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

FURTHER WORK ON THE COMPATIBILITY OF DRY POWDERS
AND PROTEIN FOAM LIQUIDS

by

P. Nash and D. W. Fittes

SUMMARY

This note describes further experimental work on the compatibility of dry powders and protein foam liquids based on a study of the critical rates of various foam liquids on petrol to which various dry powders have been added, and on the time for a fire to destroy a foam blanket on which various powders have been sprinkled. The main conclusions of other workers are summarised, and suggestions for a suitable specification test for foam-dry powder compatibility are made.

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Introduction

The extinction characteristics of fire-fighting dry powders and foams make them largely complementary for use on flammable liquid fires. Thus dry powders are rapid in their action and efficient in terms of fire area capability per pound of agent, but lack the power to seal the surface of the fire and prevent reignition from hot sources left in the fire area. Foams are slower and less efficient (of the order of $1/5$ the area per pound as compared with dry powders) but have the great advantage over all other conventional agents that they seal the fire area and allow it to cool to a safe temperature. It is therefore natural that the speed and effectiveness of dry powder, and the safety from reignition produced by foam, should be used in conjunction in those flammable liquid fires in which both speed and safety are paramount, the prime example being the aircraft crash fire with many lives at stake.

2. The practical problem

Practical tests⁽¹⁾ using protein foams and "standard" sodium-bicarbonate based dry powders with metallic stearates as water-proofing and flow additives demonstrated several years ago the large degree of incompatibility between these agents, which showed itself as a highly accelerated breakdown rate of the foam blanket on the fire and frustrated the possibility of their combined use. It has been estimated that the fire-fighting potential of an aircraft crash tender with an output of 3-400 gallons/min of foaming solution could be reduced to about $1/10$ th of its normal value by the distribution of 200-300 lb of the powder on the fire area. While the flow additive - a known foam-breaker - was shown to be largely responsible, it was appreciated that the subject was complex, and that many factors would need to be taken into account in reaching a final solution. The problem, then, was to devise a suitable, efficient fire-fighting powder which could be used in conjunction with fire-fighting foam, with only a strictly limited increase in the rate of destruction of the foam by the fire.

3. Factors likely to affect compatibility

A complete study of the subject should include an assessment of the effect of all factors likely to affect compatibility, of which the most obvious are:

- a) the nature of the powder.
- b) the nature of any flow additives, water proofing agents etc., added to the powder.
- c) the nature of the foam liquid.
- d) the nature of the flammable liquid involved in the fire, with special reference to any additives.
- e) the method and order of application of powder and foam with special reference to the degree of turbulence in the fire area, and consequent intermixing of foam and dry powder.
- f) interactions between any combinations of factors a) to e).

4. Requirements for a realistic laboratory test

A primary screening test for compatibility should be used to eliminate those powders which are clearly unsuitable, and this should be followed by a refined test which provides an accurate assessment over the limited range of acceptable compatibility.

Test results are often only strictly applicable to the arbitrary conditions of the test, which may tend to accentuate the effect of one factor and suppress the effect of another. The final test should, if possible, subject the powder to the correct balance of test conditions representative of the worst conditions of practical use.

One of the leading foam and dry powder manufacturers in the United Kingdom uses a range of six different fire tests according to the stage of selection, and the fire conditions, that he wishes to represent; and bearing in mind the type of dry powder (e.g. whether heat-decomposed or not) and density of powder application that he is considering.

In our work on dry powder-foam compatibility at the Joint Fire Research Organization, we have made use of three experimental methods, none of which we would regard as entirely suitable as a final specification test, but all of which have proved valuable in sifting some of the effects of the various factors. At the time of writing, this work is by no means complete, but has nevertheless produced some interesting conclusions. The three test methods, referred to here as I, II and III, are as follows:

Method I Effect of powder on fire control characteristics

A test fire (Fig 1) of 5 lmp gallons of unleaded "regular grade" motor spirit is ignited in a 3 ft diameter x 4 in deep circular steel tray. After a 1 minute "preburn" period, foam from a laboratory foam generator⁽²⁾ is projected into the centre of the fire, the nozzle being 8 feet from the centre of the tray and 4 feet above the liquid surface. The foam, which is applied at one of a number of selected liquid rates, is made from a 3 per cent premixed solution and has the following properties.

Expansion	8
Critical Shear Stress ⁽³⁾	400 dynes/cm ² ± 10 per cent

The radiant intensity of the fire is measured by three radiometers placed at equal intervals round the fire, the time to achieve "9/10th control" of the fire being the interval from start of foam application to reduction of the radiant intensity to 1/10 of its initial value. By plotting a curve of "time to control" against "liquid rate of application", the critical rate of foam application below which fire control cannot be achieved, is deduced. Similar tests are made in which 0.5 lb of the powder agent under review is sprinkled uniformly over the petrol surface before ignition, this quantity having been found sufficient⁽⁴⁾ to produce the maximum effect. Comparisons in the "control time-rate" curves obtained with and without powder may now be made.

Method II Effect on the stability of a foam layer of powder sprinkled in its surface

In this test, the arrangements are identical with those of Method I, but the procedure is different. After a preburn period of 1 minute, foam is applied at a solution rate of 0.14 gal/ft²/min, approximately 7 times the critical rate for foam without powder added. Application is continued until the fire is reduced to 10 per cent of its initial intensity. Application is now stopped and the time for the fire to recover to 1/3 of its initial intensity is measured. Similar tests are now made in which 1 1/4 lb of each of the powders under review are sprinkled uniformly on the surface of the foam blanket at the end of foam application. Comparison of the burn-back times to 1/3 initial intensity are now made. The foam used in this test has the following properties:

Expansion

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Critical Shear Stress 500 or 200 dynes/cm²

Method III N.R.L. Compatibility test

This test, described by Jablonski and Gipe⁽⁵⁾, consists of measuring the drainage rate from a pan of foam, the upper surface of which is irradiated at a given intensity, and comparing with the drainage rate from a similar pan of foam on the surface of which 10 grams \pm 0.1 gram of the powder under review has been sprinkled. Whereas Jablonski and Gipe made their foams in a kitchen mixer, at J.F.R.O. we have prepared our foams in the laboratory foam generator, and made them up from 3 per cent solution, at an expansion of 11, critical shear stress of 750 dynes/cm² and $1/4$ drainage time of 30 minutes.

5. Assessment of the effect of different factors by Methods I, II, III

The different powders tested are listed in Table 1, and the foam liquids in Table 2. In Fig 2, the "9/10 control time" for Foam Liquid V (Method I) is plotted, with various powders added, against the solution application rate, expressed as a multiple of the critical rate for foam without powder (0.02 gal/ft²/min). The critical rates of foam application with the various powders present are listed in Table 3, also expressed as multiples of 0.02 gal/ft²/min.

Table 4 shows the "burn-back times" (Method II) for foams made from foam liquid V, with various powders added. It also shows the "burn-back ratio", i.e. the ratio of burn-back time without powder to the burn-back time with powder. N.R.L. ratios are also given (Method III).

Examination of the fire test results (Methods I and II - Tables 3 and 4) suggests that the degree of foam breakdown due to powders containing the metallic stearate is fairly strongly influenced by the composition of the base powder. Comparing powders with a stearate content of 0.2 per cent, sufficient to retain flow properties, places them in the following order of compatibility on the basis of the three tests, using foam liquid V. The dotted lines divide the powders into those giving ratios of critical rates, N.R.L. ratios, and inverse ratios of burn-back times greater and less than 2, considered to give⁽⁴⁾ approximately the same acceptance level in each test.

Degree of Compatibility	Test I	Test II	Test III
High	NO POWDER	NO POWDER	NO POWDER
	K ₂ SO ₄ (fine)	K ₂ SO ₄	K ₂ SO ₄
	(Cement		
	(Na Cl	Cement	Cement
	-----	-----	-----
	K ₂ SO ₄ (coarse)	(NH ₄) ₂ CO ₃	(NH ₄) ₂ CO ₃
	(NH ₄) ₂ CO ₃	Na ₂ B ₄ O ₇	NaHCO ₃
		Na ₂ CO ₃	Na ₂ CO ₃
		Na HCO ₃	Na ₂ B ₄ O ₇
Low			

The table shows that only fine potassium sulphate, sodium chloride and cement were acceptably compatible, in these tests.

