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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

AIR FOAM IN THE CONTROL AND EXTINCTION OF PETROL FIRES BY SURFACE APPLICATION

by

R. J. French and D. Hird

Summary

This note describes an investigation of the influence of the characteristics of air-form on its ability to control and extinguish petrol fires and on the stability of the foam blanket on the fire area.

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1. Introduction

In the application of foam to the surface of burning petrol there are three main aspects to be considered. They are:

(a) its ability to control and extinguish the fire when applied at normal liquid rates;

(b) its ability to maintain a sufficiently protective blanket on the petrol surface after the fire is extinguished;

(c) its critical rate of application i.e. the minimum rate of application which will enable the fire to be controlled.

The relative importance of each of these three factors will vary with the particular circumstances under which the foam is being used, but the following generalizations may be made. For small contained fires and spill fires, which form the majority of incidents, the greatest need is to control the fire quickly in order to limit damage and spread of fire; extinction by the continued application of foam will follow control since the apparatus available is adequate. In these small fires the maintenance of a good foam blanket after extinction may not be of great importance. The need for an enduring foam blanket may, however, become of major importance when dealing with large fires involving extended operations, multiple fires or obstructed fires. The critical rate of application only becomes important when the equipment resources are limited in relation to the fire situation. The purpose of this investigation was to study the influence of the following factors on the fire-fighting properties of foam:

type of compound;
concentration of foam compound;
critical shear stress of foam;
expansion of foam.

These factors have been varied independently as far as possible to help in understanding their separate effects. In practise the critical shear stress and expansion are dependent on the type and concentration of foam compound and the foam-making equipment used. The significance of the experimental results in terms of practical equipment are also discussed in this report.

2. Apparatus

Motor spirit (74 octane) was used in all the experiments and was contained in a tank giving a petrol surface area of 3 sq. ft. The tank was constructed of 18 S.W.G. brass, the upper section being of circular cross section 23 7/16 in. internal diameter and 4 in. deep, while the lower section was conical in shape and was fitted at the bottom with a 2½ in. diameter x 23½ in. long glass measuring tube. This tube was used for measuring the amount of foam solution draining from the foam applied to the petrol surface. The tank was supported in a stand which carried four radial arms to which radiometers could be attached for use in the manner of previous experiments(1). This apparatus is shown in Plate 1.

3. Details of foam compounds investigated

Identification	Type	Remarks
A *	Hydrolised keratin	No longer in large scale use.
B	Hydrolised keratin	Has largely replaced Compound A in most applications
C *	Hydrolised blood	Very similar in general characteristics to Compound B.
E	Wetting agent	Not generally accepted as suitable for fire fighting.
N	Hydrolised protein	Meets same specification as Compound B and C.
P	Hydrolised keratin	Made as Compound B but has had stabilizing salt subsequently removed.

* Examined in previous investigation(1).

4. Experimental

4.1. Determination of the ability of a foam to control and extinguish a fire

The time to control a fire was determined from records of the radiation from the fire as measured by the four radiometers; both 2/3 and 9/10 control times were measured and the extinction time was also determined. A 30 sec. preburn time was used in the majority of the experiments. Foams with an expansion/of 7 and a range of critical shearing stresses and corresponding 25 per cent drainage times(2) were produced from compounds B. E, N and P in 1 to 10 per cent concentrations; compound B was used for the majority of the tests. The foam was applied to the surface of the petrol through a ½ in. B.S.P. teepiece situated with its outlets just above the petrol surface. Rates of application of foaming liquid from 0.035 to 0.15 gal. $ft^{-2}min^{-1}$ were used. The application of foam was continued in each test until the fire was extinguished.

4.2. Determination of the stability of the foam blanket

The stability of the foam produced on the petrol surface while extinguishing a fire was determined by measuring the rate of drainage of foaming solution during the 10 to 12 min. from the moment of commensement of foam application. Foams of expansion 7 and with a range of critical shear stresses were used, made from compounds B, E, N and P in various concentrations. The liquid rate of application was 0.10 gal. $ft^{-2}min^{-1}$ in all these tests.

Additional tests were made to obtain some indication of the effect of the temperature of the petrol surface layer. This was done by using a range of preburn times on the test fire and the temperature was measured by a mercury in glass thermometer immediately after the fire had been extinguished.

4.3. Determination of the critical rate of application

At the critical rate of application the rates of loss of liquid from the foam by drainage and evaporation just balance the rate of application. At slightly higher rates of application the fire is extinguished and at rates of application below the critical rate extinction is not possible. The critical rate was determined by adjusting the rate of foam application to the test fire until equilibrium conditions were established with a small but constant (5 per cent) reduction in radiation from the fire. The rate of drainage from the foam under these conditions was measured and the rate of loss of water by evaporation could then be calculated.

The critical rate of application determined in this way gave slightly lower values than by estimating the asymptote to the control time - rate of application curve.

Foams made from compound B in concentrations between 1 and 10 per cent were investigated over a range of critical shear stress and expansion. A number of experiments were also made with foams from compounds E, N and P.

5. Experimental results and discussion

5.1. Control and Extinction

The experimental results (Figs. 1 to 10) show that the two most important factors affecting the time taken to control a fire with foam are the rate of application to the fire (R) and the fluidity of the foam. The critical shear stress (S) of a foam is a convenient index of its fluidity and Fig. 1 shows results for Compound B which illustrate the effect of foam fluidity found with all the compounds tested. Concentrations of foam solution of 1, 3 and 10 per cent were used to produce foams with a range of critical shear stress. It is evident that the concentration of foam compound has some effect on the control time at the lowest rate of flow and at low values of critical shear stress, and this is most marked at low rates of application. For example, there is some increase in the control time with 1 per cent solutions when the critical shear stress is reduced below about 0.4 lb/ft^2. The effects of the concentration and shear stress on the $^9/10$ control time and on the time taken to extinguish the fire are similar to those for the $^2/3$rd control time shown in Fig. 1.

If it is assumed that there is little breakdown of the foam as it covers the fire area, then it can be shown(3) that the control time should be proportional to $^S/R$. The relation between the $^2/3$rd control time and $^S/R$ for Compound B is shown in Fig. 2, for rates of flow from 0.035 to 0.15 gal. ft^{-2}min^{-1} and shear stresses from 0.3 to 1.6 lb/ft^2. The relationship does not hold for rates of flow near the critical rate, where the foam is appreciably destroyed in controlling the fire.

