F.R. Note No. 202/1955
Research Programme
Objective C1

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

THE USE OF WATER IN FIRE-FIGHTING

by

P. Nash and D. J. Rasbash

SUMMARY

Experiments are described relating to the use of water, in the form of jets, sprays or foam, in the extinction of fires in both solids and liquids. It is shown that there is a critical rate of application of water below which extinction cannot take place. The effect of various factors on critical rate and on the quantity of the water used to extinguish the fire is discussed.

September, 1955.

File No. F.1000/10/5

Fire Research Station,
Boreham Wood,
Herts.

THE USE OF WATER IN FIRE-FIGHTING

by

P. Nash and D. J. Rasbash

INTRODUCTION

In speaking to the Institution of Fire Engineers' Conference on "The use of water in fire-fighting", we are very conscious that our audience will have much more practical experience of many branches of the subject than we have. Upon reflection, however, I can see that the idea may serve a useful purpose.

The Joint Fire Research Organization has as one of its tasks the evaluation of fire-fighting materials, the determination as to how best they may be applied to those types of fires to which they are suited, and generally of providing the fundamental information necessary to the design and development of successful fire-fighting equipment and tactics. This work is usually limited of necessity to small and medium-scale experiments, but we are constantly aware of a need to test the conclusions in full-scale fire-fighting.

The Fire Brigades must generally be too pressed by the urgency of their full-scale operations to be able to deviate far from the methods of fire-fighting proven by time and experience to be efficient.

It is possible that the conclusions which we have reached from our own and other people's experiments, will offer a new line of approach to some of your fire-fighting problems and that you, on the other hand, will be able to supply practical factors which modify these conclusions.

One of the most useful ways of comparing fire-fighting materials and methods is by measuring the times taken to control or extinguish a fire when the fire-fighting material is applied at a series of different rates. This is best illustrated in Figure 1 which refers to the extinction of a fully-developed fire in a model room by means of a spray of water. It can be seen that at rates of application below a certain critical value, called the "critical rate", the fire could not be extinguished. This is illustrated by the fact that the time to extinguish becomes very very large indeed. It is also often true that there is no appreciable reduction in the intensity of the fire when the material is appli d at rates only just below the critical, although this is not shown by the graph. At rates just above the critical, however, the time needed to control or extinguish the fire falls very rapidly to a workable level. With a further increase in the rate of application, the time to extinguish diminishes more slowly.

There is every reason to believe that graphs of this type apply, with certain exceptions, to full-scale fire-fighting. They are capable of giving an estimate of the minimum size of equipment necessary to handle a fire of a certain size, or conversely, the size of fire a given array of equipment can handle. There is no hope of extinguishing the fire unless the medium can be applied above this minimum rate and it is better to prevent spread and to protect exposures, or to give a local concentration of force to hold open an escape route, than to disperse the effort over the whole fire, pending the arrival of reinforcements. The graph is drawn in terms of rate of water application per unit area of fire. If the area is doubled then the total rate of water applied to control it in a given time is doubled. As most fires, are actually or potentially growing fires at the time the Brigade reaches them, the graph also illustrates the necessity of providing a striking force capable of at least the critical rate at the earliest possible moment. By multiplying each rate of application by the corresponding time to control or extinguish the fire, the total quantity of water used at the rate of application is obtained.

In Figure 2, the total quantity of water used is shown plotted against the rate of application. According to how quickly the tail on the first graph slopes away towards zero, the tail on the second graph either rises, remains horizontal, or even falls as the rate of application increases.

Where the tail rises again, there is clearly an optimum rate of applying the water from the point of view of economy; above and below this rate, more water will be used. Where the tail does not rise, but remains level, it becomes a question of putting the fire-fighting material on the fire as fast as possible in order to get a quick reduction of intensity and limitation of fire damage, since economy is not affected. In very large fires the fireman has not much choice as to the rate of application of the material per unit fire area; he will be usually limited to a point not far removed from the critical rate. It is thus some consolation to find that the most economical rate is not very much greater than the critical.

APPLICATION TO FIRES IN BUILDINGS

Although the information obtained from the various experimental determinations of the critical and optimum rates for the extinction of well-developed fires in rooms by the use of water sprays and water jets is by no means complete, it suggests various important tendencies likely to apply in full-scale fire-fighting. The experimental rooms considered have ranged in size from models of $4\frac{1}{2}$ cu. ft to full-size rooms of 2,000 cu. ft and the information has been extended to actual fires in rooms up to 33,000 cu. ft.

The work in the $4\frac{1}{2}$-cu. ft room, (1) is naturally the most comprehensive owing to its cheapness, and it is necessary to examine the effect of various factors on the critical rate and compare, where we can, their effect at larger scales. The fire in the model room developed similarly to a fire in an ordinary living-room, attaining maximum temperatures of 700-900°C according to the degree of ventilation. The fires were extinguished by two $^1/32$-in. diameter jets which could either impinge at 90° to form a spray, or could be used as separate jets. The jets or the spray could be fixed or moved about at will.

Figure 3 compares the quantities of water used to extinguish the fire by fixed spray at different degrees of ventilation, expressed in square feet of wall area per cubic feet of room volume. Reduction of ventilation not only reduced the amount of water used at any chosen rate of flow, but reduced the critical rate of extinction very markedly. It is evident that if the water used in extinguishing the fire is all assumed to have been evaporated, and its volume is expressed in terms of the volume of the room, then in these experiments the steam would have had a volume varying from about $\frac{1}{2}$ - $1\frac{1}{2}$ times the room volume. This will be discussed later, as it suggests a possible mechanism by which the fire is extinguished.

In Figure 4 the results of moving the spray about rapidly or scanning the room are shown. It can be seen that there is a marked reduction in the critical rate and that at rates above the critical the scanned spray is always more economical in water, although the economy falls off as the rate of flow increases. This is because for the very high rates of flow the extinction occurs more and more rapidly and the time to extinction occupies less and less scans until only about a very small fraction of a scan occurs in the extinction time. The spray therefore behaves more and more as it would do if fixed. Now if scanning improves spray performance it would be expected to do so because it disperses the water better within the room. This being so, it is possible that it would effect a greater proportional improvement to a fixed jet than to a fixed spray, since a spray carries its own "built-in dispersion". In Figure 4 corresponding curves for a jet have been drawn, the scanned curve being experimental, and the other being one possible result from an arbitrary choice of fixed jet position. The curves also illustrate the degree of superiority of spray over jet. It is clearly less than the increase of economy to be obtained by scanning, which is in its turn more important for jets than it is for sprays.

To obtain the desired variation of flow in these experiments while still using the fixed 1/32-in. orifices, the pressure had to be varied from 5 - 120 Lb/sq.in., and this pressure variation was naturally accompanied by a decrease in the drop size from the spray. It can be seen, however, that once above the critical rate, the fixed spray used an almost constant amount of water to extinguish the fire, which suggests that drop size has little effect on economy. A study of the curve for the scanned jet shows that doubling the rate of flow by increasing the pressure from 30 - 120 Lb/sq.in. reduces the extinction time by 15 per cent, and thereby produces an increase of water consumption of about 70 per cent.

In making a comparison between the quantity of water used in these model tests with that used in the larger-scale experiments and in actual fires it must be borne in mind that in geometrically similar rooms the ventilation gets proportionately less as the size of room increases, owing to a natural scale effect. The increase in economy due to reduced ventilation is somewhat offset because a similar degree of scanning of jet or spray cannot be used owing to the increased nozzle reaction of the larger appliances.

The fires in model rooms were extinguished with scanned jets or sprays with about 1 gal of water per 1,000 cu. ft of room volume under the best conditions. A fixed spray with a medium degree of ventilation produced extinction with about 2 gal of water per 1,000 cu. ft. In another series of experiments [2] using sprays and jets in an 8-ft. cubic room (512 cu. ft in volume) lined with fibre insulating board and with some mock furniture of fibre insulating board extinction was obtained with 1 gal of water per 1,000 cu. ft, showing that the efficiency of the model extinction was obtainable up to at least box-room size.

In a further series of twelve experiments made by the J.F.R.O. in co-operation with the City of Birmingham Fire Brigade, in furnished rooms of about 1,500 cu. ft in volume were extinguished with the use of 8 gal of water per 1,000 cu. ft, both by jets and by sprays (Figure 5). The rate of delivery of 40 gal/min at 100 Lb/sq.in. pressure was chosen to show up any potential difference between sprays and jets. Figure 6 shows that in fact no such difference appeared, although during the course of the repeated experiments it was found possible to reduce materially the amount of water used. This was explained in the case of jet application by the increasing familiarization of the branchmen with the particular fire. For sprays the reduction was explained by the realization that water could be cut off as soon as the steam appeared at the windows (Figure 7). The sprays then required less technique in handling, but it was not immediately obvious how soon the water could be cut off, since the room was full of steam. In these experiments it was noted that there was little, if any, free water lying in the room after the extinction, which may therefore be regarded as reasonably efficient.

