THE FIRE PROTECTION OF FLAMMABLE LIQUID RISKS BY FOAMS

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The fire-fighting foam liquids available in the United Kingdom are briefly described. The principles to be observed in designing a foam protection installation are set out. They are illustrated by a case history of the protection of a chemical factory hazard in which methyl-isobutylketone and toluene were the flammable liquids and the choice of foam and application rate is described.

INTRODUCTION

This paper concerns the use of low-expansion foams, with an air to water ratio (range 5 - 15 : 1) produced by self-aspirating branchpipes. It will not consider high-expansion foams (range 500 - 1000 : 1), which are used chiefly for other purposes, nor medium expansion foams (range 50 - 150 : 1) which at present are used to only a limited extent.

It deals briefly with the different foam liquids available and which one is selected for a particular flammable liquid fire, and further, what steps are required to plan the protection of a hazard. The subject will be illustrated with a case history.

FOAM LIQUIDS AVAILABLE

There are five groups of foam liquids now available in the United Kingdom:

1. Protein
2. Fluoroprotein
3. Fluorochemical
4. All-purpose protein
5. Synthetic

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Protein foam liquid is a solution of hydrolysed protein, commonly made from hoof and horn meal. It is used at a concentration of 4 - 6 per cent in water. Until recently it was the liquid of choice for all hydrocarbon risks and is still the most widely used foam liquid.

Fluoroprotein foam liquid is a protein foam which has been modified by the addition of carefully selected perfluorohydrocarbon surfactants, which substantially increase its effectiveness. It is used at a concentration of 4 - 6 per cent in water. It is of recent introduction and its use in place of protein foam is expanding in the United Kingdom.

Fluorochemical foam is the description in the United Kingdom for the products the Americans refer to as AFFF (aqueous film-forming foam), and includes 'Light water'.* It is a solution of several synthetic long-chain fluorochemicals similar, but not identical, to those used in fluoroprotein foam liquids. It is used at a concentration of 6 per cent in water. Like fluoroprotein foam it is of recent introduction. Its adoption has progressed appreciably in America and it is gradually becoming more widely used in the United Kingdom.

Both fluorochemical and fluoroprotein foams are significant improvements upon protein foam for many risks. In any development plans these new foam liquids should be considered because they substantially increase the degree of protection which can be provided in many cases. Frequently either may serve, but in specific cases one or the other may have more appropriate characteristics.

All-purpose protein foams have been available for many years. They are protein foams which have additives to make them function on water-miscible solvent fires which protein foam will not extinguish. They are used at a concentration of 4 - 5 per cent in water. They must be applied with a minimum of force to the fuel surface and at a greater rate than is required for non-miscible liquids. In many cases they are the only effective foams and their use has increased with the growth of the chemical and petro-chemical industries.

Synthetic foams have similar active constituents to the domestic detergent liquids, but are specially selected and formulated for fire foam use. They foam very readily and efficiently. They extinguish many fires rapidly, but effectiveness may diminish when forcefully applied, and they are generally inferior to the other foams in burn-back resistance.

They are used only to a limited extent in the United Kingdom but to a greater extent in some European countries. They are the only foam liquids used for high-expansion and medium-expansion foam, and are used at a concentration of 1.5 - 3 per cent in water.

WHY USE FOAM?

Having briefly described the foams which are available it is appropriate to consider next why they are used.

Foam in effect reduces the density of water and enables it to float on flammable liquids, and so extinguish them when they are burning, which water droplets cannot do. Unlike other agents it persists on the fuel surface and thus prevents re-ignition and permits the progressive extinguishing of large fires. Foam will float around obstacles and so cover areas which could not be reached by a water spray - for example a storage tank with a collapsed roof.

*'Light water' is a proprietary name owned by 3 M's Company.

It is non-toxic, economical and simple to use. Because of these properties fires can be rapidly extinguished, which would present great difficulty using any other extinguishing agent.

A natural corollary to "why do we use foam?" is "how does it work?". There is no simple answer and the following effects may all contribute. Listed in possible order of importance they are:

1. it reflects or absorbs the radiant heat from the flames and prevents it reaching the fuel surface

2. cools the fuel surface to below its boiling point.