No powders made with a higher concentration of magnesium stearate i.e. 1.5 per cent, were acceptable on the fire tests, I and II; but two of them; viz. cement and sodium chloride, were acceptable on the N.R.L. test, III.

Tests made on powders with other additives than metallic stearate i.e. calcium hydroxyphosphate, talc and high M.P. wax, or no additive, gave the following results, using foam liquid V.

Degree of Compatibility	Additive	Test I	Test II	Test III
High	(Cal. hydrox)	Na HCO ₃	Na HCO ₃	Na HCO ₃
	(No additive)		K HCO ₃	
	(talc, wax)	Na HCO ₃	Na HCO ₃	Na HCO ₃
	(No additive)			K HCO ₃
	(Not known)	K HCO ₃		
Low				

Additional Method (IV)

Additional fire tests were made (Method IV) using the apparatus for Methods I and II, and applying the foam at a fixed solution rate of approximately 0.05 gal/min/ft² i.e. a total rate of 0.35 gal/min. The foam properties were as follows:

Expansion	8
Critical shear stress	400 dynes/in ² ± 10%
Solution strength	3%

The time to achieve "9/10 control" of the fire was measured, and is shown in Table 5. In the last two tests a special narrow boiling point range petroleum fuel was used, as compared with the commercial "regular grade" petroleum used in all previous tests. The Table shows that there are several powders, or powder mixtures, which could form an acceptable base for a foam compatible powder, if found to be suitable extinguishing agents. It also reveals a significant powder - foam liquid interaction in that powders E and V were apparently completely incompatible with foam liquids V and W, but compatible with foam liquid Z. This compares with previous results (Table 3) where differences in critical rate for the same powders and different foam liquids were usually marginal. The effect of fuel was not investigated in the foregoing tests, the narrow B.P. range fuel being introduced merely to reduce chance variations due to differences in commercial grade fuel. Certain check results, not included here, suggest however that the fuel used may itself affect compatibility.

6. Comparison of the test Methods I, II, III

While the results obtained with these three methods are broadly in agreement, they also show some variations. It has previously been shown⁽⁴⁾ that the two fire tests, I and II, give substantially the same grading of powders. The relation between the reciprocal of the N.R.L. ratio ($1/R$) and "solution critical rate" is plotted in Fig 3, and that between the reciprocal of the N.R.L. ratio and the burn-back ratio is plotted in Fig 4, for the results given in Tables 3 and 4.

Figs 3 and 4 appear to indicate that while the N.R.L. test is broadly in agreement with the two fire test methods; there is considerable scatter of individual results, the points for powders containing a comparatively large amount of metallic stearate having the greatest variation. These two curves are replotted in Figs 5 and 6, omitting the points for powder of high stearate content, and show much less variation. A statistical test shows a linear correlation between the reciprocals of the burn-back ratio and the N.R.L. ratio. A possible explanation of the discrepancy in the results of the N.R.L. test on powders of high stearate content is that the stearate is slightly soluble in the petrol, and this will render it more easily available to destroy the foam in the fire tests, than in the N.R.L. test on a dry pan. Also, some powders may form a protective coating in the surface of the foam in the N.R.L. test, which they might not do in practice. In general, the N.R.L. test is felt to be a good, simple, laboratory test for primary selection of possible compatible powders, and for batch testing of powders of similar formulation, but not necessarily suitable in its own right as a specification acceptance test.

Effect of pH of powders in solution

Jablonski and Gipe⁽⁵⁾ found that some foams were more susceptible to breakdown by sodium bicarbonate than others. They measured the pH of solutions drained from the foam, and concluded that the less stable foams were made from foam liquids which were particularly susceptible to changes in pH, as would be caused by the applied powder entering partly into solution in the foam. Hird and Fittes⁽⁴⁾ made foams from solutions made up either with distilled water or near-saturated solutions of the following salts

Sodium bicarbonate

Potassium sulphate

Sodium chloride

The liquid concentration and degree of mixing and aeration were adjusted for each foam liquid to give a chosen expansion (10-11.5) and critical shear stress (750 dynes/cm²) with foams made in distilled water. Similar concentrations and mixing effort were then used with the near-saturated solutions. The critical shear stresses, and hence the stability, of foams made with sodium bicarbonate solution were considerably less than those for foams made with distilled water. Those for foams made with potassium sulphate were generally higher, and those for foams made with sodium chloride were usually 2 to 3 times greater than those for foams made with distilled water. Potassium sulphate and sodium chloride also gave low increases in N.R.L. ratio when mixed with 0.2 per cent magnesium stearate, and from this, Hird and Fittes concluded that these two salts were likely to be particularly suitable as foam compatible powders, subject to their extinction performance and other properties being adequate.

A further study of the effect of some salts on the stability of protein foams has now been made by carrying out N.R.L. tests on foams and coarse powders (specific surface 1000 cm²/gm). These results (Fig 7) confirm that powders which give very acidic or very alkaline solutions ($4 > \text{pH} > 10$) cause a high rate of drainage from the foam. Between these limits ($4 < \text{pH} < 10$) there is no clear relationship between pH and N.R.L. ratio, but of the salts examined, those which gave near-neutral solutions caused little or no foam breakdown.

7. Choice of a specification test

In considering the requirements of a suitable specification acceptance test, it was deemed that the powder-foam combination must be subjected to conditions as searching as the most severe practical conditions, and that as realistic a balance as possible must be struck between the various factors listed in Section 3. Economy of time and material in making the test was second in order of importance. Method III was excluded as a specification test for the reasons already given, and because a fire test was felt to be necessary. Methods I and II, while giving similar gradings, were not of equal merit in practice. Thus the burn-back test, Method II, suffered from two serious difficulties. First, very close control of the foam properties was necessary, particularly of critical shear stress which affects drainage

from the foam. Second, variability of foam batches was found to influence burn-back time by at least a factor of 2. A third difficulty was that the test was not representative of U.K. practice in that powder is usually used as the first "knock-down" agent and not as a second "mopping-up" agent. This left the "critical rate" method, I, for consideration.

This method had several advantages. First, it was typical of practice. Second, it was not susceptible to large variation in results due to small differences in foam liquid batches. Third it was relatively simple to carry out, the "time to control" being a single measurement taken from the recording chart for a fire which was being gradually and continuously reduced in intensity by the foam application.

The normal solution critical rate of application to a petrol fire is approximately 0.02 gal/min/ft². Table 3 shows that even the most compatible of the powders D, G, K, Q cause some increase in the critical rate of foam solution application (although the additional results, Table 5, suggest that powder Z may not). On the basis of experience with Method I and IV, it was decided to adopt a similar test arrangement, where 0.5 lb of powder were sprinkled evenly over the fuel surface, and the foam was then applied at a solution rate of 0.35 gal/min to the burning petrol. It was found that, without the powder present, the fire was "9/10 controlled" in 1½-2 minutes, and that a reasonable acceptance level with powder present would be 9/10 control in 5 minutes. Experience with this test has since shown the necessity for a "control" test without powder present, because the variations in foam batches were sufficient to influence the acceptance of the powder, and it is proposed that a ratio of control times be adopted in lieu of an outright "acceptance time" with powder present. The fuel used in the test at present is the narrow B.P. range petroleum, but there is reason to believe that the type of fuel may affect compatibility, even where this is expressed as a ratio. Further studies are therefore necessary in this matter.

3. Conclusions from J.F.R.O. work

The work described in the foregoing note has led to the following provisional conclusions regarding the compatibility of dry powders and protein-based foams:

(1) Compatibility is dependent upon the constitution of the base powder. Of the commonly-used dry powders, sodium and potassium bicarbonates, chlorides and sulphates are capable of being treated to form compatible powders, either alone or as mixtures.

(2) Compatibility is also dependent upon the chemicals added to the powders to improve flow and water-repellant properties. Up to about 0.2 per cent of metallic stearates can be used with certain powders e.g. potassium sulphate, sodium chloride, but they are not suitable for use with sodium bicarbonate. Inert materials such as talc, mica, etc., can sometimes be used advantageously where metallic stearates cannot be used.

(3) Compatibility depends upon the nature of the foam liquid as well as upon the nature of the powder, and if complete freedom of use of all compatible powders with all foam liquids is required, it is likely to be necessary to study this interaction and to modify the foam liquid accordingly.