The slope of the line (θ) between $^S/R$ and control time (t) can be considered as a measure of the quality of the foam compound. Thus, foams made from compounds E and P would be expected to have greater values of θ than the other compounds investigation. The tests show that the results for compounds A, B and C can be expressed as

$$t = 18 + 2.7\ ^S/R \qquad \theta = 2.7$$

for compound E

$$t = 5 + 16\ ^S/R \qquad \theta = 16$$

and for compound P

$$t = 5 + 10\ ^S/R \qquad \theta = 10$$

The results for the $^{9}/10$ control time and extinction time show a s similar relationship with $^{S}/R$ although the variability of the extinction time is considerably greater. It has been shown(1) that expansion is not an important factor when foam is applied in this manner and in these experiments with foams of expansion from $3\frac{1}{2}$ to 13 have been used and no effect of expansion has been found. The time taken to control or extinguish a fire depends, therefore, primarily on the rate of application and the critical shear stress of the foam. The concentration of foaming solution has some effect at values less than 3 per cent and the type of compound can also have an effect.

5.2. Stability of foam blanket

As a measure of the stability of a foam blanket after a fire has been extinguished, the quantity of liquid remaining in the foam 10 minutes after the start of foam application was measured. The way in which this quantity depends on the concentration and critical shear stress for compound B is shown in Fig. 3. The amount of liquid required to extinguish the fire increases with the critical shear stress of the foam as shown in Section 5.1, and the proportion of the applied liquid lost by drainage decreases as the critical shear stress increases. With a concentration of foam solution of 1 per cent, there is a slightly more rapid rate of drainage than with the higher concentrations. Foams made from the wetting agent, compound D, lose 80 per cent of their liquid content in 10 minutes (Fig.4), but it can be seen that it was only possible to produce foams of low critical shear stress. Providing the concentration of the foam solution is above 3 per cent, the results for the different compounds suggest that the critical shear stress is the most important factor in determining the stability of a foam compound after a fire has been extinguished. This is substantiated by Fig. 5 where the results for the different compounds are plotted against the critical shear stress. Although there is a considerable spread about the best straight line, it is evident that stability under these circumstances is dependent more upon the critical shear stress of the foam than on the foam compound from which it is produced. It has been shown previously(4) that petrol temperature greatly influences the breakdown of a foam layer, and this is confirmed by the results shown in Fig. 6. It is not, of course, only the surface temperature that affects the drainage rate as the heat content of the body of the petrol will control how long the surface temperature is maintained. In general, long preburn times have little effect on the quantity of liquid required for extinction but do have a marked effect on the stability of the foam blanket after extinction.

5.3. The critical rate of application

The effect of the critical shear stress of the foam on the critical rate of application for foams in 3 per cent concentration from compound B is shown in Fig. 7. The way in which this critical rate of application is balanced by drainage and evaporation losses can also be seen. Fig. 8 shows the effect of concentration and critical shear stress on the critical rate of application. The evaporation loss is largely independent of concentration and only very slightly dependent on the shear stress of the foam and may be considered constant at 0.011 $\text{gal/ft}^2/\text{min}^{-1}$. Since the evaporation rate is constant, the drainage rate is the important factor in comparing the critical rates of application of different foam compounds. This drainage rate is affected by the concentration of foam compound and the critical shear stress of the foam, but is independent of foam expansion in the range 3.5 to 25 (Fig. 9).

The critical rates of application obtained from the other compounds tested, with corresponding drainage and evaporation rates are given in Table II, in comparison with typical results for compound B.

TABLE II

Compound Identification	Compound Concentration	Critical shear stress lb/ft^2	Critical rate of application gal.ft^{-2}min^{-1}	Drainage rate gal.ft^{-2}min^{-1}	Evaporation rate gal.ft^{-2}min^{-1}
B	1 3 5 10	0.20 0.35 0.45 0.85	0.0217 0.0153 0.0134 0.0109	0.0110 0.0032 0.0022 0.0002	0.0107 0.0121 0.0112 0.0107
E	5	0.20	0.0270	0.0130	0.0140
N	5	0.33	0.0170	0.0047	0.0128
P	3 10 10	0.50* 0.27 0.45	0.315 ~~0.0315~~ ? 0.350 0.308	0.0230 0.0257 0.0216	0.0085 0.0093 0.0092

*It was not possible to produce stable foams from compound P in 1 per cent concentrations or stable foams of low critical shear stress in 3 per cent concentrations.

It is interesting to note that the evaporation rate as well as being largely independent of concentration and critical shear stress is also little affected by the type of compound used.

An empirical relation between the critical rate of application and the concentration (C) and critical shear stress of the foam can be obtained for compound B. This is

$$Rcrit = 0.0175\, C^{-0.225} S^{-0.15}$$

where Rcrit = critical rate of application (gal/ft^{-2}min^{-1})
C = concentration of foam solution (per cent).
S - critical shear stress of foam (lb/ft^2).

This relation is shown in Fig. 10, where the results obtained for compounds E, P and N are also given.

6. Application to the use of Fire Brigade Equipment

So far the effect of foam characteristics have been varied independently. With Fire Brigade equipment of fixed design and fixed energy input, variation of the compound concentration will influence the expansion and the critical shear stress of the foams produced. To determine the overall effect upon the performance of the foam tests were carried out with branchpipe foams. The characteristics of the foams produced by a typical foam-making branchpipe of 50 gal/min. nominal water capacity, were measured using concentrations of 1 - 10 per cent of compound B.

Table 3

Characteristics and performance of branchpipe foams

Compound Concentration	Foam Expansion	Critical Shear Stress lb/ft^2	25 per cent drainage time. min.	$\frac{2}{3}$ control time at .035 gal. ft^{-2}min^{-1} sec.	Liquid remaining in foam blanket after 10 min.	Critical rate gal.ft^{-2}min^{-1}
1	4	0.20	2	70	25 per cent	.022
3	6	0.35	3	45	45 per cent	.015
5	7	0.45	3½	53	50 per cent	.013
10	11	0.85	10	90	65 per cent	.012

When using a branchpipe type of foam it is evident that at a very low concentration the advantages of a low critical shear stress are offset by the lack of stability and the control times are likely to be higher than with foams of higher shear stress because of this. A reasonable balance between shear stress and stability is obtained with concentrations between 3 and 5 per cent.

Conclusions

1. The time taken to control or extinguish a petrol fire with foam depends on the rate of application and the critical shear stress of the foam. There are no essential differences between the normal protein foam compounds and the concentration of foam compound is of little importance providing it is greater than 2 or 3 per cent.

2. Stability of the foam blanket after the fire has been extinguished is primarily dependent on the critical shear stress of the foam. Increasing the critical shear stress increases the stability. Soap and wetting agent compounds give foams of low stability, since it is not possible to produce foams with sufficient high values of critical shear stress from these compounds.

