TRIALS OF FOAM ON PETROL FIRES AT THE FIRE SERVICE TECHNICAL COLLEGE

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Trials of Foam on Petrol Fires at the Fire Service Technical College

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SUMMARY

A series of foam tests was carried out at the Fire Service Technical College in November 1974 on pool fires of area 84 square metres (30 feet square) using 1370 litres (300 gallons) of two star petrol (motor spirit) as fuel for each test. The foams used were protein and fluoroprotein at low expansion, fluorochemical (aqueous film-forming foam) as low expansion foam and as spray, and synthetic foam used with expansion ratio of 20-30 and at high expansion. Commercial branch-pipes and foam generators were used. The total liquid flow of extinguishing agent was controlled at 227 litres per minute (50 gallons per minute) in all trials. The solution strength used was that recommended by the manufacturers of each foam concentrate.

The times for 90 per cent and 100 per cent extinction were observed, and burn-back tests were conducted. The test fires were recorded on cine film.

Under the trials conditions, protein foam failed to extinguish the fire before the fuel was exhausted. Fluoroprotein, fluorochemical and synthetic foam all gave convincing control and extinction. Of these materials, fluoroprotein foam had much superior burn-back performance. Synthetic foam used at high expansion (700) gave very good control and extinction times.

CONTENTS

1. INTRODUCTION

Fires offering special difficulties, such as petrol and oil fires and basement fires, may be tackled by the use of foam. Various foam-making materials and equipment are now available in Brigades. Nevertheless, partly because of the comparatively infrequent use of these extinguishing agents, no generally accepted doctrine exists as to the best use of the various foams on fires of differing materials and situations. A series of controlled tests on fires of realistic size should help in the formulation of advice on the employment of these agents. This is a very wide field for technical and tactical experiment. Part of it will be covered by a project to be undertaken at Fire Research Station under Home Office sponsorship on the tactical criteria for use of medium and high expansion foam. The most pressing need is to investigate spill fires of volatile hydrocarbon, ie petrol (motor spirit, AVGAS). Fires of this nature are prominent in the results of accidents to tankers in transport.

The present report describes a series of foam tests carried out at the request of the Fire Service Inspectorate acting for the CFBAC Joint Committee on Design and Development of Appliances and Equipment. The experimental pool fires of 84 square metres used two-star petrol (motor spirit) as fuel. Extinction times and burn-back times were measured using a number of types of foam. The tests were made at The Fire Service Technical College in November 1974. Personnel taking part were from Fire Service Inspectorate and Scientific Advisory Branch, Home Office, from Fire Research Station, DOE, from the instructional staff of the Fire Service Technical College, and from Royal Armament Research and Development Establishment.

2. FOAM CONCENTRATES AND EQUIPMENT TESTED

The foam concentrates used were:

Protein foam concentrate	Reference A
Fluoroprotein foam concentrate	Reference B
Fluorochemical foam concentrate (Aqueous film-forming foam)	Reference C
Fluorochemical foam concentrate (Aqueous film-forming foam)	Reference D
Synthetic foam concentrate	Reference E

The foam making equipments used were:

A low expansion-ratio foam branch pipe, nominal liquid flow 225 litres/min	Reference P
A medium expansion-ratio foam branch pipe, nominal liquid flow 225 litres/min	Reference Q
A high expansion-ratio foam generator, maximum nominal foam output 7000 cu.ft./min	Reference R

Also used was:

A jet/spray branch	Reference S

3. TRIALS CONDITIONS

The fires were conducted in a square steel tray with 9.15 metre (30 feet) sides of height about 40 cm. This facility at FSTC is sited in an open position clear of buildings and other obstructions. The tray was cleaned by scrubbing with brooms and clean water before each test. Sufficient clean water was run into the tray to cover the steel bottom and provide a level surface. The approximate water depth required was 6 cm. On to this for each test 1370 litres (300 gallons) of two star petrol (motor spirit) was dispensed by gravity feed from a tanker, the amount having previously been metered through the FSTC petrol pump. This corresponds to a fuel depth of 16.3 mm. At an estimated free burning rate of 4 mm per minute (Refs 1,2) this would burn for 4 min 5 sec.