Even so, it is deemed necessary to test with all foam liquids approved by the Ministry of Public Building and Works.

(4) There is little data on powder-fuel interaction, but recent work, not included in this note, suggests that fuel must be included in the overall study.

(5) Of the test methods available, a "critical rate" method is preferred as a final specification test, subject to control tests without powder to eliminate the effect of foam liquid batch variation.

(6) The variations between different foam liquids make it necessary, at the present time, to test each powder against all approved foam liquids. This appears to place undue onus on the powder manufacturer, and it is suggested that a compatibility test with a special "reference" powder be introduced in the foam-liquid specification to control variation from this cause.

9. Other British work

In their examination of dry powder-foam compatibility, the Pyrene Co. (6) have used a series of 6 tests to assess the suitability of different powders. These tests are:

1. A "burn-back" test in which $3/4$ Imp. gallon of petrol, floating on water in a 2 ft x 1 ft tray, is first extinguished using a 2 gal/min branch pipe, the foam scraped level with the top of the tray, and one third of the petrol surface is then exposed. 180 grams of powder are applied evenly to the remaining foam surface, the exposed fuel reignited, and the time for the fire to destroy the blanket is measured. While this test gave a good qualitative comparison, they found it essential to measure a ratio of burn-back times, with and without powder. Results were variable, according to the wind conditions, and the powder suffered more heating than it may do in practice, and did not get mixed with the foam. Nevertheless, the method could be used to demonstrate the effect of heat-decomposable powders, or additives e.g. silicone fluids.

2. One litre of petrol in a shallow 3 ft x 3 ft tray is ignited, and then extinguished with the powder under review. A further litre of petrol is added, and the fire is reignited. After 10 seconds, foam is applied at 2 gal/min for two periods of 5 seconds each. The area of fire is recorded at known intervals after cessation of foam application. This test was found to be excellent for demonstrating large differences, but useless for selecting small differences at a high level of compatibility. The area of fire was difficult to assess sufficiently accurately.

3. Developed as an improvement of 2 above, this test utilises a small 10 in x 10 in fire. Foam prepared by mixing air at constant pressure and a 10 per cent premix solution in a glass tube containing brass eyelets, is applied through a $3/64$ in nozzle to the fire tray, containing 150 cc petrol into which 25 grams of powder has been uniformly sprinkled (0.08 lb/ft²). After a preburn of 20 seconds, foam is applied for 1 minute. This does not extinguish the fire, and compatibility is expressed as estimated percentage breakdown of the foam layer, $1/2$, 1 and $1\frac{1}{2}$ minutes after the end of foam application.

It was found necessary to use the same batch of foam liquid to minimise variations, but the test was very useful for development work as its sensitivity could readily be increased to accommodate fine comparisons particularly at high levels of compatibility. Area of foam breakdown was still the most difficult factor to judge. The arrangement is shown in Fig 8.

4. A development of 3 above, this method is intended to give even better mixing of the dry powder and foam by blowing the powder into the centre of the foam stream immediately on emergence from the branch pipe (Fig 9). Air at 70 lb/in² displaces the 4 per cent premixed foam solution from the tank, and an air bleed passes through a drier, regulating valve and thence at a pressure of 20 lb/in² to a powder dispenser. The branch pipe is rated at 2 gal/min foam solution, and the powder dispenser may be swung from the pendant to the upright (dispensing) position at will.

In the test, 1 gallon of petrol in a 3 ft x 3 ft tray is ignited and burns for 15 seconds before the foam/dry powder stream is directed at it from a distance of 56 in. After 12 seconds, application is stopped and the dispenser is swung simultaneously into the pendant position. The fire is not extinguished, and compatibility is judged by the time for complete destruction of the foam layer after the end of foam/powder application.

The degree of mixing of the foam, powder and fuel in this test is so great that even a small amount of powder has a great destructive effect on the foam. The whole range of results from complete compatibility (no powder) to minimum acceptable compatibility is compressed into a time scale of less than 4 minutes, the time for destruction of the foam layer with no powder present. The test is found to be capable of giving useful information, but poor reproducibility of results mars its usefulness.

5. This is a modification of the N.R.L. method to give higher foam expansions in the mixer, by use of injected air, constant water temperature (16°C), and, in the drainage apparatus, a continuously draining foam pan with a 50-mesh gauze strainer to prevent loss of foam as well as liquid. Special care is taken to spread the powder evenly on the foam. While reproducibility of results was found to be improved, it was felt that spreading the powder on the foam produced shielding effects not usually present in practice.

6. This is in the nature of a burn-back test on a 2 ft x 1 ft tray, on which a layer of foam had been spread, followed by removal of a quarter of the foam layer from each end of the tray, and the spreading of powder on the remainder. The free fuel surface was then ignited at each end of the tray, and after 2 minutes, the remaining foam layer is broken up with steel rods. Three minutes after ignition, foam is applied in 5 second "bursts", mixing the tray contents as much as possible. The total foam application required to fill the tray is taken as a measure of compatibility, expressed as a ratio to the amount necessary for a test with no powder added.

This test was found to give good reproducibility, and good resolution at a high level of compatibility. The effect of the intimate mixing of powder, fuel and foam under fire conditions is considered to be typical of the most severe practical conditions. It is suggested as a standard test at one level of powder loading, 0.5 lb/ft² being the figure recommended.

The following results show a comparison of three of the methods, for a range of three powders.

Method:-	1	2	6
Ratio:-	<u>Blank</u> <u>Test</u>	<u>Test</u> <u>Blank</u>	<u>Test</u> <u>Blank</u>
NaHCO ₃ + 1 per cent calcium hydroxy phosphate	1.4	2.1	1.3
Foam-compat. powder	0.9	0.7	1.2
NaHCO ₃ + 0.2 per cent mag. stearate	5.3	22.5	6.8

References

1. N.R.L. letter 3250-72/49. "Effect of Fire Extinguishing Dry Chemicals (Bicarbonate Base) on Mechanical Foam Blankets. 1/6/49. PETERSON, H. B. and TUVE, R. L.
2. FRY, J. F. and FRENCH, R. J. J. appl. Chem., 1951, 1, 425-9.
"A mechanical foam generator for use in laboratories".
3. FRENCH, R. J. J. Sci. Instrum., August, 1960, Vol. 37, 307-308
"Foam Viscometer".
4. F.R. Note No. 418/1960. "The effect of various powdered materials on the stability of protein foams". HIRD, D. and FITTES, D. W.
5. N.R.L. Report No. 5329 (23/6/59). "A new method for determining the degree of compatibility of dry chemical powders with mechanical foams. JABLONSKI, E. J. and GIPE, R. L.
6. Private communication, Pyrene Co., Ltd.

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Table 1

Description of powders tested

	Powder Identification Letter	Powder/Additive	Specific* Surface cm ² /gm
Proprietary British powders	A	Sodium bicarbonate/3% talc 1.5% mag. stearate	3,990
	B	Sodium bicarbonate/1% calcium hydroxyphosphate	1,100
	C	Sodium bicarbonate/2% talc, 2-2.5% high M.P. wax	1,370
	D	Potassium sulphate/Not stated	3,350
Proprietary U.S.	E	Potassium bicarbonate/Not stated	2,930
Non-proprietary powders	F	Ammonium Carbonate/0.2% mag. stearate	1,000
	G	Cement/0.2% mag. stearate	3,340
	H	Cement/1.5% mag. stearate	3,730
	J	Potassium bicarbonate/None	2,340
	K	Potassium sulphate/0.2% mag. stearate	1,670
	L	Potassium sulphate/0.2% mag. stearate	2,700
	M	Potassium sulphate/1.5% mag. stearate	2,460
	N	Sodium bicarbonate/0.2% mag. stearate	1,050
	O	Sodium borate/0.2% mag. stearate	1,240
	P	Sodium chloride/0.2% mag. stearate	1,100
	Q	Sodium chloride/0.2% mag. stearate	2,810
	R	Sodium chloride/1.5% mag. stearate	2,260

*Lea & Nurse Method - British Standard 12.

