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A LABORATORY BURN-BACK TEST FOR FIRE FIGHTING FOAMS

by

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SUMMARY

This note describes the development of a laboratory scale burn-back test. The effects of changes in the properties of the foam on its burn-back resistance have been investigated and the results used to produce a standard test method.

This method has been used to compare eight commercially-available foam liquids, and to determine the compatibility of fluorochemical and protein foams with reference to their burn-back resistance.

KEY WORDS: Foam, Burn-back, Compatibility Test

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INTRODUCTION

Accidents involving liquid hydrocarbons, such as aircraft crash fires or bulk storage tank fires, are commonly extinguished by the use of foam. The foam must also be capable of protecting the fuel from re-ignition, or at least must prevent rapid re-propagation of the fire from any ignition source. This ability of the foam to prevent rapid resurgence of the fire is known as its 'burn-back resistance'. There are a number of published methods for measuring burn-back resistance. In the United Kingdom, Defence Standard 42-3[1] measures the burn-back resistance indirectly by noting the drainage rate of foam used to extinguish a 0.28 m^2 (3 ft^2) fire. In the United States, Federal Standards O-F-555C[2] and MIL-F-24385[3], which cover protein and fluorochemical foam respectively, both include a burn-back test. An investigation of burn-back times was also made in the United States by Geyer, G.B.[4] but he found that wind effects rendered his results unreliable. This criticism can be made of all tests too large to be conducted in the laboratory. In addition to the errors introduced by variations in wind speed, large tests are too costly in time and materials to allow sufficient repeats to obtain reliable results. This note describes the development of a laboratory-scale burn-back test which provides a convenient and accurate method for investigating this property of foams. The various parameters governing the burn-back resistance of foams were explored and the results used to produce a standard test method.

MATERIALS

Foam Liquids

Series 1

Protein A_1	— a commercially available protein-based foam conforming to DEF 42-3
Protein A_2	— a commercially available protein-based foam superseding A_1 also conforming to DEF 42-3
Fluoroprotein B_1	— a foam liquid as above but containing a fluorochemical additive
Fluoroprotein C_1	— as above but from a different manufacturer
Fluorochemical D_1	— a synthetic foam liquid based on fluorinated hydrocarbons, designated FC 196
Synthetic E	— a detergent-based foam liquid, commercially available as a high-expansion foaming agent.

Series II

Protein A_3	— A later batch of protein A_2.
Protein F	— a commercially available protein-based foam liquid from another manufacturer conforming to DEF 42-3.
Fluoroprotein B_2	— a later batch of fluoroprotein B_1.
Fluoroprotein C_2	— a later batch of fluoroprotein C1.
Fluorochemical D_2	— a later batch of fluorochemical D_1 designated FC 200.
Synthetic G	— a detergent-based liquid as synthetic E but from a different manufacturer.
Synthetic H	— a synthetic foam liquid of unknown composition from a continental manufacturer.

Fuels

S.B.P - a narrow boiling point petroleum spirit manufactured by Shell-Mex B.P. as a hydrocarbon solvent. It has a boiling range of 62° to 68°C.

AVGAS - an aviation gasoline specified as: Shell 100/130 Avgas F-18 to D.Eng.R.D. 2485. Its flash point is below - 18°C and its distillation range is 10 per cent - 40 per cent at 75°C, minimum 50 per cent at 105°C, minimum 90 per cent at 135°C.

AVTAG - a wide-cut aviation turbine fuel specified as: Shell Avtag F-45 without F.S.I.I. or A.I.A. to D.Eng.R.D. 2486. Its flash point is below - 18°C and its distillation range is minimum 20 per cent at 290°C, 50 per cent at 370°C and 90 per cent at 470°C. It is equivalent to the United States J.P. 4 specification.

AVTUR - an aviation turbine fuel specified as Shell Avtur/50, F-35 without F.S.I.I. Aeroshell turbine fuel 650 to D.Eng. R.D. 2494. It has a minimum flash point of 38°C.

In the second series of tests the hydrogen used as an ignition source was a normal commercial grade.

Experimental Method

The object of this programme of experiments was to develop a reproducible laboratory burn-back test. The size of the fire, method of foam production and means of application were all selected with this objective in view. All fires in this series of tests were carried out in a large laboratory beneath a 3 m (10 ft) diameter extraction hood. The distance of the fire tray below the hood was varied until the hood collected the smoke without affecting the fire. Foam used in the tests was supplied by a laboratory foam generator[1] at a rate of 0.011 l/s (0.15 gal/min). This foam generator can produce foams of widely varying properties and this ability

was used to investigate the effect of such changes on burn-back time.

The $0.15m^2$ tray used in this series of experiments is shown in Fig.1 and Plate 1. It was made of 18 gauge steel sheet and was 60 cm (23.6 in) long, 25 cm (9.8 in) wide and 10 cm (3.9 in) deep. This size was chosen as being small enough to use in a laboratory, and being suited to the foam output of the laboratory generator.

Another factor which limited the size of the tray was the method of extinction chosen. It was desirable to apply the foam to hot fuel. The simplest way to achieve this was to allow the fuel to burn for a predetermined time, and then to smother the fire with an asbestos sheet. This precluded any cooling of the fuel before the foam was applied and ensured that there was no contamination of the tray or fuel.

Following the preburn time the hot fuel was covered with an even layer of foam. This was achieved by applying the foam, produced in the laboratory generator, via a spreading nozzle. This is shown in Fig.1 and Plate 2. The foam was applied for 30 seconds at the standard rate to give a coverage of 2.2 l/m^2 (0.47 gal/ft^2). In the initial tests the foam properties were approximately matched to those of a commercially available 3.8 l/s (50 gal/min) branch pipe. This method was replaced in the final series of tests by the use of a model branch pipe[5]. Properties of the foam under test, as produced by the model branch pipe, were carefully matched in the generator and this foam was used in the burn-back test.

After laying the foam blanket it was necessary to provide a suitable source of re-ignition.

A number of different methods were considered but finally it was decided to use gas supplied from a sparge pipe below the fuel surface (see Fig.1). This method has several advantages: It is difficult for the foam to flow back and extinguish the fire in the initial stages of the test; a certain amount of disturbance, typical of a fire situation, is produced in the fuel by the gas bubbles; the foam is exposed immediately to the destruction caused by the shallow, high temperature convection currents which precede an advancing flame front; finally, this form of ignition is convenient, non-contaminating and highly reproducible. Initially, town gas at 63.5 mm (2.5 in) water gauge was used to supply the sparge pipe but owing to the present changes in gas supplies, this was replaced by hydrogen which was chosen because it is a widely-available reference gas. It was used at a pressure of 76.2 mm (3 in) water gauge.

The time from the ignition of the gas jets to the time when the tray was full of flame was recorded as the burn-back time. This end point was chosen as it was easily observed and provided a realistic measure of the protection afforded by the foam.

Using the above equipment, the various factors affecting burn-back resistance were investigated. The preburn time was varied from 0 to 6 minutes. The effect of

the age of various foams before reignition was measured. The effect of quantity was measured by increasing the application time at the standard rate. The effects of variations in shear, drainage, and the concentration of the foaming solution on burn-back time were also investigated. In addition to the experiments using the standard equipment, a short series of tests were carried out to determine the effect of forceful application of the foam to the fuel. This was achieved by supplying the foam from a 7.1 mm (0.28 in) diameter jet 50 cm (19.7 in) vertically above the fuel surface. At an expansion of eight, this gave a foam velocity of 2.3 m/s (7.5 ft/sec). The results of this form of application were recorded and compared with those for gentle surface application.

Standard Test Method

From the results of these experiments the standard test method was derived as follows:

1. The properties of the foam under test, as produced in the model branch, are accurately matched in the laboratory foam generator.
2. 6 litres of the chosen test fuel with primer if necessary, are poured into the tray and lit with a gas torch.
3. The fire is allowed to burn for three minutes and then it is smothered with an asbestos board.
4. The fire is left covered for one minute while the foam generator is started. The board is then removed and foam is applied, via the spreader, for thirty seconds to give an even foam blanket over the fuel.
5. The hydrogen line is connected to the tray, and one minute after the end of the foam application, the gas is turned on and ignited.
6. The time from the ignition of the gas jets to the point when the tray is full of flame is recorded as the burn-back time.
7. The hydrogen is turned off and the fire is extinguished with the board. The remaining fuel is discarded and the tray is thoroughly washed and cooled before the next test.

This standard test method was used to compare eight commercially available foam liquids and to assess the compatibility of protein or fluoroprotein with fluorochemical. This was achieved by applying 15 seconds of fluorochemical foam followed by 15 seconds of protein or fluoroprotein foam. The burn-back figures obtained were compared with those of the foams tested individually.

RESULTS

The results of these experiments are shown in Tables 1 to 7. Selected data are also shown in Figs 3 to 12. The results are discussed in the next section.

DISCUSSION

Laboratory-scale experiments are attractive in that the conditions under which they are made can be closely controlled. By ensuring that the fuel and tray were

free from contamination, that the foam properties from the generator closely matched those of the model branch pipe and that the tray was protected from draughts, a high degree of reproducibility was achieved. In the series of tests on commercially available foam liquids using the standard test method in its final form, the variation between repeat tests averaged $\pm$ 5.15 per cent of their mean value. By replacing the mild steel tray with one made of stainless steel, it should be possible to improve this figure still further.

PREBURN TIME

The effects of variations in preburn time were measured on four foams; Protein A_1, Fluoroprotein B_1, Fluorochemical D_1 and synthetic E. Two fuels, Avtur and S.B.P. were used. The results of the 79 tests in this group are shown in Table 1 and Figs 3 to 6. Preburn times from 0 to 6 min were investigated using the standard test method. When considering tests in this series in which Avtur was used without preburn, it should be noted that the fuel was not primed and even without foam present, it took over three minutes for the fire to involve the whole tray.

It can be seen from Figs 3 to 6 that, with two exceptions, all foams followed a similar pattern of resistance to hot fuel. An increase of the preburn time from 0 to 3 minutes caused a rapid loss in burn-back resistance, but from 3 minutes onward this effect diminished. Fig 2 provides a possible explanation of this effect. It shows the rise in temperature of the 5 mm (0.2 in) surface layer of Avtur with increasing preburn times. This rise is most rapid in the first 3 minutes which it begins to level out.

