Fire Research Note
No.615

FOAM FOR AIRCRAFT CRASH FIRES (3)
(TERMINAL REPORT - LABORATORY FILE NO. 12/1)

by

P. NASH, D. W. FITTES and D. D. RICHARDSON

FIRE
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SUMMARY

This report describes experiments on some large scale simulated aircraft fires, to determine the influence of the rate of application of foaming solution, and the physical properties of the made foam, on the time and quantity of foaming solution required to control fire.

It concludes that rate of application has a significant effect on the time to control the fire, and the quantity of foaming solution used. Of the physical properties, expansion does not appear to have a significant effect. Critical shear stress appears to have an optimum value of 400-500 dynes/cm^2 at which the fire is controlled most quickly, and the effect of this optimum appears to be more pronounced at the lower rates of application of foaming solution. While the effect of drainage was not measured directly, it is clearly advantageous to obtain the lowest drainage characteristic, consistent with the optimum shear stress.

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MINISTRY OF TECHNOLOGY AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

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Introduction

In major aircraft fires, speed and efficiency in fire control are paramount, if danger to life and property is to be minimised. Recent full scale experiments in America[1] show that under the worst conditions, occupants of an aircraft surrounded by a large area of burning fuel can only survive for a few minutes. Speed in reaching the fire is vitally important, and as all major fire-fighting facilities have to be brought to the fire, it is essential to make the utmost use of them in order to gain control of the fire as rapidly as possible.

This note describes a research programme into the optimum use of protein-based foams against simulated aircraft crash fires. The programme, which was carried out by the Joint Fire Research Organization at the Ministry of Aviation Fire Training School, Stansted, Essex, was one in which the Ministry of Aviation, Ministry of Public Building & Works, and Ministry of Defence co-operated. It was divided into two parts, in the first of which foam of various physical properties was applied to a "standard" simulated aircraft crash fire, at three rates of application of foaming solution. In the second part, a more detailed study was made, at the lowest rate of application of foaming solution, in order to determine more closely the effect of the physical properties of the foam, viz. expansion and critical shear stress, or stiffness. The first part of the programme was completed in the Summer of 1964 and the second part in the Spring of 1965.

A gas turbine operated foam generator, described in F.R. Note No. 583[2] and capable of producing large quantities of foam having various controlled physical characteristics, was developed for use in this programme of experiments. Two previous preliminary experimental programmes[3,4] have shown the importance of rate of application in the rapid extinction of simulated aircraft crash fires. Their results have not, however, given a positive guide to the relative importance of the physical properties of the foam.

Experimental method

The foam used in the experiments was made from a 6 per cent pre-mixed solution of a proprietary foam liquid. The physical characteristics of the foams used lay generally within the following ranges:

Solution rate of application	50 to 200 gal/min.
Expansion	6 to 20
Critical shear stress	150 to 1,250 dyn/cm^2

A diagram of the experimental area is shown in Figure 1, and a typical experimental fire is shown in Plate I. The fires were made in a bunded area 35 ft by 25 ft which contained a mock aircraft fuselage consisting of a 20 ft long by 5 ft diameter steel tube with four 40 gallon steel drums to represent mainplanes and engine nacelles. The surface of the concrete bund was covered by approximately one inch depth of water, onto the surface of which about 250 gallons of aviation kerosene (AVTUR) was poured for each experiment.

This was ignited, and the fire was allowed to burn for about 60 sec. before the application of foam commenced. Foam was projected (Figure 1) onto the fire from a position facing one of the four corners of the bund, the corner chosen depending on the wind direction. Most of the experiments were made in winds having a velocity of less than 15 ft/sec. The radiant intensity of the fire was measured by four radiometers placed symmetrically around the fire, and the time to reduce the radiant intensity to one-tenth of its initial value i.e. ("9/10 control") was measured.

An experienced fireman operated the monitor in the experiments, and before the commencement of the experimental programme, five preliminary tests were made to give the operator experience with the experimental fire.

Experimental results

The results of the tests are shown in Tables 1, 2 and 3 for rates of application of foaming solution of 50, 125 and 200 gal/min. respectively. The tables show the physical characteristics of the foams used and the 9/10 control time of each fire. These times were estimated by an observer and, in most cases, were also calculated from the radiation record taken during the test.

In the analysis of the results, the 8/10 and 6/10 control times were also calculated and plotted against the various foam properties. There was some variation in the recorded maximum intensity of the fires due to changes in ambient conditions, such as wind direction, temperature, relative humidity etc. The 9/10, 8/10 and 6/10 control times were therefore "normalised" relative to the average initial radiant intensity of the experimental fires. Examination of these values gave no further information additional to that given by the analysis of the "un-normalised" 9/10 control times, and the final analysis is therefore based on recorded 9/10 control times or, where no radiation record is available, on the observed 9/10 control time.

Discussion

The 9/10 control time is shown plotted against foam expansion in Figure 2 for experiments at a rate of application of 50 gal/min. All the results at this rate are plotted irrespective of the critical shear stress of the foams. No clear relation between expansion and control of the fire is shown in Figure 2. In order to avoid any masking of a possible effect by the use of the wide range of critical shear stress of the foams, the results of experiments with foams within a limited critical shear stress range (400 to 620 dyn/cm^2) were plotted in Figure 3. This figure confirms that there is no apparent correlation between the control of the fire and foam expansion.

9/10 control times are shown plotted against critical shear stress of the foam for the three rates of application in Figure 4a (200 gal/min 4b (125 gal/min) and 4c (50 gal/min).

Figure 4a suggests that the 9/10 control time diminishes slowly with shear stress, down to a minimum value at about 500 dyn/cm^2. At lower values still, the control time again increases, but rather more rapidly than on the other side of the minimum. At the intermediate rate of application of 125 gal/min (Figure 4b), 9/10 control time diminishes slowly with shear stress, down to a minimum value at about 300 dyn/cm^2, and may increase again at lower values, although there were insufficient experimental points to confirm this.

At the lowest rate of 50 gal/min (Figure 4c), there is a more rapid diminution of 9/10 control time with shear stress than at the other two rates, the value reaching a minimum at about 400 dyn/cm^2. At lower shear stresses, the 9/10 control time increases rapidly and in the experiments it was observed that foams of about 300 dyn/cm^2 and below broke down rapidly and gave little protection from re-ignition of the fire. Two curves showing the relation of 9/10 control and shear stress for surface application[5] are also shown for comparison in Figure 4c for two foam liquids A and B. It will be noted how similar they are to the third curve for monitor application to the simulated aircraft fire.