Ignition was by an electrically fired cartridge suspended a few centimetres above the petrol surface at one side of the tray. A pre-burn time of one minute was allowed from ignition to the start of foam application. This pre-burn time was considered sufficient to allow the fire column to attain equilibrium and for the burning rate to steady (Reference 3), while allowing reasonable economy in fuel costs.

Foam was applied from the upwind side. Application was made as gently as possible to avoid churning the surface and to minimise contamination of foam by fuel. The time to extinction of 90 per cent of the fire area was noted, as was the time to 100 per cent extinction. After extinction, foam application was continued for a further 30 seconds. This was intended to provide a standard condition for the burn-back test which could be regarded as representing practical circumstances of use in fire-fighting operations.

A metal frame one metre square with sides about 25 centimetres in height was then placed in the large fire tray in the centre of the upwind side. Foam within this frame was scraped out with a plywood paddle, about 10 litres of petrol was added and ignited by a torch. When the fire in the frame was well developed, the frame was pulled out of the tray by attached wires. The time elapsing from this point until the entire fire tray was covered by flame was taken as the burn-back time.

The total liquid supply, that is foam concentrate plus clean water, was controlled at 227 litres per minute (50 gallons per minute), equivalent to 2.73 litres/m^2/min. This constant rate is appropriate to the various branches and generators used, and provides a basis for comparison between the various foams. The percentage of concentrate used in the water was that recommended by the maker of each material.

4. INSTRUMENTATION AND OBSERVATION OF TRIALS

A water tender and control van were sited together upwind of the fire site. They functioned as a centre for control and instrumentation of the tests.

Figure 1 is a diagrammatic representation of the hydraulic system. Clean water from the pump passed through a standard in-line inductor and an electromagnetic flowmeter, then through two 75 foot lengths of 1¾ inch hose to the foam branchpipe or generator. The foam compound to be used was poured into an open drum. From this it was lifted by a small electrically-driven gear-pump* and passed through a second electromagnetic flowmeter before reaching the in-line inductor. (The inductor served merely as a convenient piece of plumbing, rather than fulfilling its normal function). The gear-pump was provided with an electrical variable-speed drive control, and both flowmeters were linked to digital displays. By adjusting the main pump throttle and the gear-pump control, the operator could secure flowmeter readings indicating a total liquid flow of 227 litres per minute (50 gallons per minute) containing the specified percentage of foam concentrate. This arrangement ensured that the solution strength and flow supplied to the hose line were accurately known and controlled.

The low and medium expansion-ratio branchpipes used in the tests had no foam concentrate pick-up tubes. The high expansion-ratio generator used had such a tube, but this was blanked to permit operation with a pre-mixed solution as described.

Observations of the progress and timing of each fire were made by three observers equipped with split-second-hand stop-watches. The figures reported are means of these timings. The conduct of each fire test was recorded by 16 mm colour cine-photography. The camera and two operators were placed in the cage of a hydraulic platform, generally at about 9 metres in height, and at a distance of about 36 metres from the nearest part of the fire tray. The direction of view of the camera was approximately broad-side to the wind direction. An electrically controlled clock with large dial, and minute and second hands, was placed near the fire tray conveniently in the field of view of the camera. The clock was started about 30 seconds before ignition, which took place at zero indicated time. The clock provided an accurate means of timing the cine records, and, together with other means, enabled co-ordination of the action of the pump operator, the branch man and his number two, the observers, camera operators, and a safety crew of two fire officers, who stood by with water spray branches in case of mishap.

For each trial, the wind speed was measured by a portable anemometer sited on open ground near the fire tray. The anemometer head was one metre above ground. The approximate wind direction was also noted.

Measurements were made on the trials ground of foam quality in respect of expansion ratio, drainage time, and shear stress. These served as a general check on the quality of the foam concentrates and on the correct functioning of the foam producing equipment. These trials-ground figures were compared with the results of laboratory tests made at FRS on samples of the concentrates.