The remaining full-scale experiments in rooms were made by the Ministry of Home Security who found 4 gal/1,000 cu. ft necessary to control a fully-developed fire in a furnished room of 1,400-cu. ft capacity. The Building Research Station controlled fires in a 2,000-cu.ft room with 2 gal/1,000 cu. ft. The National Board of Fire Underwriters extinguished fires in 900-cu. ft rooms with various appliances using pressures up to 600 Lb/sq.in. for jet and for spray. The results show extinctions varying from 4 gal/1,000 cu. f. using a 200-Lb/sq. in. impinging jet spray, to 15 gal/1,000 cu. ft using spray and then jet at 600 Lb/sq.in. In the above experiments, no attempt appears to have been made to select the most economical rate of delivery, so direct comparisons are difficult. The work does, however, show broadly that fires in such rooms may be extinguished with about 8 - 10 gal/1,000 cu.ft.

The following factors regarding the mechanism of extinction can be observed from these experiments. Assuming perfect mixing an amount of steam equal to about 40 per cent of the volume of the room would be required to inhibit the combustible vapours. This requirement would have to be increased if it were considered that the combustible gases leaving the room had also to be inerted. If no mixing occurred then a volume of steam equal to that of the room would be required. If steam is lost from the room in addition, the volume would need to be even greater. In the tests performed by the National Board of Fire Underwriters' (4) and at the Building Research Station, as well as in actual fires reported by Lloyd Layman (5) the amount of steam used corresponded to about twice the room volume, that is some two or three times the proportion used in the small model-room tests. In the Ministry of Home Security tests, the factor was about 4.

It may be shown, by calculating the amount of heat required to turn all the water to steam in the model room tests that the heat in the combustible gases in the room is not alone sufficient. The water must therefore have absorbed heat from the solid surfaces of the room. This may well explain why drop size, and with it pressure, has little significance in fires of this type. So long as the drop is small enough to be successfully evaporated when striking a hot surface, then extinction by smothering with steam will not be adversely affected. The hot surfaces are, in their turn, cooled just sufficiently to prevent their ignition when cooling is terminated and this may be effected by a uniformly-distributed layer of water 1/1,000 in. thick.

As the size of the room is increased, however, the size of its internal surfaces becomes less in comparison with its volume, due to the scaling law mentioned earlier. It becomes progressively more difficult to provide the steam required to fill the room, by evaporation of the water at the hot surfaces. The mechanism of extinction then probably changes gradually from one of smothering with some cooling of the solids, to one of much cooling of the solids with some smothering. This may well provide the explanation of the reduction in the efficiency of extinction as the size of the room is increased.

APPLICATION TO LIQUID FUEL FIRES

With a liquid fire the critical rate of application of water by sprays depends on the size of drops, and on the current of entrained air; moreover the spray most suitable for a fire in one type of liquid may be inappropriate for another.

Drop size

In general a decrease in drop size improves the efficiency of a spray as long as the drops can reach the base of the flames and the burning liquid. Figure 8 gives an indication of how the drop size of a spray affects the extinction of different liquid fires. This table gives the extinction time of six different liquid fires for sprays within the drop size range 0·28 - 0.49 mm. With all the liquids the finest spray was quite efficient; this was particularly noticeable for volatile liquids (petrol, benzole, alcohol) where there was a marked decrease in efficiency as the drop size was increased, whereas with transformer oil and gas oil there was a small increase in efficiency. With petrol and benzole the flame was extinguished and the finest spray was best presumable because it could extract heat most easily from the flames. With the alcohol fire extinction was caused in most tests by dilution of the surface layers; the finest spray was most efficient in this case because it brought about the least mixing with undiluted alcohol below these layers. The high boiling liquids were extinguished either by cooling the liquid below the fire point, or by causing sufficient steam to be generated at the surface to smother the flames. The finest sprays were slightly less efficient because the intense sputtering they produced on application to the fire intensified the fire and delayed further access of spray to the burning liquid. Further tests on transformer oil fires with considerably coarser sprays within the range of drop size 0·4 - 3 mm showed that the extinction time increased in approximately direct proportion to the increase in drop size, i.e. doubling the drop size doubled the extinction time. For petrol fires, and drop sizes of 0·2 - 0·6 mm, the extinction time was approximately proportional to the fourth power of the drop size, i.e. doubling the drop size increased the extinction time by a factor of about 16.

The entrained air current

When sprays are applied downward to a fire an increase in entrained air current increases the spray efficiency. This air current increases the access of the spray drops to the seat of the fire by blowing the flames aside. This is illustrated in Figure 9 which shows two sprays of similar drop size and rate of flow to the fire area acting downward on the transformer oil fire. One spray (a) has a low entrained air velocity and the flames can burn upwards against it, the other spray (b) has a high entrained air velocity which pushes the flames aside bringing about a shorter extinction time. The entrained air current appears to assist in the extinction of a petrol fire, in which the flame itself is extinguished, in quite a different way. Thus when sprays are applied downward to a petrol fire an increase in entrained air current continues to reduce the extinction time even when the air current is much greater than the upward motion of the flames (about 8 - 10 ft/sec). Moreover it has been found that hand application of water spray to a petrol fire is much more efficient when the spray is applied nearly vertically to a fire than when it is applied horizontally across the fire. Thus spray from a single pair of 1/32-in. impinging jets at a pressure of 100 Lb/sq.in. could not extinguish a 1-ft diameter petrol fire when applied horizontally but could do so when applied from an angle of about 60° to the horizontal. After a petrol fire has been burning about 6 - 10 sec, there is often a sudden improvement in the ease of extinction. The above facts can be explained if it is assumed that the entrained air current can help extinction of the flames by diluting the combustible vapour. The entrained air current is usually considerably in excess of the amount of air required to reduce the vapour evolved from a fire to a concentration at which it cannot burn. In order to dilute the vapour effectively the entrained air must be able to mix rapidly with it and this occurs most readily when the spray is applied vertically rather than horizontally to the fire, and if there is a thick zone of vapour above the liquid as in the case when the fire has been burning for some time.

Rate of flow

An increase in rate of flow of water to the fire area increases the spray efficiency. This is illustrated in Figure 10 which shows the specific effect of rate of flow for three different fires. In practice it is very difficult to vary the rate of flow of spray to a fire without varying the entrained air current and the drop size and one therefore obtains a composite result caused by the variation of these three factors. Thus if the rate of flow to a fire were increased by increasing the number of nozzles spraying on the area, both the entrained air current and drop size would be increased. Nearly all tests carried out so far have indicated that an increase of rate of flow brought about in this way, not only reduces the extinction time but also reduces it to the extent of using less water in bringing about extinction. This point is illustrated in Figure 11 which gives the results of tests in which the rate of flow of sprays from 1/32-in. impinging jets to a petrol fire 1-ft. diameter was increased by increasing the number of pairs of jets used. Both the extinction time and the quantity of water used in the extinction decreased as the rate of flow increased.

Practical aspects

To place the above information in perspective it is necessary to say a few words on the properties of sprays available for fighting liquid fires. These sprays have drop sizes ranging from 0·4 to 3·0 mm at pressures of

100 Lb/sq.in., non-directional sprays in general being finer than directional sprays. However, the entrained air velocity of non-directional sprays falls off very rapidly as the distance from the nozzle is increased such that at 8 ft below the nozzle this velocity is of the order of 3 to 4 ft/sec; with directional spray nozzles the velocity of the entrained air current at the centre of the spray at this distance is usually well in excess of 10 ft/sec.

For the extinction of petrol fires a fine spray (drop size less than 0.3 mm with a rate of flow of about $\frac{1}{3}$ to $\frac{1}{2}$ gal/sq.ft/min) is required. There is no practical fire-fighting spray available which has these properties and it would be very difficult to obtain such a spray by means of a pressure nozzle unless the orifice sizes in the nozzle were made very small; the latter procedure would introduce a number of other practical difficulties. However nozzles based on 1/16-in. impinging jets could be made to give sprays which approach the above properties. It is possible to extinguish petrol fires very quickly with coarse sprays (drop size 1 - 2 mm) when applied downwards to a fire as long as the rate of flow and the entrained air current are high (2gal/sq.ft/min, and 30 ft/sec respectively). These sprays on the other hand have the disadvantage that they cause violent splashing of the liquid which spreads the fire outside the area of effective control. The chief drawback in using water sprays for petrol fires is that small pockets of fire established in a recess or a corner are usually more difficult to extinguish than a fire burning over a flat surface. For this reason water sprays are unreliable when used for this purpose and should only be used when a more satisfactory extinguishing medium is not available.