3. forms a seal over the fuel surface which retains the vapour and cuts off the oxygen supply from the fuel

4. generates steam and dilutes the oxygen concentration

DEFINING THE HAZARD

When faced with a protection problem the first step to take is to define the hazard. It will usually be straightforward to establish what flammable liquids are at risk and it is very important to do so. When advice is sought upon a foam protection system any mistake or ambiguity in the liquids involved, and their storage temperature, could prove a critical error. This point should also be remembered when process changes are made and new solvents introduced, then the protection system must be re-examined.

The next step is to accept that fires do occur.

Knowing what the flammable liquids are, and accepting that a fire situation can develop, the possible size of fire must be determined. An important guide is that the fire size is governed by the surface area and not the volume of the fuel. A 10 m diameter tank will be equally difficult to extinguish whether it is one quarter or three-quarters full. Various factors may be present in an accident situation: explosion may blow the top off a fixed roof tank, a floating roof may be damaged and sink, resulting in a fire covering the entire tank area, tanks may overflow or pipelines may be fractured, flooding bunds, process areas, ditches under pipe runs and roadways with burning fuel. Large quantities of water, used to cool adjacent plant by monitor, branchpipe or sprinkler systems, may carry burning fuel along drain channels and into the surrounding area. All such possibilities should be considered in estimating the maximum fire area which may have to be dealt with. For existing risks this should be done by an on-site inspection and for new developments at a very early stage in the design process. Possible fire size can be reduced significantly by specific attention to such points as bund design - their sub-division, floor slopes and drainage, the siting and spacing of tanks, pipe-runs, and pumps. At the design stage improvements are often possible at little or no extra cost, but may be very costly or impossible at a later stage. A very simple example is drain channels - a channel 15 cm wide and 30 cm deep is only half the fire problem of one with the dimensions reversed.

Enlisting assistance

When the hazard has been defined it is important to ensure that all interested parties are brought fully into the picture at an early stage. Much help will be forthcoming from such as the Chief Officer of the public Fire Service, the

Petroleum Officer, HM District Factory Inspector, the factory manager and his safety officer, the solvent supplier and the fire protection industry.

Further information required

Completion of the foam protection specification requires answers to the following questions:

1. Which type of foam liquid is to be used?

2. How much foam liquid is required?

3. What equipment and how many men are necessary?

4. How much water is required?

5. How much will it cost?

The following case history describes how these questions were answered in one particular set of circumstances.

THE CASE HISTORY

General description. The Fire Research Station was asked if it could assist in deciding on the fire protection required in one section of a chemical manufacturing plant.

The problem related to part of a building in a large plant. It contained a complex of reaction vessels, pumps, pipelines, intermediate storage tanks, centrifuges, dryers, etc. They were arranged on several levels, with open stairways between floors, and with many pipelines and vessels penetrating the floors. The intermediate storage tanks varied in size up to 10 m^3 capacity. A serious fire in the building would cause a major dislocation of production and so a substantial effort was warranted to provide a high level of fire protection.

Two flammable liquids provided the major fire hazard: methylisobutylketone (MIBK) and toluene. A sprinkler system was being installed which was appropriate to protect the building structure and plant supports. It would not however assure the rapid control and extinction of a fire resulting from a major spillage of the two solvents. The water spray from the sprinklers would not directly reach all the areas over which the solvents might spread because of the shadow effects of the many plant items. Water alone could not extinguish these solvents efficiently, as can be surmised from their physical properties shown in Table 1. It could also be seen that firemen attacking the fire from outside the building would be very fortunate if they could obtain a direct view of any serious spillage and be able to direct their spray/jets to the entire burning surface.

Dry powder fire extinguishers were provided in the building.

The major firefighting requirement would be provided by the area fire brigade with a response time of two min.

If a foam could be available which would enable fires of both solvents to be extinguished, and protected from re-ignition, it would materially improve the firefighting ability of the brigade. It would also increase the probability that first-aid action, even if not successful, would arrest fire progress effectively until the brigade arrived.