The two exceptions to the above pattern are Protein A_1 and Fluorochemical D_1 when used on Avtur. In the first case, the foam produced by the standard improvers was of such poor quality that very little protection was provided after 3 minutes preburn and none at all after 4 minutes.

The second exception, that of Fluorochemical D_1, proved more difficult to explain. As shown in Fig 5, the burn-back resistance fell rapidly as preburn time was increased from 0 to 30 seconds but as it was increased further, the burn-back times improved to equal or exceed the original figures. A maximum was reached at 2 minutes after which the graph falls away as normal.

Initially, as it was known that Fluorochemical D_1 was less effective on high volatility fuels, it was thought that the destructive rise in fuel temperature was being temporarily negated by the loss of a light fraction during the preburn. To test this theory, samples of the fuel were taken after 0, 1 and 3 min preburn. These samples were analysed in a gas chromatograph but no significant differences were found. A series of repeats was then made in the critical range, and close observation was kept on the way in which the foam was destroyed. It was discovered

that, with up to thirty seconds preburn, the fire burnt back steadily destroying the foam just in front of the advancing flames. In tests employing a longer preburn flickers of flame ran ahead of the main fire reducing the foam to a thin layer. This thin foam appeared far more resistant to heat and its formation is the most probable cause for the anomalies in the results.

From these results, it was decided to adopt a 3 minute preburn in the standard test. This figure was chosen as changes in both fuel and foam conditions had become more uniform by this point, thus improving the reproducibility of the test. Another more practical factor considered when adopting this figure was the survival time in the case of aircraft surrounded by flame. It has been shown by Geyer G.B.[4] that the fuselage of an aircraft will fail in only 40 seconds in a severe Avtag (JP4) fire. It is unlikely, therefore, that passengers could survive a greater period than 3 minutes in a large fire.

STANDING TIME

The effect of the age of the foam blanket was the next factor to be investigated. It was thought that this would prove to be one of the main parameters governing the speed of burn-back. Contact with hot fuel causes an increase in the drainage rate of foams and the longer this contact is maintained, the more vulnerable the foam becomes to radiant heat.

The results of these tests are shown in Table 2 and Fig 7. Five foams, Fluoroprotein C_1, Fluoroprotein B_1, Protein A_1, Fluorochemical D_1 and Synthetic E were tested on S.B.P. The burn-back resistance was measured after 1 minute, 10 minutes and 20 minutes.

There was a surprisingly small difference between the protection afforded by foam that is one minute old and that which is twenty minutes old. For example the burn-back time of Fluoroprotein C_1 has been reduced by 6 per cent while in the same period the foam has lost 62 per cent of its liquid content. This indicates that the drainage rate of a foam has only a limited effect on its burn-back resistance.

It can be seen that the fluoroproteins have a considerably superior burn-back resistance to the other three foams but that there is relatively little change in the order of performance with age. Because of this uniformity the figure of one minute of ageing was chosen for the standard test method.

CONCENTRATION

Fig 8 and Table 3 show the results of variations in the concentration of the foaming liquid on the burn-back resistance of the foams. Standard protein foams, such as Protein A_1 are usually applied at 4 per cent concentration. This series of tests was made to discover what effect changes in this figure had on burn-back resistance, and if an optimum concentration could be found. A typical expansion

of 8 to 1 was used and the shear stress and 25 per cent drainage times were kept as constant as the changes in concentration would allow.

It can be seen from Fig 8 that burn-back resistance rises rapidly with concentration until a figure of 6 per cent is reached. From this point there is only a gradual improvement in burn-back time with large increases in concentration. These figures show that an optimum concentration of 6 per cent exists for Protein A_1 on S.B.P., and that any higher concentration would not show sufficient improvement to justify the increased cost of materials and their transport.

SHEAR STRESS AND DRAINAGE TIME

The effect of the shear stress and 25 per cent drainage time of the foam on burn-back resistance are considered together. These two properties are closely related and only small changes in one can be made without affecting the other.

Fig 9 and Table 4 show the results of variations in shear stress and 25 per cent drainage time of Protein A_1 on its burn-back resistance. The importance of good foam qualities in obtaining a high burn-back resistance is clearly illustrated in Fig.9. High shear, high drainage time foams show great advantages over the more fluid faster draining ones in this application. This type of foam would also show advantages when used on large tank fires where, due to the size of the fire, extinction would necessarily be slow and the foam would be subject to a high level of radiant heat. In the case of aircraft crash fires, however, the extinction time must be kept to a minimum. This is best achieved by very fluid foams with inherently low burn-back resistance. These foams used for initial attack should always be reinforced by a second, more substantial foam layer as soon as possible.

QUANTITY OF FOAM APPLIED

The quantity of foam required to extinguish a fire and to protect the fuel from re-ignition is obviously an important factor in deciding on the fire-fighting requirements necessary to protect any particular hazard, Fig 10 and Table 5 show the effect of altering the quantity of foam applied to the standard fire.

Initially there is a rapid improvement in burn-back resistance with increasing weight of foam, but beyond 5 l/m^2 (0.11 gal/ft^2) this improvement is greatly reduced. There is no justification, therefore, in building up deep layers of foam when the agent may be better employed elsewhere.

JET APPLICATION

It has been shown by Hird, D., Rodriguez A and Smith, D[6] and Tucker, D., Griffiths, D., and Corrie, J[7] that the fire-fighting effectiveness of foams is greatly reduced by forceful application. Tests 157 to 174 were carried out

using this method of application to determine its effect on burn-back resistance. Table 6 shows the results of these tests and Fig 11 compares them with those obtained using gentle surface application.

Fig 11 shows that both Protein A_1 and Fluorochemical D_1 gave a superior performance when used as a jet on Avtur. On Avtag and S.B.P. there was little difference between the two methods and on Avgas the results were significantly worse when the foam was applied as a jet. The jet of foam, apart from any cooling action of its own, stirs up quantities of cool fuel from below the layer heated by the fire. In the case of Avtur these combined cooling effects may be sufficient to lower the temperature of the fuel below its ignition point. In the case of the higher volatility fuels, however, this effect is negated by the large quantities of flammable liquid entrained in the foam.

COMPARISON OF EIGHT COMMERCIALLY AVAILABLE FOAM LIQUIDS

To demonstrate the scope of the standard test method, two practical examples of its use were chosen. The first was a comparison of eight commercially available foam liquids as used on the three common aviation fuels; Avtur, Avgas and Avtag. The foam properties were carefully matched to those of the model branch pipe in each case, and the standard test method was followed in every respect.

Fig 12 and Table 7 show the results of this series of tests. Foams based on proteins proved to be superior to all synthetic foams except Fluorochemical D_2, the best overall results being shown by Fluoroprotein C_2. As can be seen from Fig 12, protein-based foams had a generally better performance on Avtur than on the two higher volatility fuels. The opposite was true of synthetic foams, again with the exception of Fluorochemical D_2. This suggests that while synthetic foams have some degree of resistance to penetration by fuel vapour they do not share the protein-based foam's resistance to fuels of high surface temperature such as Avtur.

COMPATIBILITY

The second example of the use of this test involved the compatibility of Fluorochemical D_2 and Protein A_3 or Fluoroprotein C_2. A 15 second application of Fluorochemical was followed by an equal application of either Protein or Fluoroprotein. This represents a fire, initially attacked with fluorochemical foam and then covered with protein or Fluoroprotein foam, either to complete extinction or to provide protection against re-ignition.

The results of these tests are shown in Table 8, and the burn-back times for the individual foams are shown for comparison. It can be seen that in all cases there was a loss of burn-back protection as a result of mixing the foams. This loss of protection is apparently due to greatly increased drainage rates which have been found to occur in this situation[8].

CONCLUSIONS

1. In over two hundred tests, a laboratory-scale burn-back test has been developed which serves as an excellent reference method for comparing this property of foam liquids. Because it is possible to exercise close control over all the relevant factors affecting this size of test, it has been possible to achieve a high degree of reproducibility. This is an important advantage when foams of very similar performance are being considered. The test should also prove sensitive enough to detect any deterioration in performance of a foam liquid before it becomes potentially dangerous. This test should prove an ideal tool for investigating these properties of current foams and assessing the suitability of new ones.

2. It is shown in Figs 8 and 10 that an optimum concentration and depth of foam exists for Protein A_1 on S.B.P. Further tests should be carried out for different foam-fuel combinations. The results gained from this work could provide a useful guide to the improvement of post-extinction protection.

3. Fig 9 underlines the need for the foam produced to be of sufficient stability to meet the requirements of long-term protection. Where a large fire is being fought with limited foam supplies and control can only be gained gradually, the ultimate extinction of the fire will depend to a great extent upon the heat resistance of the foam. A compromise between fluid foams which give rapid control and more stable foams which give greater heat resistance must be made, having regard to the type of fire being fought.

4. The laboratory burn-back test has revealed significant differences between different foam liquids and successive batches of the same foam liquid. It has been shown that changes in shear stress, drainage rate, weight of foam, age of foam, type of fuel and its temperature, all affect burn-back resistance. To obtain more complete data, large-scale tests should be made to establish the relevance of these differences in practical situations and to determine any improvements achieved by employing the optimum figures suggested by these tests.