Foam was collected for the trials-ground tests by directing the branchpipes at a range of 20 feet into the bin described in Reference 4. Samples were taken from this. Expansion ratio was found by weighing a 2440 ml plastic jug of foam. Shear stress was determined by a torsional vane viscometer as described in References 5 and 6. The 25 per cent drainage time was measured using a 6320 ml drainage pan of depth 20 cm as described in Reference 7.

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* Autometric Pumps Limited, Waterside, Maidstone, Kent. Model GP½/125/E

During conduct of the test fires, opportunity was taken to make measurements of the heat flux as a contribution to other work in hand at FRS under Home Office sponsorship (Reference 8). Similarly, after conclusion of the burn-back timings, some preliminary tests in fire conditions were made of an experimental FRS 200 litres/min. foam branchpipe. Both these activities will be reported elsewhere.

5. RESULTS

5.1 Foam Properties

Table 1 shows the measured foam properties to be associated with the fire tests. The properties obtained using branchpipes P and Q on the trials ground are shown compared with laboratory foam tests made at FRS on samples of the foam concentrate used. Where appropriate, the figures in Table 1 represent the means of a number of measurements made.

All the foam concentrates used can be considered of good quality. The low expansion-ratio branchpipe P performed well and gave good foam with all concentrates. The nominal expansion ratio for branchpipe Q is 80-90, but it gave an expansion-ratio of only 27 when operated with the concentrate recommended by the makers at the recommended solution strength. This foam did not therefore fall within the accepted meaning of the term "medium-expansion".

No measurements were made on the properties of the foam produced by the high expansion-ratio generator.

5.2 Fire Tests

Table 2 gives results of 14 fire tests, shown in 6 groups according to foam type. After ignition by the electrically fired cartridge, the fires grew to cover the full tray area within about 5 seconds.
Quick final extinction was often noticeably dependant on the branchman's skill in dealing with small areas of flame persisting at the tray edges. In some tests, development of the burn-back did not extend to 100 per cent of the tray area, owing to exhaustion of the fuel.

More detailed notes follow:

Protein foam, low expansion-ratio, Test 10

30 per cent of the tray area was free of flame after foam application for 2 minutes, 90 per cent after 3 minutes 40 seconds, and 100 per cent after 4 minutes 17 seconds. Reignition for the burn-back test failed to produce a fire of significant size, indicating that the fuel was exhausted. At the estimated burning rate of 4 mm per minute, the petrol supply of 1370 litres (300 gallons) should burn for 4 minutes 5 seconds without foam application. This is consistent with the time from ignition to termination of the fire of 5 minutes 17 seconds, remembering the pre-burn time of one minute allowed. It is clear therefore that the fire terminated as a result of exhaustion of fuel, and that foam application did not produce control or extinction in this test.

As indicated in the discussion below, it should be remembered that the application rate used in these tests was about half that normally recommended for protein foam.

Fluoroprotein foam, low expansion-ratio, Tests 6 and 7

A noticeable feature was the good control shown in the burn-back tests, particularly the slow growth in the early stages of the burn-back. Thus in Test 6, the fire took 3 minutes 46 seconds from removal of the burn-back frame to grow to a circle of about 8 feet diameter, filled 30 per cent of the fire tray area after 4 minutes 46 seconds, reaching 100 per cent fire after 5 minutes 24 seconds. Growth was progressive, no flame propagation occurring along the metal tray edges containing the foam layer in either test.

Fluorochemical foam, low expansion -ratio Tests 1, 2, 3 and 11

Reignition for the burn-back test was noticeably difficult, evidently a consequence of the surface film formed by this type of extinguishant. However, when ignition did occur, flame was observed several times to propagate rapidly along the metal tray edges or to follow a track through the foam raft, to the farther parts of the tray. In the burn-back fires of tests 1, 2 and 3, the fire did not grow to 100 per cent coverage of the tray, being limited by fuel exhaustion at about 60, 70 and 50 per cent respectively.

Fluorochemical spray, Tests 4 and 5

A small amount of visible foam was produced by the spray branch used. The effect could be described as a scum. Reignition for the burn-back test did not present the difficulty noted above with fluorochemical foam. The burn-back reached 80 and 90 per cent in these two tests.