EXPERIMENTAL INVESTIGATIONS

Appropriate information on the performance of foam on fires of these two solvents was not available from the literature and it was decided to conduct an experimental investigation.

Four classes of foams were chosen for the initial tests: 2 proteins, 2 fluoroproteins, 1 synthetic, and 1 fluorochemical. All-purpose protein foam was not included and because a satisfactory answer was obtained from among the 4 types of foam selected the all-purpose protein foams were not used - although they may also have been satisfactory.

0.24 m^2 laboratory fires were first used with gentle surface application of the foam. MIBK fires were used first because it was anticipated that it would be the more difficult solvent to extinguish. Protein foam was rapidly destroyed by MIBK and would not extinguish the test fires. Further 0.24 m^2 fires used forceful application to simulate more closely the practical situation of applying foam from a branchpipe. These tests enabled fluorochemical to be selected as the foam with the best performance, the fluoroproteins being second choice, and noticeably less effective. The experiments were then increased in size using tray fires in the open, up to 2.84 m^2. For some of these tray tests the fluorochemical was applied as a spray: its film-forming properties enabling it to function when so applied, as well as when applied as a foam. This simplified the experimental technique because spray nozzles of any capacity are available while foam branchpipes with identical characteristics are only available in a limited number of the small sizes required for these tray tests. Both MIBK and toluene were used. Finally tests were made using 7.6 m^2 fires with both solvents.

Altogether a total of approximately 60 experimental fire tests were conducted. The extinction time and the 90 per cent control time were recorded for each fire - in this case the 90 per cent control time is the time for the fire area to be reduced to $^1/10$ of its initial area.

Figs 1 - 4 show the more important results, Table 2 gives the results for the 7.6 m^2 fires.

Fig. 1 is the critical application rate curve for the 0.24 m^2 laboratory fires of MIBK, using gentle surface application of fluorochemical foam. The performance of fluorochemical foam on MIBK, when applied gently, compares well with the best performance of foams on hydrocarbon fires in similar tests.

Fig. 2 shows the results of MIBK tray fires up to 2.84 m^2, using fluorochemical foam from a 5 l/min branchpipe. It can be seen that the control times compare well with the gentle surface application tests, but the extinction times are longer. This was because mixing of foam and fuel made it difficult to extinguish the last flickers of flame. Fig. 3 is for a similar series of tray fires using the fluorochemical as a spray instead of as a foam and the results obtained are very similar. Fig. 4 shows that fluorochemical spray also dealt with toluene fires effectively but there is a noticeable difference from the MIBK fires: the control times were much longer, but once control was achieved, extinction followed very quickly. The critical application rate is also higher at 0.04 l/m^2 s as compared with 0.03 l/m^2 s for MIBK fires.

The application rate to be provided was decided from the curves on Figs 2, 3 and 4. It should be above 0.04 l/m^2 s otherwise the toluene fire will not be extinguished. 0.08 - 0.16 l/m^2 s is indicated as a satisfactory range which gave good control and extinction of both fires, the upper limit being because the quantity of fluorochemical required to extinguish the MIBK fires rose rapidly at the higher application rates.

In addition to obtaining the required information on application rates a number of other useful observations were made. The MIBK fires produced comparatively little smoke, and burnt with an unusually large area of bright flame. This caused high radiation and the fires were difficult to approach without protective clothing. Toluene fires on the other hand were extremely smoky and would rapidly smoke-log a building and prevent entry. The variation in the ease of ignition of MIBK according to the ambient temperature was very noticeable. It illustrates a useful practical point with solvents having a flashpoint in the ambient temperature range. If plant condensers are kept in good order and not overloaded the solvent can be kept below its flashpoint and will be much safer than if condensers are allowed to run hot.

Residual small flames on MIBK fires are almost invisible and great care is necessary to ensure that the fire has been completely extinguished, particularly when it is close to hot metal. A 1.9 m (75 in) diameter tray fire of MIBK was noted as appropriate for training plant operators. It can just be extinguished with a 9 l (2 gal) stored-pressure fluorochemical extinguisher. Without experience the operator would probably retreat from a fire of this size.