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Table 1
The effect of pre-burn time on burn-back resistance

Test No	Foam Compound	Fuel	Pre-burn time (min) (sec)	Burn-back time (min) (sec)	Remarks
1	Protein A	S.B.P.	0	7 - 26	Ambient 18°C
2	"	"	1 - 00	5 - 25	
3	"	"	1 - 00	4 - 54	
4	"	"	2 - 00	3 - 23	V.Large flash at ignition whole tray involved. This is
5	"	"	2 - 00	4 - 22	a characteristic of all tests on SBP over 1 min P.B. with Protein
6	"	"	4 - 00	2 - 31	
7	"	"	4 - 00	4 - 04	
8	"	"	4 - 00	3 - 42	
9	"	"	6 - 00	1 - 41	
10	"	"	6 - 00	2 - 32	
11	"	Avtur	0	8 - 12	NB.Avtur at 17°C takes
12	"	"	0	8 - 41	3 min 20 sec to reach full flame without foam. After 1 min P.B.repropagation is instantaneous.
13	"	"	1 - 00	2 - 05	100 ml SBP used to ignite fuel, at
14	"	"	1 - 00	2 - 18	start of preburn.
15	"	"	2 - 00	1 - 05	Foam boiled on contact
16	"	"	2 - 00	1 - 00	- do -
17	"	"	4 - 00	< 5 sec	Fuel on surface at 120°C after preburn
	Fluoro-protein				
18	C	S.B.P.	0	10 - 00	
19	"	"	0	10 - 44	
20	"	"	1	10 - 12	)
21	"	"	1	10 - 31	)
22	"	"	2	10 - 06	)Small initial
23	"	"	2	10 - 18	)flashovers lasting
24	"	"	4	8 - 14	)only 1-3 sec
25	"	"	4	8 - 24	)
26	"	"	6	7 - 42	)
27	"	"	6	8 - 04	)

Table 1 continued

Test No	Compound	Fuel	Pre-burn time (min) (sec)	Burn-back time (min) (sec)	Remarks
	Fluoro-protein				
28	C_1	Avtur	0	19 - 16	Gas jets extinguished briefly at start of test
29	"	"	0	20 - 06	
30	"	"	1	12 - 31	
31	"	"	1	12 - 49	
32	"	"	2	11 - 47	
33	"	"	2	10 - 02	
34	"	"	4	7 - 10	
35	"	"	4	8 - 56	
36	"	"	6	6 - 28	Fuel boiling before
37	"	"	6	5 - 10	foam application
38	Synthetic	S.B.P.	0	7 - 24	
39	E	"	0	7 - 22	
40	"	"	1	3 - 35	Large flashover at 2 min 50 sec destroyed half of foam blanket
41	"	"	1	3 - 11	
42	"	"	2	3 - 09	
43	"	"	2	2 - 27	
44	"	"	4	2 - 16	
45	"	"	4	2 - 20	
46	"	"	6	2 - 03	
47	"	"	6	2 - 10	
48	"	Avtur	0	8 - 46	
49	"	"	0	7 - 00	
50	"	"	1	3 - 43	
51	"	"	1	3 - 58	
52	"	"	2	3 - 07	
53	"	"	2	3 - 01	
54	"	"	4	1 - 11	)Virtually no protection
55	"	"	4	1 - 38	)as flickers over
56	"	"	6	0 - 20	)whole surface
57	"	"	6	5 sec	)immediately
58	Fluoro-	S.B.P.	0	7 - 24	
59	chemical	"	0	7 - 18	
60	D_1	"	1	6 - 30	
61	"	"	1	6 - 19	
62	"	"	2	3 - 42	

Table 1 continued

Test No	Foam Compound	Fuel	Pre-burn time (min (sec)	Burn-back time (min) (sec)	Remarks
63	Fluoro-	S.B.P.	2	3 - 48	
64	chemical	"	4	2 - 58	
65	D_1	"	4	3 - 06	
66	"	"	6	2 - 52	Preburn fire difficult to extinguish and tray was cooled slightly
67	"	"	6	2 - 50	Temporary burn-back at 2 min 36 sec
68	"	Avtur	0	12 - 55	Gas jet extinguished once at start
69	"	"	0	13 - 38	
70	"	"	0 - 30	9 - 55	
71	"	"	1	9 - 21	
72	"	"	1	10 - 21	
73	"	"	1	9 - 39	
74	"	"	2	13 - 41	)Many short lived
75	"	"	2	13 - 56	)flickers across
76	"	"	2	13 - 54	)foam during burn-back
77	"	"	4	9 - 24	)
78	"	"	4	9 - 48	)
79	"	"	6	7 - 14	)
80	"	"	6	7 - 2	)

Table 2

The effect of Foam Age on burn-back resistance

Fuel: SBP Preburn time 1 min

Test No.	Foam Compound	Standing time min sec	Burn-back time min sec	Remarks
81	Protein A_1	1	7 - 05	
82	"	1	8 - 40	P.B.fire difficult to extinguish Fuel cooled
83	"	1	7 - 12	
84	"	1	7 - 21	
85	"	10	5 - 15	
86	"	10	4 - 48	
87	"	10	4 - 54	
88	"	20	3 - 00	
89	"	20	2 - 41	
	Fluoroprotein C_1			
90	"	1	11 - 48	
91	"	1	10 - 17	
92	"	1	9 - 51	
93	"	1	10 - 00	
94	"	1	9 - 58	
95	"	10	9 - 05	
96	"	10	9 - 25	
97	"	20	8 - 59	
98	"	20	8 - 49	
	Fluoroprotein			
99	B_1	1	14 - 12	Possible fluorochemical contamination
100	"	1	14 - 53	
101	"	1	15 - 19	
102	"	1	15 - 09	
103	"	1	15 - 12	
104	"	10	14 - 21	
105	"	10	14 - 02	
106	"	20	13 - 50	
107	"	20	14 - 02	
108	"	20	14 - 18	
109	"	20	12 - 42	Possible contamination
110	Synthetic E	1	8 - 06	
111	"	1	7 - 52	
112	"	1	7 - 20	
113	"	1	7 - 29	
114	"	1	7 - 02	
115	"	10	5 - 24	
116	"	10	5 - 46	
117	"	20	3 - 51	
118	"	20	3 - 06	
119	Fluorochemical	1	6 - 45	
120	D_1	1	6 - 47	
121	"	1	6 - 47	
122	"	10	4 - 48	
123	"	10	4 - 39	
124	"	20	2 - 59	
125	"	20	2 - 48	

Table 3
The effect of concentration of compound on burn back

Foam: Protein A_2 Fuel: SBP

Test No	Concentration %	Burn back time (min)	(sec)	Remarks
126	2	5	01	)
127	2	4	37	)
128	4	6	42	)
129	4	8	15	)
130	6	9	56	) Expansion 8
131	6	10	19	) Shear stress 10.8 to 14.1 N/m^2
132	8	10	25	) $\frac{1}{4}$ drainage time 1 min 52 sec
133	8	10	28	) to 3 min 14 sec
134	10	10	51	)
135	10	9	55	)
136	15	11	41	)
137	15	11	5	)

Table 4
Effect of shear stress and drainage time on burn back time
Protein: A_2 4% concentration Expansion 8

Test No	25% drainage time (min)	(sec)	Shear stress N/m^2	Burn back time (min)	(sec)	Remarks
138	1	03	7.7	3	49	)Total flash-over at
139	1	10	7.7	4	33	)ignition lasting 3-4 sec
140	2	02	11.5	4	45	
141	2	17	11.5	5	01	
142	2	12	13.5	9	51	
143	3	08	16.0	12	56	
144	3	06	16.0	12	59	
145	4	58	19.2	15	58	
146	7	36	27.0	19	22	
147	11	40	31.4	20	38	

Table 5

The effect of the quantity of foam applied to the burn back time

Protein: A_2 Expansion 8 shear stress 12.8 N/m^2

25% Drainage time 2 min

Applied at 0.011 l/s (0.15 gal/min)

Fuel: SBP Preburn 3 min

Test No	Time of application (min)	(sec)	Quantity applied (ℓ)	(gal)	Burn back time (min)	(sec)
148	0	20	0.2	.05	3	48
149	0	20	0.2	.05	3	35
150	0	30	0.3	.075	7	01
151	0	30	0.3	.075	7	26
152	0	40	0.45	0.1	9	36
153	0	40	0.45	0.1	9	58
154	1	00	0.68	0.15	11	25
155	1	00	0.68	0.15	11	38
156	2	00	1.36	0.3	13	39
157	2	00	1.36	0.3	13	31

Table 6

Results of 14 mm (0.56 in) jet application of Fluorochemical D_1 and Protein A_1. 3 minutes preburn

Test No	Foam liquid	Fuel	Burn back time (min)	(sec)	Remarks
157	Protein A_1	Avtur	6	05	
158	"	"	6	17	
159	"	"	5	40	
160	"	Avtag	4	01	
161	"	"	3	41	
162	"	Avgas	1	24	Initial flash-over
163	"	"	1	23	
164	"	SBP	1	42	Initial flash-over
165	"	"	1	39	
166	Fluorochemical D_1	Avtur	14	07	
167	"	"	14	01	
168	"	"	13	56	
169	"	Avtag	9	24	
170	"	"	9	26	
171	"	Avgas	3	41	
172	"	"	3	45	
173	"	SBP	3	00	
174	"	"	3	04	

Table 7

Comparison of eight commercially available foam liquids on the standard burn-back test

(Foam properties matched to model branchpipe)

Test No.	Foam	Fuel	Burn-back time min	sec	Remarks
175	Synthetic G	Avtur	2	19	
176	" "	"	2	11	
177	" "	Avtag	1	56	
178	" "	"	1	48	
179	" "	Avgas	3	15	
180	" "	"	3	38	
181	Synthetic E	Avtur	2	42	
182	" "	"	2	27	
183	" "	Avtag	2	15	
184	" "	"	2	20	
185	" "	Avgas	4	17	
186	" "	"	5	00	
187	Fluorochemical D_2	Avtur	15	00	)Difficult to
188	" "	"	14	30	)light $1\frac{1}{2}$ min to
189	" "	"	17	44	)establish flame
190	" "	Avtag	14	00	)do., 30 sec to
191	" "	"	15	10	)light
192	" "	Avgas	11	22	
193	" "	"	11	22	
194	Synthetic H	Avtur	0	49	
195	" "	"	0	50	
196	" "	Avtag	0	35	
197	" "	"	0	40	
198	" "	Avgas	1	28	
199	" "	"	1	03	
200	Fluoroprotein B_2	Avtur	22	33	
201	" "	"	21	39	
202	" "	Avtag	21	15	
203	" "	"	21	45	
204	" "	Avgas	14	30	
205	" "	"	13	52	
206	Fluoroprotein C_2	Avtur	31	15	
207	" "	"	29	44	
208	" "	Avtag	25	16	
209	" "	"	24	45	
210	" "	Avgas	13	39	
211	" "	"	14	27	
212	Protein F	Avtur	8	57	
213	" "	"	9	47	
214	" "	Avtag	7	38	
215	" "	"	8	40	
216	" "	Avgas	9	05	
217	" "	"	8	08	
218	Protein A_3	Avtur	25	28	
219	" "	"	26	35	
220	" "	Avtag	15	08	
221	" "	"	13	47	
222	" "	"	22	25	
223	" "	Avgas	19	48	
224	" "	"	19	44	

Table 8

The effect of the incompatibility of Fluorochemical D_2 with Protein A_3 or Fluoroprotein C_2 on burn-back resistance

Foam applied for 15 seconds each. Results for single foams are shown for comparison.