With fires in heavy oils small flame pockets can be easily extinguished by cooling the liquid. Moreover the effect of drop size is not so critical as with petrol and although coarse sprays do cause splashing it is of less importance because of the high viscosity of the oil. The chief requirement for a rapid extinction with these liquids is that the spray should reach the burning liquid at a rate of flow of about $\frac{1}{2}$ to $1\frac{1}{2}$ gal/sq.ft/min, the rate of flow increasing as the drop size increases.

An increase in pressure at a given nozzle will increase the rate of flow and the entrained air velocity in the spray and reduce the drop size. All these factors will tend to increase the nozzle efficiency although the effect will be less for pressures greater than about 100 Lb/sq.in. than at lower pressures because of the smaller effect of the pressure on the drop size. However it is not possible to increase the pressure with a given nozzle indefinitely since other factors such as the reaction at the nozzle and the power of the pump come into play which limit the rate of flow that can be handled. An analysis [6] in which these factors have been taken into account has indicated that an increase in pressure at the nozzle to values well above 100 Lb/in^2 is unlikely to be advantageous.

WATER APPLIED AS FOAM

Another method of extinguishing liquid fuel fires is, of course, by the use of foam, and the criterion of critical rate, can also give useful information with regard to this. For comparison purposes it is simplest to consider the foam application in terms of the quantity of foaming liquid applied. The following illustrations relate to petrol fires in particular.

When applying foam by applicator to the surface of petrol at varying rates it is found that there is a critical rate curve, of which Figure 12 is typical. For a given compound and given foam properties this curve is the same for fires up to 250 sq.ft in area, although there is no information for larger fires at the moment. It can be seen that as in the case of water sprays and jets the critical rate sets the minimum size of equipment, but at rates of 4 - 5 times the critical, the extinction reaches its greatest economy.

Foam should therefore be applied as quickly as possible and certainly at not less than this critical rate since economy is not adversely affected by increasing rate. Of course, the curve shown in Figure 12 will vary for different compounds, and for varying physical properties of the foam.

Critical and optimum rates are not the only important qualities of foam. Its stability on the hot petrol is most important, especially where two or more adjacent fires give risk of re-ignition to fires already extinguished. Soap and wetting agent foams can, for example, because of their high fluidity, give more economical extinction to petrol fires at certain rates, but their life on hot petrol may be reckoned in minutes instead of the hours for which a protein foam may well be stable. As shown in Figure 13, a petrol fire may be extinguished with 8 gal of wetting agent foaming liquid per 100 sq.ft, where 12 - 20 gal of protein foaming liquid would be required, though due to the rapid break-down of the wetting agent it would have to be applied at a rate of $5\frac{1}{2}$ gal/100 sq.ft/min compared with the 2 - 3 gal/100 sq.ft/min of the protein compound.

Where foam is applied by projecting it against the far edge of the tank, or against a baffle, the critical rate may be similar to that using an applicator, but at higher rates of flow the quantity used is generally greater. Thus the consumption of a soap foam may be expected to increase from 8 - 18 gal of foaming liquid per 100 sq.ft, and of a protein foam from 12 - 20 to 20 - 25 gal of foaming liquid per 100 sq.ft. It is evident that while a low critical rate is important for those large fires where the apparatus available is stretched to capacity, a fluid foam possessing an acceptably low drainage rate on the hot liquid is also valuable in keeping down foam consumption at the higher and more economical rates of foam application.

In the base injection or sub-surface application of protein foams to petrol storage tanks, it has been shown experimentally [7] that once again, critical rate curves may be drawn. In work carried out at the Fire Research Station on a 9-ft diameter x 30 ft high tank (Figure 14), a rate of application of $7\frac{1}{2}$ gal of foaming liquid per 100 sq.ft of petrol surface was found to be economical, and extinguished a fire in a tank of this size in approximately 5 min. In this type of application however, another factor must be considered, the quantity of petrol "picked-up" by the foam on its journey to the surface of the petrol. If the petrol "pick-up" exceed 10 per cent by volume of the foaming liquid, it will ignite when the initial fire collapses and a "foam blanket fire" will ensure. This will be illustrated in a film shown during the discussion period. The "foam blanket fire" will then be sufficient to destroy the foam layer, even though application is continued indefinitely. The amount of petrol "picked-up" is governed by the expansion and critical shear stress of the foam at the surface. Thus a low expansion foam must be injected, and this foam must have a low drainage rate, so that its expansion when it reaches the surface has not increased unduly. An ideal expansion at injection is $3 - 3\frac{1}{2}$, together with a drainage of not more than a quarter of the liquid content of the foam in 3 min, and a critical shear stress not exceeding about 160 dynes/sq.cm. The conflicting requirements of high fluidity and low drainage in a low expansion foam are difficult to meet, and in fact only a small number of existing protein compounds can meet them. Given one of these compounds, however, the production of suitable foam is not difficult, and may be accomplished by equipment in common use. It was found in the experiments at the Fire Research Station [8] that by passing the output from a mechanical foam generator (or pressure foam maker) into a suitably-sized centrifugal pump, and thence to the input to the tank, sufficient energy was introduced into the foam to give it the necessary low drainage, while retaining, with a suitable compound, high fluidity. If the critical rate curves for the 9-ft. diameter tank apply to larger diameters, a mechanical foam generator having a flow of 60 gal of water per min at 150 Lb/sq.in., in conjunction with a centrifugal pump of 120 gal/min capacity, is capable of extinguishing a fire on a 40-ft diameter tank. Similarly three 250-gal/min foam generators would be needed to deal with a fire on a 140-ft diameter tank.

CONCLUSIONS

In conclusion, I should like to reiterate the importance of critical rates in the application of water to fires.

First, the very existence of critical rate means that the fire cannot be extinguished at lesser rates. Experience shows that even at rates only just below the critical, very little reduction of fire intensity can be achieved. Surrounding the fire to prevent spread, damping-down of exposures, and possible local concentrations on escape routes are the order of the day.

Every effort needs to be made to concentrate sufficient effort on a growing fire, so that the increasing threshold level for water application does not remain long out of reach of the increasing number of appliances.

Where sufficient force is available, the quickest "knock-down" is usually the best, which implies the highest possible rate of application. Where water supplies are limited, however, it should be remembered that there is a most economical rate of application sometimes in existence. This is not much greater than the critical rate for scanned sprays and jets against fires in buildings.

With foam application, the most economical rate of application is from four to five times the critical rate. There is thus no need to restrict the total rates of application on grounds of economy of foam compound.

Critical rate, and the quantity of water used at other rates, are both affected by the method of application. A knowledge of the most economical methods of application is valuable, since they can give reduced use of water and foam compound for the same speed of extinguishing the fire.

ACKNOWLEDGMENTS

The authors wish to acknowledge the work of Dr. Thomas and Messrs. Rogowski, French and Smart, on which they have drawn for this paper.

REFERENCES

(1) THOMAS, P. H. and SMART, P. M. T. The extinction of fires in enclosed spaces. Department of Scientific and Industrial Research and Fire Offices' Committee Joint Fire Research Organization F.R. Note No. 86/1954.

(2) Fire Research 1950. Department of Scientific and Industrial Research and Fire Offices' Committee London, 1951. H.M. Stationery Office.

(3) THOMAS, P. H. and SMART, P. M. T. Fire extinction tests in rooms. Department of Scientific and Industrial Research and Fire Offices' Committee Joint Fire Research Organization F.R.Note No. 121/1954.

(4) Characteristics of water spray nozzles, including those designated as fog nozzles for fire fighting use. U.S. National Board of Fire Underwriters Chicago, 1944.

(5) LAYMAN, L. Attacking and extinguishing interior fires. Boston, 1952. National Fire Protection Association.

(6) RASBASH, D. J. The relative merits of high and low pressure water sprays in the extinction of liquid fires. Department of Scientific and Industrial Research and Fire Offices' Committee Joint Fire Research Organization F.R. Note No. 199/1955.

(7) FRENCH, R. J. and HINKLEY, P. L. The extinction of fires in petrol storage tanks by the base injection of air-foam. Department of Scientific and Industrial Research and Fire Offices' Committee Joint Fire Research Organization F.R. Note No. 100/1954.