3. At the critical rate of application, the rate of application of foam is balanced by the rate of loss of water by drainage and evaporation. The evaporation loss has been shown to be independent of the type of compound and foam properties and equal to 0.011 gal.$ft^{-2}min^{-1}$. It is, therefore, the foam properties, which control the rate of drainage under these conditions, which affect the critical rate of drainage. These have been shown to be the critical shear stress of the foam, the concentration and type of foam compound.

4. A reasonable balance between the conflicting requirements of a low critical shear stress for rapid control of the fire and a higher critical shear stress for foam stability can be obtained with the normal foam-making branchpipe with foam compound concentrations between 3 and 5 per cent.

Acknowledgments

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References

1. FRENCH, R. J., HINKLEY, P. L. and FRY, J. F. Surface Application of Foam to Petrol Fires. Chem. and Ind. 1956, 260-265.

2. SAVAGE, Nicola. The Relationship between Critical Shear Stress and 25 per cent Drainage Time of Air-Foams. Department of Scientific and Industrial Research and Fire Offices' Committee, Joint Fire Research Organization, F. R. Note 344/1958. February 1958.

3. FRENCH, R. J. and HIRD, D. The critical thickness of a foam blanket. Department of Scientific and Industrial Research and Fire Offices' Committee, Joint Fire Research Organization, F. R. Note 439/1960.

4. FRENCH, R. J. and HINKLEY, P. L. The Resistance of Fire-fighting Foams to Destruction by Petrol. Journal of Applied Chemistry, 1954, 513-516.

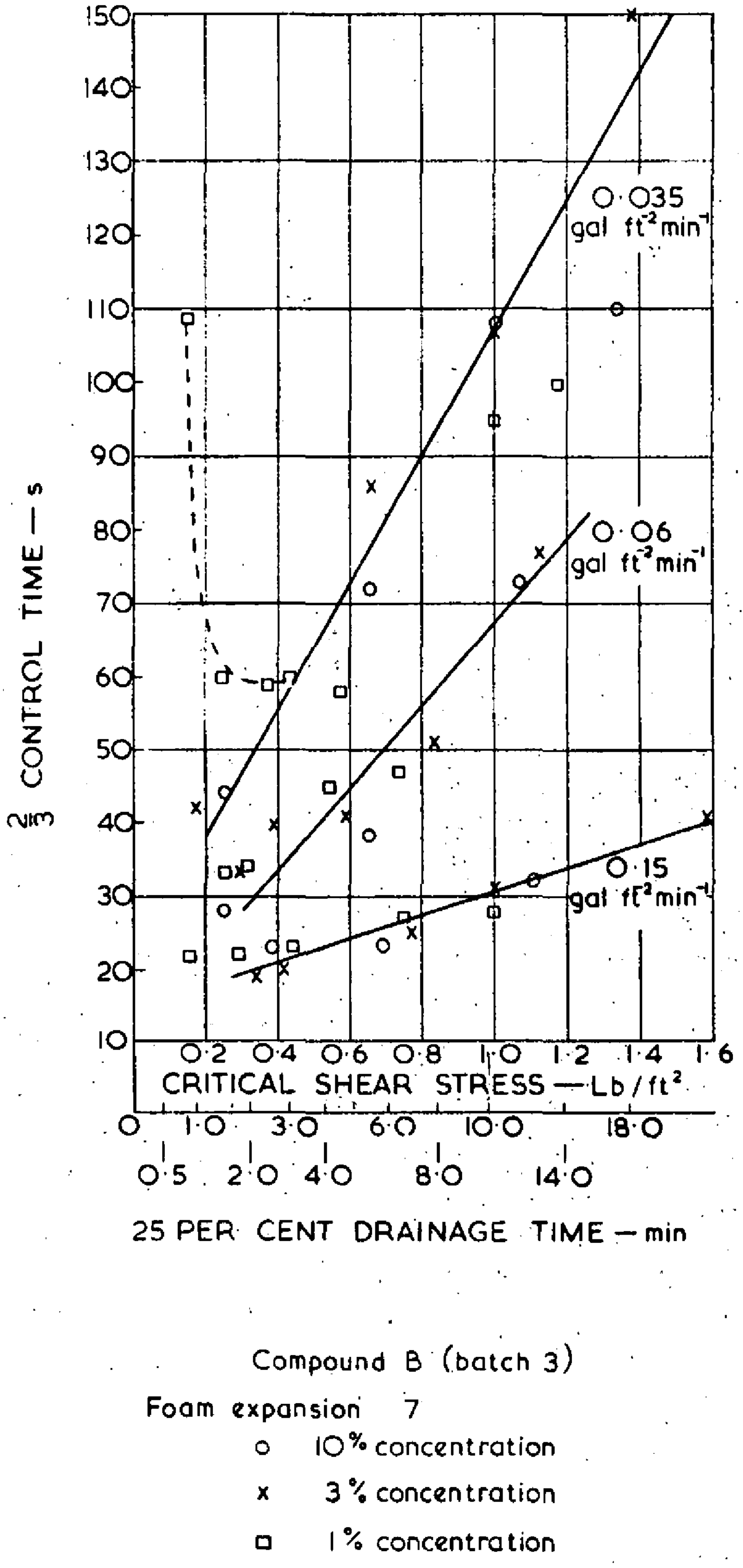

FIG. 1. FACTORS AFFECTING CONTROL TIME
(Critical shear stress v. control times for 3 rates of application)