Test No	Fuel	Foam	Burn-back time (min)	(sec)
	Avgas	Fluorochemical D_2	11	30
	Avgas	Fluoroprotein C_2	14	00
225	Avgas	Fluorochemical D_2 + Fluoroprotein C_2	9	58
226	"	" "	9	52
	Avtur	Fluorochemical D_2	15	00
	Avtur	Fluoroprotein C_2	30	00
227	Avtur	Fluorochemical D_2 + Fluoroprotein C_2	12	02
228	"	" "	13	12
	Avgas	Protein A_3	19	45
229	Avgas	Fluorochemical D_2 + Protein A_3	9	06
230	"	" "	9	37
	Avtur	Protein A_3	26	00
231	Avtur	Fluorochemical D_2 + Protein A_3	12	03
232	"	" "	11	58
233	S.B.P	" "	6	45
234	"	" "	8	17

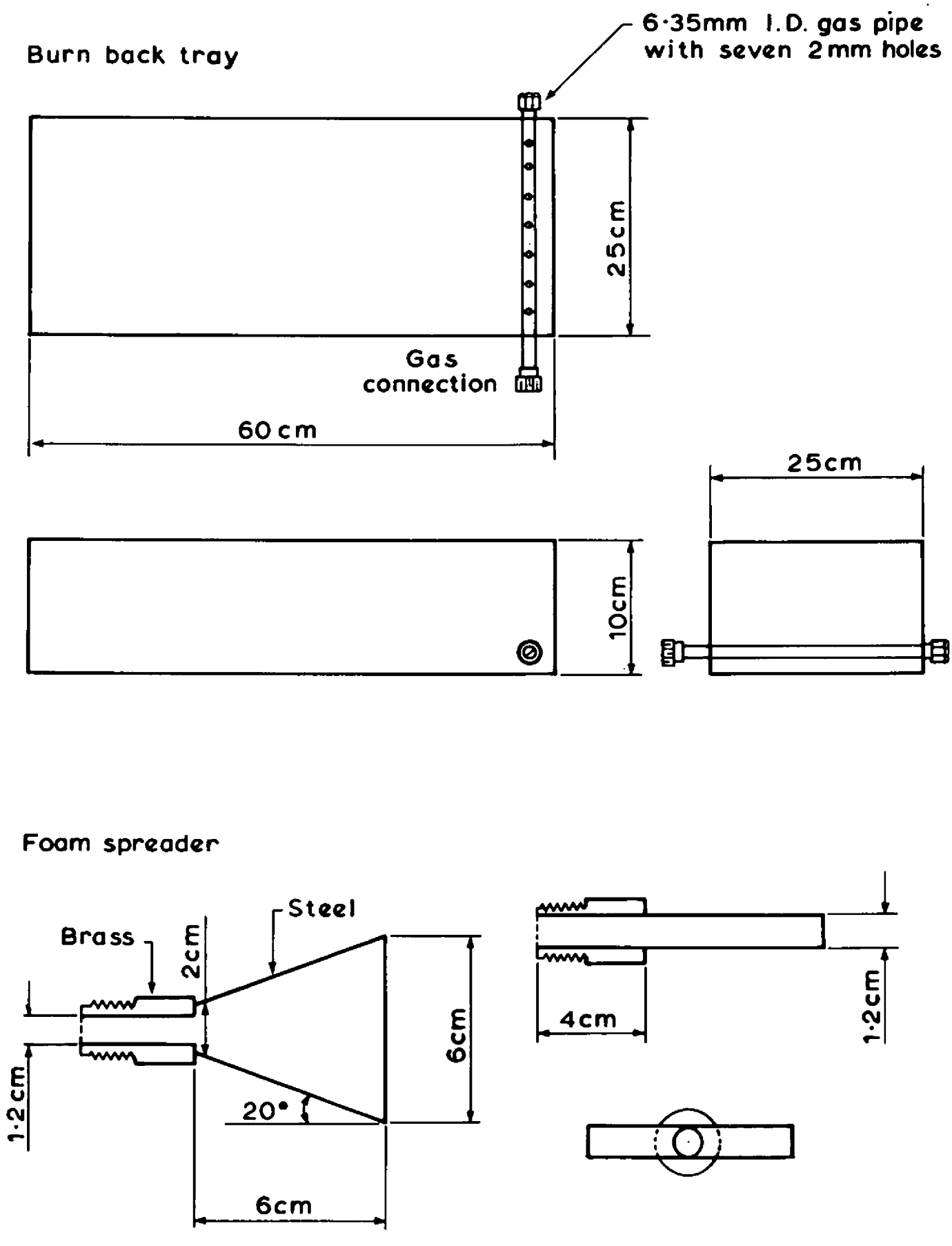

Figure 1 Equipment used

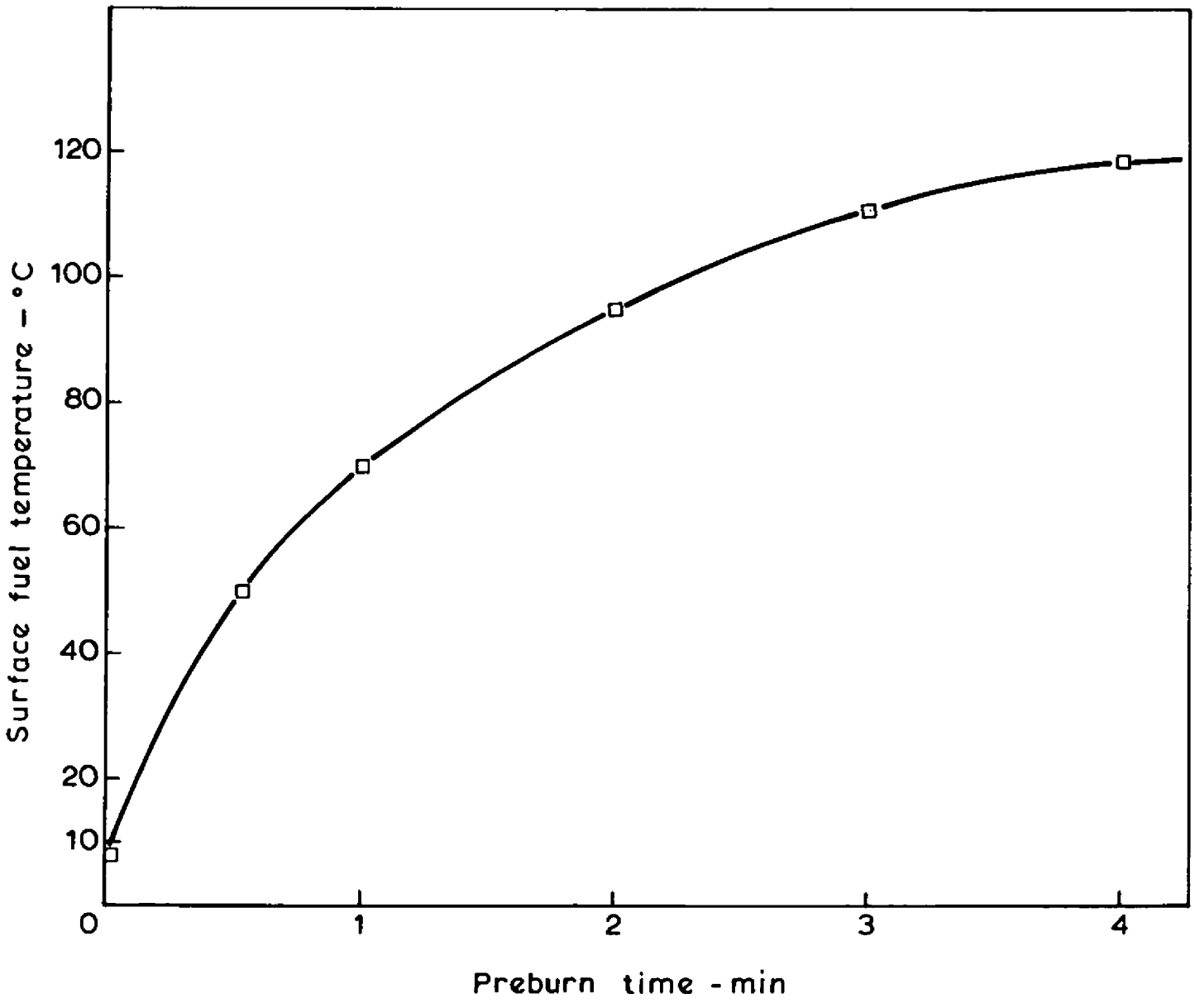

Figure 2 The effect of increased preburn time on the surface temperature of Avtur