(8) Fire Research 1954. Department of Scientific and Industrial Research and Fire Offices' Committee London, 1955. H.M. Stationery Office.

ERH

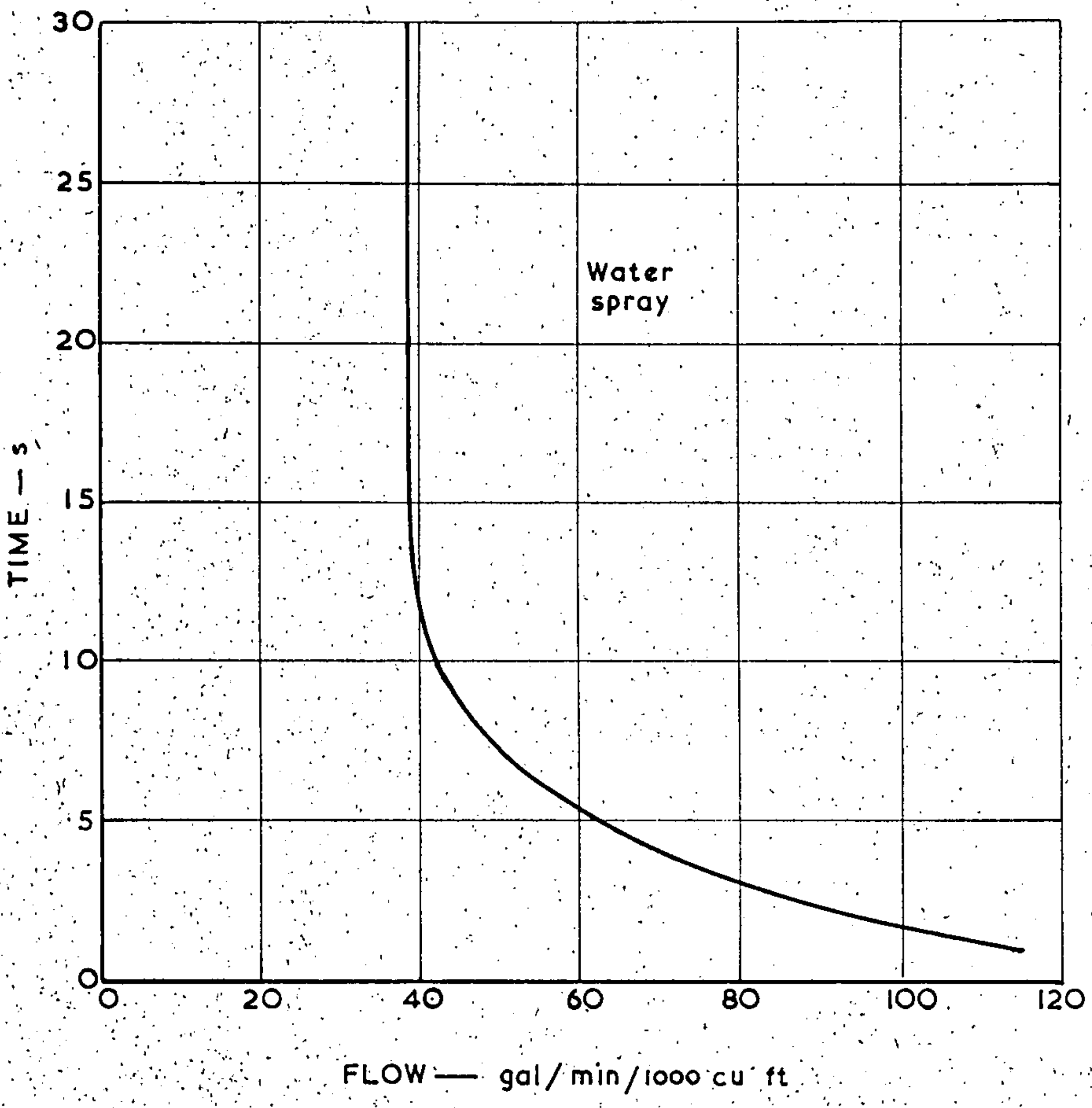


FIG.1. TIME TO EXTINGUISH FIRE IN MODEL ROOM AT VARIOUS FLOWS

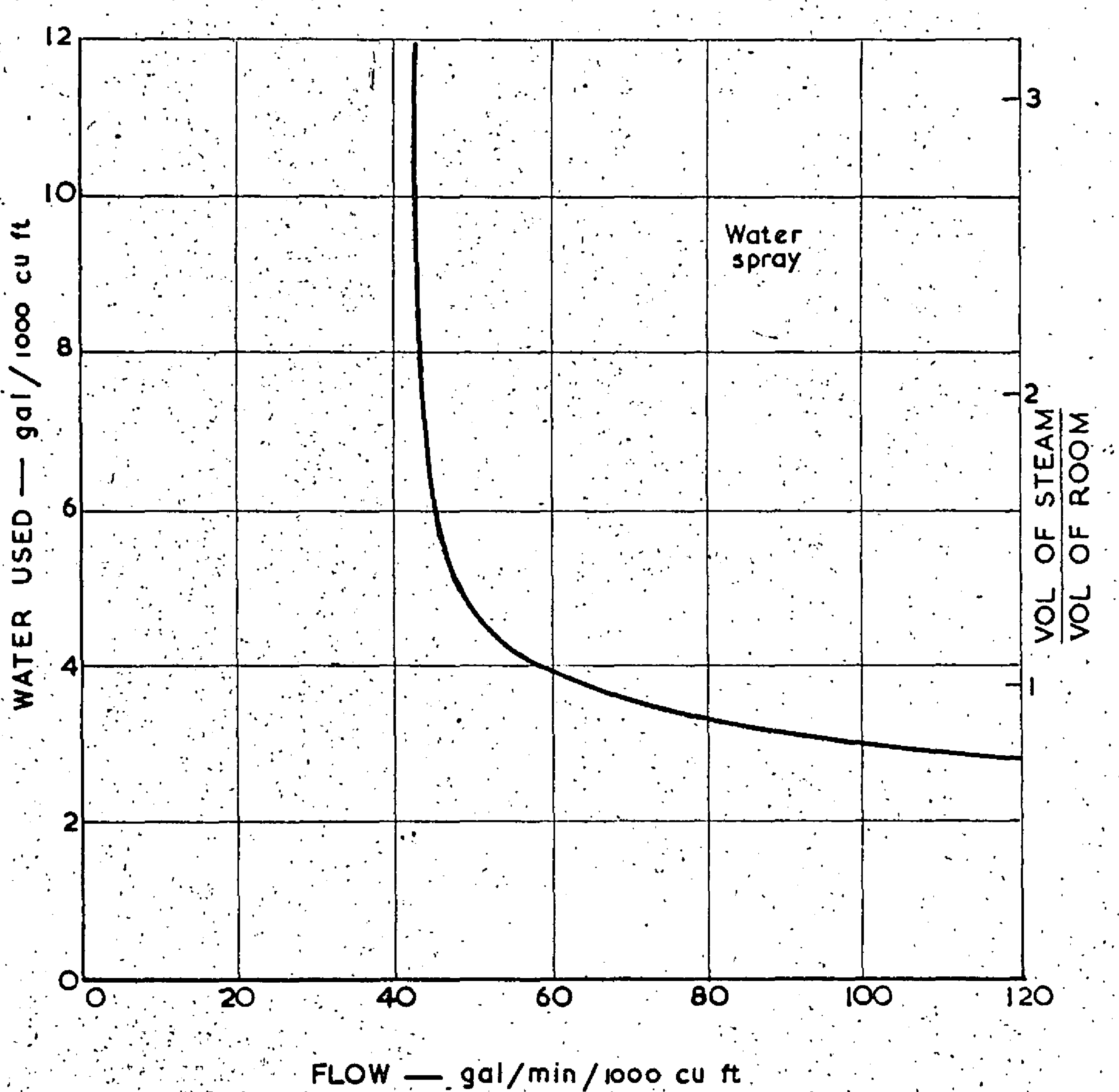


FIG. 2. WATER USED TO EXTINGUISH FIRE IN MODEL ROOM AT VARIOUS FLOWS

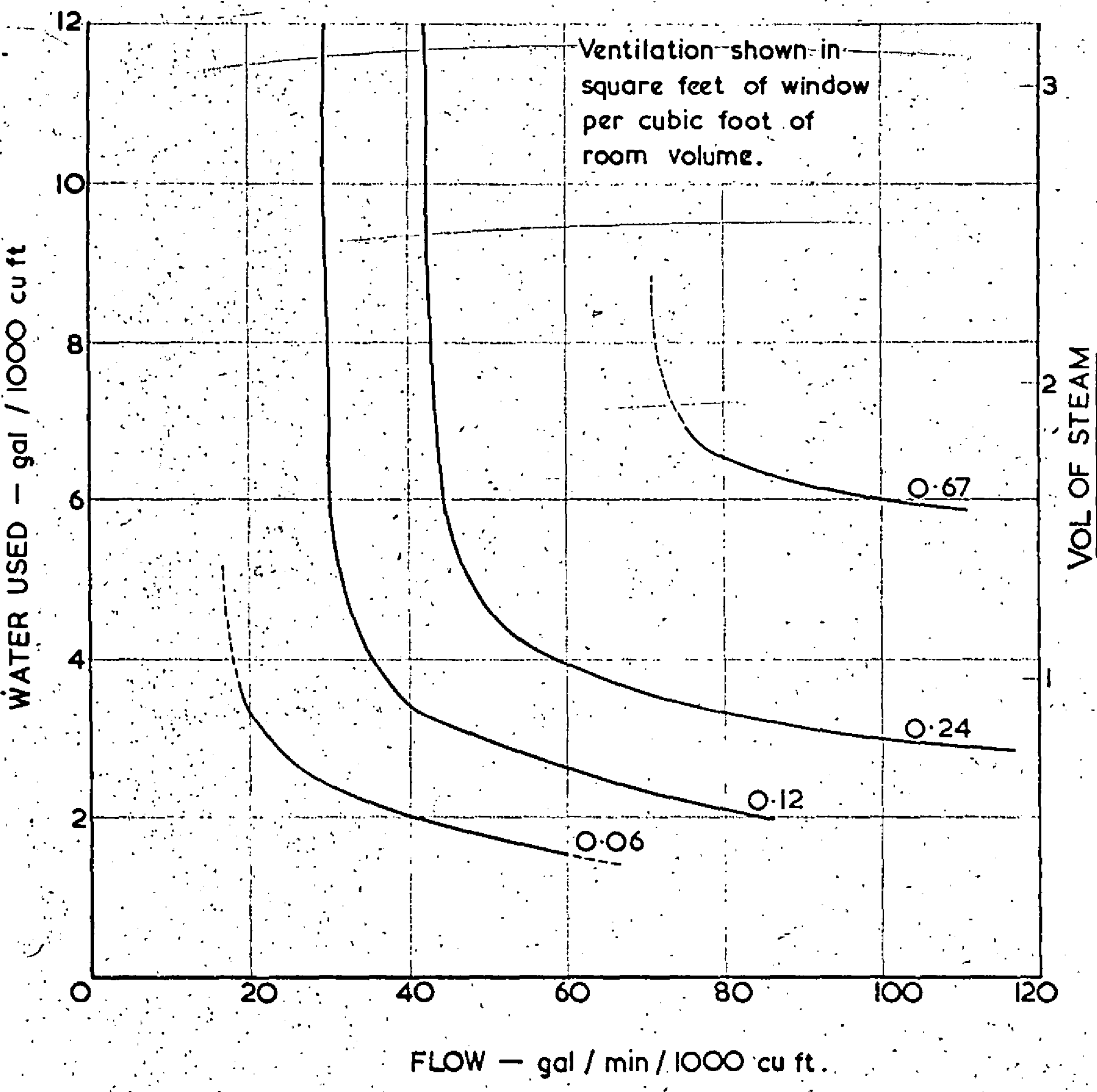


FIG. 3. EFFECT OF VENTILATION ON WATER USED TO EXTINGUISH FIRE.

