on 1 square metre area of the fuel surface. Recommended rates of application will vary depending on the foam type and fuel.

There is a critical application rate below which the fire cannot be extinguished and above this there is a recommended rate which will vary depending on the method of application. The most recent Home Office guidance was issued to brigades in a Dear Chief Officer letter (Number 10/91) in November 1991 which supplemented information given in the Manual of Firemanship.

The additives tested in these petrol trials were Fluoroprotein Foam (FP), Aqueous Film Forming Foam (AFFF) and Film Forming Fluoroprotein Foam (FFFP). The fuel depth for the trial was shallow (approximately 50 mm) representing a spill fire. The relevant application rate was 4 lpm/m² for AFFF and FFFP foam types and 5 lpm/m² for FP foam type. It was hoped to use the same rate for all the tests. It was therefore decided to use the lowest rate currently recommended to the fire service (4.0 lpm/m²) for all foam types for the preliminary tests to determine whether FP could be used at this lower rate.

Branchpipe

A pilot study on low expansion foam-making branchpipes was carried out by FEU and reported in 1986. For the purposes of the study, four branchpipes were chosen, all with flows of about 225 litres per minute. These were the Angus F225, the Angus F225H, the Chubb FB5X MKI and Chubb FB5X MKII. These branchpipes were the ones in most common use on first line appliances in the United Kingdom.

The hydraulic characteristics of the branches, the foam pattern and throw and the quality of the finished foam were measured in the pilot study. The Angus F225 had the shortest throw and a very tight "rope-like" stream. The Angus 225H and the Chubb branchpipes gave generally similar patterns.

The Chubb branchpipes gave foam which was more fluid with a much shorter drainage-time than the Angus ones. The report noted that the significance of this difference in foam properties required assessment in full scale fire tests, but this comparison had not been carried out before these current tests. In the absence of such results, the longer draining foam would be considered the better, particularly for burnback resistance.

For the lead-free petrol tests the Angus F225 was rejected because of the short throw and the Chubb FB5X MKI because a later version was available. The latest Chubb branchpipe, the FB5X MKII, was chosen on the basis that if this was successful, then better performance could be expected from the Angus 225H.

Fuel

Lead as lead tetra-ethyl (or lead tetra-methyl) has been used for about 60 years to improve the performance (octane rating) of the hydrocarbon mixtures which constitute petrol but health and environmental concerns have resulted in the progressive reduction in amounts of lead in petrol from 1974 onwards. The reduction of the lead content has led to the use of oxygenates, for example ethers and alcohols, as alternative octane improvers. Oxygenates are only used when the octane rating cannot be achieved cost effectively by refinery processes in both leaded and unleaded fuels.

At the time of the setting up of the tests, Methyl Tertiary Butyl Ether (MTBE) had been widely used in European Continental petrol and was increasingly appearing in UK blends. Alcohols, notably tertiary butyl alcohol (TBA) and methanol were also used intermittently as components in gasolines in Europe and, provided the fuels conform to the British Standards, could in theory be imported for sale in the UK. At present, however, the likelihood of this happening is low since alcohol-containing gasolines are unsuitable for the distribution system in the UK.

European Directive 85/210/EEC defines the permitted lead and benzene contents of both leaded and unleaded petrol, while 85/536/EEC, the 'Oxygenates Directive', specifies the national flexibility and composition limits for oxygen-containing components which may be added to both leaded and unleaded petrol. UK petrol specifications are set by the British Standards Institution: BS 4040 (1988) for leaded petrol and BS 7070 (1988) for unleaded petrol. These permit a virtually infinite number of oxygenate combinations up to the limits prescribed in those standards which reflect the requirements of 85/536/EEC.

As noted earlier, both leaded and unleaded grades may contain oxygenate additives. In practice, the higher octane unleaded grades are more likely to contain oxygenates: this is because oxygenates are being added primarily for their high octane qualities to replace, in part, the octane benefit previously conferred by the lead alkyls.

