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THE EXTINCTION OF FIRES IN PETROL STORAGE TANKS BY THE BASE INJECTION OF AIR-FOAM

by

R. J. French and P. L. Hinkley

Summary

The investigations reported here show that the production of a foam blanket on the surface of petrol in a large tank is practicable, and that extinction is possible, by the injection of foam at the bottom of the tank. The foam produced from many compounds is considerably contaminated with petrol on its way to the surface and although the fire can always be greatly reduced in intensity the burning of the petrol contained in the foam may prevent extinction.

Extinction was possible with one particular foam compound, not at the moment in general use, by using it in a 3 per cent solution to produce a foam of low expansion and low critical shearing stress but at the same time with a low rate of drainage. The production of such a foam by any self-aspirating type of equipment would probably not be possible, and the development or modification of a foam pump might well be required.

Some suggestions are made of the limiting requirements for practical installations, with the reservation that the figures given should be confirmed by tests on a much larger scale.

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I Introduction

The extinction of fires in fuel storage tanks by the base injection of foam is attractive in that the product lines can generally be used for the purpose and little modification is likely to be needed to existing installations. Further, these product lines are not usually susceptible to damage by fire in the tank or the bund or by an explosion which may sometimes precede the fire. Past work on this method of tank fire-fighting has been surveyed by Thomas (1).

The problem of extinguishing fires in petrol storage tanks is fundamentally different from that of extinguishing fires in tanks containing high flash point fuel. With petrol there is little chance of boil over or slop over since the hot zone has a temperature of less than 100°C (2). However, in this case it is impossible to extinguish the fire by cooling alone and it is necessary to form a coherent blanket on the surface of the petrol which will protect it from the radiation from the flames above. This problem of forming a suitable blanket is complicated by the contamination of the foam by petrol.

Tuve and Peterson (3) and other workers (4) have investigated petrol tank fires but no actual extinction of fires in tanks containing a depth of more than about 10 ft. of petrol has been reported. (The "successful extinction" mentioned by Thomas (1) cannot be so regarded since "vapour continued to burn round the periphery of the tank.").

The purpose of the investigations described in this report was to determine whether base injection was a reliable method of fighting petrol tank fires. It was also hoped to be able to recommend the optimum foam for base injection into petrol storage tanks to give certain extinction.

II Experimental equipment

(1) Small scale tank

The small scale experiments were carried out in a tank shown diagrammatically in Figure 1. This was made of 20 S.W.G. sheet steel and was 2 ft. diameter at the top. To reduce the amount of petrol required in the tank the lower part was tapered down to 6 in. diameter. The injection inlet on the bottom was ⅝ in. diameter.

(2) Large scale tank

The large scale experiments were carried out in a tank 9 ft. diameter and 30 ft. high made of ¼ in. steel plate (see Figure 2). This was erected vertically on a concrete base 27 ft. diameter having a 4 ft. 6 in. high brick wall built on its periphery to form a bund capable of holding all the contents of the tank. The tank was originally closed at both ends and for these experiments four quadrants were cut out of the upper end leaving a 6 in. wide band round the edge and a 12 in. wide cross in the middle.

The tank was surrounded by a 30 ft. high scaffolding structure and a wooden platform 23 ft. by 18 ft. was erected 4 ft. below the top of the tank. Two ladders were provided, with a secondary platform about 12 ft. up, for access to the main platform. A metal chute was erected leading from one corner of the platform to the ground to give means of rapid escape in case of emergency. The general arrangement of the tank and its surrounding structure is shown in Plate 1 and Figure 3 and a view of the top of the tank in Plate 2.

A 1 in. drain valve was fitted 3 in. from the bottom of the tank and two 2 in. inlets were provided 12 in. from the bottom. One of these inlets was extended radially inwards to within 6 in. of the centre of the tank. Only this latter inlet was used for the base injection of foam, the other being used mainly for the filling and replenishment of the tank with petrol as required.