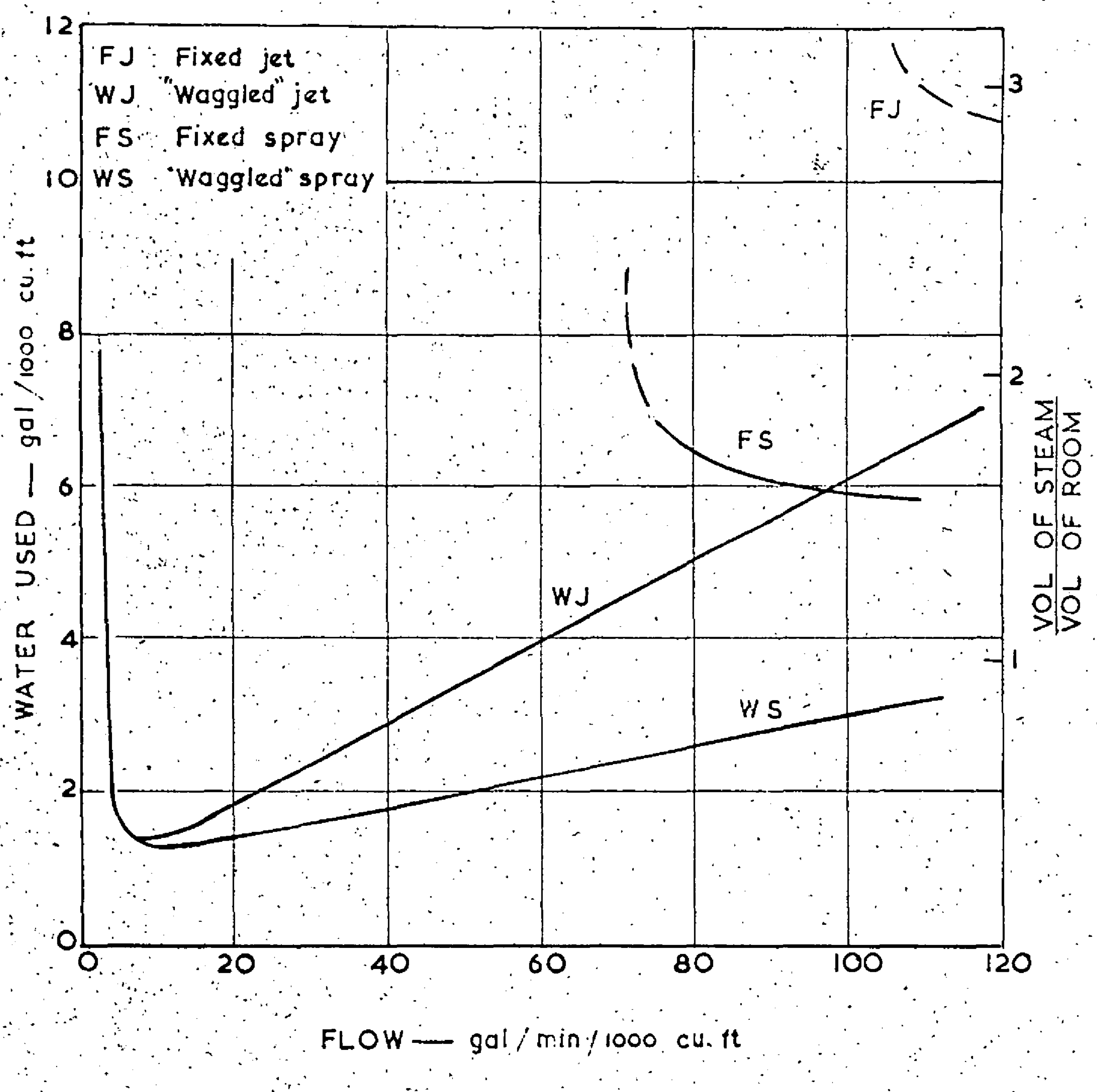


FIG. 4. EFFECT OF MOVING JET OR SPRAY ON WATER USED TO EXTINGUISH FIRE

FIG. 5. EXPERIMENTAL FULL SCALE FIRE IN BIRMINGHAM

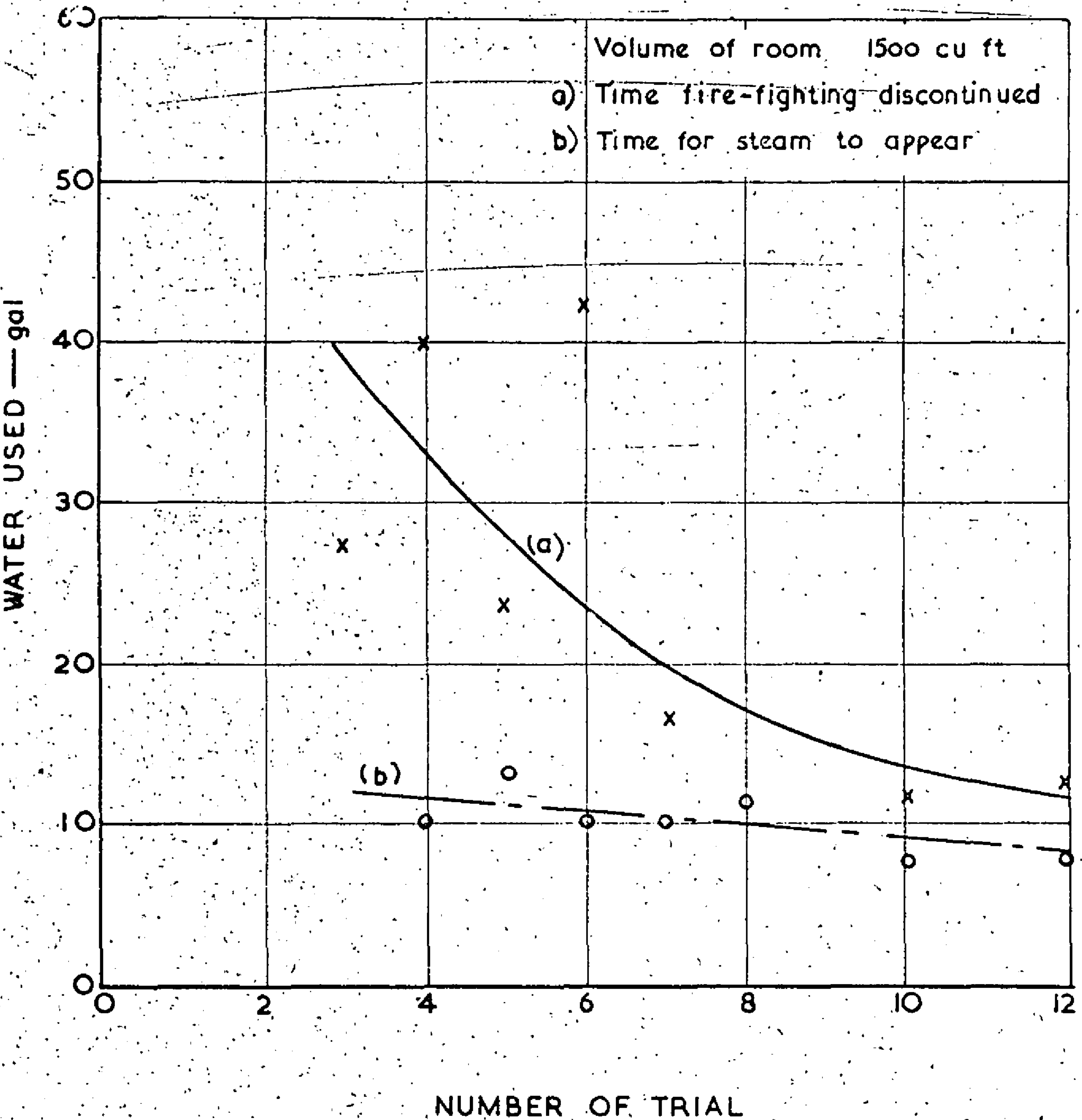


FIG. 6. QUANTITY OF WATER USED TO EXTINGUISH FIRE IN LIVING ROOM

FIG.7. STEAM COMING FROM WINDOW OF ROOM AFTER 10 SECONDS APPLICATION

Drop size of spray	Alcohol	Benzole	Petrol	Kerosene	Gas oil	Transformer oil