In real situations very few flammable liquid fires are extinguished in a minute or less as are the experimental tray fires. Access to the fire may be difficult, and smoke-logging in a building can delay finding the fire. The fire may have burned for a period before action is taken and metal objects which are involved in the fire will require cooling; the direction of foam jets onto the fuel surface may be hampered by vessels and pipelines, and high winds may deflect foam streams. It is therefore a matter of judgment and experience to decide the total quantity of foam to be provided. Consideration must be given to how long it will take to obtain further supplies from another site or a strategic stockpile. The IMCO discussions on the foam protection for tankers are a useful guide in this respect, suggesting application times varying from 15 minutes to over 1 hour.

RECOMMENDATIONS

1. Protein foam is useless for MIBK fires.

2. Fluorochemical will effectively control and extinguish MIBK fires. It has to be applied gently, preferably as a dispersed foam jet. It is also effective applied as a fine spray.

3. Application rates of fluorochemical foam <u>must</u> be above 0.04 l/m^2 s (0.05 gal/ft^2 min) and preferably in the <u>range</u> 0.08 - 0.16 l/m^2 s (0.10 - 0.20 gal/ft^2 min).

4. The above rates also control and extinguish toluene fires.

5. As soon as an MIBK fire is under control, one branchpipe is sufficient to complete extinction economically.

6. Small residual flames on MIBK fires are very difficult to see, and extreme care is necessary to ensure extinction has been achieved.

7. A significant post-extinction protection is provided by the fluorochemical on both MIBK and toluene fires; foam probably being superior to spray in this respect.

8. MIBK fires are readily controlled but difficult to extinguish, while with toluene fires the reverse applies (with fluorochemical).

9. A useful training exercise for plant operators is the use of a 9 l (2 gal) stored-pressure fluorochemical foam extinguisher on a tray fire - 1.9 m (75 in) diameter, (2.84 m^2 (30.5 ft^2) area) using 35 l (7.5 gal) of MIBK as fuel.

10. A total application time of 20 - 30 min is suggested as a basis for determining foam liquid requirements.

11. After fluorochemical foam, fluoroprotein foams gave the best performance on MIBK fires and could be used in a disaster situation if fluorochemical foam liquid stocks were exhausted.

12. When the dry powder extinguishers in a plant are refilled, a fluorochemical compatible powder should be used.

13. The detailed planning of fire protection requirements should start at an early stage of plant construction.

CONCLUSION

This case study concerned an operational unit and although it does not provide a good illustration of the importance of minimizing fire control problems by attention to plant and building layout at the design stage, it does provide a good illustration of the importance of carefully assessing the hazard and ensuring that the protection provided will match the hazard.

When the hazard has been clearly defined and the protection requirements determined, their provision and the determination of their cost will usually present no difficulties.

In this particular case the hazard was exceptionally large, appropriate information on the solvents involved was not available, but the Fire Research Station was able to programme the necessary investigations. In many cases the Fire Service will be able to advise what protection is required. The insurance companies, the equipment manufacturers and the fire consultants also have data on specialized hazards, or know where it is available. Advice should always be sought first from these sources.

TABLE 1 - Properties of methylisobutylketone and toluene

	MIBK	Toluene
Chemical formula	$C_6H_{13}O$	C_7H_8
Specific gravity	0.8	0.9
Solubility in water percentage weight/weight	1.9	0.05
Boiling point °C	118	110
Flashpoint °C	23	4.5
Lower flammable limit percentage by volume	1.4	1.2
Toxicity (threshold limit value - ppm)	100	200

TABLE 2 - *Large tray fires of MIBK, and of toluene, with fluorochemical foam and spray*

Fire area 7.6 m^2 (82 ft^2)
Spray application rate - 0.14 l/m^2 s (0.17 gal/ft^2 min)

Test No.	Fuel	Wind velocity m/s		90 per cent control time s	Extinction time s
38	MIBK	5		24.5	53
39	MIBK	5		14.5	49.5
40	MIBK	5		12	42
			Av.	17	48
41	Toluene	5 - variable		28	45
42	Toluene	5 - variable		24	51
			Av.	26	48
43*	MIBK	2		10	45