Table 2

Description of foam liquids used

Identification Letter	Description
V	Hydrolysed keratin, stabilised with ferrous sulphate
W	Keratin, hydrolysed with lime, stabilised with ferrous salts
X	Hydrolysed blood, stabilised with ferrous salts
Y	U.S. Concentrate (1)
Z	U.S. Concentrate (2)

Table 3

Values of Critical Rate* (Method I)

Powder Identification	Critical Rate Ratio			
	Liquid V	Liquid W	Liquid X	Liquid Y**
A	≥ 10	-	-	-
B	$\geq 2.5 < 5$	-	-	-
C	$\geq 5 < 10$	$\geq 2.5 < 5$	-	-
D	$1\frac{1}{2}$	$< 2\frac{1}{2}$	$< 2\frac{1}{2}$	$< 2\frac{1}{2}$
E	$\geq 12 < 16$	$\geq 2\frac{1}{2}$	-	$\geq 2\frac{1}{2}$
F	6	-	-	-
G	< 2	-	-	-
H	6	-	-	-
J	$\geq 14 < 16$	-	-	-
K	$1\frac{1}{2}$	2	$< 2\frac{1}{2}$	-
L	$2\frac{1}{2}$	-	-	-
M	-	-	-	-
N	$\geq 5 < 8$	$\geq 5 < 8$	$\geq 14 < 16$	-
O	-	-	-	-
P	-	-	-	-
Q	2	-	-	-
R	5	-	-	-

* Expressed as multiples of the critical rate without powder viz. 0.02 gal/min/ft².

** Only a small quantity available.

Table 4

Burn-back times (Method II) and N.R.L. ratios (Method III)

Foam liquid V only

Powder Identification	Burn-back times (Method II)				N.R.L. ratios (Method III)	
	Stiff foam (500 dynes/cm ²)		Fluid foam (200 dynes/cm ²)		R	I/R
	Time (min)	Ratio	Time (min)	Ratio		
None	19.9	1.0	11.1	1.0	1.0	1.0
A	2.5	7.96	1.9	5.84	14.0	0.07
B	9.4	2.12	6.4	1.73	3.1	0.32
C	3.4	5.85	1.9	5.84	5.7	0.18
D	15.0	1.33	5.3	2.09	1.0	1.0
E	-	-	-	-	-	-
F	9.4	2.12	-	-	5.7	0.18
G	11.8	1.69	7.9	1.40	1.6	0.63
H	5.2*	3.82	-	-	1.4	0.71
J	6.1	3.26	-	-	8.5	0.12
K	-	-	-	-	-	-
L	-	-	-	-	-	-
M	4.6	4.32	-	-	5.3	0.19
N	3.0	6.63	1.7	6.52	16.0	0.06
O	5.7	3.49	-	-	23.0	0.04
P	5.3*	3.75	-	-	23.4	0.04
Q	-	-	-	-	-	-
R	5.7	3.49	-	-	-	-

$$\text{Burn-back ratio} = \frac{\text{Burn-back time (no powder)}}{\text{Burn-back time (with powder)}}$$

The means given are the results of at least 2 tests except where marked

Table 5

9/10th Control Times for Various Foams and Powders (Method IV)

Powder Identification	Powder/Additive	9/10th Control Time				
		Liquid V	Liquid W	Liquid X	Liquid Y*	Liquid Z*
D	Potassium sulphate/Mica/0.2 per cent mag. stearate	140 (1.0)	85 (1.0)	290	103	-
E	Potassium bicarb./unknown	N.C. (25)	N.C. (20)	-	N.C.	150 (2.3)
G	Cement/0.2 per cent mag. stearate	220	-	-	-	-
K	Potassium sulphate/0.2 per cent mag. stearate	290 (1.0)	159	290	-	-
Q	Sod. chloride/0.2 per cent mag. stearate	203	-	-	-	-
S	Pot. sulphate, sodium chloride, tricalcium phosphate/0.2 per cent zinc stearate	287	85	-	-	-
T	Pot. sulphate, potassium chloride, talc, 0.2 per cent mag. stearate	218 (1.8)	-	-	-	-
U	As T, 0.5 per cent mag. stearate	287 (3.2)	-	-	-	-
V	Sod. bicarbonate based, to MIL-F-19563(Aer)	N.C. (7.3)	N.C. (6.6)	-	-	173 (1.0)
W	Pot. chloride, pot. sulphate, talc, 0.5 per cent mag. stearate	111	92	119	-	-
X	As W, also tricalcium phosphate, 0.4 per cent mag. stearate	-	88	103	-	-
Y	NO POWDER. B.P. 60-70°C Boiling range fuel	56	60	-	-	-
Z	As Y, but proprietary sod. bicarbonate powder	52.5	54.4	-	-	-

*Only small quantities of these liquids available.

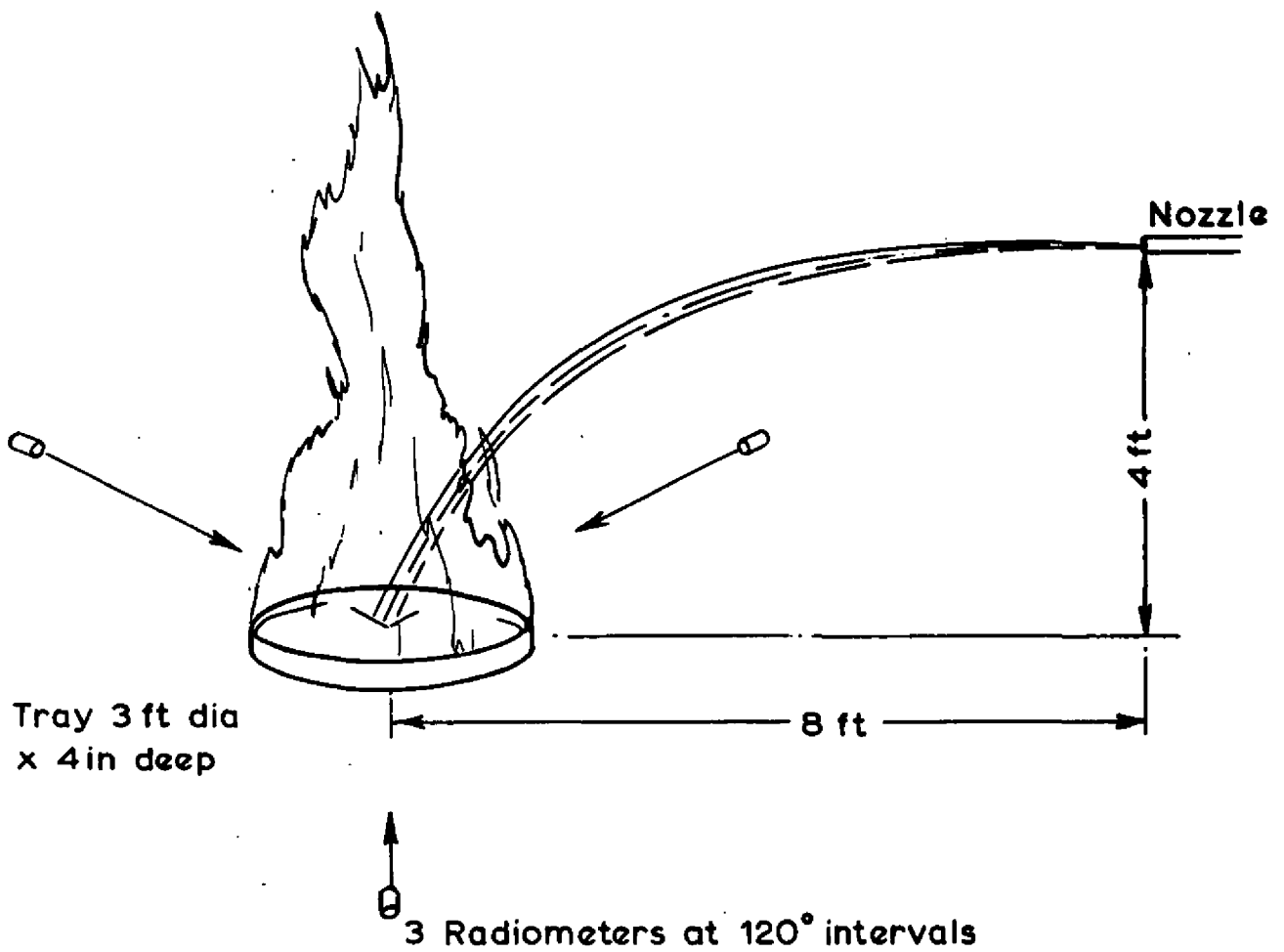
/N.R.L. ratio shown in brackets.