Synthetic foam, expansion -ratio range 20-30

Tests 13 and 14

These two tests were conducted using the low expansion -ratio branchpipe. As indicated in Table 1, the expansion ratio of the foam was found to be about 21. During the burn-back of Test 14, flame was observed to propagate along the edge of the fire tray.

Tests 8 and 9

These two tests were conducted using a nominally "medium expansion-ratio" branchpipe However, the expansion obtained was only 27 (Table 1), and the foam properties were not substantially different from those of Tests 13 and 14.

Synthetic foam, high expansion -ratio, Test 12

The high expansion-ratio foam generator used was adjusted to produce foam at the low end of the available expansion-ratio range, nominally 700. The generator was equipped with about 3 metres of collapsible polythene ducting. The generator, with ducting, was moved towards the upwind corner of the fire tray by four firemen after foam production had started. The foam blanket extended steadily across the fire tray, giving systematic and progressive extinction. During the burn-back test, flame propagation along the tray edges was observed.

5.3 Summary of Fire Test Results

Table 3 summarises the fire test results under 6 headings.

It is considered that the limited number of tests and the spread of experimental results do not justify a distinction between the results for Fluorochemicals C and D, and these are averaged together.

Similarly, the results for synthetic foam using branchpipes P and Q are averaged together under the heading "expansion ratio 20-30".

Figure 2 presents the summarised results in graphical form.

6. DISCUSSION

The discussion is best conducted in terms of the classical critical-application-rate curve (Ref 9). For a particular extinguishing method and type of fire, this curve plots extinction or control time against rate of application per unit area of fire. Extinction and control times increase as the application rate is reduced, eventually rising asymptotically to indicate a critical rate of application below which extinction or control is not obtained.

For the purposes of fire tests, such as the present, where a number of foams are to be compared, a common application rate per unit area must be chosen which lies above the various critical rates for extinction. On the other hand, the application rate per unit area must not be so large as to be unrealistic. The size of the test fire, therefore, must be commensurate with the liquid flow rate of the branchpipes and generators used. The common liquid flow rate chosen of 227 litres per minute (50 gallons per minute) is generally commensurate for test purposes with the petrol fires of 84 square metres (900 square feet) used.

However, a significant result in the present series is the one not shown in Fig 2, namely the failure of protein foam in test 10 to secure control or extinction.

Reference 10 quotes a figure for protein foam for the critical rate for extinction of 1.22 litres/m^2/min of liquid. This is for gentle application to petrol fires of 0.28m^2.

The rate of application used in the present tests was 2.73 litres/m^2/min of liquid. Reference 10 also gives a formula for extinction time which indicates that, at this rate of application, an extinction time of about 8 minutes should apply to test 10 (in the absence of fuel exhaustion), if the data for gentle application to small fires could be extrapolated to the present tests.

However, Reference 11 describes experiments on petrol and kerosene fires of 0.28m^2 which indicate that the critical rate for forceful application by foam jet exceeds the critical rate for gentle application. The effect is most marked for protein foams and for petrol fires. It appears to be related to the entrainment of petrol in the foam, which becomes flammable, and is destroyed by burning.

Reference 12 indicates that there is an additional effect depending on the fire size. A critical rate for liquid of 3.4 litres/m^2/min was obtained when applying protein foam by jet to petrol fires of 1.6m^2. However, an application rate of 4.9 litres/m^2/min applied by branchpipe to a petrol fire of 37m^2 failed to secure control or extinction.

Two further large scale tests may be quoted in which protein foam was applied forcefully to petrol fires. Reference 13 describes a test made on a 9 m. diameter tank. When foam was dropped 4.3m from a pourer to the petrol surface, a liquid application rate of 8.0 litres/m^2/min did not secure control or extinction. Reference 14 describes an experiment at Gravenchon on a 12m diameter tank of petrol when no control was obtained using application by foam cannon at an estimated 5.9 litres/m^2/min of liquid.

The experimental results quoted above were obtained using pre-burn times not exceeding 5 minutes. If pre-burn times of many minutes are involved, the effect of the zone of hot fuel formed is to increase the critical foam rate still further (Reference 10).