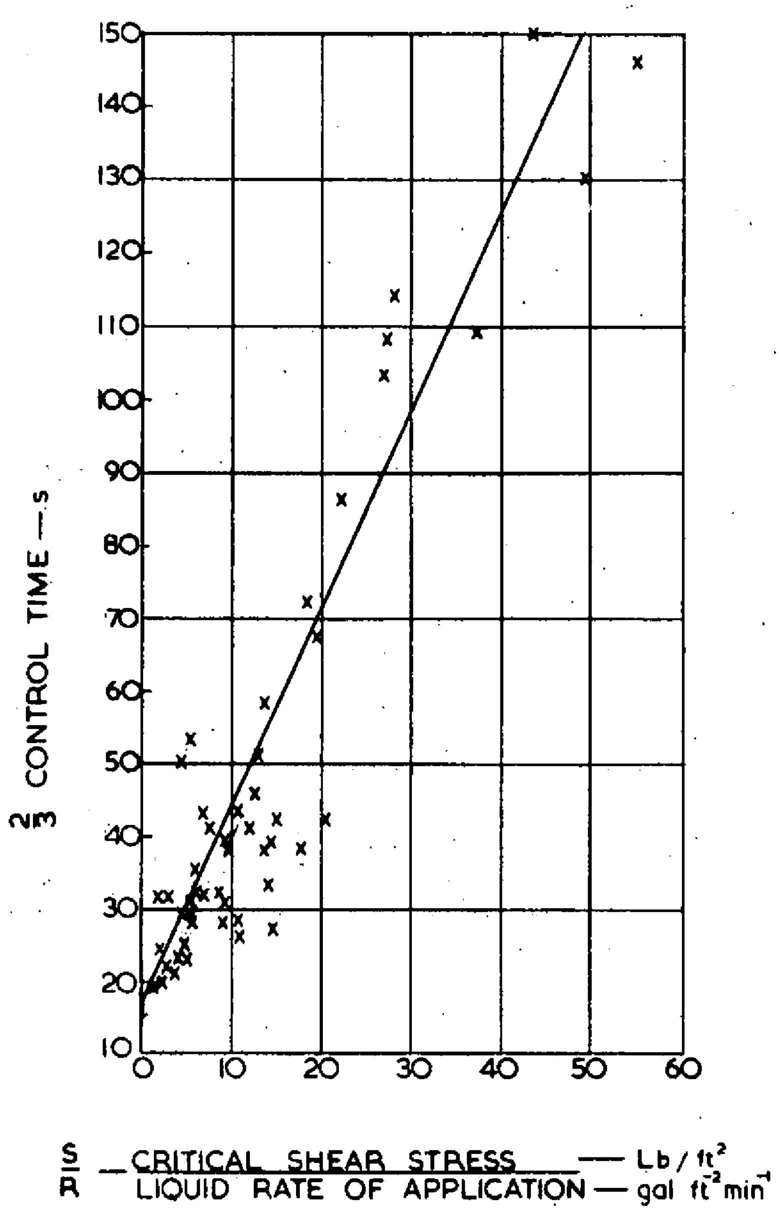

FIG. 2. CONTROL TIME AS A FUNCTION OF $\frac{S}{R}$
(COMPOUND B)

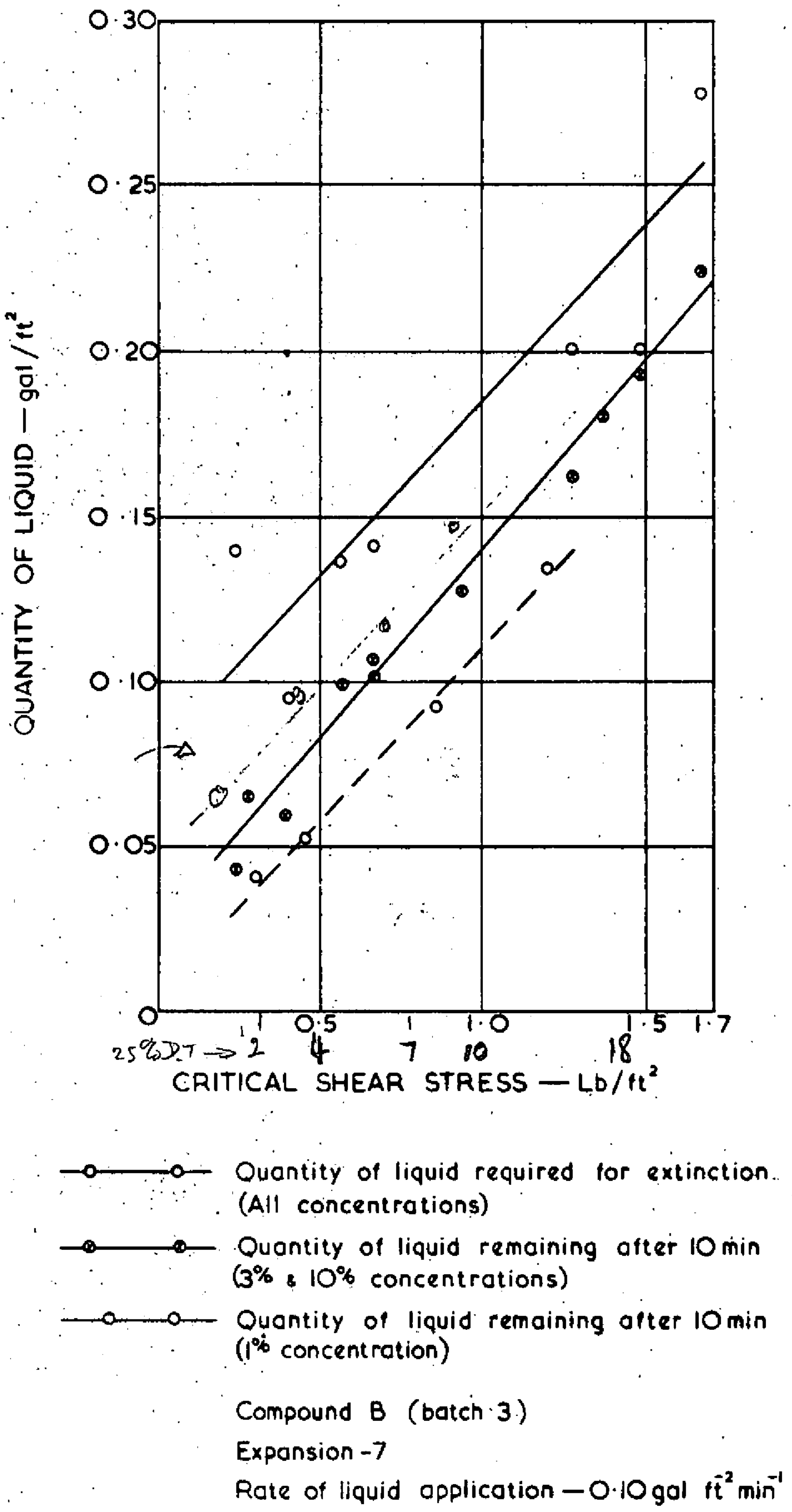

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FIG. 3. STABILITY OF FOAM BLANKET (COMPOUND B)