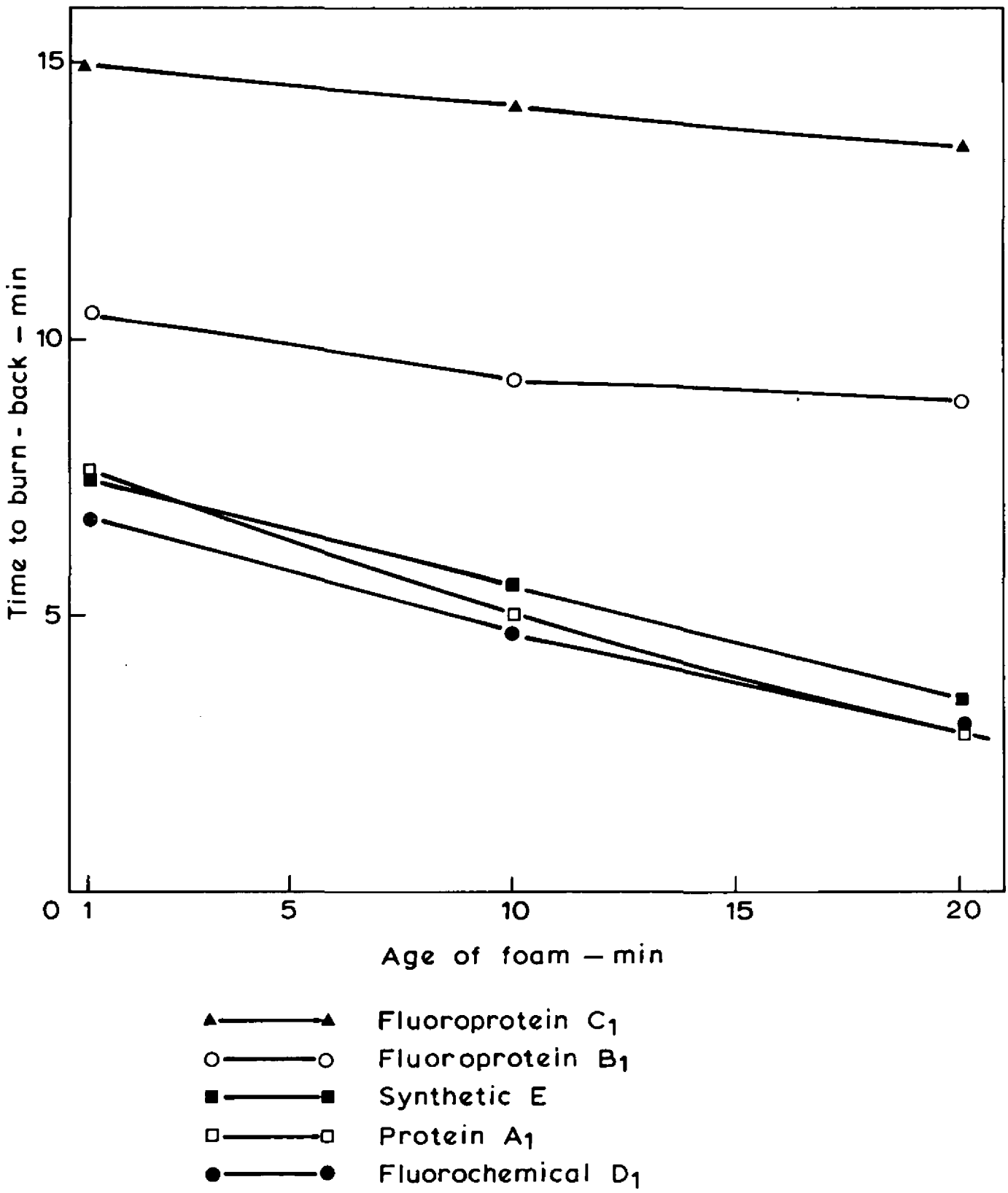

Figure 3 The effect of foam age on burn-back resistance

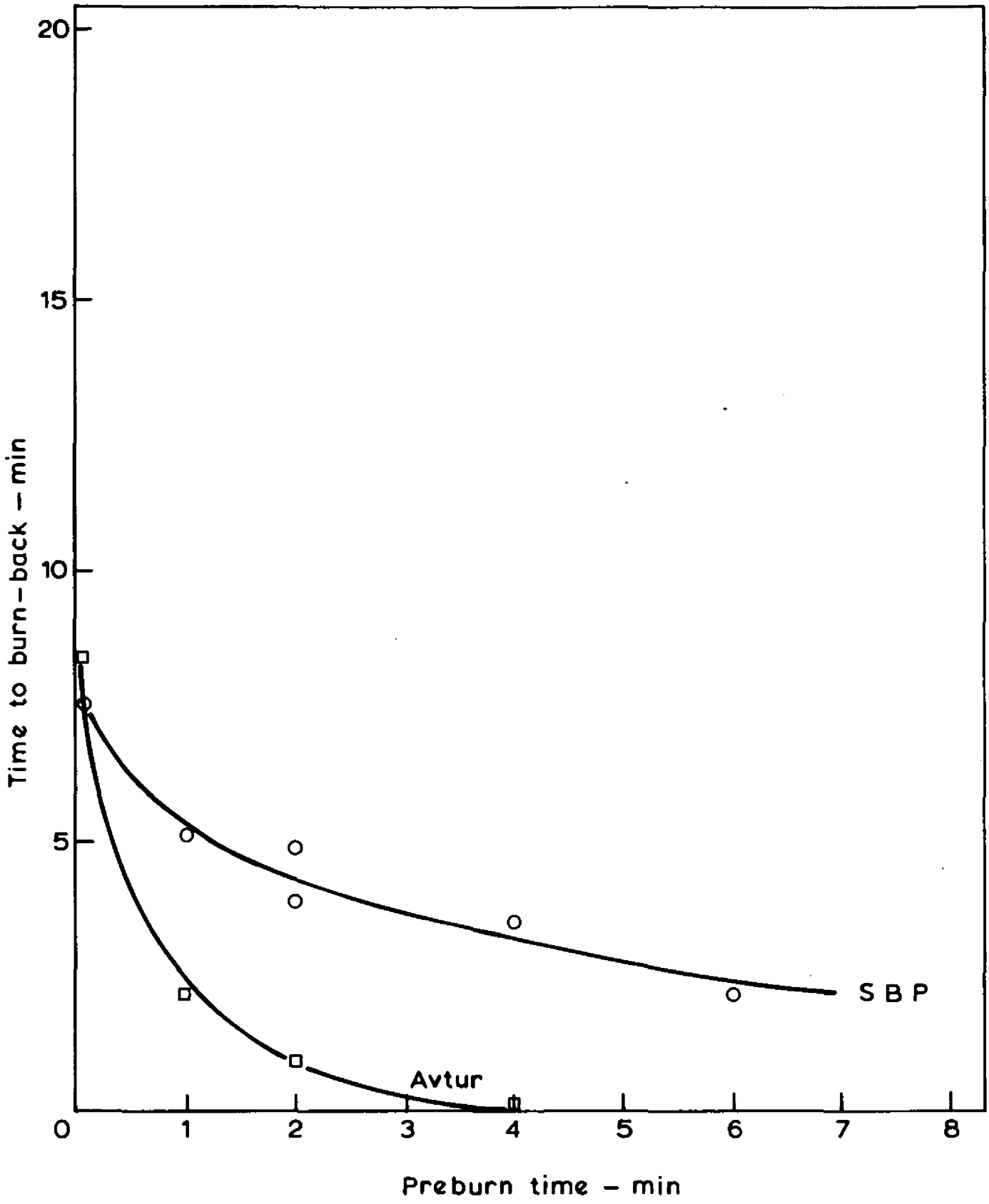

Figure 4 The effect of changes in preburn time on burn-back resistance: Protein A_1 on Avtur and S B P

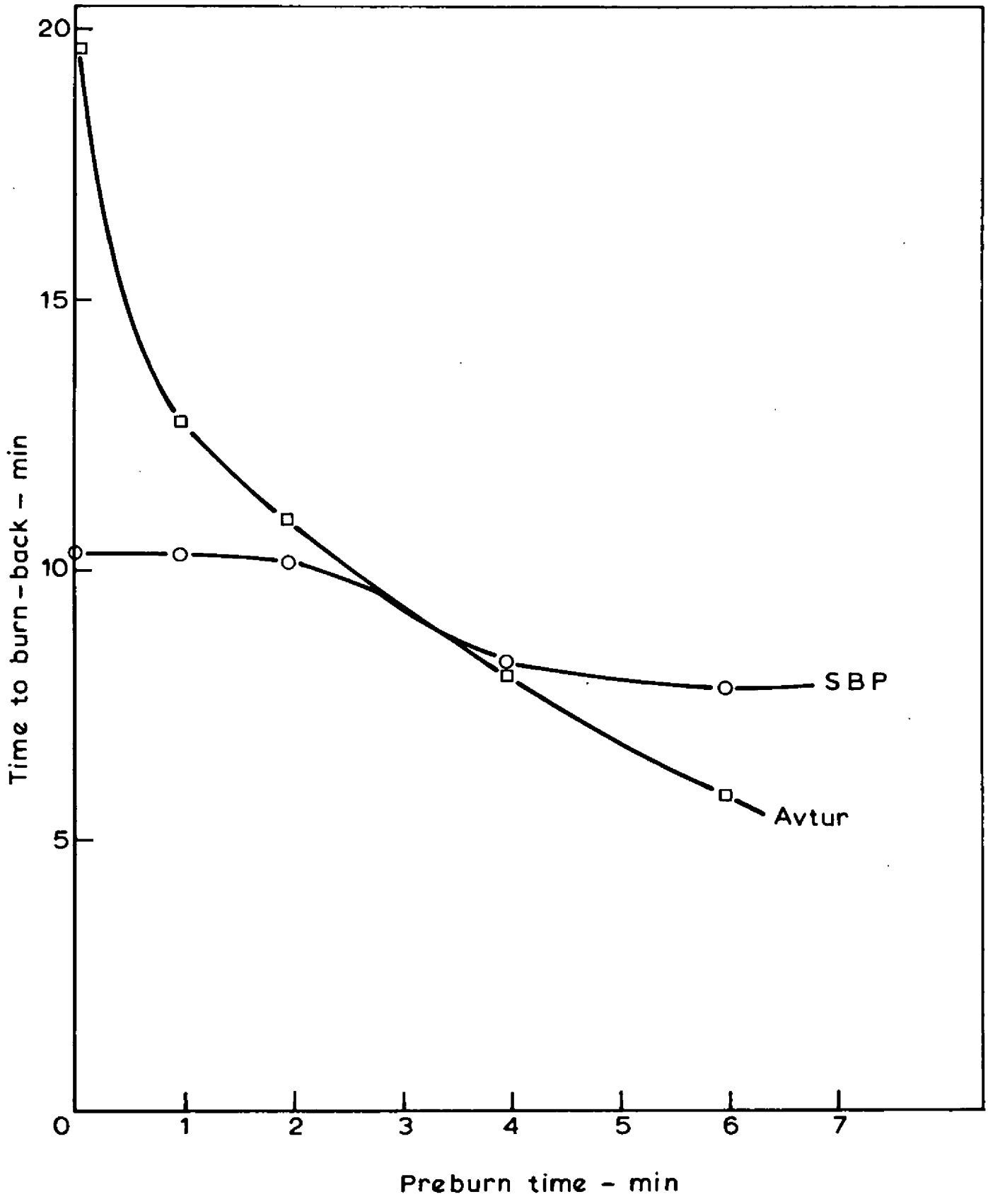

Figure 5 The effect of changes in preburn time on burn-back resistance: Fluoroprotein C_1 on Avtur and S B P