*In test 43 the fluorochemical was applied as foam at 0.11 l/m^2 s (0.134 gal/ft^2 min)

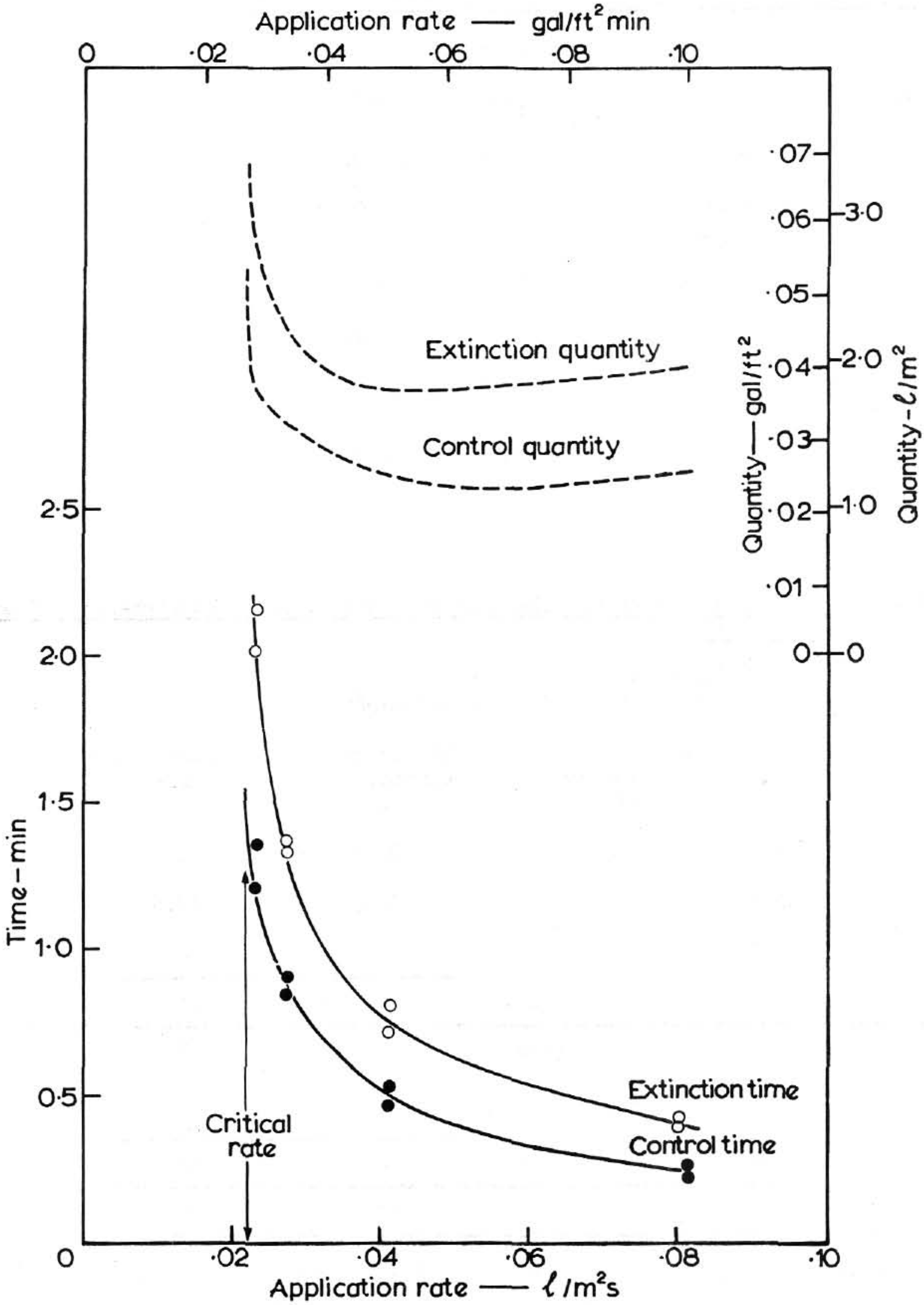

Fig. 1 : Critical application rate - fluorochemical foam on MIBK $0.24 m^2$ ($2.6 ft^2$) fires - gentle surface application