Table 6

Compatibility and pH of aqueous solutions of powders
(See Fig. 5)

	Salt	pH of aqueous solution*	N.R.L. test ratio R
1	Boric acid crystals	4.2	1.1
2	Ammonium chloride	6.5	1.0
3	Ammonium nitrate	6.6	1.1
4	Potassium sulphate	7.0	1.4
5	Sodium chloride	7.0	1.0
6	Ammonium carbonate	10.2	1.8
7	Sodium bicarbonate	8.5	3
8	Oxalic acid	0.9	20.4
9	Potassium bicarbonate	8.3	5.8
10	Sodium hydroxide	12.5	7.8
11	Potassium hydroxide	13.7	10.6

*Concentration of 5 gm per 100 ml distilled water at 20°C.

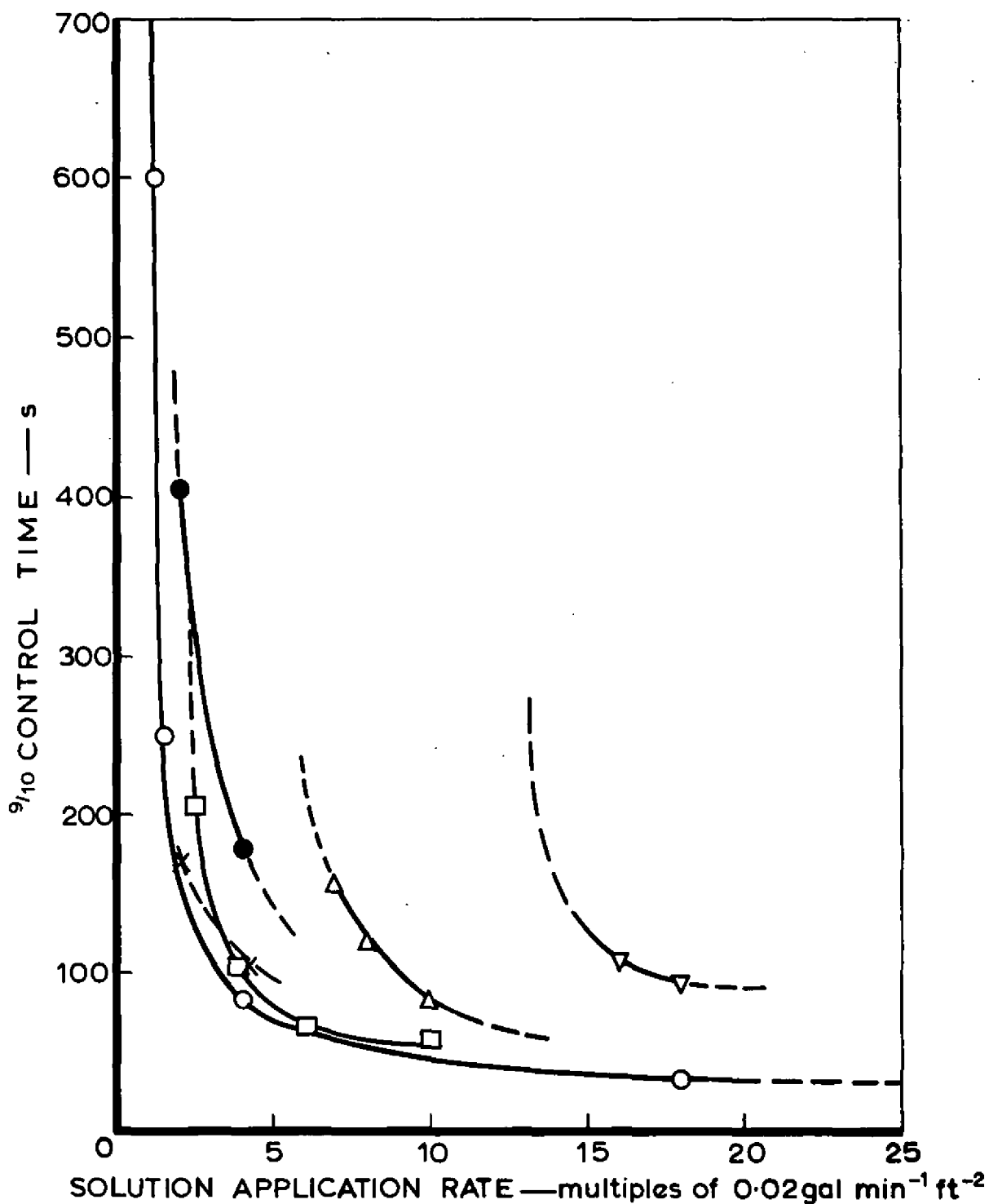


Solution application rate

Method I — various

Method II — 0.14 gal min⁻¹ft⁻²

FIG. 1. EXPERIMENTAL ARRANGEMENT, METHODS I AND II

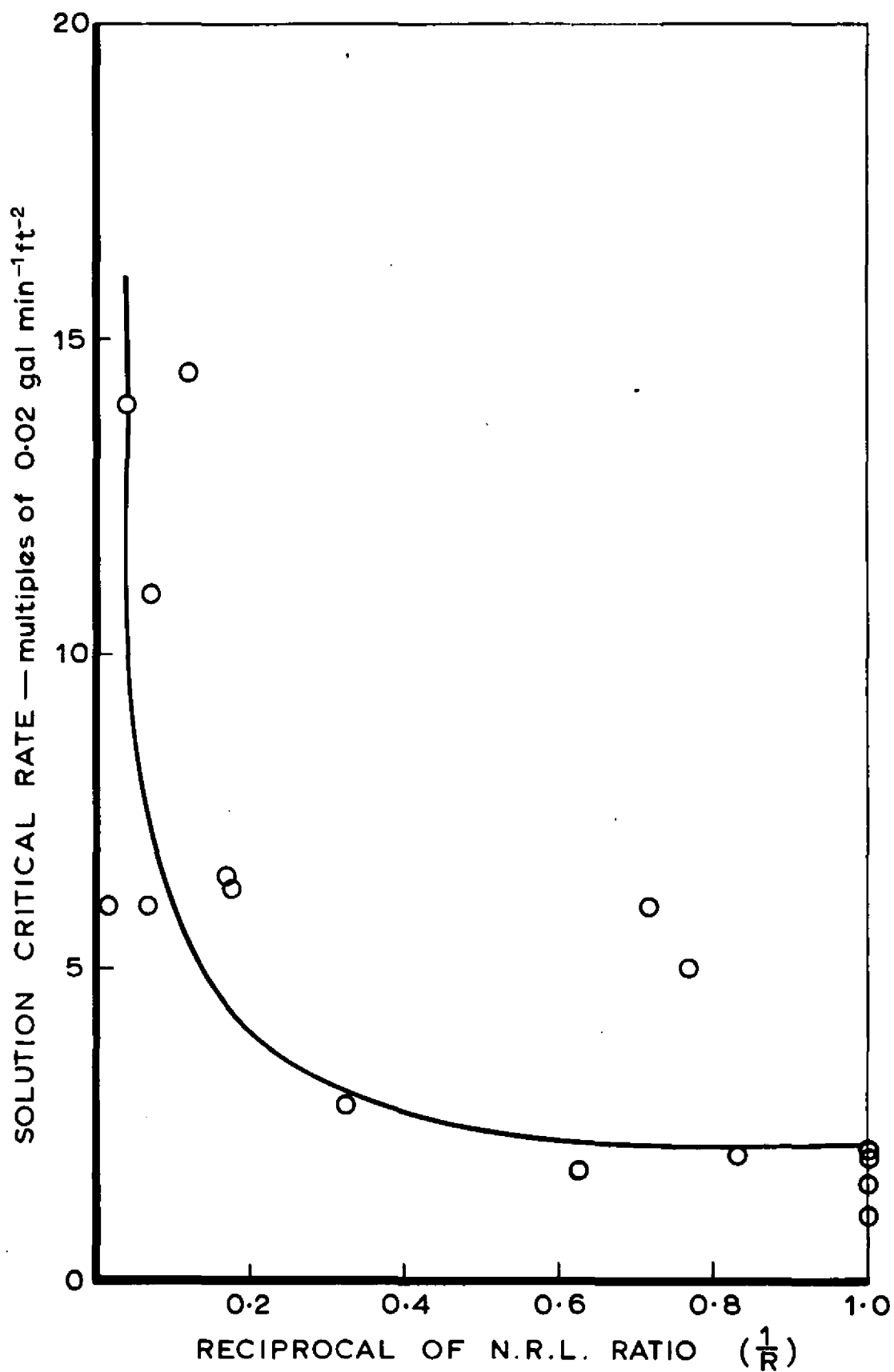


Foam liquid V on burning petrol containing these powders :