Critical shear stress is extremely important in surface application where the foam has to flow from a fixed point, or points, to cover the surface of the flammable liquid. When foam is applied by monitor or hand-held branchpipe as is usual in aircraft fires, "placing" of the foam is possible and the influence of critical shear stress is likely to be less marked than for surface application. The curves of Figure 4a, b and c, confirm this hypothesis, the rate of increase of 9/10 control time with shear stress being much less marked than for the surface application curves (foam A and foam B) of Figure 4c. Figure 4c shows that an increase in the critical shear stress value from the apparent optimum of 400 dyn/cm^2 to, say, 600 dyn/cm^2 would not seriously effect the control of an aircraft fire, for monitor application. A reduction in critical shear stress to, say 200 dyn/cm^2 however, is likely to cause a serious increase (approaching 100 per cent) in the time to control the fire.

The effect of critical shear stress can be further shown by a consideration of the relationship between rate of application and the 9/10 control time of the fire given in Figure 5. Curves are shown for foams within three ranges of critical shear stress, i.e. fluid foams of less than 275 dyn/cm^2, foams of intermediate critical shear stress 400 to 750 dyn/cm^2, and stiff foams of over 825 dyn/cm^2. At the higher rates of application of 125 and 200 gal/min, control times are short, and the effects of critical shear stress variation are not substantial. As the rate of application is reduced towards 50 gal/min., however, the control times increase rapidly for all the foams, but the control times for the foams of intermediate shear stress are the least of the three ranges, at rates below about 50 gal/min.

The quantity of foam solution to control the fire, derived from Figure 5, is shown in Figure 6 for the various rates of application at the three levels of critical shear stress. The smallest quantity of solution for fire control in the experiments was about 66 gal (or 0.08 gal/ft^2) when foam of the intermediate shear stress was used. The smallest quantities of solution, with foams of lower ($<$ 275 dyn/cm^2) and higher ($>$ 825 dyn/cm^2) critical shear stress, are about 88 gal and 91 gal (i.e. about 0.10 gal/ft^2) respectively. The trend of the curves suggests, however, (Figures 5 and 6), that even less solution might be used to control the fire if foam of the intermediate shear stress were applied at a rate less than 0.06 gal ft^{-2}min^{-1}.

It was observed during the experiments that little foam adhered to the hot "fuselage", even those foams having a high critical shear stress sliding off readily. A possible reason for this is that the foam in immediate contact with the hot metal formed a gas layer over which the rest of the foam could slide easily from the fuselage. In the later stages of the experiments when the metal was cooler, some of the stiffer foam did adhere to the "fuselage".

Comparison of the use of synthetic surfactant agents and protein foam

While it is not possible to make a complete comparison of the use of new synthetic surfactant agents and protein foams on simulated aircraft fires, some idea of the scale of comparison can be obtained from these and other results(6). The synthetic agent used on its own is capable of extinguishing a 400 ft^2 petrol fire, with minor obstructions(7), with the application of 0.05 U.S. gal/ft^2 of fire area, where the foam is made with a refrigerant gas. Where the foam is made with air, as is the case for protein foams, a total quantity of 0.07 U.S. gal/ft^2 is required, i.e. 0.06 Imp. gal/ft^2 or approximately 0.6 lb of solution per ft^2. At the present cost of approximately 7 dollars per U.S. gallon of foaming agent (used in 25 per cent solution), the cost to extinguish 1 ft^2 of fire would be about 0.12 dollars.

The quantity of protein foam liquid in solution with water required to extinguish a flammable liquid fire depends upon the type of flammable liquid and the properties and rate of application of the foam. The following results have been obtained in various experiments at the Fire Research Organization.

Table 1 - Quantities of foaming solution required for extinction of various fires

Fire area ft^2	Flammable liquid	Quantity of foaming solution to extinguish Imp. gal/ft^2	Reference
3	Narrow boiling point range petrol	0.15 - 0.20	Standard M.O.P.B. & W. acceptance test
100	Motor spirit (petrol)	0.06 - 0.10*	(8)
875	AVTUR	0.09 - 0.15*	Present report
900	Petrol	0.12 - 0.32*	(9)

*Estimated from radiation records.

By suitable selection of foam properties and rate of application, it is readily possible to achieve extinction with 0.15 Imp. gal/ft^2 of fire area, using a 5 per cent solution of protein foam liquid in water. Thus the cost of extinction, based on the bulk purchase cost of 1 dollar per Imp. gallon of foam liquid, or 1½ dollars per Imp. gallon for small quantities, is in the range 0.008 to 0.012 $dollar/ft^2$.

Thus the cost of extinction with synthetic surfactant material appears to be about 10 to 15 times that of extinction with protein foam, at prevailing prices. If all the foaming solution, i.e. water plus agent, has to be carried to the fire ground, the surfactant foam solution will show an advantage of 2½ : 1 in the weight of solution needed. If only the agent has to be carried to the fire, the protein foam will show an advantage of about 2 : 1 in the weight of agent needed.

Conclusions

(1) Variation of foam expansion in the range 6 to 20 did not materially affect the time to control the simulated aircraft fire, at any of the rates of application used in the experiments.

(2) Variation of critical shear stress showed that foams having a value of 400-500 dynes/cm^2 were the most effective in controlling the fires. Foams of higher or lower critical shear stress were not so economical, and in particular, the foams of lower critical shear stress were not sufficiently stable, giving less protection against reignition of the fuel.

(3) When foam of critical shear stress 400 to 750 dynes/cm^2 was applied to simulated aircraft fires including burning aviation kerosene, the minimum quantity of solution to achieve 9/10 control of the fire was found to be about 0.08 gal/ft^2. At lower rates of application than those used in the experiments, an even smaller quantity would be likely to be required.

(4) Foam even if it is comparatively stiff, was unlikely to adhere to the hot metal surfaces of an aircraft fuselage involved in fire. If the fuselage were cool, however, some foam might adhere for a period. Foam is not likely to be useful as an insulator on a fuselage which had already become hot. Its value as a coolant to the fuselage should, however, be investigated more fully.