The choice of fuel was made after advice from the Petroleum Industry on the most suitable combinations to represent blends towards the upper limits of oxygenate concentrations which could potentially be present in the UK. Although, for the reason given above, the use of alcohol-containing blends in the UK is unlikely, these fuels would tend to be more demanding of the foam performance during firefighting. An alcohol blend was therefore included in the series of fuel mixtures to be tested. The three fuel types agreed for testing were:

Fuel 1 - Unleaded petrol with no oxygenates. This was 95 octane premium unleaded petrol.

Fuel 2 - Unleaded petrol with a moderate oxygenate level, using an alcohol component of 3% Methanol and 2% Tertiary Butyl Alcohol (TBA). This gives a Total Oxygen Content of 1.93% which approaches the UK maximum of 2.5%.

Fuel 3 - Unleaded petrol with 15% MTBE. This is the maximum allowed under EEC Directive and is greater than that allowed in the British Standard for use in the UK.

At the planning stage of the tests, the standard for volatility was being renegotiated and it was expected that the volatility value would be reduced by the end of 1992. Although this reduced volatility would result in a less severe fire, it was decided to use the lower figure. The reduced volatility specification was expected to be current at the time that the results of the tests would be widely promulgated. It was decided that all the fuels should have the same volatility (as measured by the Reid Vapour Pressure) and that this would be maximum allowed in the new standard. If possible, it would be arranged that all the fuel mixtures would contain broadly similar proportions of aromatic and aliphatic hydrocarbons.

Each fuel was analysed by the supplier before delivery and samples were taken from the tanker at the test site by the FEU for independent analysis.

Additives

The high cost of these trials precluded testing every type of foam available so it was decided to use 3% FP, AFFF and FFFP foams, because these were the foam types most commonly used in the fire service.

One test with alcohol resistant AFFF (AFFF-AR), at 3% concentration, was included because of current interest from some brigades in using a 'universal' concentrate.

Figure 1: Fire during preburn

FIRE TEST PROCEDURES

The tests were performed in a purpose built $56m^2$ circular tray on the Fire Service College fireground. The tray had a concrete base and metal circular rim. For each test, 3000 litres of fuel were dispensed from a tanker into the tray. No water base was used because some of the petrol additives were soluble in water. The fuel was ignited and allowed a one minute preburn before the foam stream was applied to the upwind side of the tray. A general view of the fire during the preburn is shown in Figure 1.

The branchman, an experienced fire officer, applied primary aspirated foam to the tray surface, attempting to cause minimum disturbance to the fuel. Until 90% control was achieved the branchman held the branch steady and after this he used his discretion in the tactics necessary to achieve extinction.

Five minutes after the fire was extinguished, a burnback test was performed to assess the resistance of the foam blanket to flame. A propane torch was applied to the foam surface until the fire was well developed (Figure 2).

Figure 2: Burnback rig in position

Throughout the tests, observers noted the progress of the fire fighting, the times to 90% control and extinction and the times to 25% and 100% burnback. Radiometers were used to measure heat radiation and all tests were recorded on colour video equipment.

The foam solution was produced using an in-line inductor as a convenient way for introducing concentrate into the hoseline. However, the concentrate was lifted from its container using an electrically driven gear pump and passed through a flowmeter before reaching the inductor. A second flowmeter was introduced into the hoseline to monitor the solution flowrate to the branchpipe. The pump operator monitored the flowrates of solution and concentrate and by adjusting the main pump throttle and gear pump he accurately controlled the concentration. After each test, samples of foam were collected and the foam properties measured.

As far as possible, standard procedures were used for all the tests and all relevant parameters such as temperatures and wind conditions were recorded.

After the trials, a number of medium scale tests were carried out with the fuels from the main tests using 144 litres of fuel for each test. The procedures used followed the draft European Standards for foam concentrates.

RESULTS

Preliminary Tests

Preliminary tests were carried out on unleaded fuel with no oxygenates, to establish test procedures and to determine the branchpipe and application rates that should be used for the main tests.

These preliminary tests showed that the service's minimum recommended application rate of 4 lpm/m² produced acceptable results with AFFF and FFFP using the Chubb FB5X MKII branch. The 90% control times were less than one minute and 100% extinction was achieved by 4 minutes 30 seconds.