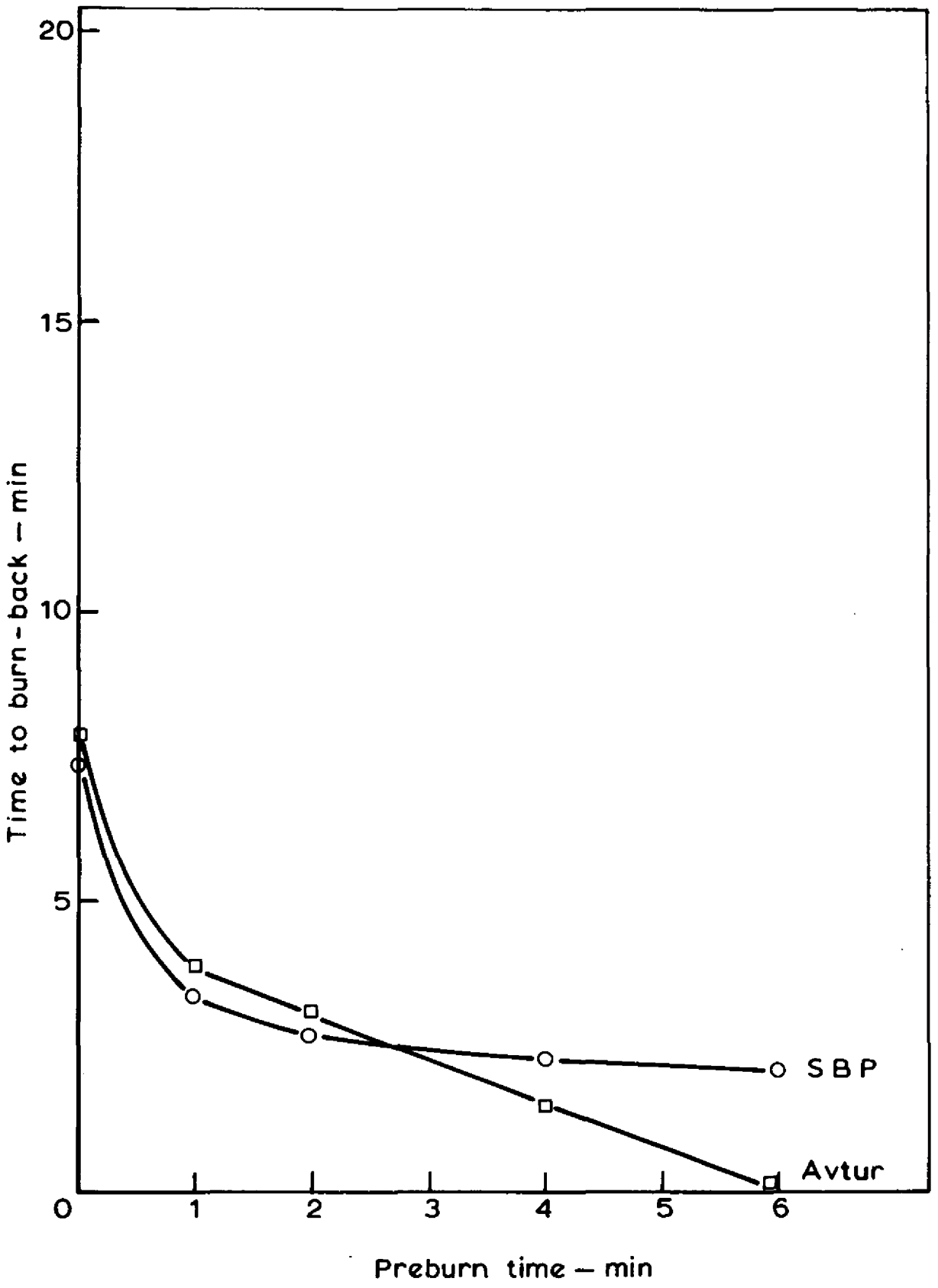

Figure 6 The effect of changes in preburn time on burn-back resistance: Synthetic E on Avtur and SBP

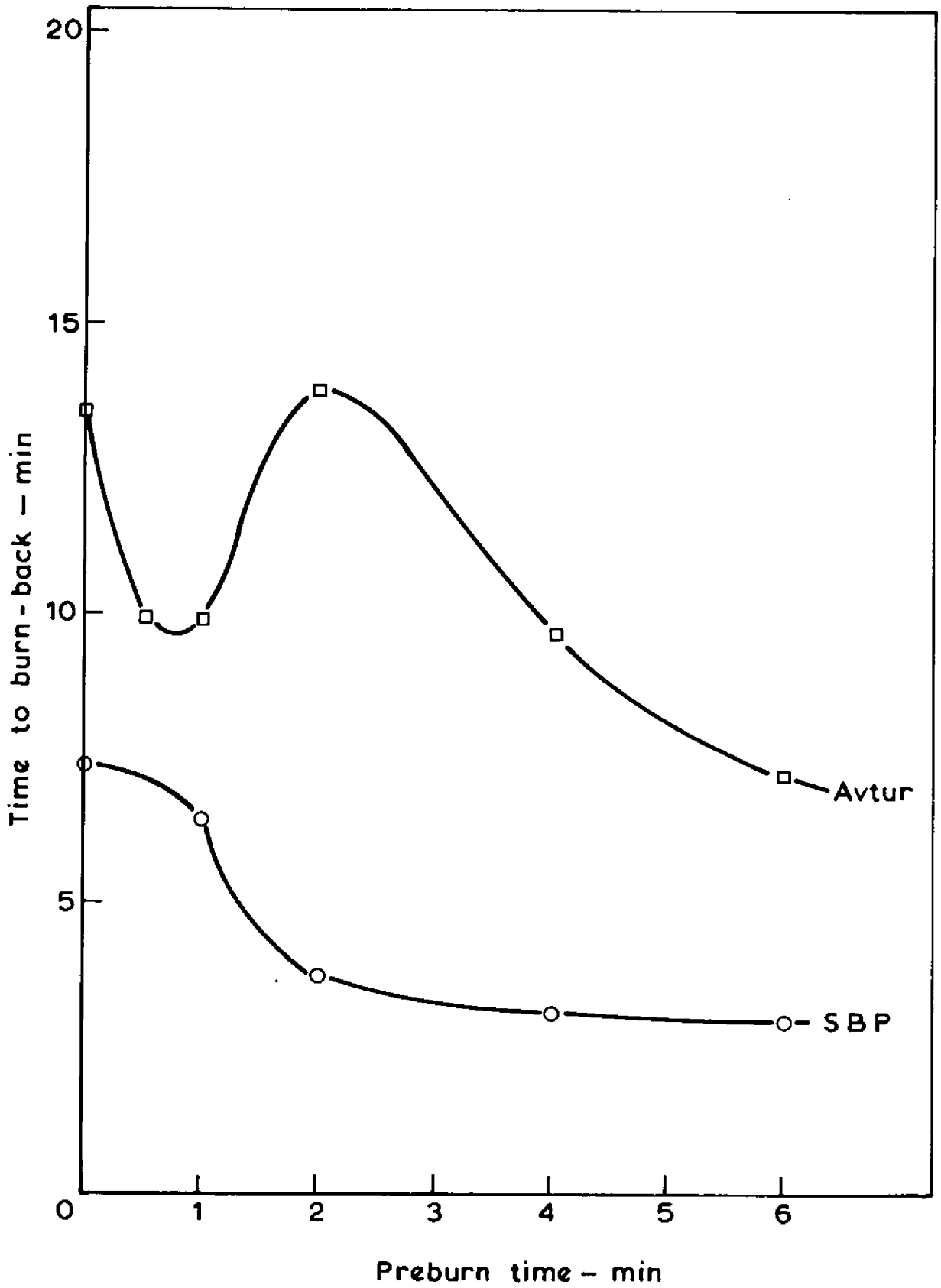

Figure 7 The effect of changes in preburn time on burn-back resistance: Fluorochemical D_1 on Avtur and SBP