Future development

The need for urgent and efficient fire-fighting 'against' aircraft fires could be met by utilising the principle of the experimental turbine foam generator, used in this investigation, in a foam-laying helicopter. The main gas-turbine engine, or engines, used in a large helicopter, would provide a small proportion of its compressed air (about 3 to 5 per cent) to make and eject foam onto the aircraft fire, either from above or from the ground nearby. Only simple low pressure tankage, pipe-work and monitors would be required. Some present day helicopters can carry a payload of about 6,500 lb. Assuming the foam-making equipment would weigh about 1,000 lb the helicopter could carry about 550 gal. of foaming solution. The equipment could be designed to make foam having a critical shear stress of 400 to 500 dynes/cm^2, the optimum value shown by the experiments. Foam expansion in the range 6 to 20 would not be important in the control of aircraft fires and a comparatively low expansion foam of, say, 10 to 1, would enable a larger proportion of the air to be used to eject the foaming solution from its tank. If 2 lb/sec of compressed air were available from the gas turbine engine or engines, the rate of discharge of foaming solution would be approximately 300 to 400 gal/min, which is comparable with the output of some of the largest land-based appliances at present in use.

Acknowledgment

Thanks are due to the staff of the Ministry of Aviation Fire Service Training School, Stansted, for their assistance in carrying out the experimental programme, and to the various Government Departments who co-operated in this work.

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Table 1

$^{9}/_{10}$ control times for rate of application
50 gal/min. (0.06 gal ft^{-2}min^{-1})

Expansion	Critical shear stress (dyn/cm^2)	Wind speed (ft/sec)	$^{9}/_{10}$ Control time (sec)		Remarks
			Observer	Recorder	
7.2	150	7	120	114	Complete extinction difficult due to foam breakdown.
6.2	260	11	about 120	112	Intensity of the fire did not decrease during 60 sec. after control due to foam breakdown.
6.9	400	7	75	70	-
11.0	400	7	65	-	Foam broke down fairly rapidly after control.
10.0	740	3	75	65	-
12.2	240	13	75	85	-
14.0	320	13	65	68	Foam broke down rapidly after control and gave little protection against re-ignition.
12.2	600	$<$ 10 variable	85	87	-
13.5	950	6	90	97	-
19.0	450	14	70	70	-
18.5	620	7	110	97	-
21.0	980	8	90	Estimate 130	88 per cent control in 110 sec. Little foam adhered to the fuselage.
22.0	1,250	10	100	98	-
24.0	530	10	65	63	Foam broke down fairly rapidly after control.

Table 2

$^9/_{10}$ control times for rate of application
125 gal/min. (0.14 gal $ft^{-2}min^{-1}$)

Expansion	Critical shear stress (dyn/cm^2)	Wind speed (ft/sec)	$^9/_{10}$ Control time (sec)		Remarks
			Observer	Recorder	
6.8	220	10	48	38	-
8.0	430	13	41	-	-
11.9	400	14	45	43	-
12.2	690	14	60	60	-
13.9	900	12	38	36	Little foam adhered to the fuselage.
19.2	840	15	65	-	Little foam adhered to the fuselage during initial part of test. Some foam did adhere to upper surface of the fuselage later when it had cooled.

Table 3

$^{9}/10$ control times for rate of application
200 gal/min. (0.23 gal $ft^{-2}min^{-1}$)

Expansion	Critical shear stress (dyn/cm^2)	Wind speed (ft/sec)	$^{9}/10$ Control time (sec)		Remarks
			Observer	Recorder	
6.0	150	6	40	40	Highest control time at 200 gal/min. Probably due to high foam drainage.
5.9	330	13	30	35	-
12.5	720	13	19	-	Fire reduced to a few flickers in 20 sec. Foam applied as fine spray due to cross wind. Very thin layer on fuel (about $\frac{1}{2}$ in thick) at end of test.
11.7	900	22	30	-	-
12.5	1,250	11	35	-	-
17.3	1,120	23	28	29	-
21.0	1,400	15	34	-	Little foam adhering to fuselage at end of test.