However, when FP was deployed under the same conditions it took 14 minutes for 90% control and the test was terminated at 16 minutes without extinction. FP proved unable to extinguish the fire with the Chubb FB5X MKII even when the application rate was increased to the recommended minimum of 5 lpm/m². It only proved possible to achieve successful extinction with FP when it was applied with an Angus 225H branches at an application rate of 5 lpm/m².

The tests confirmed the guidance in the DCO Letter 10/91 that FP must be used at a higher application rate than AFFF or FFFP.

Unleaded petrol with no oxygenates - Fuel 1

The results of the extinction tests are given in Figure 3 which records the 90% and 100% extinction times in minutes and seconds. The results of the burnback tests are given in Figure 4; the 25% and 100% burnback times are recorded.

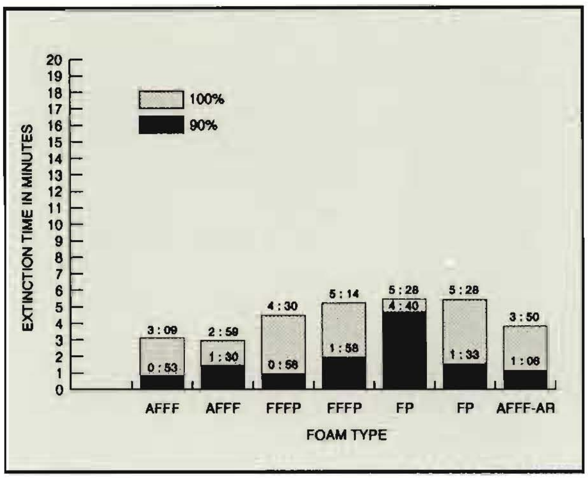

Figure 3: Extinction test results for Fuel 1

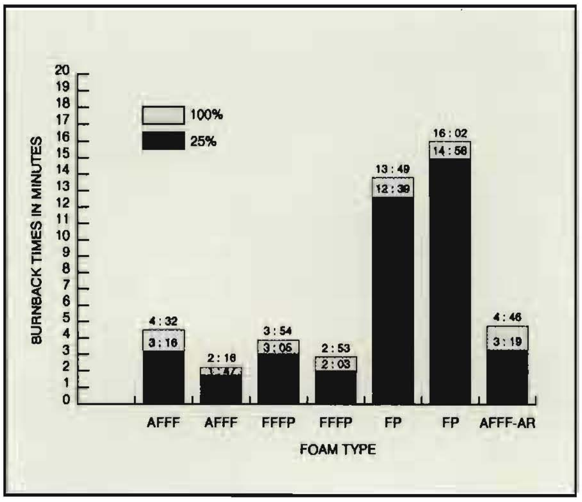

Figure 4: Burnback tests results for Fuel 1

AFFF and FFFP gave convincing extinction at 4 lpm/m² using the Chubb FB5X MkII. FP also gave gave satisfactory extinction used at 5 lpm/m² with the Angus 225H. The single test with AFFF-AR gave results similar to those of AFFF and FFFP.

The burnback tests using AFFF, FFFP and AFFF-AR produced similar results, with small flames developing over the foam surface and tray rim shortly after the burnback flame was applied. The foam blanket did resist a major burnback for several minutes before the flames quickly spread to the whole tray area. The performance of FP was much better with 25% burnback times in excess of 12 minutes.

Unleaded fuel with alcohols - Fuel 2 and Unleaded petrol with MTBE - Fuel 3

The extinction and burnback results are given in Figures 5 and 6.