Symbol	Powder
O	None
X	D
□	Q
●	H
Δ	K
▽	E

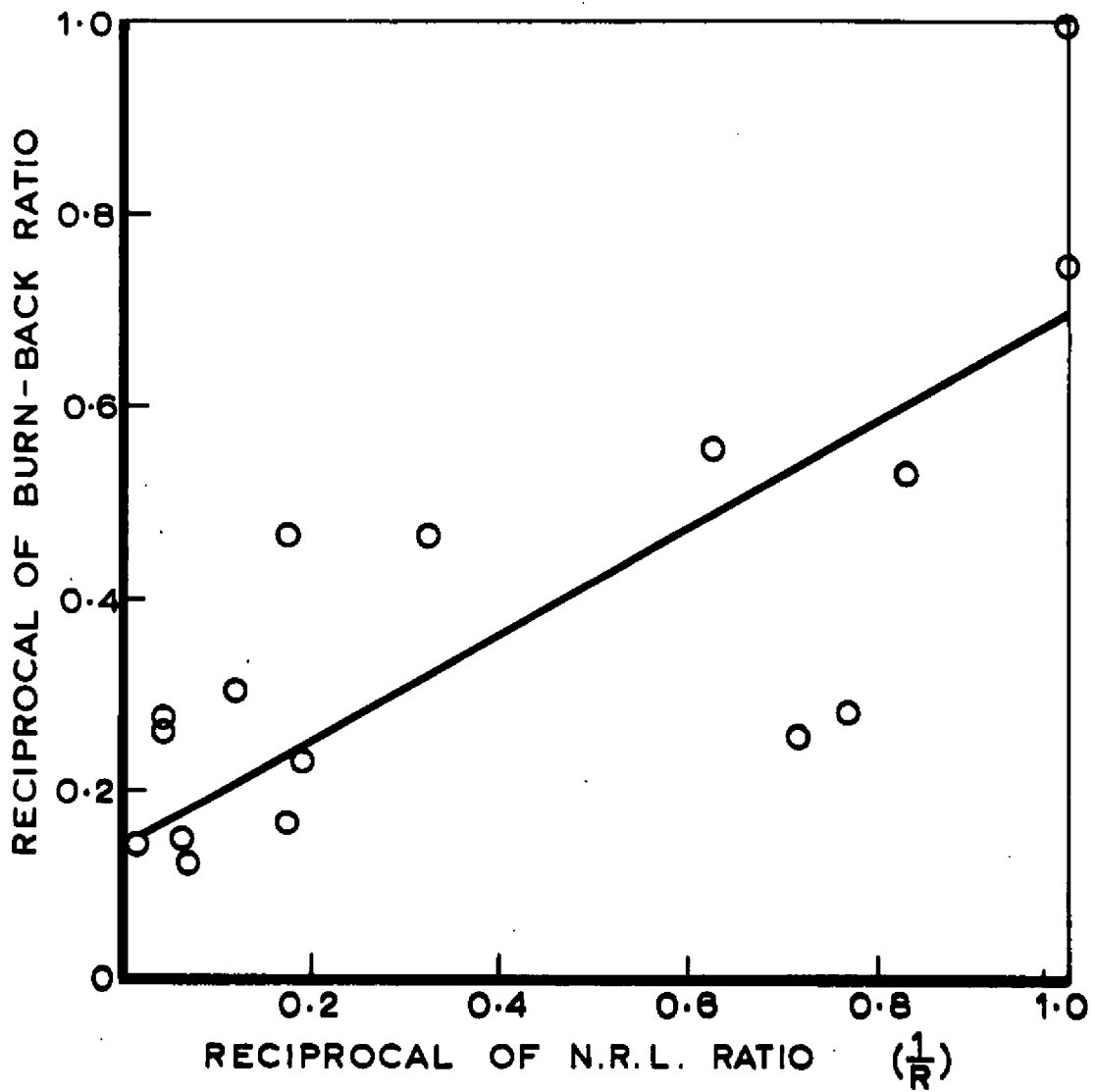
FIG. 2. FIRE CONTROL TIMES (METHOD I) WITH VARIOUS POWDERS

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Foam liquid V on burning petrol containing various powders

FIG. 3. RELATION BETWEEN CRITICAL RATE AND N.R.L. RATIO (R)



$$\text{Burn-back ratio} = \frac{\text{Burn-back time (no powder)}}{\text{Burn-back time (powder)}}$$

FIG. 4. RELATION BETWEEN BURN-BACK TIME AND N.R.L. RATIO (R)