There is therefore substantial evidence that protein foam applied forcefully (as by branchpipe) to large petrol pool fires cannot be relied upon to produce control at the liquid rate of 4.9 litres/m^2/min (0.10 gallons/sq.ft./min) recommended by the Manual of Firemanship. The result of test 10 in the present series is consistent with this statement.

The results plotted in Figure 2 may be described as follows:

Fluoroprotein, fluorochemical and synthetic foams all gave convincing control and extinction at the liquid rate of 2.73 litres/m^2/min. The relatively large difference between 90 and 100 per cent extinction times reflect the geometry of the fire tray, and the tendency for small pockets or wisps of flame to persist, sheltered by the vertical metal tray sides, when foam was applied by branchpipe.

The most rapid control and extinction were obtained in the single test using high expansion-ratio synthetic foam: a helpful factor here may have been the effect of the vertical tray sides in containing the foam. Fluorochemical spray and foam were nearly as rapid, followed closely by fluoroprotein foam.

Regarding burn-back performance, fluoroprotein foam was outstanding. The progress of the burn-back fires was slow and progressive, and a good seal was maintained at the metal tray edges. Both fluorochemical and synthetic materials gave quicker and less predictable burn-backs, the fire sometimes propagating along the metal tray edges, or along weaknesses in the floating foam raft.

Of the low expansion-ratio foams, therefore, fluoroprotein combined good extinction and burn-back performance. Fluorochemical material gave slightly quicker control and extinction, but with much poorer burn-back times. A useful feature here may be the ability to apply the material by spray, avoiding the necessity for a foam branch proper. Synthetic foam produced by a conventional low expansion-ratio branch also gave extinction performance greatly superior to protein foam: this would be a useful fact where stocks of this material are kept for use at medium and high expansion. Synthetic foam used at high expansion-ratio gave excellent extinction.

Generally, the results obtained from the present tests on 84 square metre fires with low expansion-ratio foams are consistent with those obtained from small-scale laboratory fires (eg Reference 5). The tests produced no information on the use of synthetic foam at medium expansion-ratio owing to the malfunction of the (nominally) medium expansion-ratio branch.

Table 4 gives an indication of the relative costs of the foam concentrates. Using the recorded times for extinction, the cost of each concentrate used to secure extinction is calculated. In the case of protein foam, an optimistic estimate is used. (See discussion above.) These figures, of course, refer only to the conditions of the trials, ie to petrol fires of 84 square metres and liquid application rates of 2.73 litres/m^2/min, and they must not be used to make global judgements. Nevertheless, in these conditions the cost effectiveness of fluoroprotein foam is much greater than that of protein, bearing in mind the good burn-back properties of fluoroprotein and the uncertain extinction properties of protein foam on large petrol fires. One may also note the high cost of using fluorochemical and the low cost of using high expansion synthetic foam.

7. CONCLUSIONS

Using test fires of 1370 litres (300 gallons) of petrol in a tray of 84 square metres (30 feet square) and a foam solution application rate of 2.73 litres/m^2/min, it was found that:

1. Protein foam did not effect extinction before the fuel was exhausted.

2. Fluoroprotein, fluorochemical and synthetic foam all gave convincing control and extinction.

3. The burn-back fires developed much more slowly and more predictably with fluoroprotein than with fluorochemical and synthetic foams.

4. Synthetic foam used at high expansion-ratio (700) gave very good control and extinction times.

8. RECOMMENDATIONS

1. In view of the poor extinction performance of protein foam on petrol fires, consideration should be given to its replacement by a more effective low expansion-ratio foam in Fire Service practice.

2. Since this series of trials gave no information on the use of medium expansion-ratio foam on petrol fires, this deficiency should be remedied by further tests.

3. Tactical trials of all types of foam should be extended to cover petrol fires with larger pre-burn times, to other fuels than petrol, and to a variety of special situations, including fires involving obstructions or difficulties of access.

9. ACKNOWLEDGEMENTS

Acknowledgements are due to staff of the Fire Research Station for advice and help in the planning and conduct of the tests, to staff of the Fire Service Technical College also for liberal assistance, and to staff of the Royal Armament Research and Development Establishment for undertaking the cinephotographic recording.