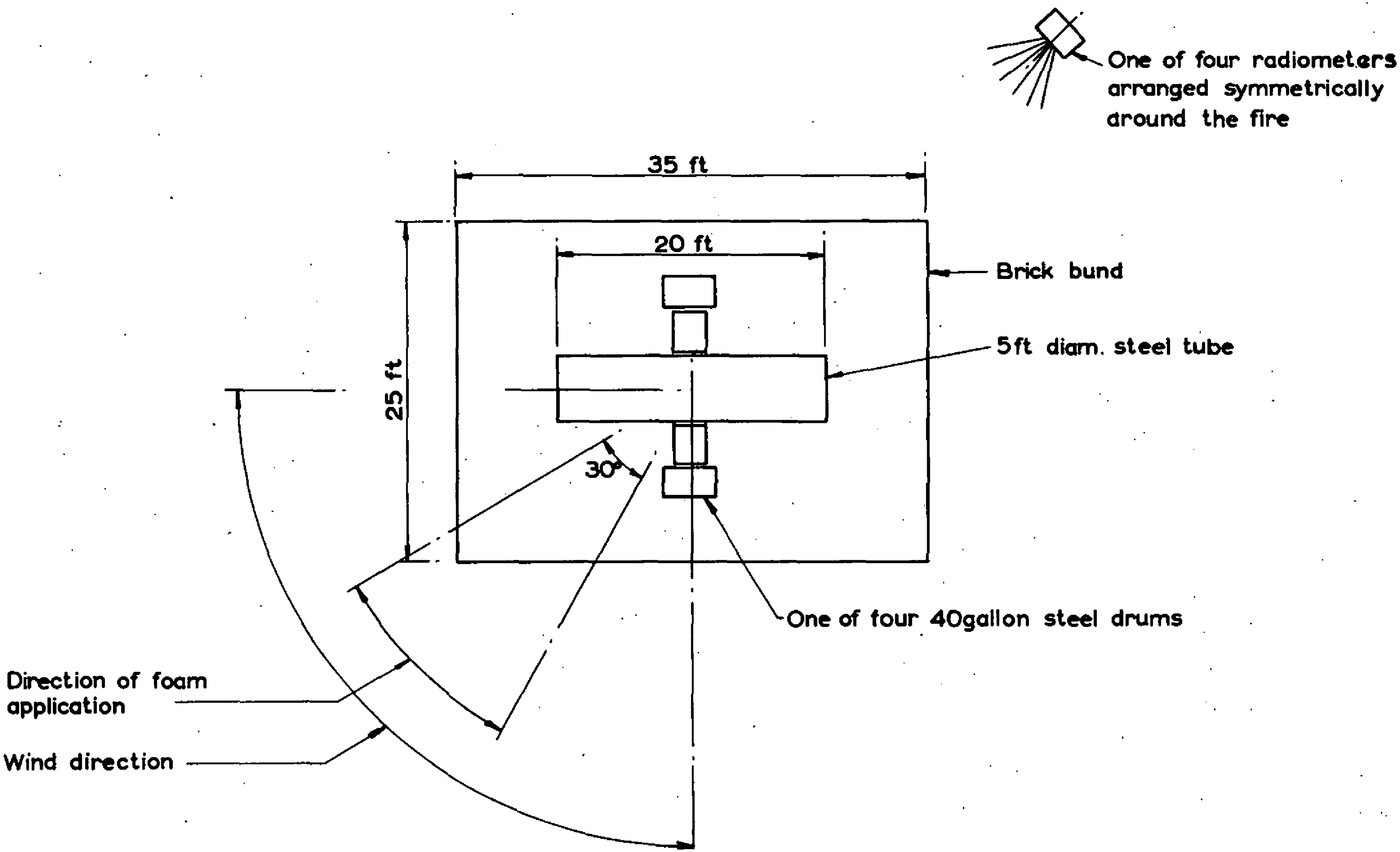

FIG. 1. DIAGRAM OF TEST AREA

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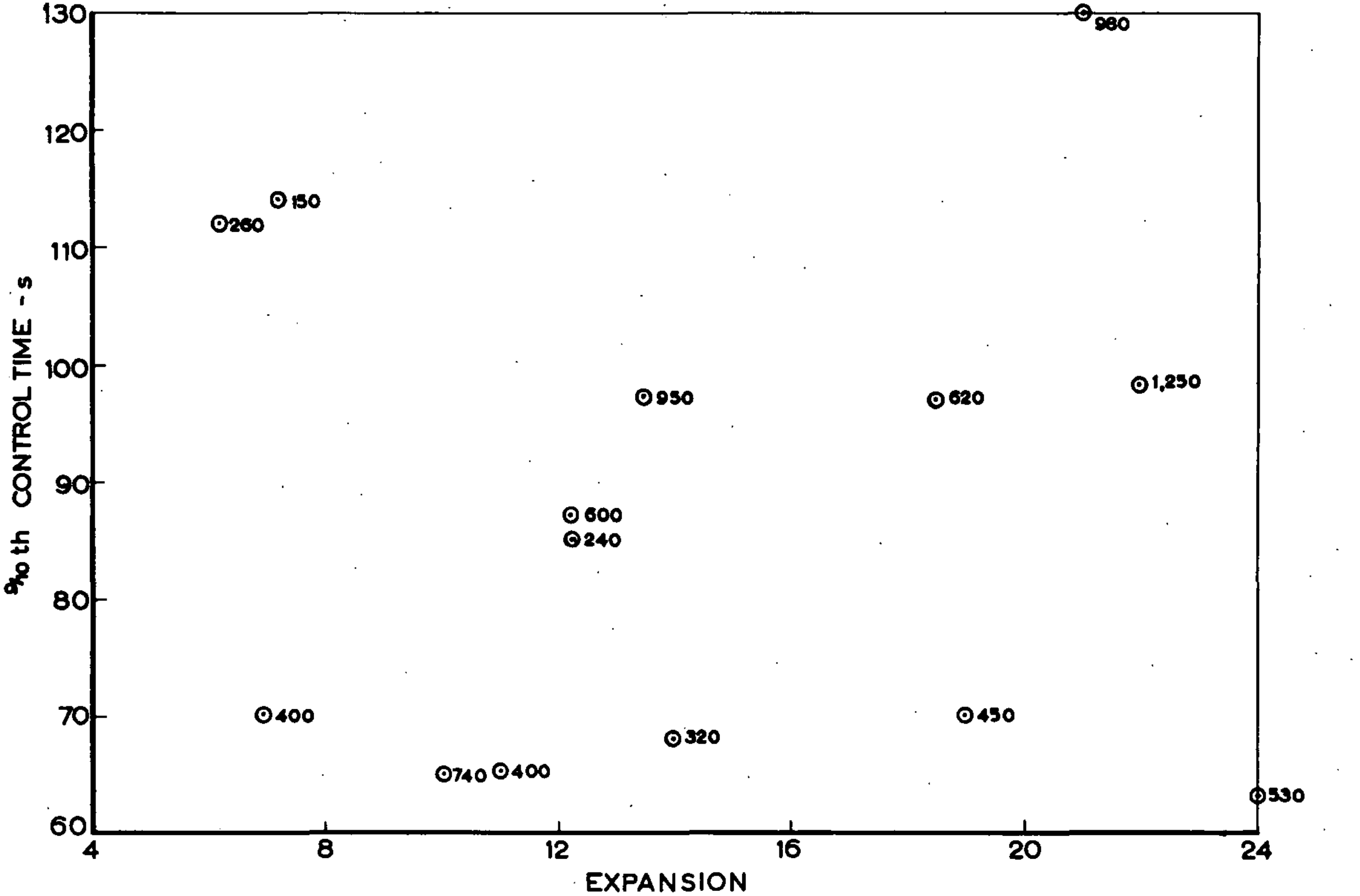

Rate of application — 50 gal / min
Critical shear stress — 150 to 1,250 dyn/cm^2 (See numbers at each point)