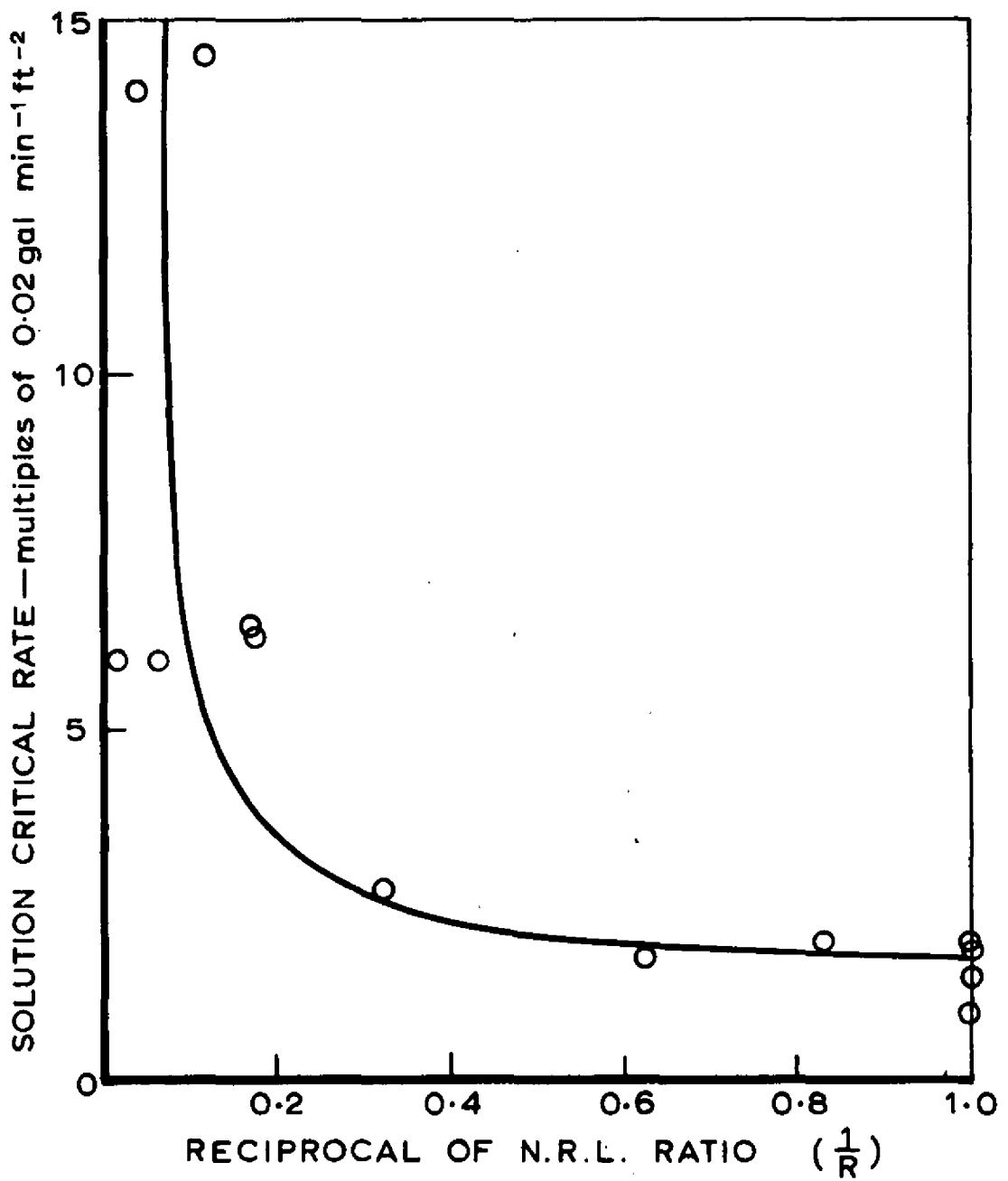


FIG. 5. RELATION BETWEEN SOLUTION CRITICAL RATE AND N.R.L. RATIO EXCLUDING POWDERS WITH HIGH STEARATE CONTENT

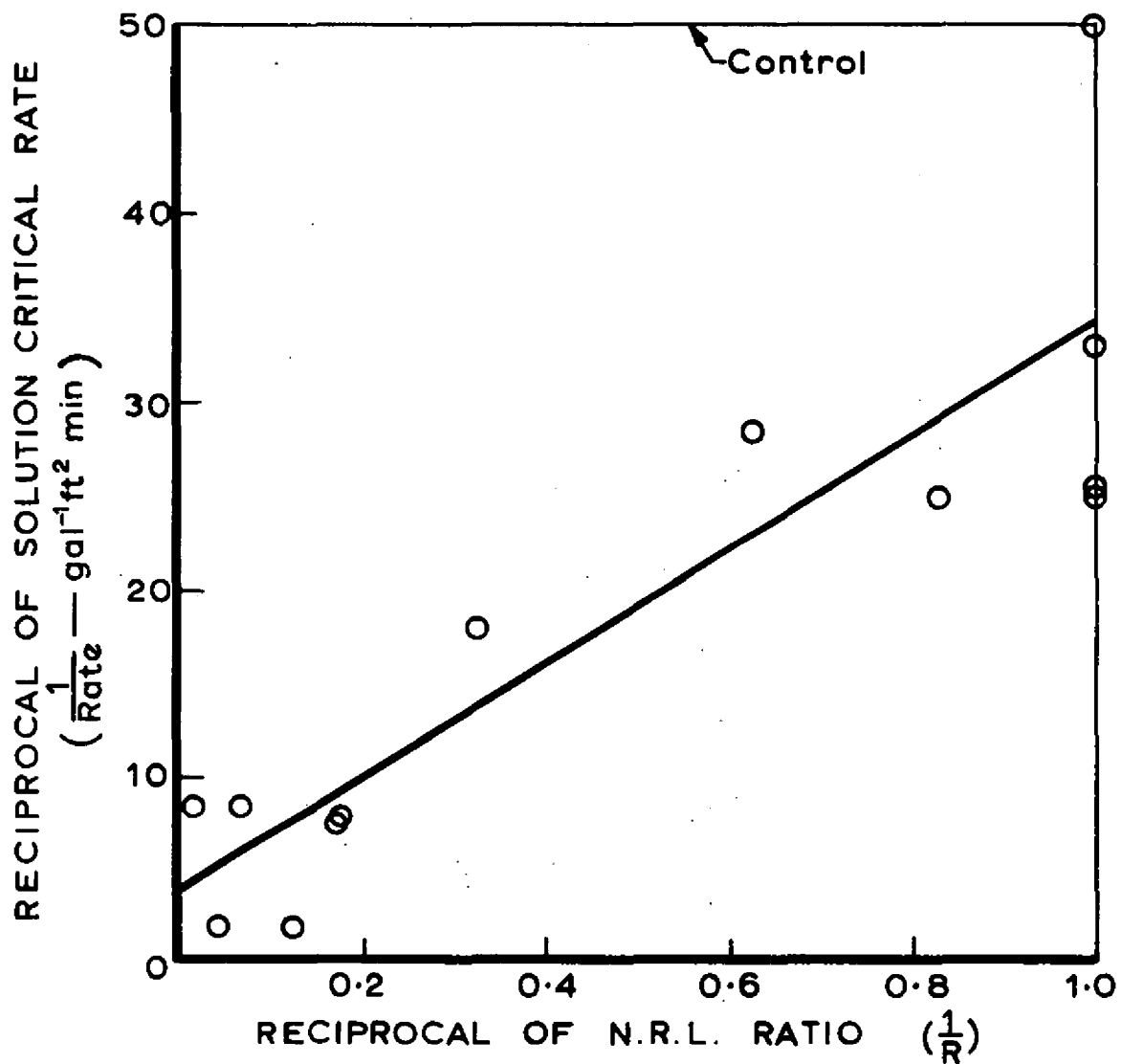


FIG. 6. RELATION BETWEEN RECIPROCALLS OF CRITICAL RATE AND N.R.L. RATIOS EXCLUDING POWDERS WITH HIGH STEARATE CONTENT