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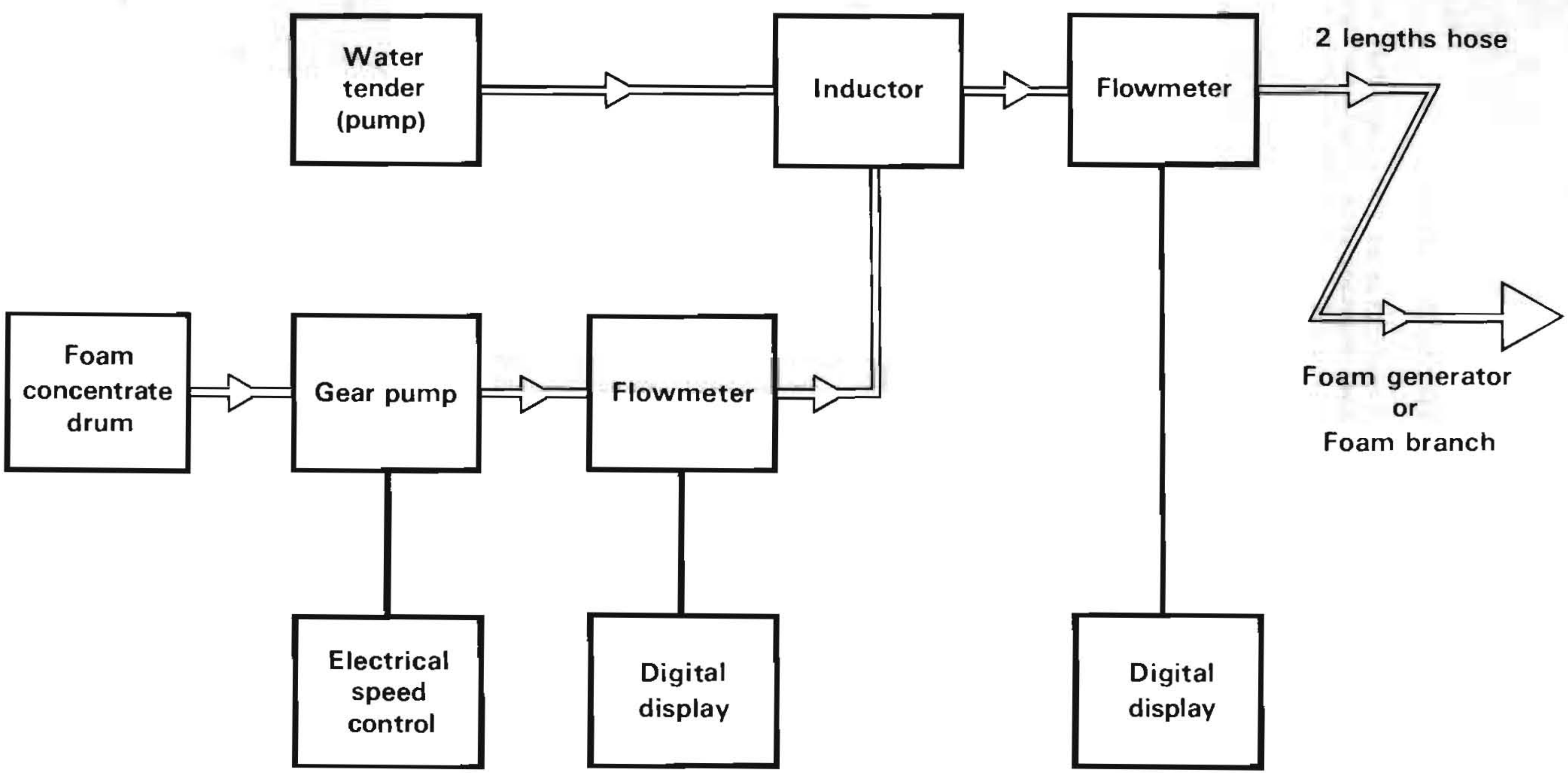
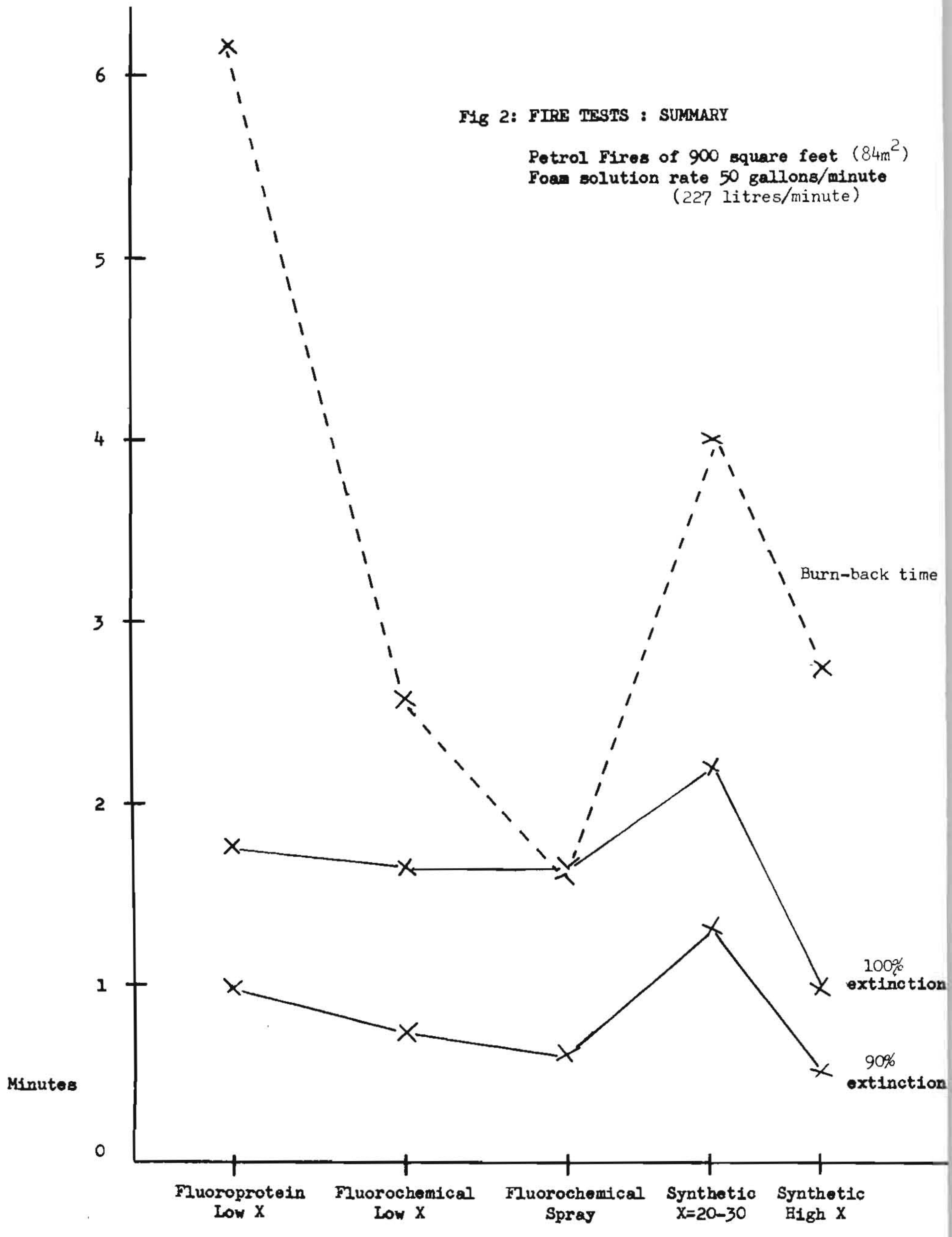