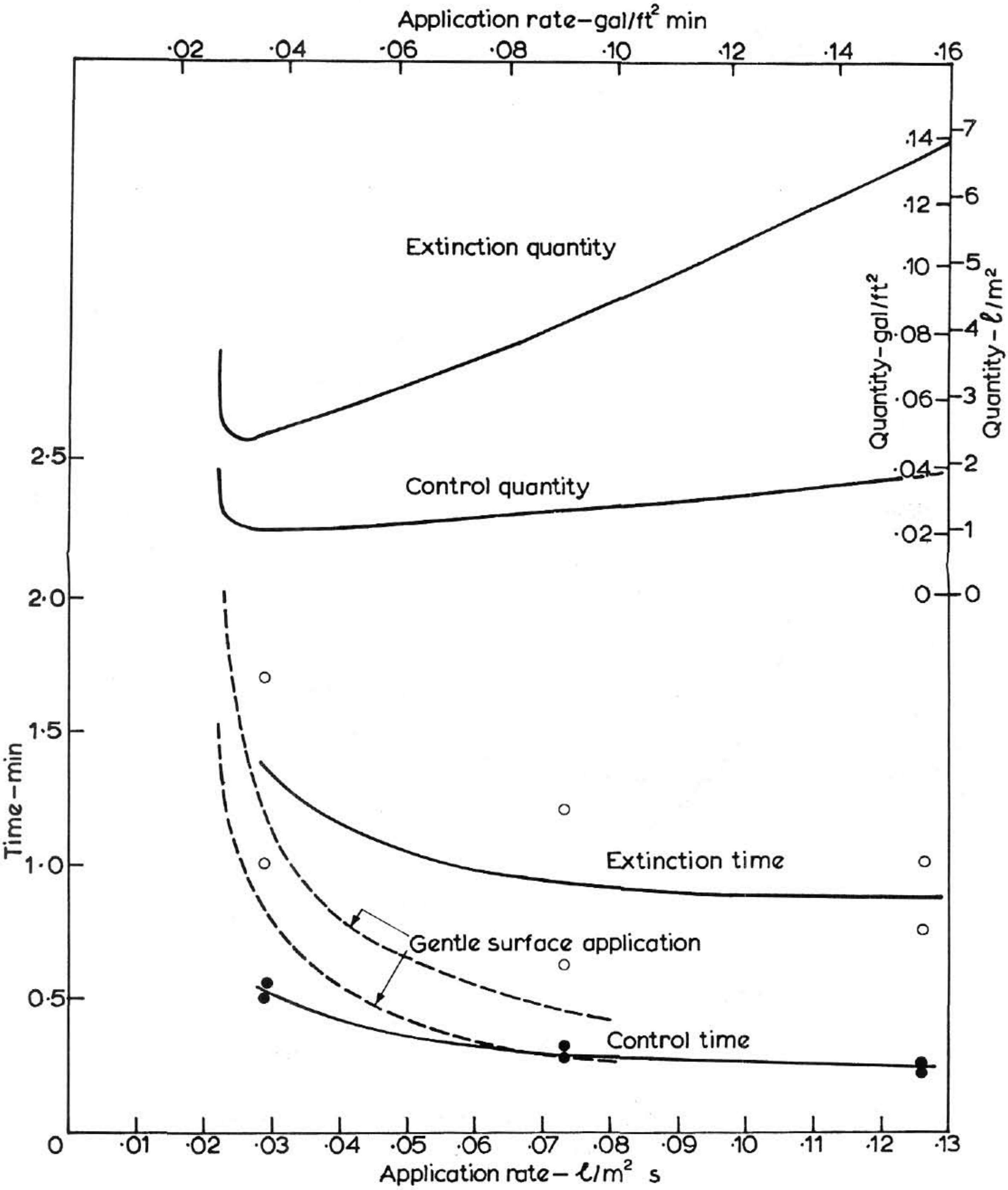

Fig. 2 : Fluorochemical foam on MIBK tray fires – 5 l/min branchpipe – 0.66, 1.14, 2.84 m^2 fires