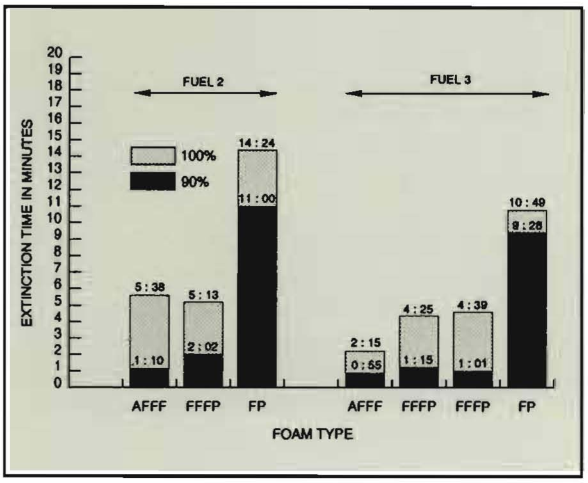

Figure 5: Extinction test results for Fuels 2 and 3

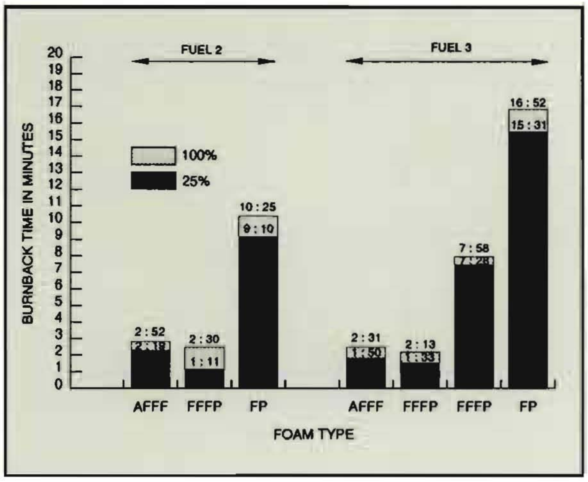

Figure 6: Burnback test results for Fuels 2 and 3

With Fuels 2 and 3, both AFFF and FFFP at 4 lpm/m² gave convincing control and extinction with a Chubb FB5X MKII Branch. FP at 5 lpm/m² with the Angus 225H Branch did not achieve 90% control until 11 minutes with Fuel 2 and 15 minutes with Fuel 3. The fire was only eventually extinguished after allowing the foam stream to hit the ground outside the tray and flow over the bund wall and gently onto the fuel surface. This tactic is referred to as indirect application. The burnback test results were similar to Fuel 1 with minimal resistance from AFFF and FFFP; FP showed superior performance.

Only three tests are reported with Fuel 2 because of a branch malfunction on one test.

A single test was carried out with Fuel 3 using FFFP and the Angus 225H branch at 4 lpm/m² This did not show significant change in the extinction performance but it did give improved burnback times. The significant change in the measured foam properties was that FFFP had a longer drainage time when used with the Angus Branch.

Medium Scale tests

The 90% control times from the medium scale tests supported the results from 56 m² tests, AFFF and FFFP showing similar performance for extinction and burnback. However 100% extinction was not achieved because of small flames remaining around the tray rim that could not be extinguished with the fixed foam branchpipe. This is a known limitation of the proposed European Standard test.

It was only possible to test FP on the unleaded fuel with no oxygenates and although this gave a much longer 90% extinction time than AFFF or FFFP, it did achieve extinction.

DISCUSSION

Foam Types

The results indicate that there was no difficulty in extinguishing all three fuels tested using AFFF and FFFP with the Chubb FB5X MKII branch at the mimimum recommended application rate of 4 lpm/m². The single test with AFFF-AR on Fuel 1, showed similar performance to AFFF and FFFP.

FP had to be used at 5 lpm/m², again the minimum recommended rate, and with the Angus branchpipe to extinguish the unleaded fuel (Fuel 1). With the other two fuel types, the 90% times were much longer than with the other foam concentrates and indirect application was required for extinction. The branchmen were never confident with the use of FP because of the flaring that occurred wherever the foam stream hit the foam surface.

FP was more successful when the foam stream was applied indirectly. This gave gentler application as would be achieved with a backplate, frontplate or objects which could be used to serve the same purpose. Gentle application is advocated by the fire service wherever possible.

The burnback times of FP were the longest showing that FP had better burnback resistance. However, care must be taken in comparing tests where the extinction times were very different, because the burning characteristics of the fuel change as it burns down, and because long application times allow a deep foam blanket to build up.