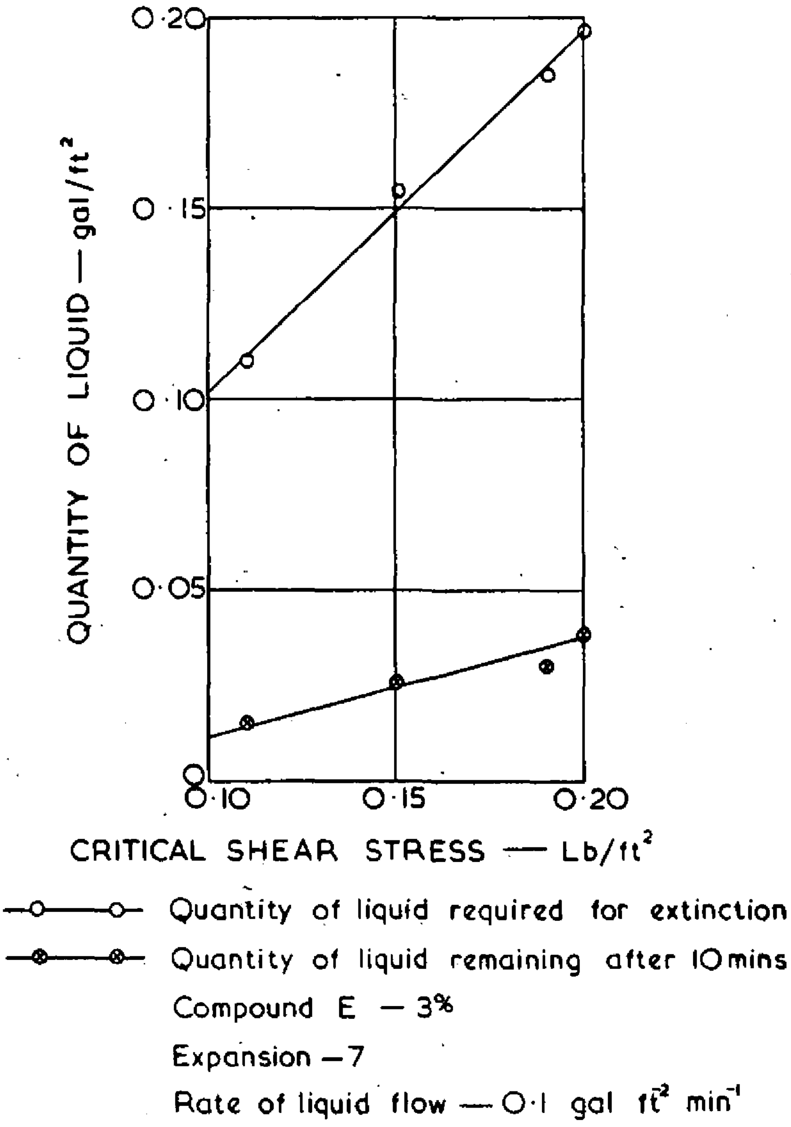


FIG. 4. STABILITY OF FOAM BLANKET (COMPOUND E)

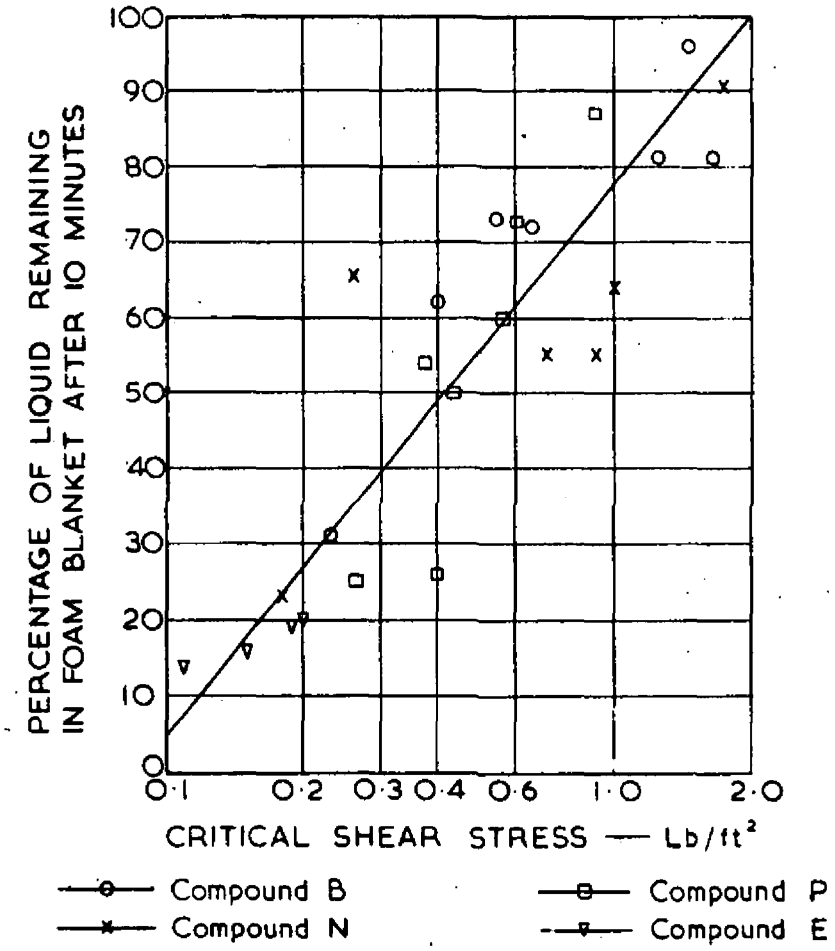
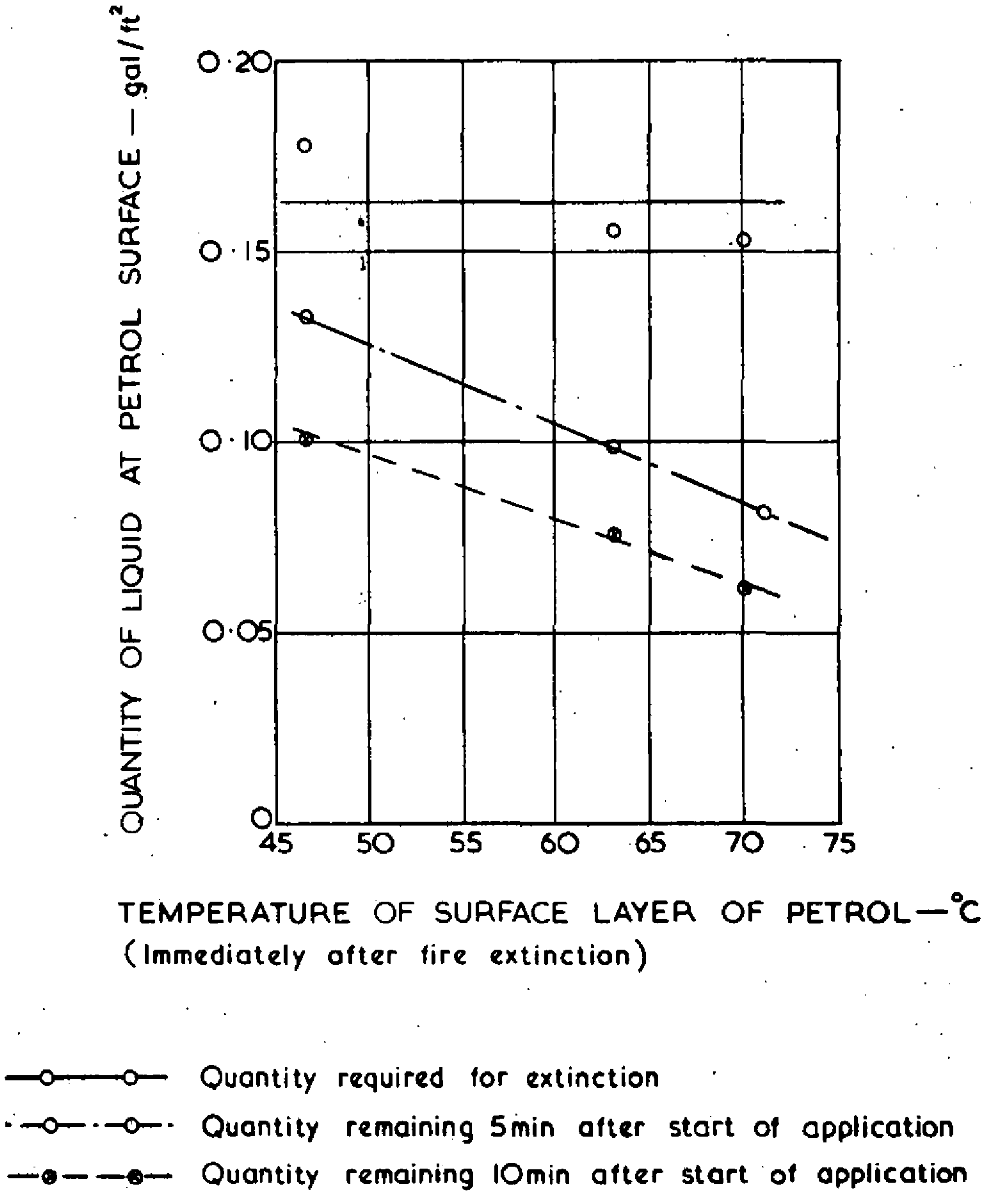