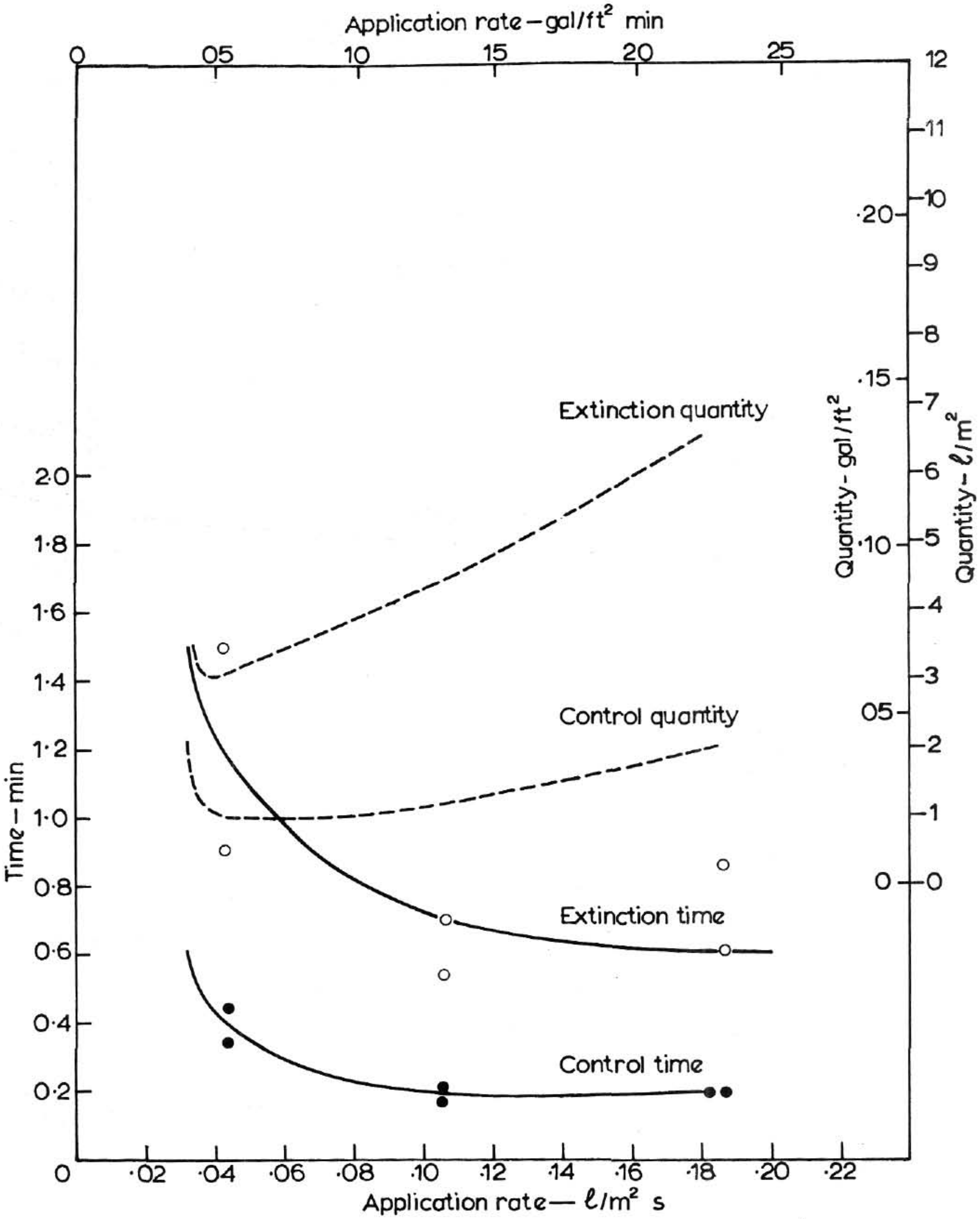

Fig. 3 : Fluorochemical spray on MIBK tray fires - 7.25 l/min (1.6 gal/min) spray jet