0•28	2•9	9•3	10•9	4•7	5•8	5•8
0•39	147	57	37	12•1	6•8	5•6
0•49	499	*	93	22•7	4•4	3•2

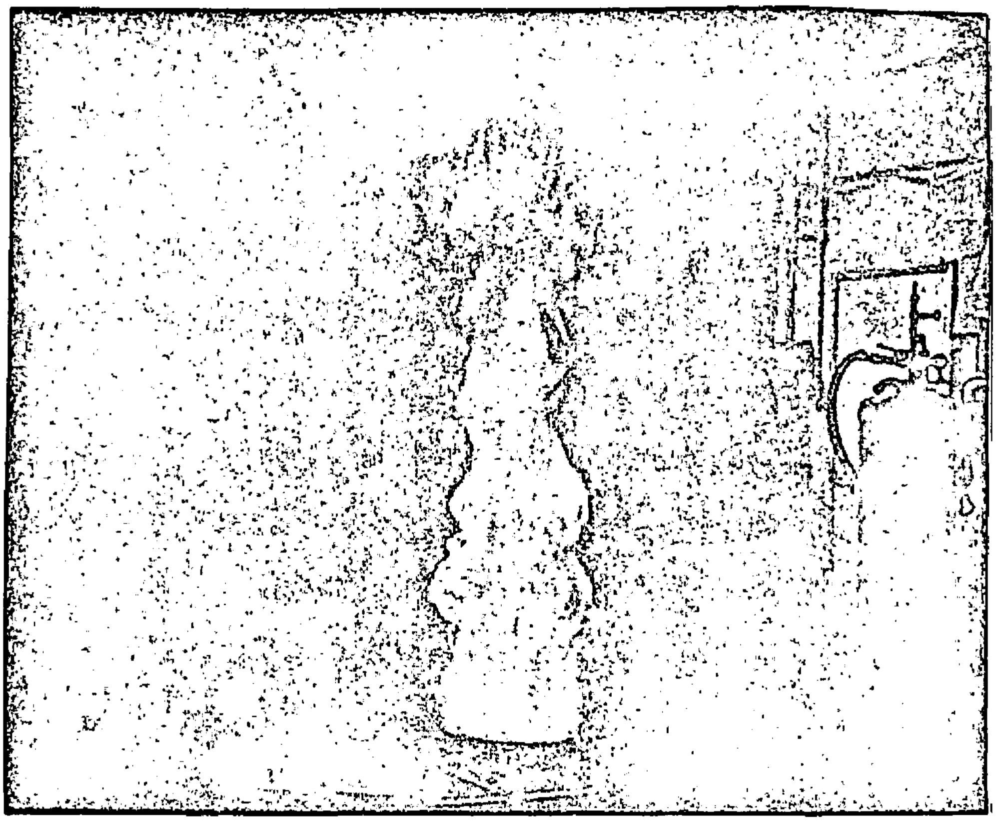
*No extinction in 3 out of 6 tests.

Geometric mean of 6 tests at preburning times between 2 to 8 minutes.

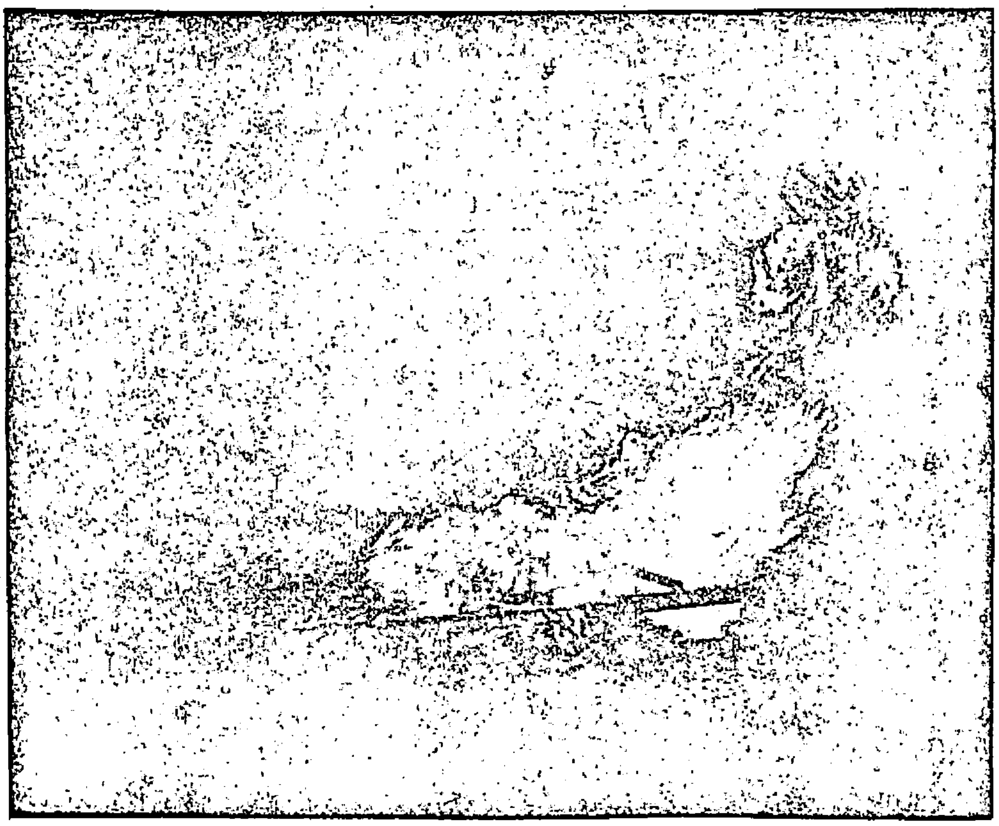
Rate of flow $\frac{1}{3}$ gal ft^{-2} min^{-1}; entrained air velocity 11•5 to 12•5 ft/sec.