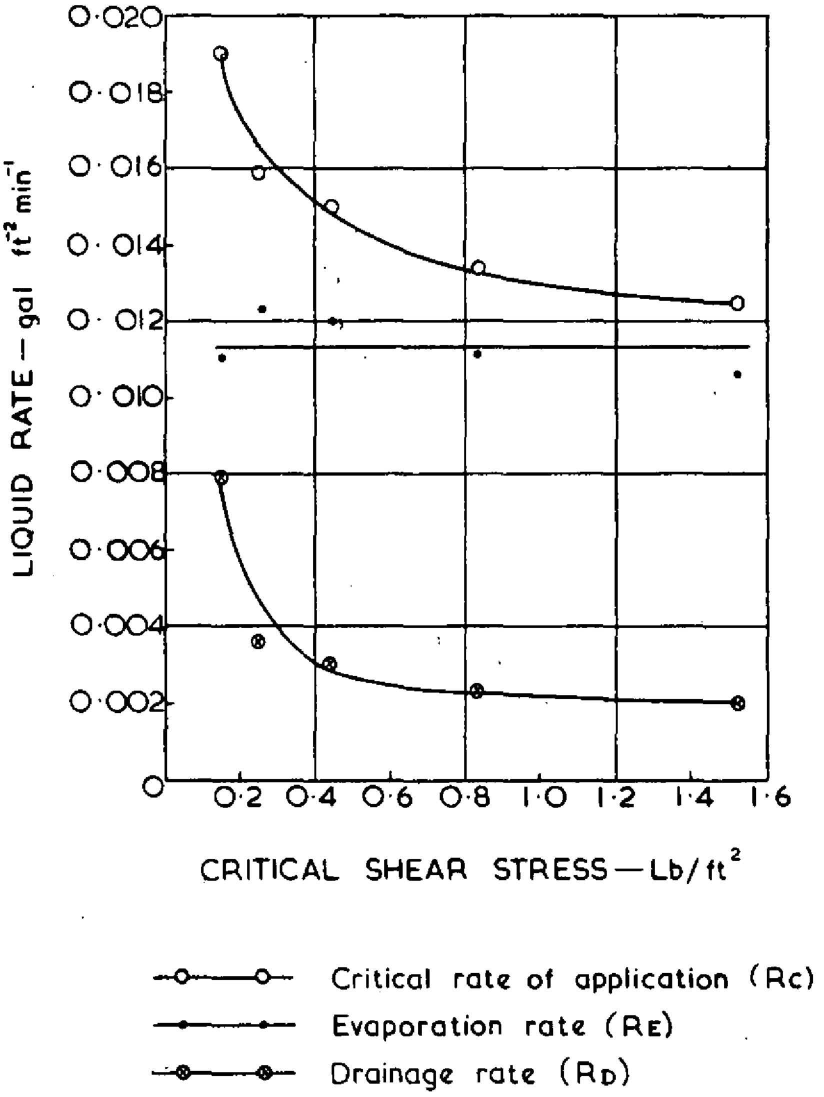
FIG. 5. RELATION BETWEEN CRITICAL SHEAR STRESS AND FOAM STABILITY



Compound B (batch 3)
Foam expansion — 7
Rate of application — 0·1 gal ft^{-2} min^{-1}