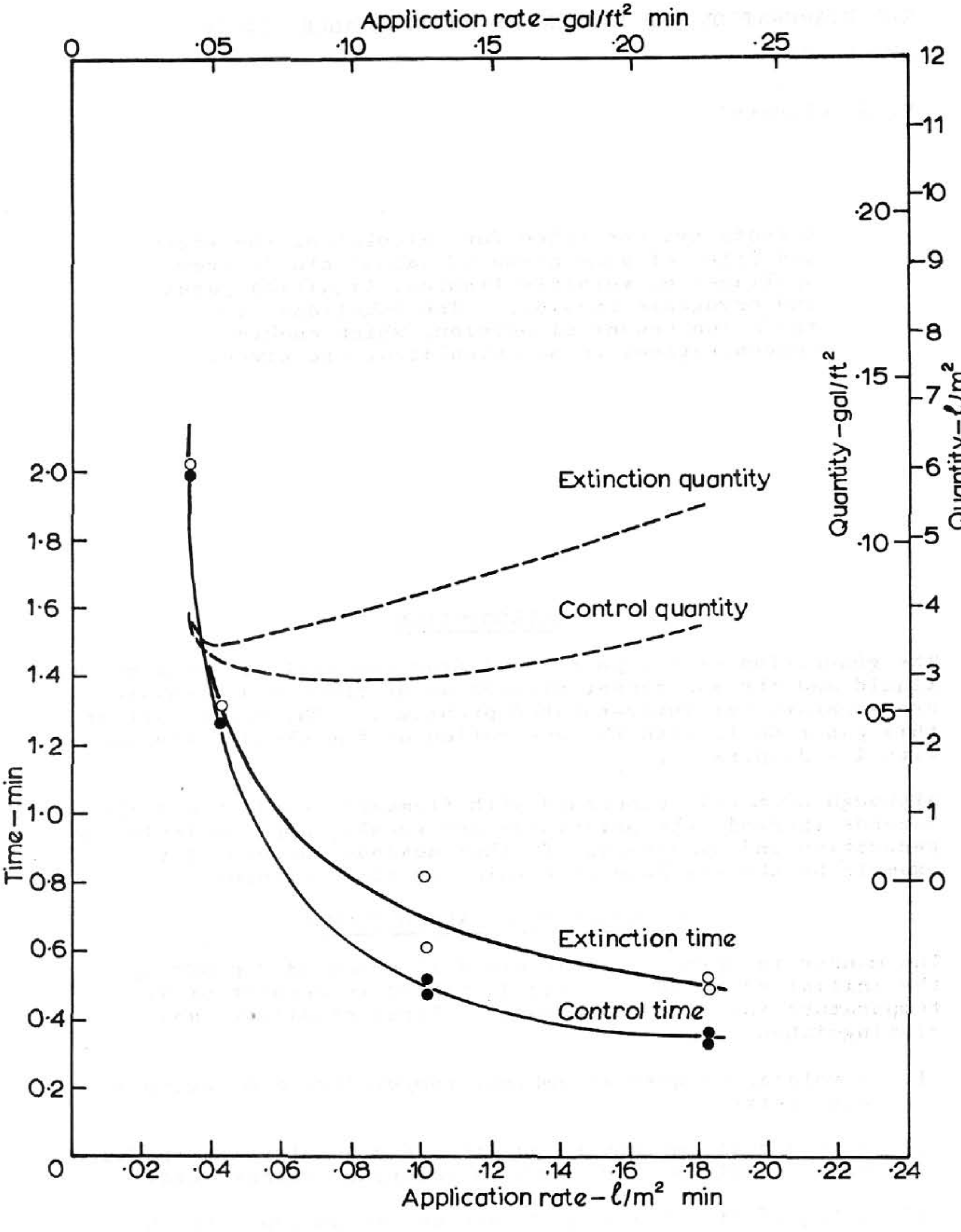

Fig. 4 : Fluorochemical spray on toluene tray fire – 7.25 l/min (1.6 gal/min) spray jet