In selecting foam additives, brigades should consider the relative importance of extinguishing and burnback performance. FP has the better burnback performance.

AFFF and FFFP have significantly better extinguishing performance.

From the results achieved with good quality AFFF and FFFP, there would appear to be no justification for using alcohol resistant type concentrates for petrol fires.

Branchpipe

The tests have supported the pilot study results and shown that with FP and FFFP the performance of the Chubb branchpipe is inferior to that of the Angus 225H. The use of the Angus Branchpipe with AFFF was not explored but it is reasonable to expect that this would also result in a better foam. The one test with the Angus 225H with FFFP did not show a significant change in extinction times but a superior burnback resulted. The foam properties showed the 225H gave an increase in expansion ratio but, more significantly, the drainage time was doubled.

Satisfactory performance with all the fuel types was achieved with the Chubb Branch when using AFFF and FFFP, but use of the Chubb branch with FP cannot be recommended.

Repeatability of tests.

Where tests have been repeated with the same branchpipe, concentrate and fuel there were variations in the results. A minimum of three tests employing the same conditions is ideally required to assess repeatability, although more are desirable. However, the size and cost of the tests impose practical limits. It was decided at the preliminary meetings between the Home Office and the petroleum industry to carry out 1 test only for each fuel type/foam type combination. One additional test was reserved to test for repeatability, if problems did not require that a test be discounted. More than 4 tests are reported with Fuel 1 because this fuel was used in the preliminary trials.

Wherever possible, test conditions and procedures were standardised. However, in large scale outdoor tests the temperatures and wind conditions cannot be controlled and these contribute to the variability of the tests.

Tactics of foam application

It was decided to apply foam to the fuel surface as gently as possible without the use of a backplate or frontplate. Direct application is the most testing condition likely to be experienced operationally because, in practice, there may be surfaces on to which the foam stream can be directed so that the foam flows more gently on to the fuel surface. The tests showed that AFFF and FFFP were more tolerant of direct application than FP.

After 95% extinction had been achieved, the final extinction was very much dependent on the tactics of the firefighter. When the remaining flames were attacked with the direct foam stream, this caused flaring. The recommended application rate is essential to bring the fire under control but, when small flames remain around the tray area, a gentler application, at a lower flow rate may prove more effective. The use of medium expansion foam may be useful at this stage because this does flow gently onto the foam surface and at this stage of the firefighting the limited throw of medium expansion would not be necessarily a restriction. It was not possible to explore these variations in tactics during these trials.

CONCLUSIONS

The trials have shown that, using AFFF and FFFP through a Chubb FB5X MKII branchpipe at 4 lpm/m^2, there was no difficulty in extinguishing all the fuels tested. No difficulty is expected with petrol formulations in the current standards using the Chubb FB5X MKII or Angus 225H branchpipes under these conditions.

FP only achieved extinction with the unleaded fuel with no oxygenates when used at an application rate of 5 lpm/m^2 and with an Angus 225H branchpipe. Extinction was not achieved with the other two fuels without using indirect application. The burnback performance of FP was better than that of AFFF and FFFP.

The tests have shown that foams applied with the Angus 225H have superior performance than when applied with the Chubb FB5X MKII.

In selecting foam additives, brigades should consider the relative importance of extinguishing and burnback performance. FP has the better burnback performance. AFFF and FFFP have significantly better extinguishing performance.

Providing that brigades follow the guidance in the Manual of Firemanship, as amended by the DCO Letter 10/91, no problems would be expected when using good quality AFFF or FFFP against petrol formulations permitted by current and likely future standards.

ACKNOWLEDGEMENTS

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FURTHER INFORMATION

The following reports provide more detail on the work described:

SRDB Publication 9/87
Pilot Study on Low Expansion Foam-Making Branchpipes,
B P Johnson and P L Parsons 1986.

SRDB Publication 27/89
Portable Fire Extinguisher Trials Against 89B Fires of Leaded and Unleaded petrols,
A A Briggs and B P Johnson. 1989.

FRDG Publication 5/92
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J A Foster, 1992.

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