FIGURE 8

EXTINCTION TIMES (SECONDS) OF LIQUID FIRES WITH WATER SPRAYS



SPRAY A. ENTRAINED AIR VELOCITY 7·5 ft/sec
EXTINCTION TIME — 15·5 sec



SPRAY B. ENTRAINED AIR VELOCITY 15·4 ft/sec
EXTINCTION TIME 8·8 sec

FIG. 9. ACTION OF ENTRAINED AIR STREAM IN WATER SPRAY ON EXTINCTION OF AN OIL FIRE

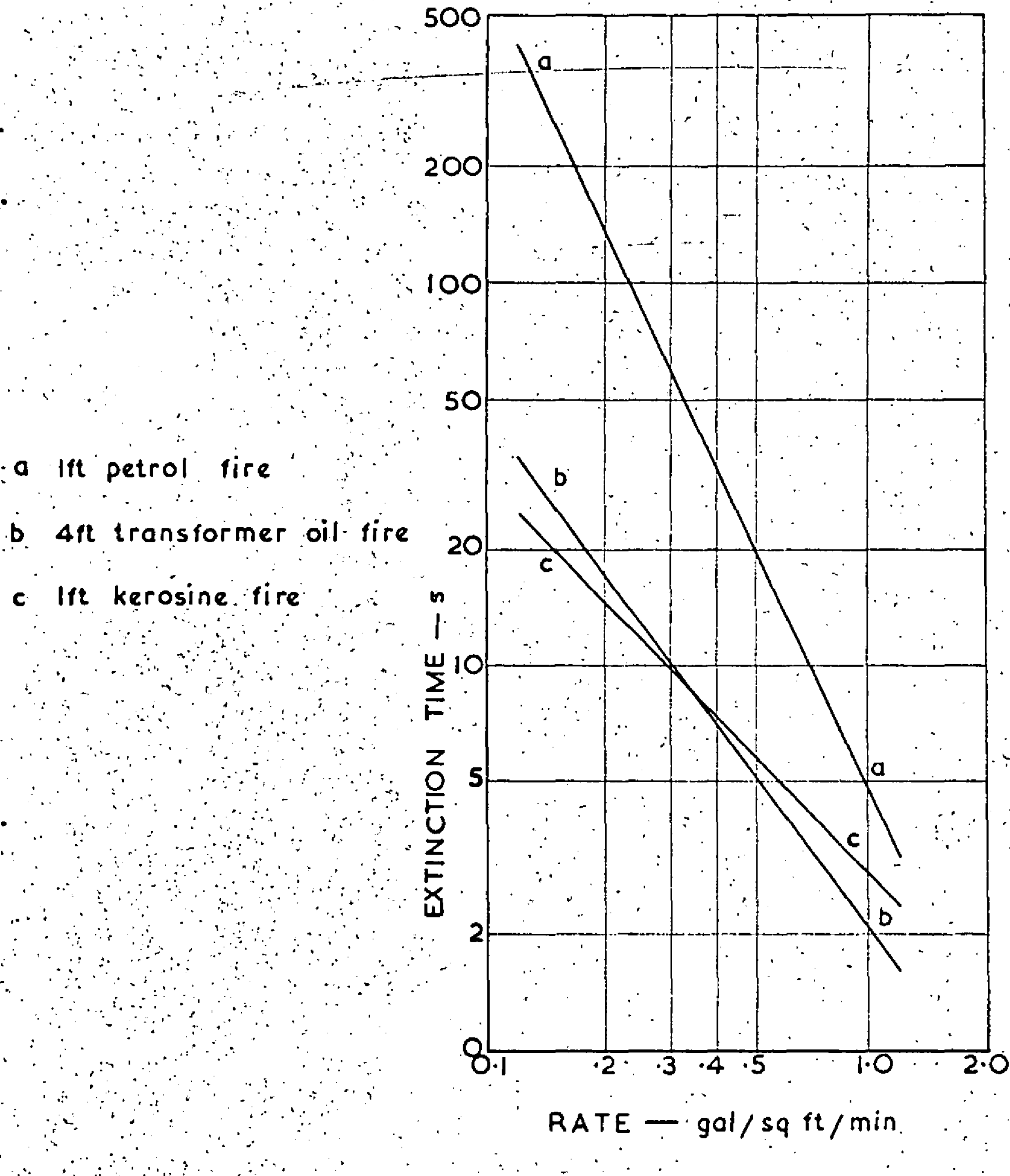


FIG. 10. EFFECT OF RATE OF FLOW OF WATER SPRAY ON THE EXTINCTION OF LIQUID FIRES

(DROP SIZE 0·4 mm, ENTRAINED AIR VELOCITY 12 ft/s)

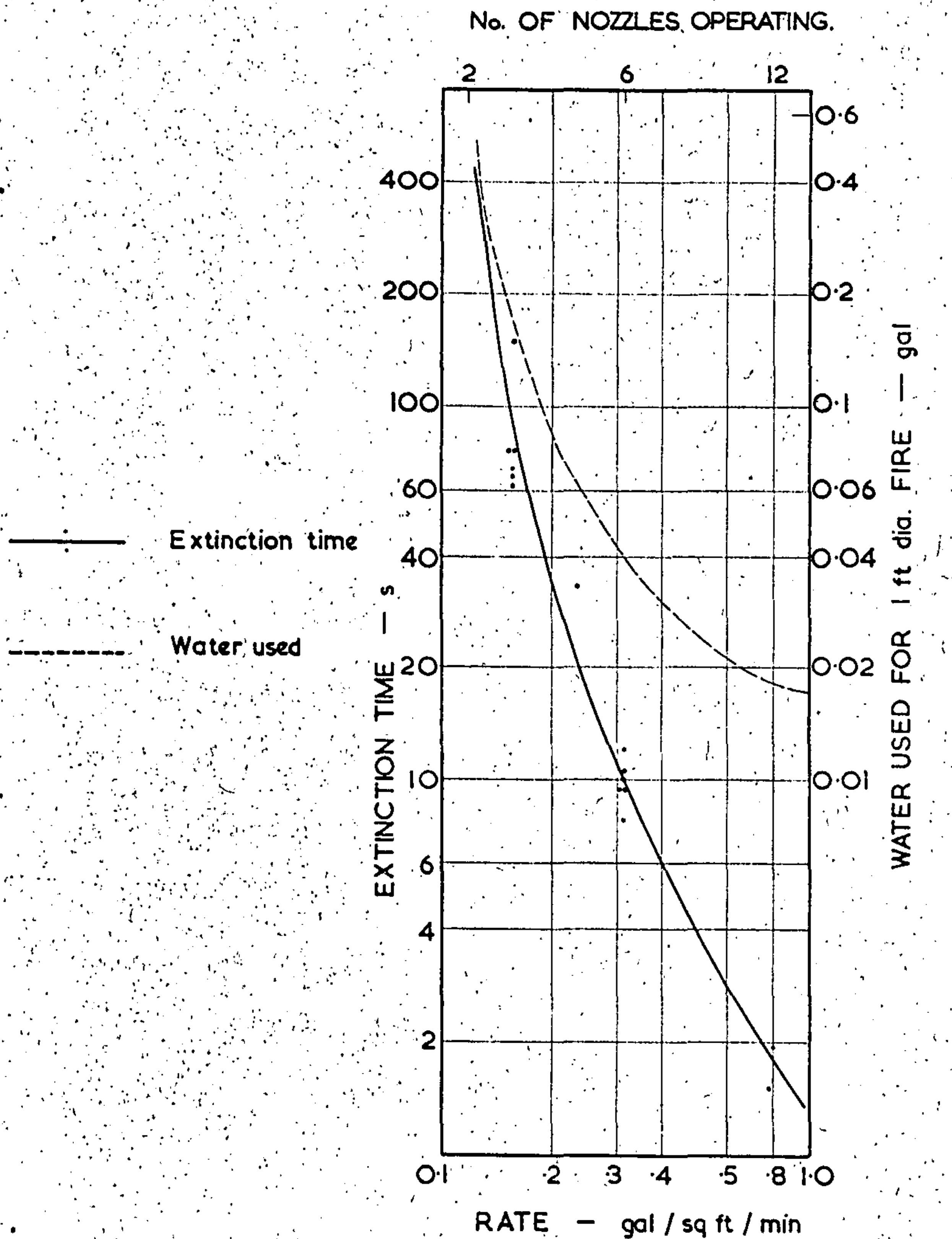


FIG. 11. EFFECT OF RATE OF FLOW OF WATER SPRAY ON EXTINCTION OF A PETROL FIRE.