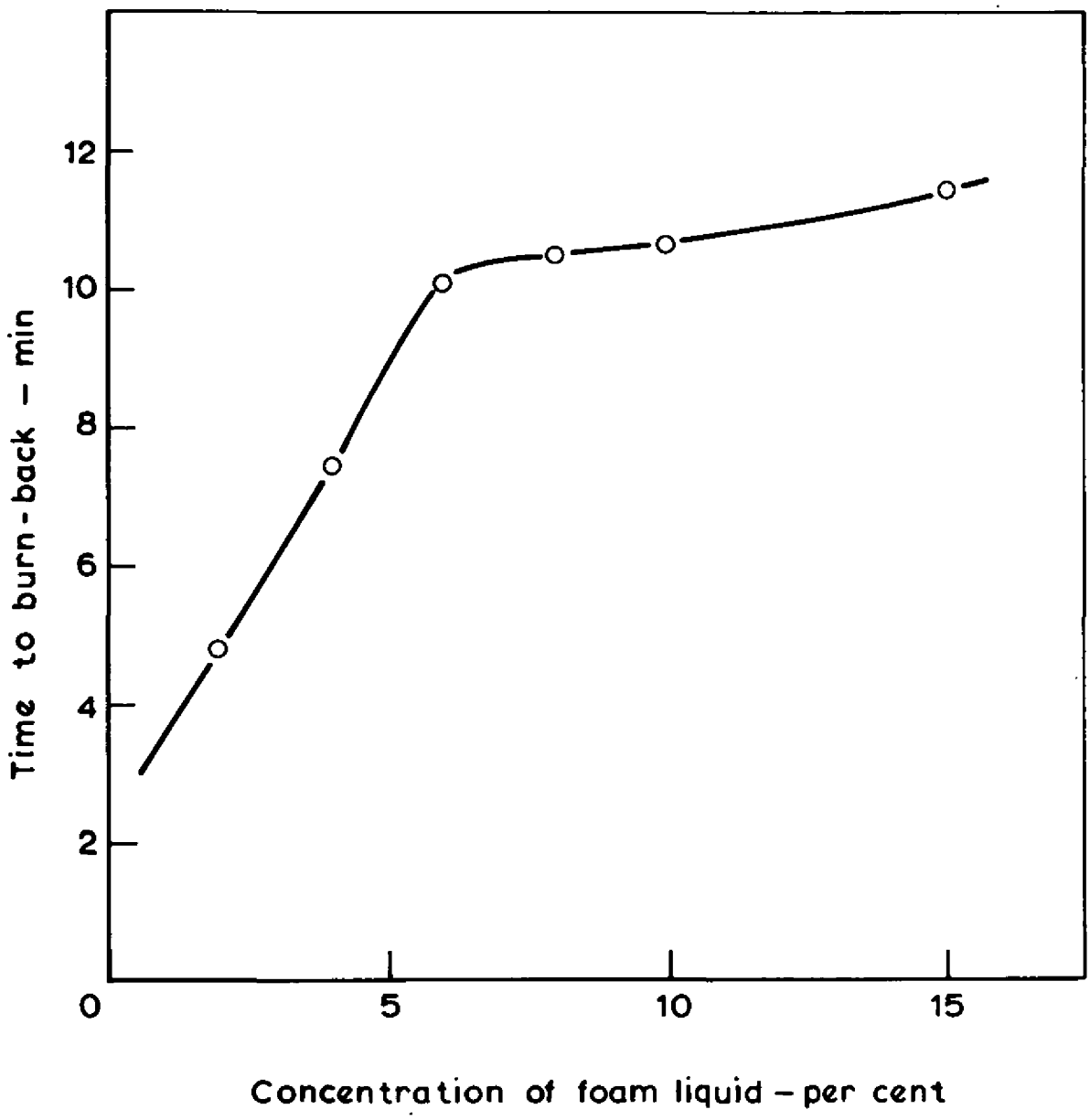

Figure 8 The effect of changes in concentration on burn-back resistance: Protein A_2 on S B P

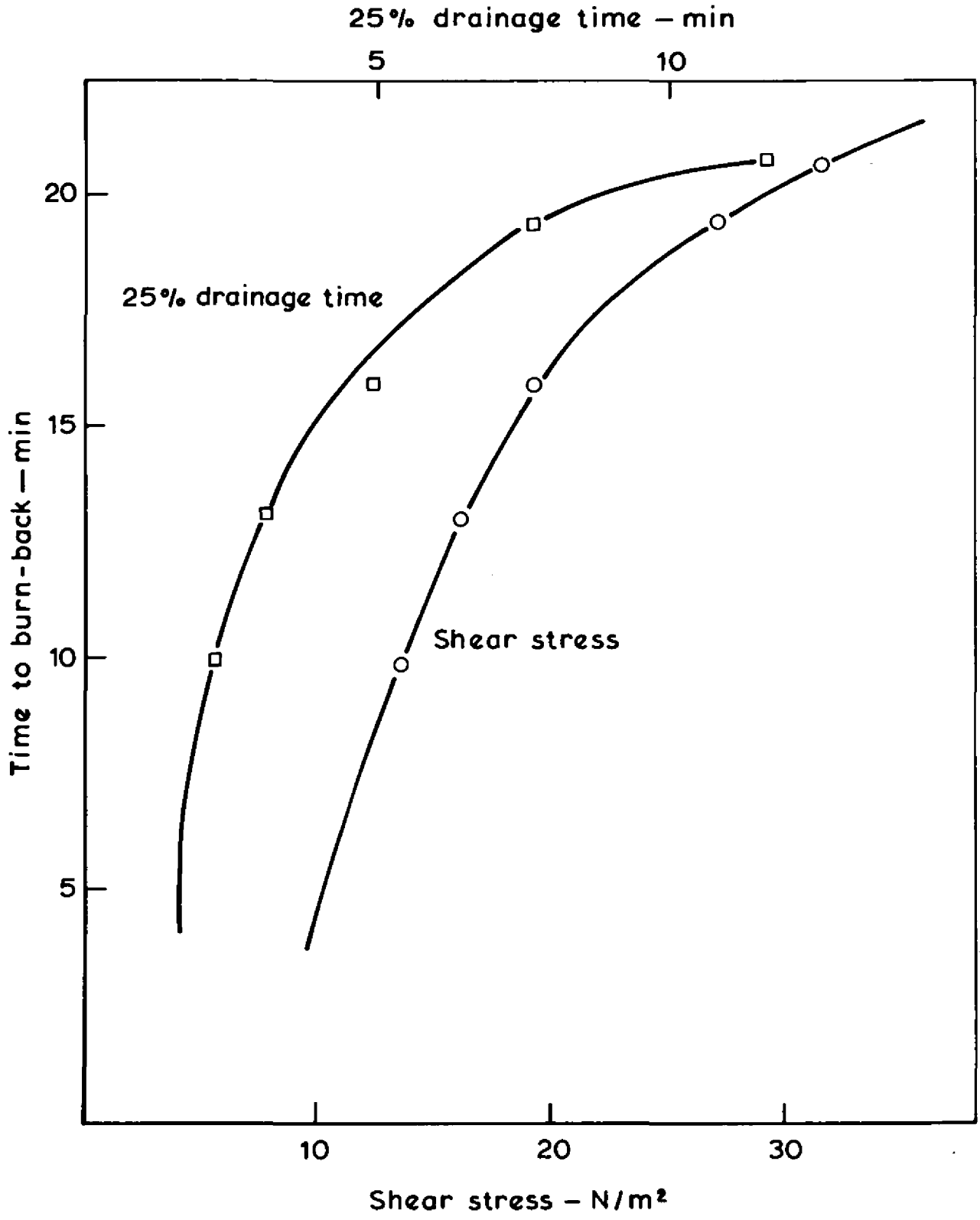

Figure 9 The effect of changes in shear stress and 25% drainage times on burn-back resistance: Protein A_2 on SBP

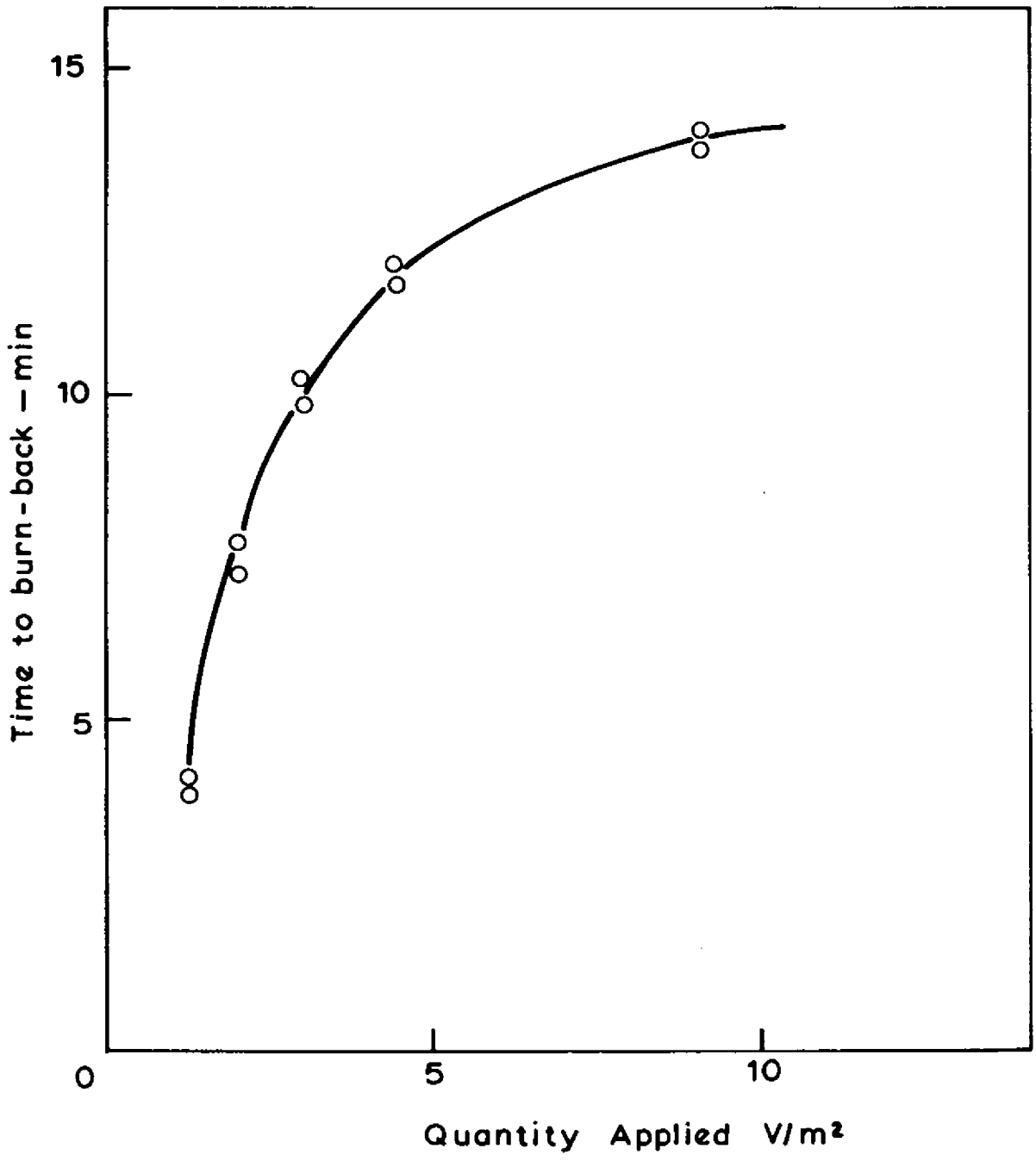

Figure 10 The effect of changes in the quantity of foam liquid applied on burn-back resistance: Protein A_2 on S B P