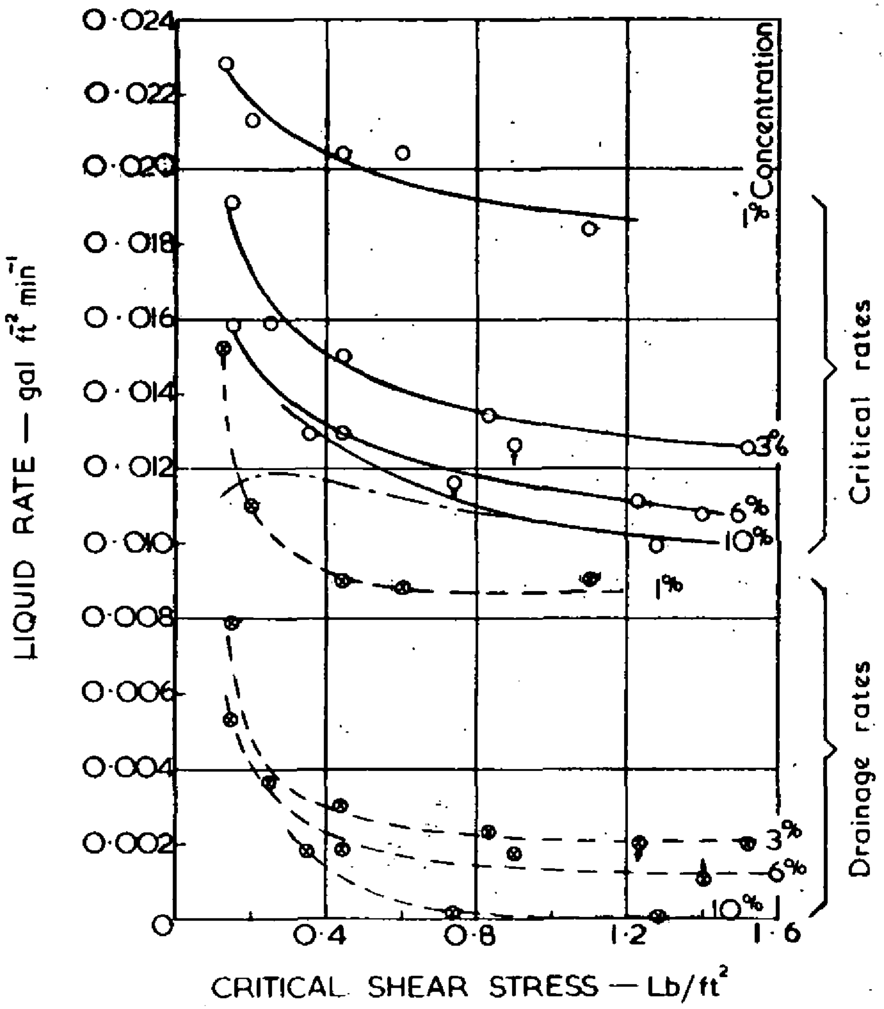
CRITICAL SHEAR STRESS — 0·8 Lb/ft^{2}

FIG. 6. EFFECT OF PETROL TEMPERATURE ON DRAINAGE FROM FOAM BLANKET



Compound B (batch 1)
Expansion — 7
Concentration — 3%
$R_C = R_D + R_E$

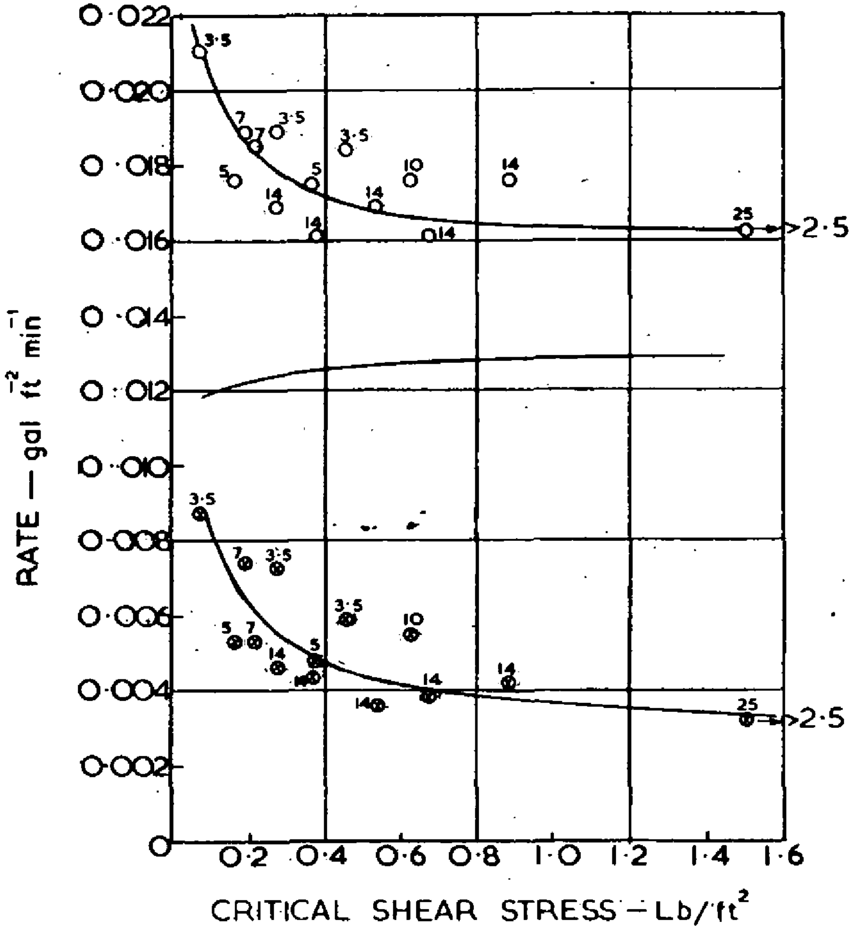
FIG. 7. EFFECT OF CRITICAL SHEAR STRESS ON CRITICAL RATE OF APPLICATION



—·—·— Evaporation rate (mean for all concentrations)

Compound B (batch 1)
Foam expansion — 7

FIG. 8. EFFECT OF CONCENTRATION ON CRITICAL RATE OF APPLICATION



Numbers indicate foam expansion
—○—○— Critical rate
——— Evaporation rate
—⊗—⊗— Drainage rate
Compound B (batch 3)
Concentration — 3%