FIG. 2. EFFECT OF EXPANSION ON FIRE CONTROL

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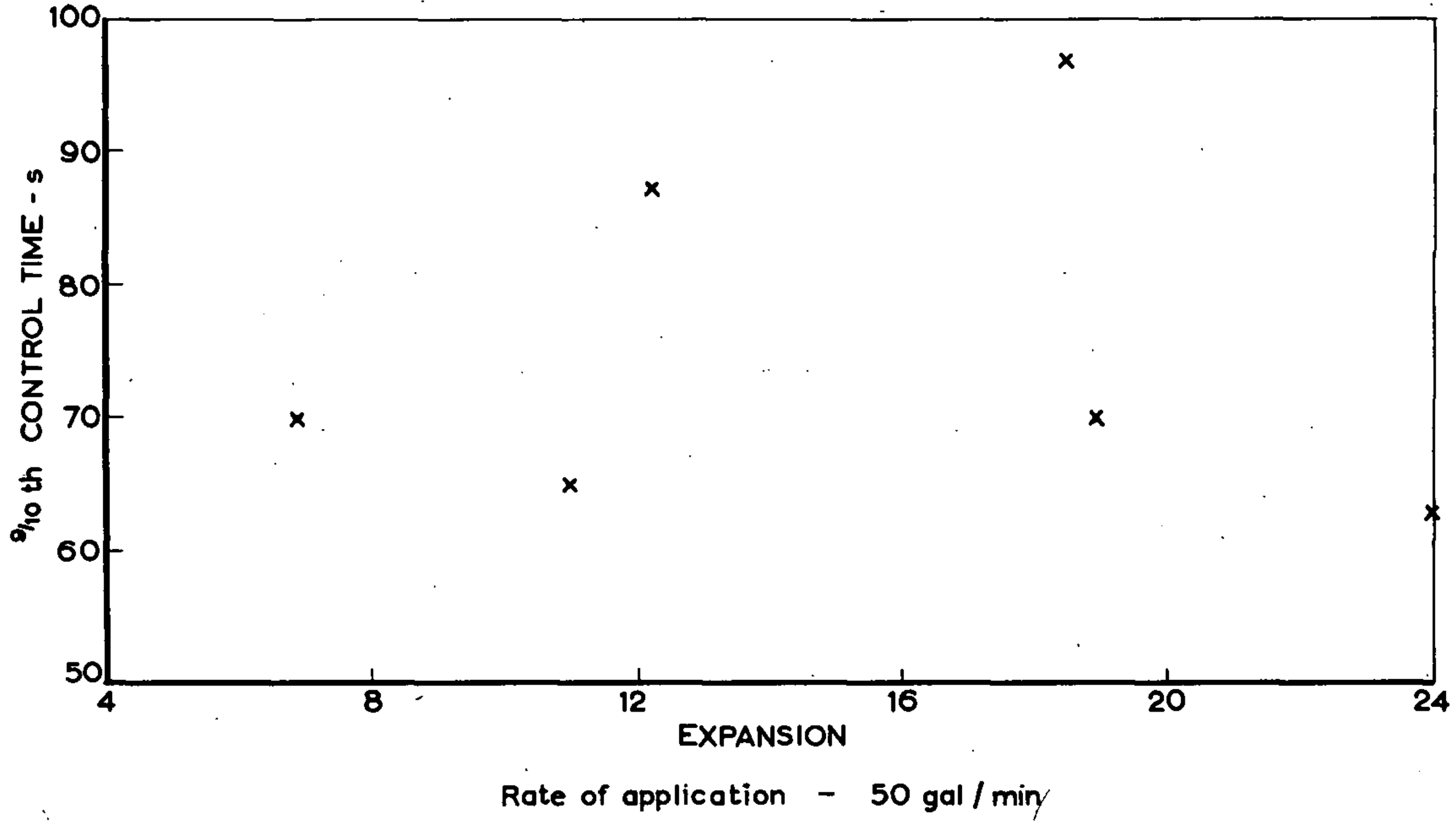

FIG. 3. EFFECT OF EXPANSION ON FIRE CONTROL. TESTS WITH FOAMS OF CRITICAL SHEAR STRESS 400 TO 620 dyn /cm^2

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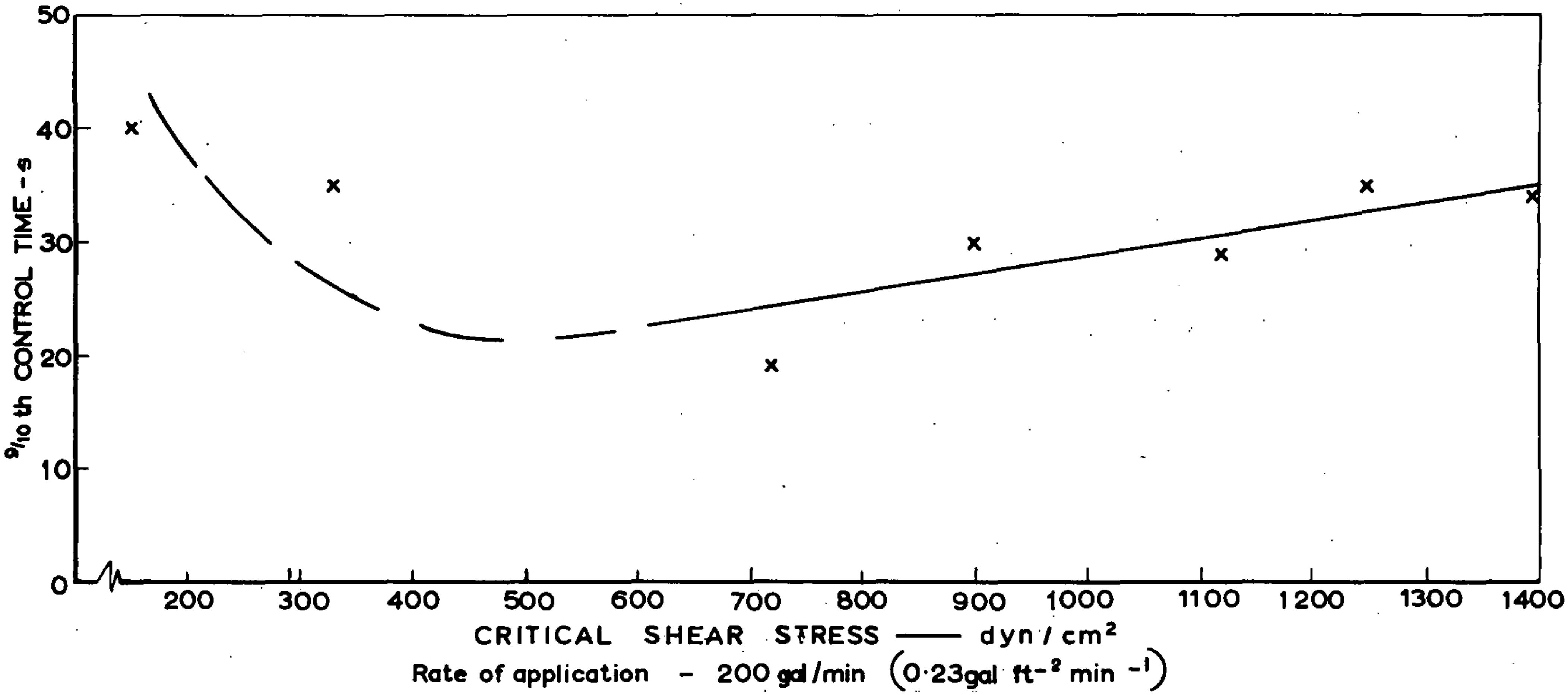