The tank was initially filled with 10,800 gallons of Pool petrol and during the ten months of the experiments was replenished with 3,550 gallons, 750 of these being Pool petrol and the remainder a standard grade. All the tests were carried out with the petrol level between 2 ft. and 3 ft. 3 in. from the top of the tank giving an effective depth of between 25 ft. 9 in. and 27 ft.

A No. 0 foam-making branchpipe was fitted below the wooden platform and was connected by 2 in. pipe to an inlet in the side of the tank 1 ft. 3 in. from the top. Water could be supplied to this through a 1 in. riser and by this means foam could be applied to the petrol surface in an emergency or if extinction was not obtained by base injection. Four $\frac{1}{2}$ in. sprinkler heads were fitted above the platform so that the boards could be wetted down before a fire test or if they caught fire during a test. A circle of $\frac{3}{4}$ in. pipe containing a series of inwardly-facing holes was fitted round the top of the tank so that the metal could be cooled as required. Two more 1 in. risers were used to supply water to these appliances. A permanent foam applicator was hung over the bund wall and could be supplied from a No. 5 foam generator should a bund fire occur. For all tests hose lines were run to these appliances from a mobile pump drawing water from a 3000-gallon canvas dam.

Two thermocouples were fitted to the tank plates, one in the side 7 in. from the top and the other in a limb of the cross 2 ft. 6 in. in from the tank edge. These were fitted so that a check could be kept on the tank temperature, cooling water being applied if it became too hot.

Four radiometers, of the type used in the surface application tests (5), were supported 3 ft. above the top of the tank at the four corners of a square of 45 ft. diagonal. These were used in only a few tests.

Foam was produced by means of a compressed air foam generator (6) from which it passed through 10 ft. of $1\frac{1}{2}$ in. rubber tubing into 30 ft. of $1\frac{1}{2}$ in. pipe followed by 45 ft. of 2 in. pipe to the edge of the bund. At this point a 2 in. tee-piece was fitted and this had a 2 in. valve on one limb through which the foam could be allowed to pass to waste. The 2 in. pipe then continued through the bund wall via a non-return valve and a shut-off valve into the inlet at the bottom of the tank. The valves at the bottom of the tank are shown in Plate 3. With this arrangement it was possible to allow the foam to flow to waste until the pipes were running full of new foam and samples had been collected. Then, with the shut-off valve open, the valve on the tee-piece would be closed, and the pressure would rise until the non-return valve opened and foam entered the tank. The actual moment of injection could be observed on a pressure gauge in the line, the reading on which would rise to a maximum value equivalent to the head of petrol at the moment the non-return valve opened.

III Small scale experiments

(1) Measurement of petrol pick-up

Previous experiments (6), (3) on the base injection of foam into petrol tanks have shown that the extinction of a fire may be prevented by the burning of the petrol picked up by the foam on its way to the surface. The first experiments with the 2 ft. tank were made to determine the amount of petrol picked up by foams of different physical characteristics. A standard protein compound (hydrolised keratin - referred to as compound A in previous reports (5)) was used in a 3 per cent solution. This was chosen as typical of the compounds in general use for surface application. The expansion factor of the foam was varied between 3 and 9 and the critical shearing stress was maintained as near to 200 dynes per sq. cm as was practically possible. Further tests were carried out for expansion factors of from 5 to 9 with a critical shearing stress of 400 dynes per sq. cm to find out the effect of this latter factor. In all cases samples of the foam arriving at the top were taken and all were found to be flammable. With foams having expansion factors greater than about 4 (which is lower than that normally used for top application) the foam sample was sufficiently contaminated with petrol to be completely destroyed by the burning of the latter.