FIG. 9. EFFECT OF EXPANSION ON CRITICAL RATE OF APPLICATION

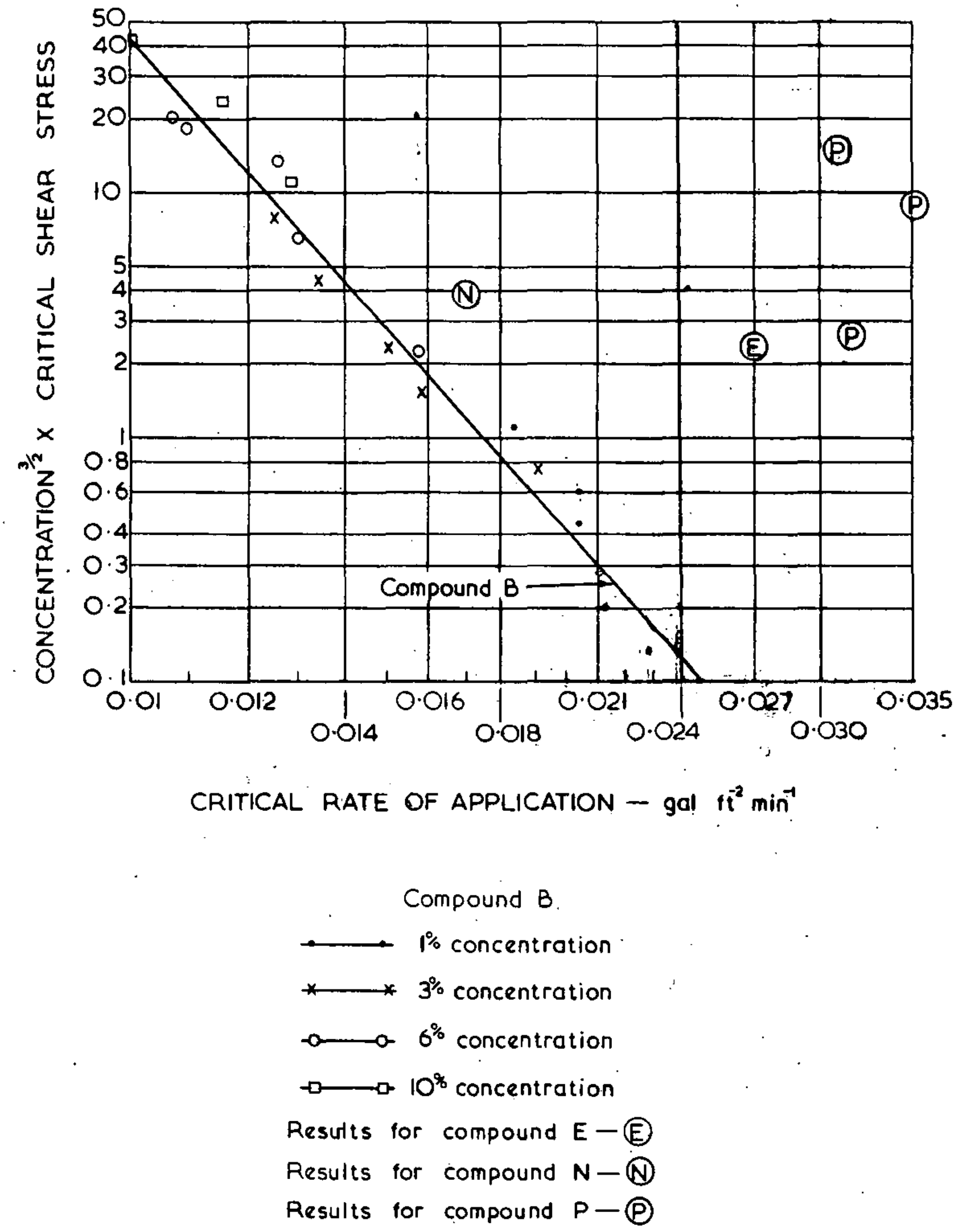
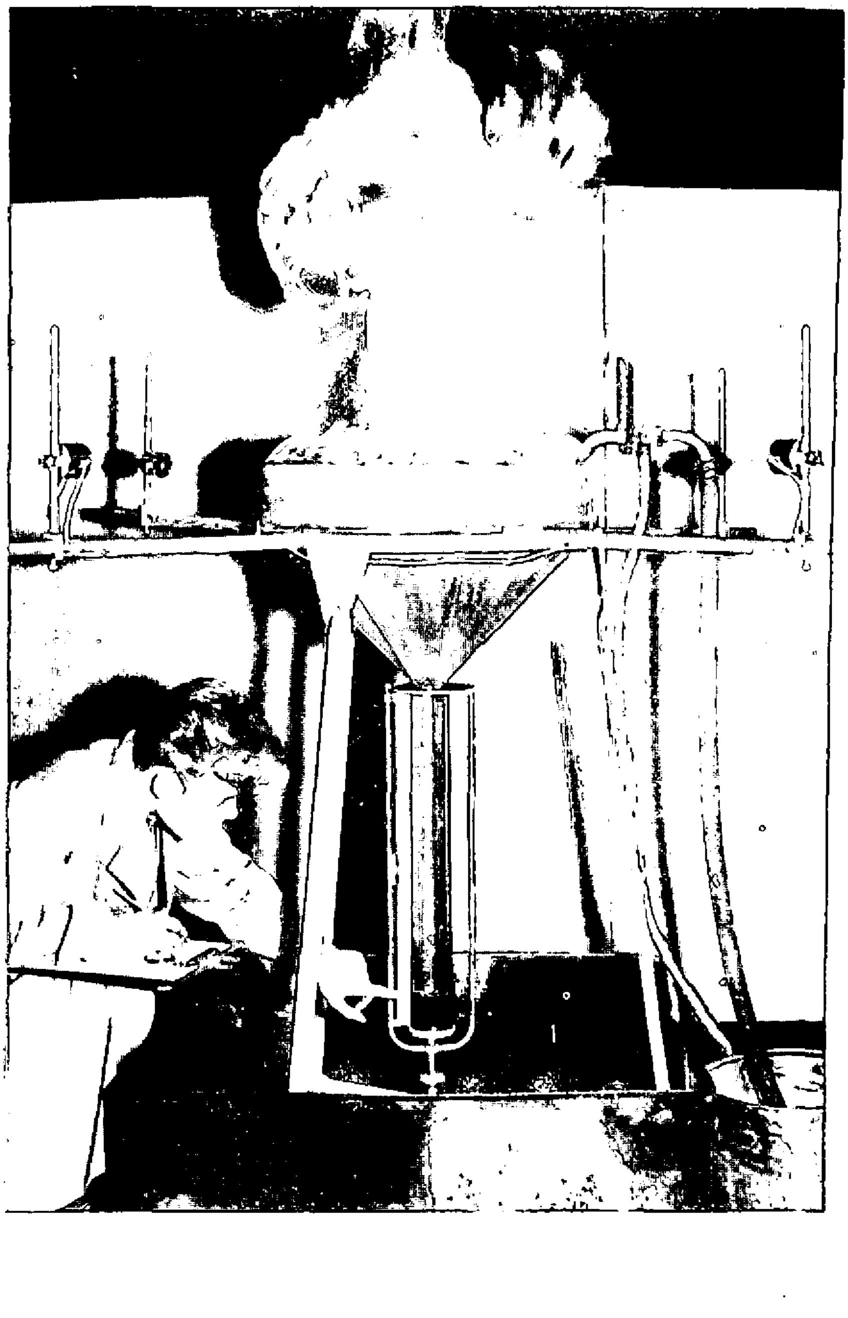


FIG. 10. FACTORS AFFECTING CRITICAL RATE OF APPLICATION



TEST APPARATUS

PLATE 1

[illegible] (5)

[illegible] 25% DDT [illegible] drainage for [illegible].

[illegible] (7)

25% DDT v 2/3 control.

C. vex (8) [illegible] B[illegible]

10 min. Drainage v [illegible]. 2/3 [illegible]