FIG. 4 a. EFFECT OF CRITICAL SHEAR STRESS ON FIRE CONTROL

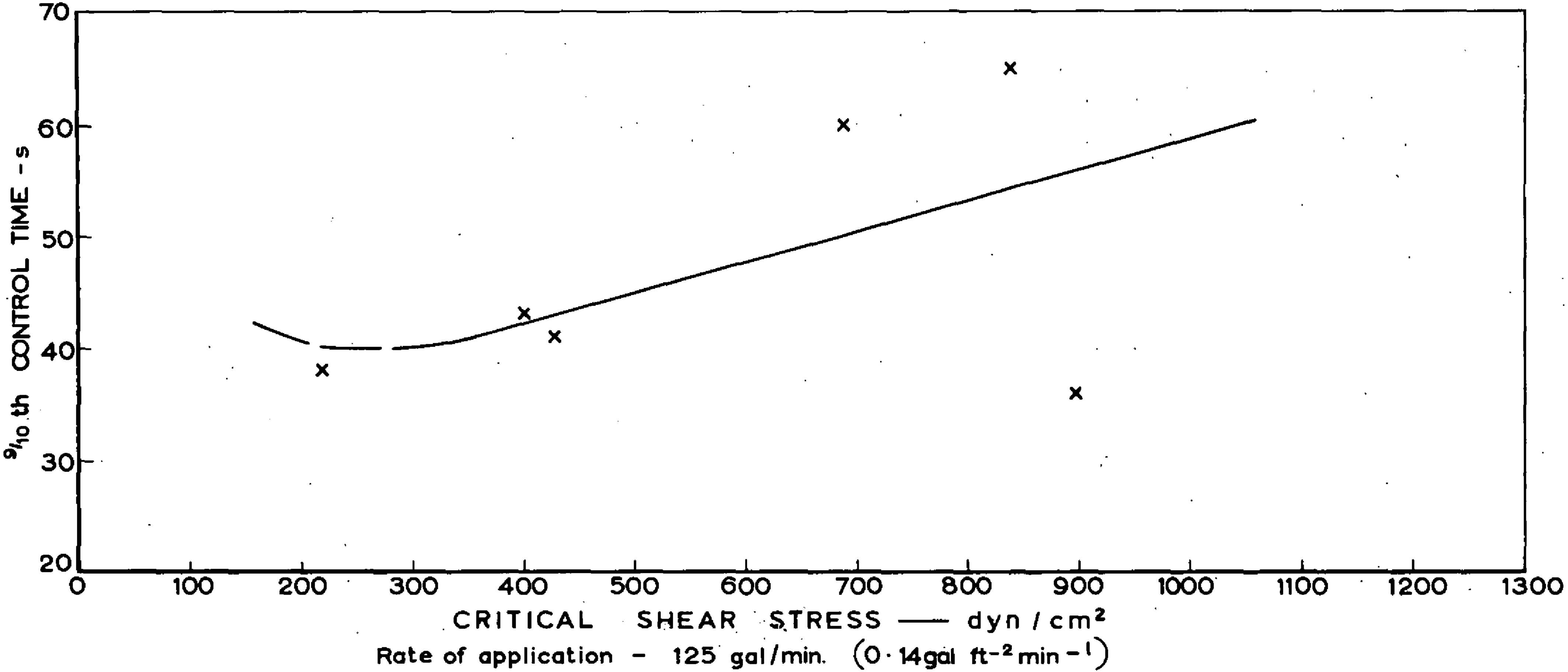

FIG. 4b. EFFECT OF CRITICAL SHEAR STRESS ON FIRE CONTROL

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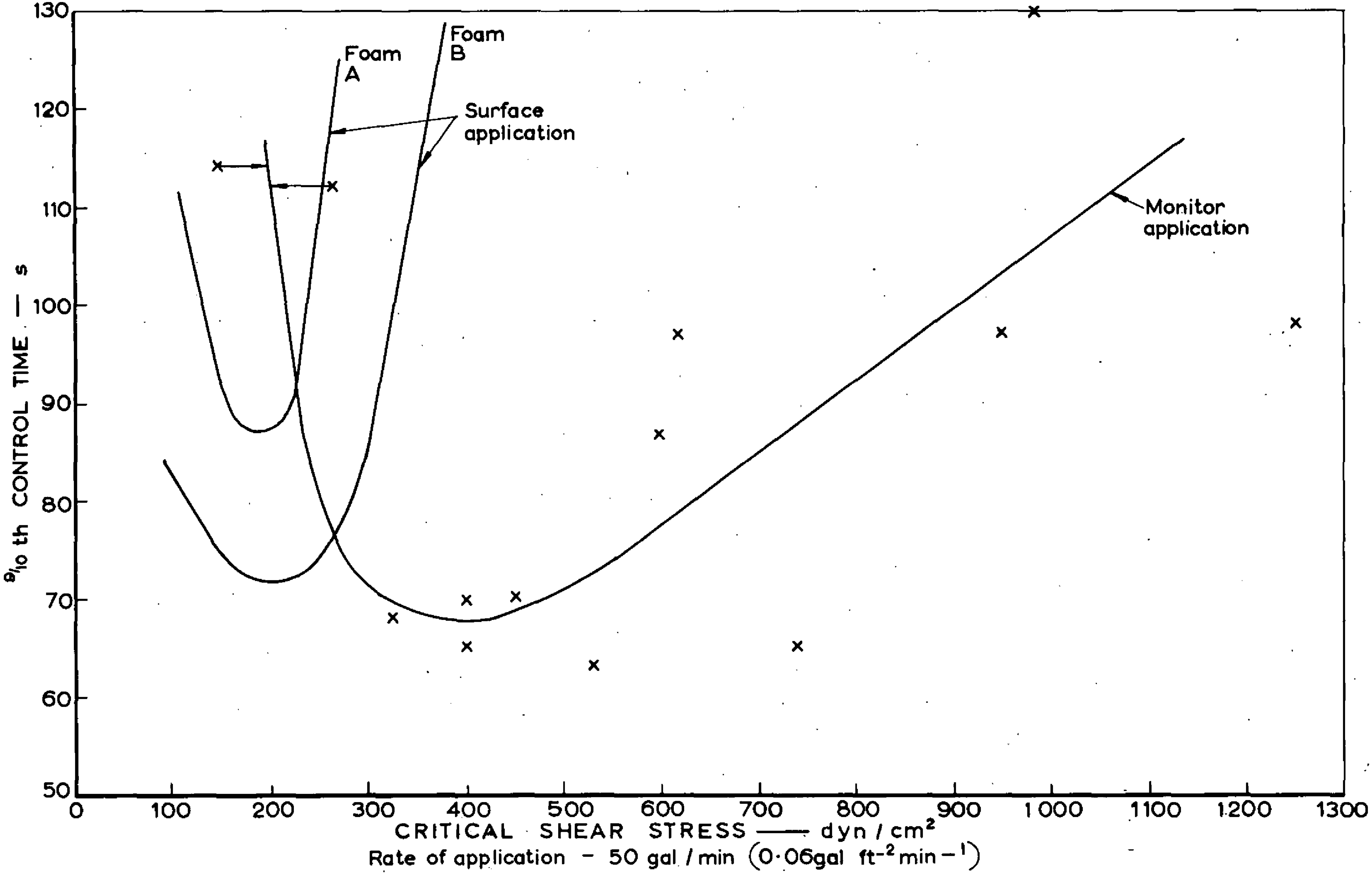