RATE OF FLOW VARIED BY VARYING NUMBER OF NOZZLES OPERATING.

(1/32 in. IMPINGING JET NOZZLE, PRESSURE 85 lb/in^2)

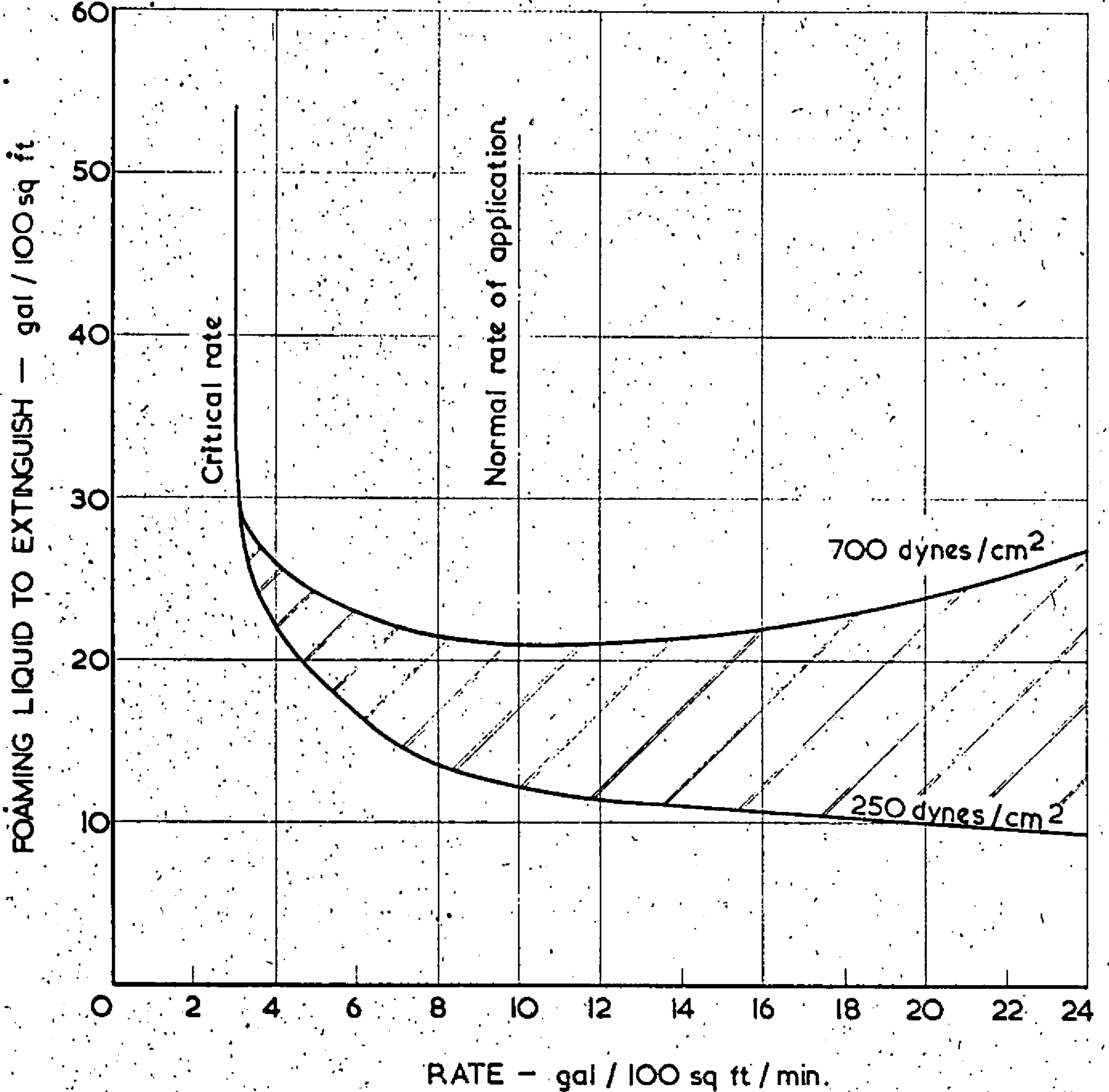


FIG. 12. PROTEIN FOAMING LIQUID REQUIRED TO EXTINGUISH PETROL FIRE, BY APPLICATOR.

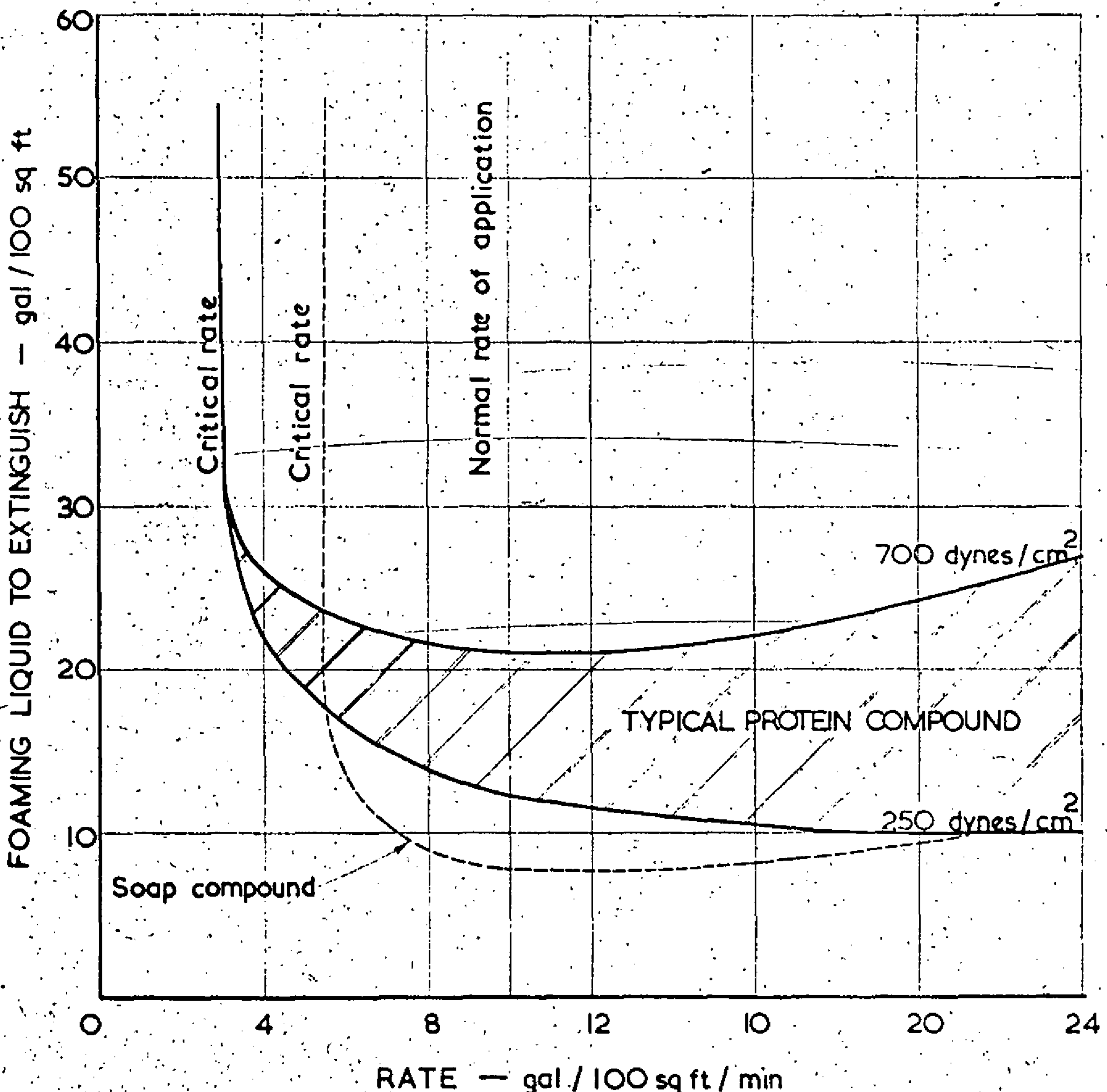


FIG. 13. COMPARISON OF QUANTITIES OF PROTEIN AND SOAP SOLUTIONS REQUIRED TO EXTINGUISH PETROL FIRE.