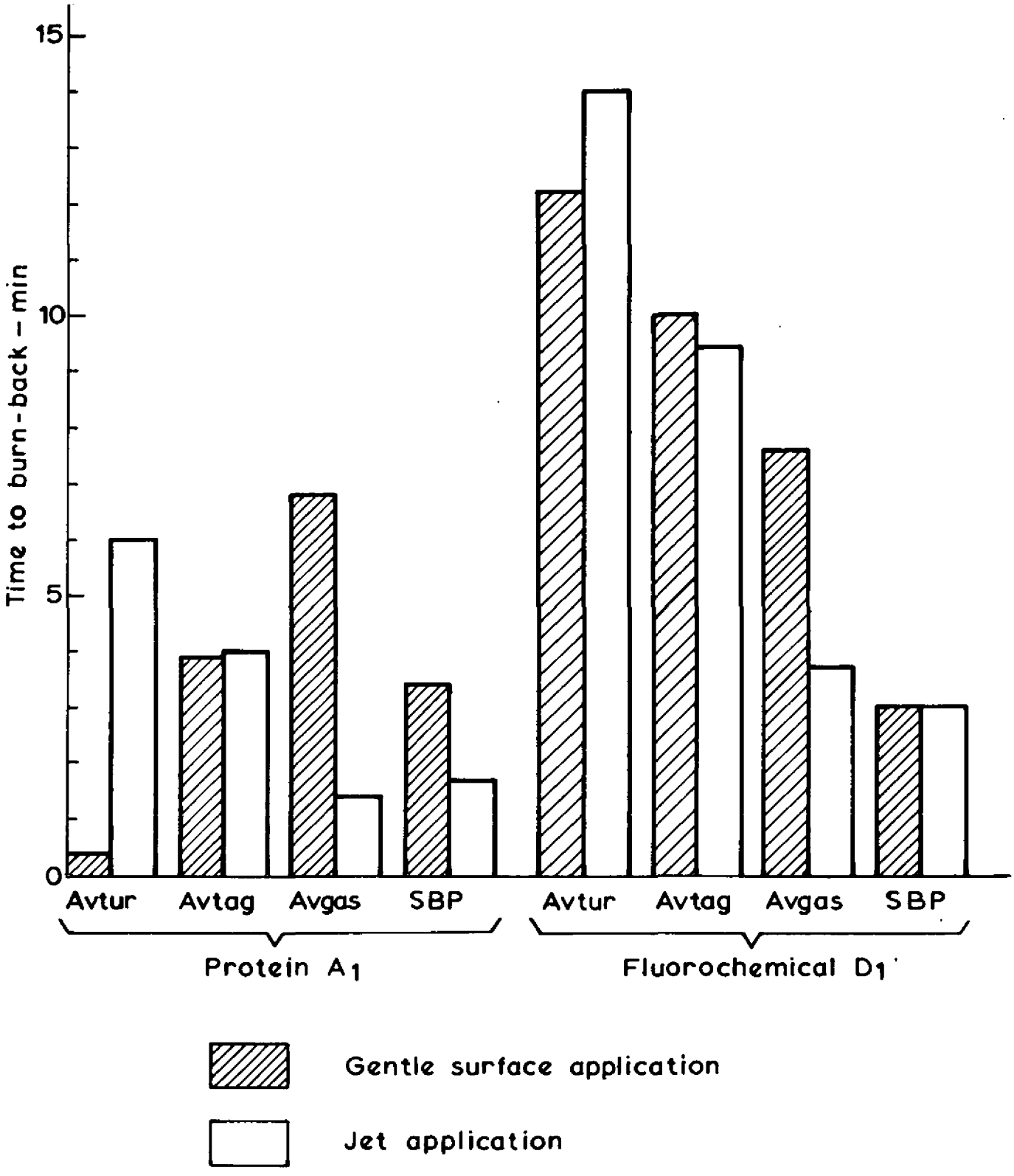

Figure 11 A comparison of jet application and gentle surface application of foam against burn-back time

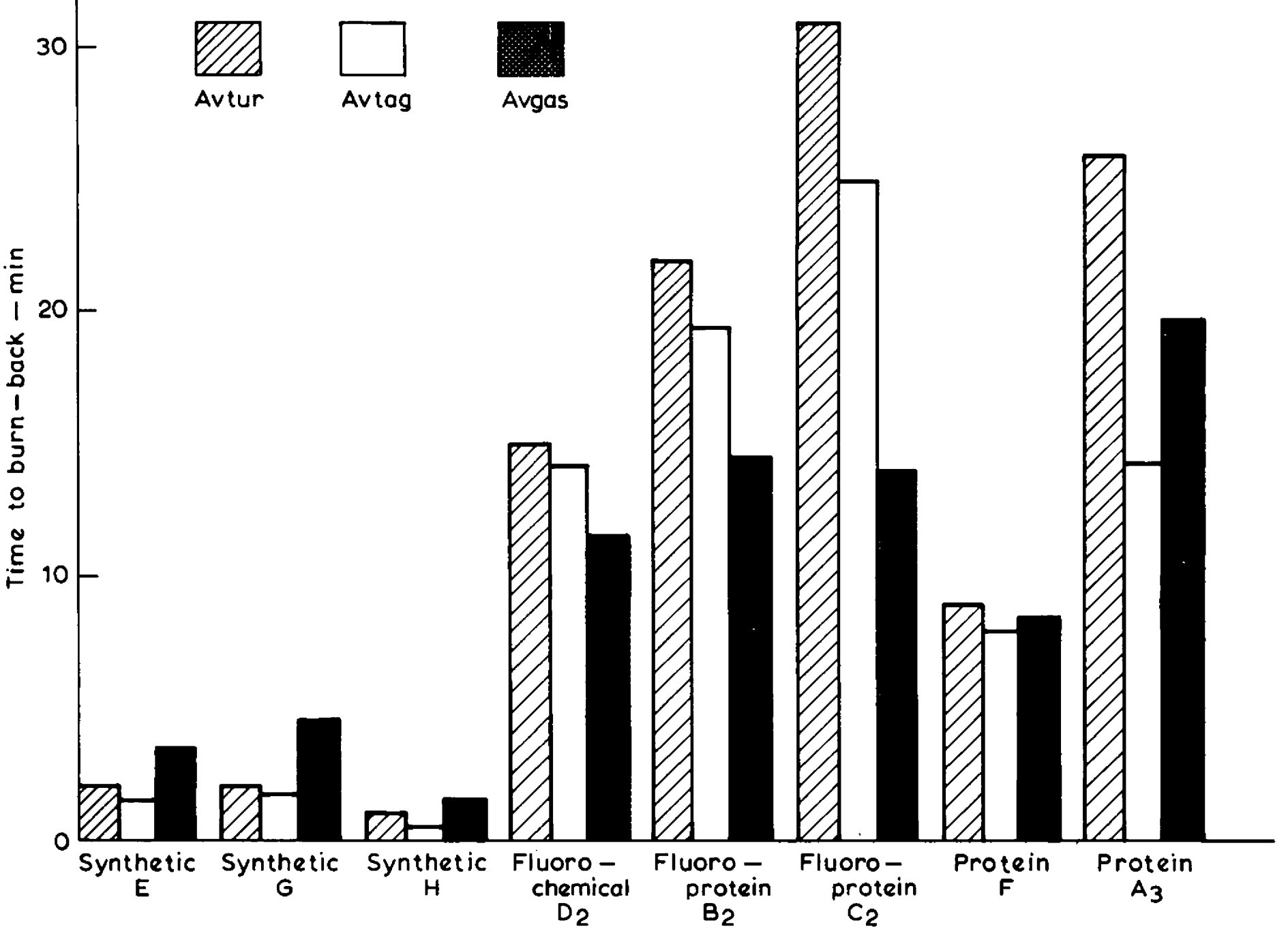

Figure 12 A comparison of eight commercially available foam liquids on three aviation fuels

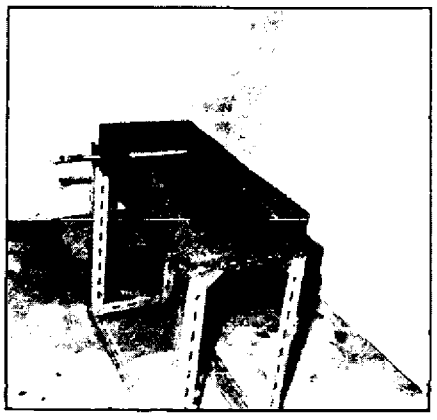

Plate 1

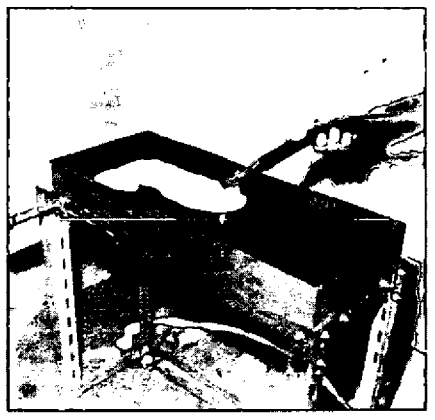

Plate 2

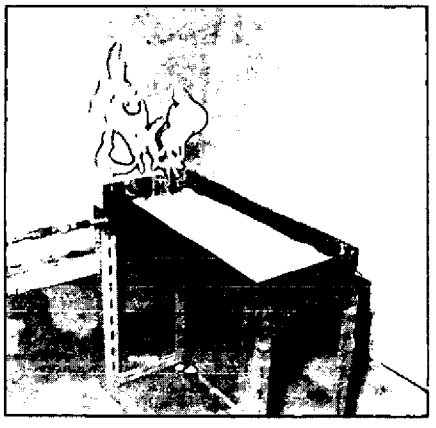

Plate 3

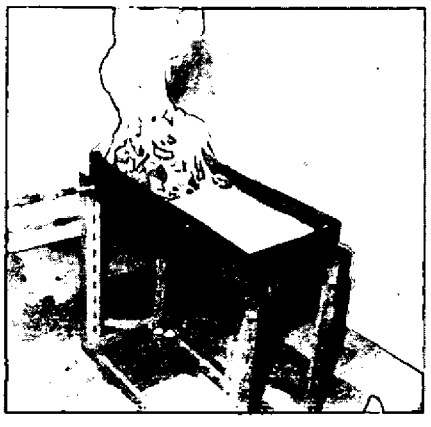

Plate 4

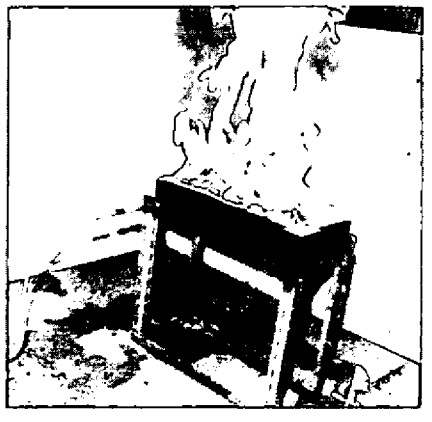

Plate 5

PLATES 1 to 5 VARIOUS STAGES OF
THE BURN-BACK TEST