Rate of application – 50 gal / min (0·06 gal ft^{-2} min^{-1})

FIG. 4c. EFFECT OF CRITICAL SHEAR STRESS ON FIRE CONTROL

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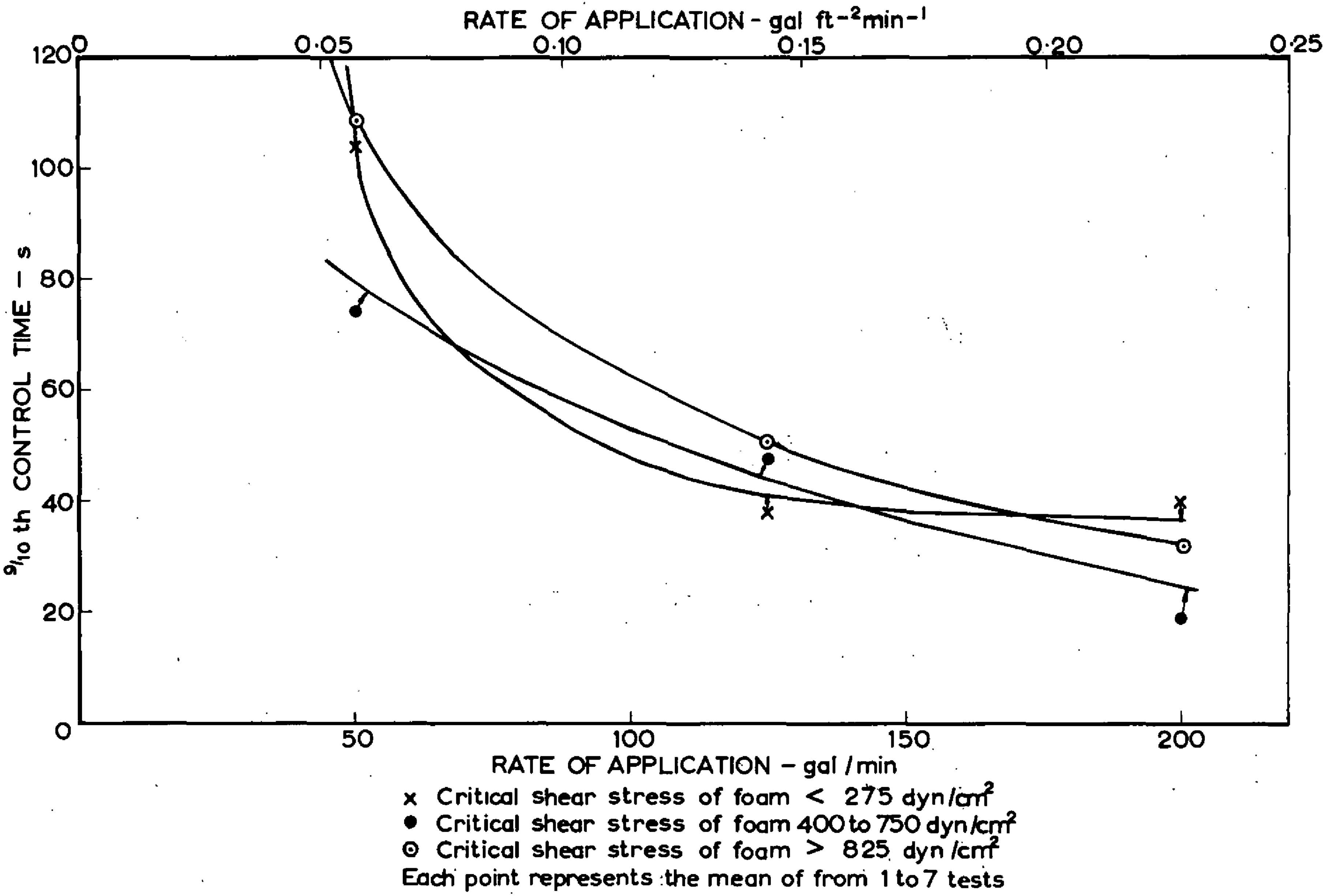