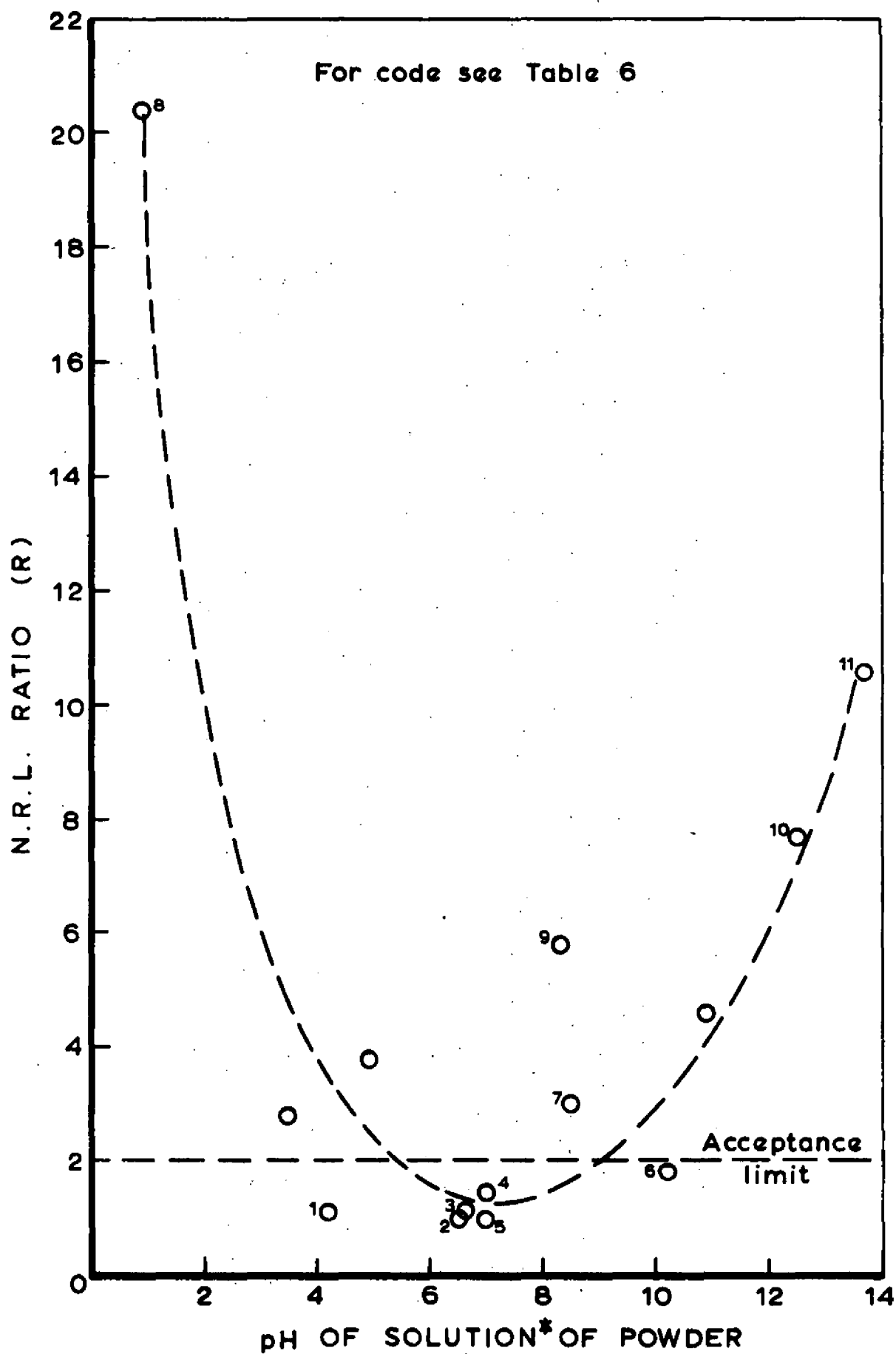


FIG. 7. N.R.L. RATIOS FOR POWDERS GIVING VARIOUS pH IN AQUEOUS SOLUTION

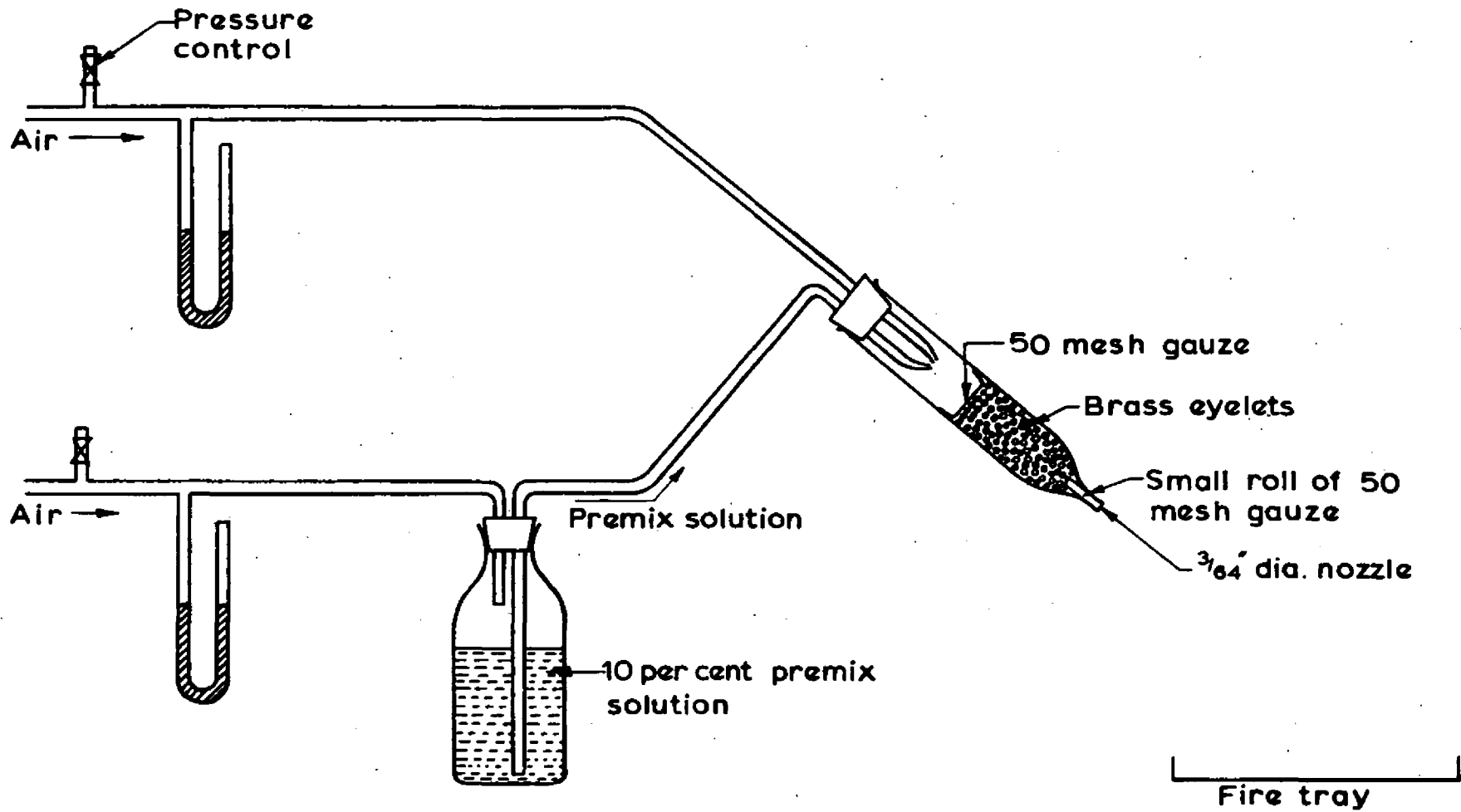


FIG. 8. COMMERCIAL TEST METHOD No. 3

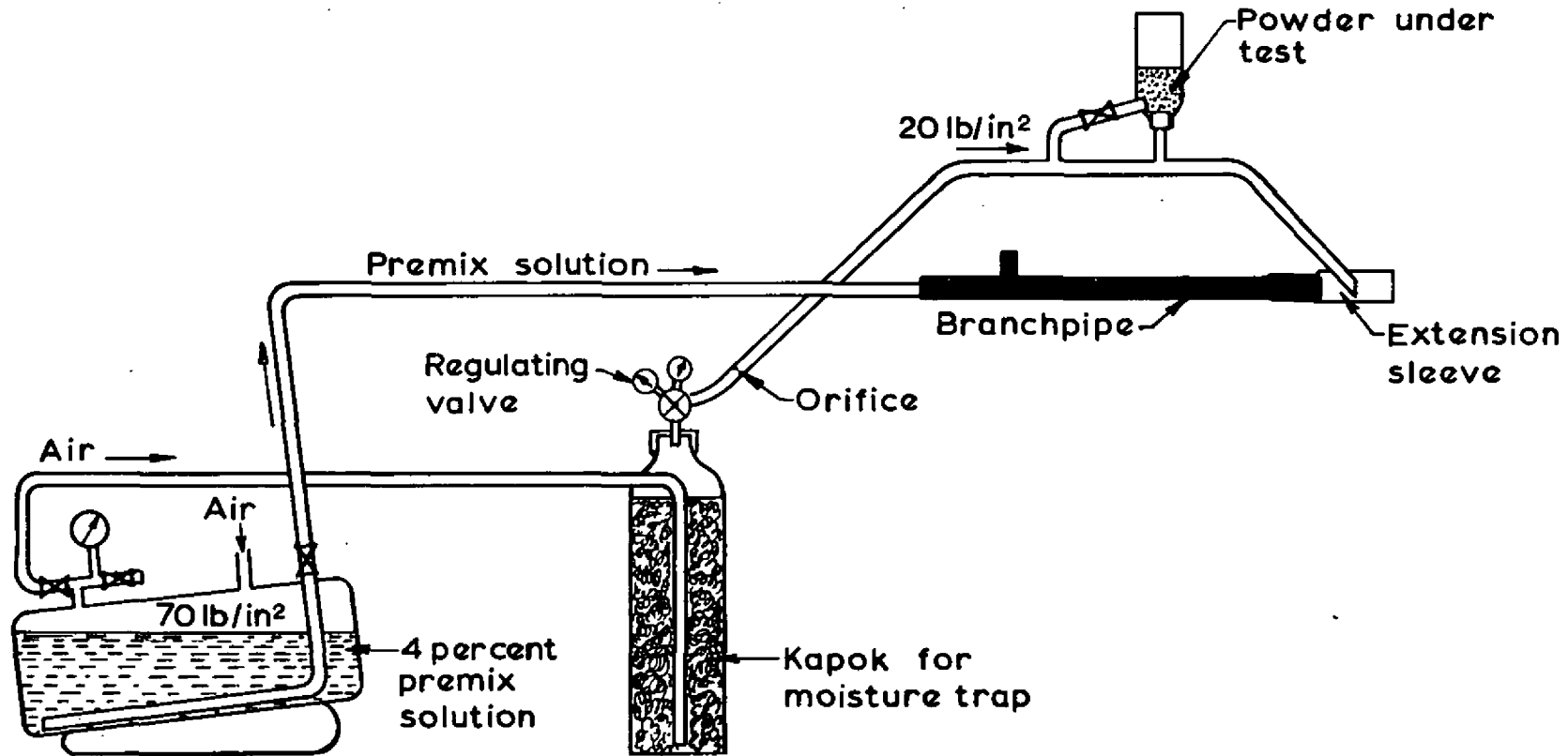


FIG. 9. COMMERCIAL TEST METHOD No. 4