Fig. 1 EXPERIMENTAL ARRANGEMENT OF HYDRAULICS.



(X denotes expansion ratio)

Foam application

Removal of burn-back frame

Fig 3. Photographs of Fire Tests

Foam type	Foam concentrate	Solution strength %	FRS laboratory branchpipe 51./min				Branchpipe P				Branchpipe Q			
			Temp °C	Expansion ratio	Shear Stress N/m²	Drainage time min sec	Temp °C	Expansion ratio	Shear Stress N/m²	Drainage time min sec	Temp °C	Expansion ratio	Shear Stress N/m²	Drainage time min sec
Protein	A	4	20.2	9.3	32.0	8-41	11.8	9.0	12.8	5-55				
Fluoroprotein	B	4	19.3	9.2	29.4	10-03	12.6	10.0	12.2	7-11				
Fluorochemical	C	6	18.5	9.5	5.1	4-35	11.8	12.0	4.4	2-55				
Fluorochemical	D	6	20.2	9.6	5.4	4-40	11.8	12.8	5.0	3-50				
Synthetic	E	3	20.7	9.8	9.0	8-28	11.0	20.5	8.7	11-41	11.8	27.0	6.7	9-46

TABLE 1: FOAM PROPERTIES: TEST MEANS

Foam type	Expansion range	Test No	Foam concentrate	Solution %	Foam branch	Wind Speed mph	Date 1976	Wind Direction degrees	Time	Air temperature °C	90% extinction min sec	100% extinction min sec	Burn-back time min sec
Protein	Low	10	A	4	P	1-2	5/11	Variable	11.00	13.5	No	effective	extinction
Fluoroprotein	Low	6	B	4	P	2	31/10	320	11.25	10.0	0-55	1-36	5-24
"	"	7	B	4	P	1	31/10	320	3.00	10.5	1-03	1-55	6-55
Fluorochemical	Low	11	D	6	P	4-6	6/11	200	11.00	8.2	0-55	1-33	1-45
"	"	1	C	6	P	11-23	28/10	320	3.30	8.0	0-47	2-14	3-15
"	"	2	C	6	P	9-18	29/10	290	11.30	7.5	0-28	1-23	3-01
"	"	3	C	6	P	9-17	29/10	290	3.00	7.5	0-45	1-27	2-15
Fluorochemical	Spray	4	C	6	S	7-12	30/10	290	10.45	6.0	0-31	1-49	1-52
"	"	5	C	6	S	9-18	30/10	310	3.00	4.0	0-39	1-27	1-19
Synthetic	20-30	13	E	3	P	4	7/11	130	11.00	9.8	1-18	2-03	3-27
"	"	14	E	3	P	6	7/11	140	3.00	9.8	1-23	1-57	3-02
"	"	8	E	3	Q	7	1/11	260	11.00	9.5	1-24	2-47	5-28
"	"	9	E	3	Q	6	4/11	350	3.00	8.8	1-11	2-02	3-53
Synthetic	High	12	E	1½	R	6-11	6/11	200	3.30	10.0	0-30	1-00	2-45

0 6-18 25/10 11.30

TABLE 2 : FIRE TEST RESULTS

Foam type	Expansion range	90% extinction min sec	100% extinction min sec	Burn-back time min sec	Number of fire tests averaged
Protein	Low	No effective extinction			1
Fluoroprotein	Low	0-59	1-46	6-10	2
Fluorochemical	Low	0-44	1-39	2-34	4
Fluorochemical	Spray	0-35	1-38	1-36	2
Synthetic	20-30	1-19	2-12	3-58	4
Synthetic	High	0-30	1-00	2-45	1

TABLE 3 : FIRE TESTS : SUMMARY

Foam type	Product reference	Concentrate cost † per gallon	Solution strength %	Extinction time recorded min sec	Cost of concentrate used for extinction
Protein	A	75p	4	8-00 ††	£12 ††
Fluoroprotein	B	£2-00	4	1-46	£7-10
Fluorochemical	C	£4-00	6	1-39 †††	£19-80
Synthetic expansion 20-30	E	£2-00	3	2-12	£6-60
Synthetic high expansion	E	£2-00	1½	1-00	£1-50

TABLE 4 : FOAM COSTS

† approximate cost at time of trial

†† an optimistic estimate : fuel was exhausted before extinction in trial : see Discussion

††† mean figure for spray and foam

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