FIG. 5. EFFECT OF RATE OF APPLICATION ON CONTROL OF FIRE FOR FOAMS OF DIFFERENT CRITICAL SHEAR STRESS VALUE

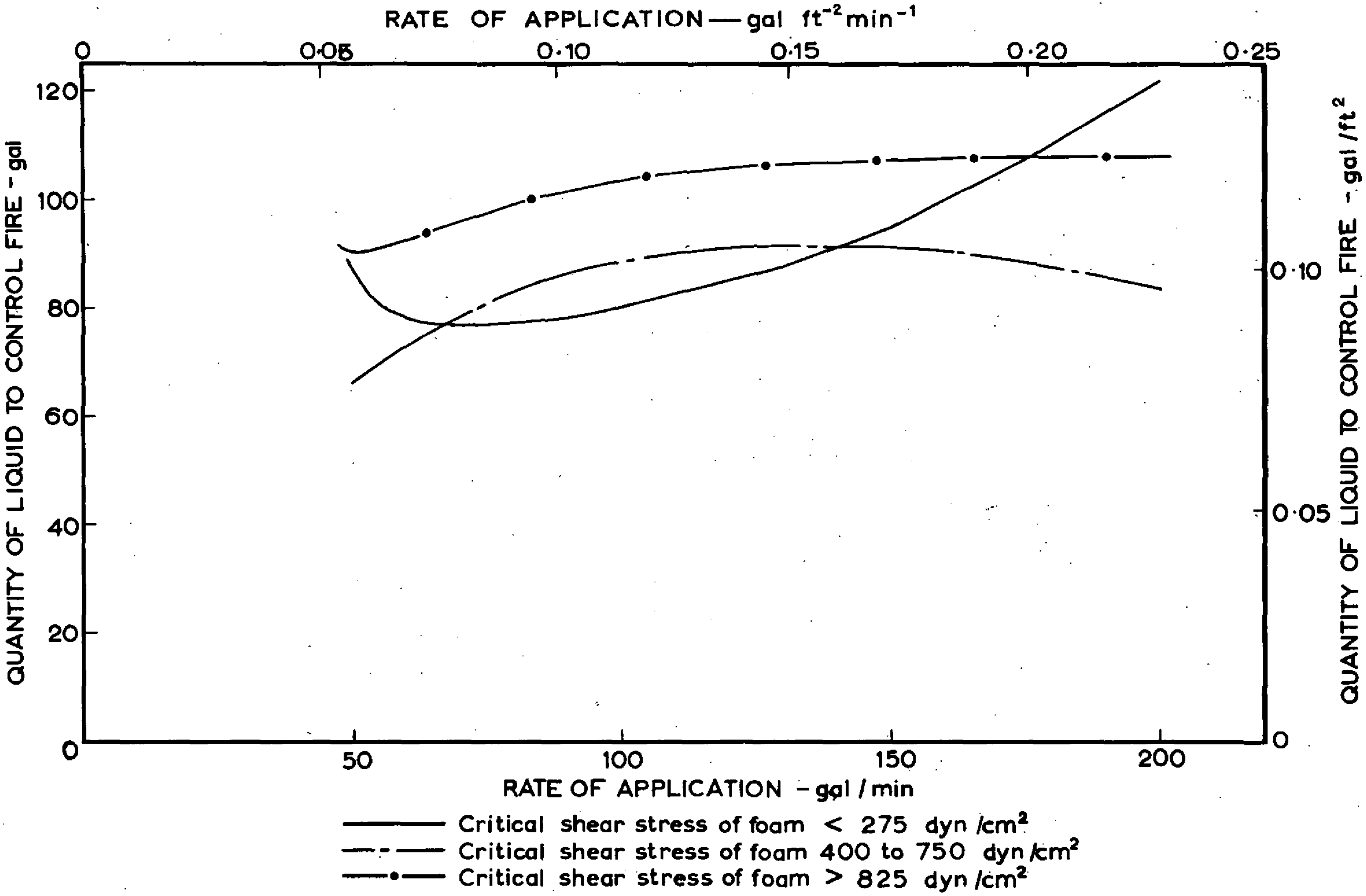

FIG. 6. QUANTITY OF FOAMING SOLUTION TO CONTROL THE FIRE

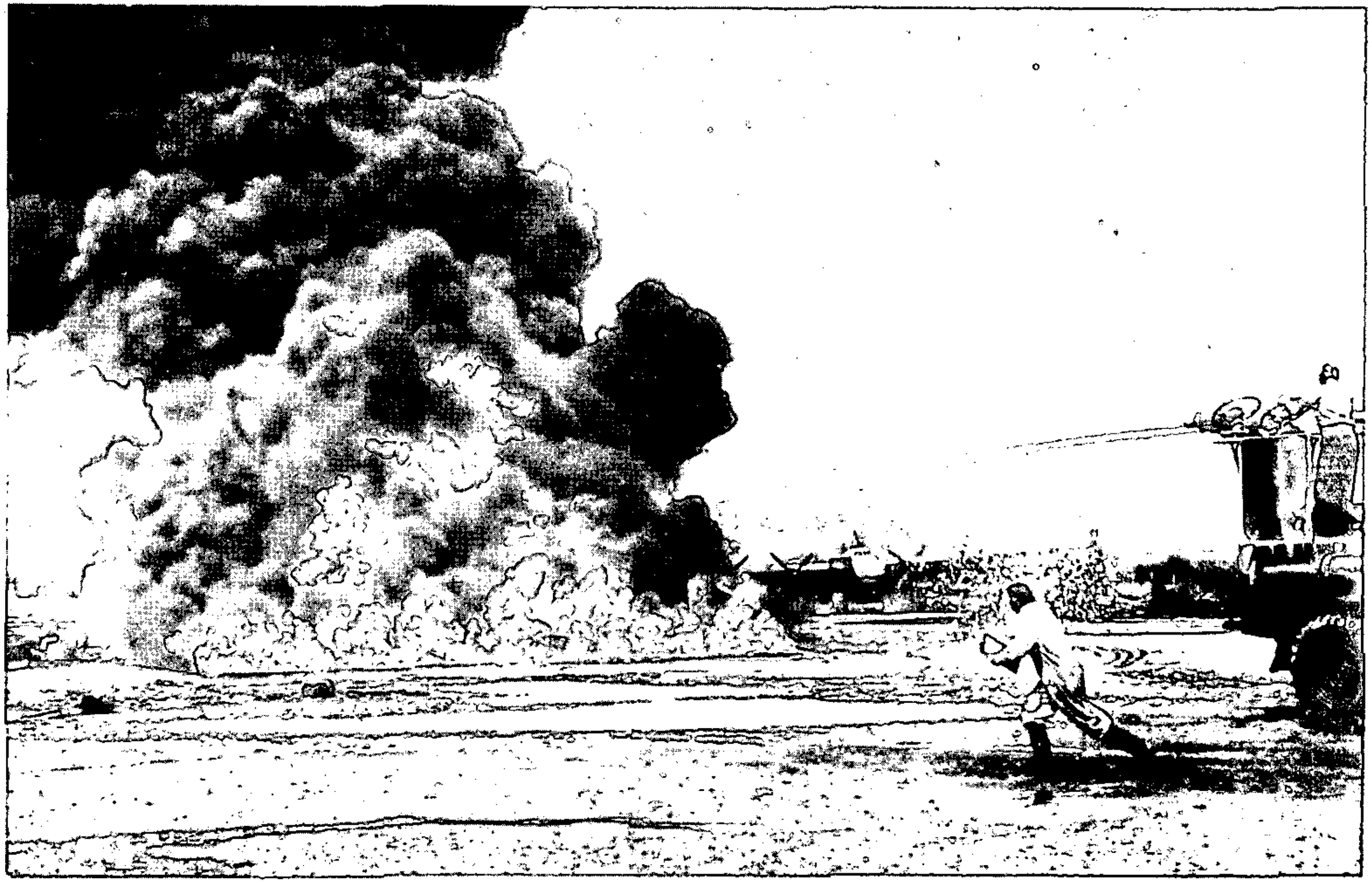

PLATE 1