Other samples were taken from the surface by means of a perforated scoop, care being taken to avoid picking up petrol from below the foam layer, and were transferred to cans of known volume for analysis. A simple method of estimating the petrol content of the foam was adopted but it was later found that this method was not sufficiently accurate, giving values that were too low. A more accurate method was used later (see Appendix A), and it was found possible to apply an approximate correction to the results by the first method. All figures in this note are either those obtained by the later more accurate method or are suitably corrected. The liquid content of the foam sample was measured so that the proportion of the injected liquid reaching the surface could be measured.

These tests confirmed the results of other workers (3) by showing that the amount of petrol picked up greatly increased as the expansion was increased. Foams with the higher critical shearing stress picked up more petrol though this effect was not so large.

It was evident that an examination of foam of low expansion would be most profitable and most of the subsequent work was carried out with foams having expansions between 2½ and 4.

(2) The distribution of petrol within the foam layer

In an attempt to find out how the petrol picked up is contained in the foam, the small tank was filled with petrol that had been heavily dyed red. Foam having an expansion of 5, which ensured a high pick-up of petrol, was injected into this tank until a layer approximately 2 in. thick had been formed on the petrol surface. It was noted that, initially, before the surface was completely covered appreciable quantities of petrol were thrown up onto the surface of the foam to form small pools, but these rapidly dispersed or evaporated. The layer was sliced through with a steel rule and the dyed petrol could be seen to be present as evenly distributed globules; the diameter of these globules was from 0·2 to 3 mm and a few of them appeared to contain bubbles of air. Individual flakes of foam did not appear to contain any such globules and it seems that the petrol is trapped between the flakes as they flow together to form the blanket.

(3) Fire tests - control and extinction

A series of fire tests was performed on the 2 ft. tank using an expansion of 4 and a range of rates of injection. In these experiments the radiometers were placed at the four corners of a square of 10 ft. diagonal, and the control time was calculated, as in the surface application experiments (5), as the time taken to reduce the radiation to ⅓ of its value at the moment of foam application. Determination of the petrol pick-up and the proportion of the liquid arriving at the surface were made before each fire test. The petrol temperature was between 8 and 16°C and a 30 second preburn period was allowed. The rate of injection was varied between 0·10 and 0·02 gal. of liquid per sq. ft. per min. In all cases the fire was extinguished in from 2 to

40 min. and controlled in from 20 to 45 sec. The petrol pick-up in these tests was between 9 and 11 volume of petrol per 100 volume of liquid arriving at the surface and between 55 and 70 per cent of the injected liquid reached the surface.

A few experiments were carried out in which the petrol content of the foam was artificially increased by injecting additional petrol into the foam line. Where the petrol content was greater than about 12 volume per 100 volume of liquid extinction was not possible.

Other experiments were performed with the petrol at different temperatures. The petrol was heated by allowing a long preburn period with intermittent air stirring until the required temperature was reached. As the petrol temperature was increased the pick-up increased and at 60°C had reached 21 volume per 100 volume of solution and extinction was not possible. Figure 4 shows these results in graphical form. Figure 5 shows a radiation record of a test in which the foam was too highly contaminated for extinction to be possible; this curve gives a typical representation of the progress of a fire in which extinction was not achieved. In this experiment the fire was rapidly controlled and as surface became completely covered the radiation was reduced to as little as 5 per cent of the maximum, but as the flames collapsed a foam fire developed which the continued injection of foam would not reduce.

In one experiment in which the petrol pick-up was just below the allowable maximum, it was observed that a small foam fire went on burning for up to 40 min. when the upper part of the foam layer had been destroyed over its whole area. The fire finally died out leaving a thin scorched foam blanket. With foams of low petrol content the radiation would fall rapidly to a minimum and extinction would occur almost as soon as the surface was covered, there being virtually no foam fire. The radiation record of such a fire, using foam containing 7 volume of petrol per 100 volume of liquid, is shown in Figure 6.

Figure 7 shows the relationship between the control time and the rate of application obtained from these tests in comparison with a typical curve obtained for surface application (5).

The general conclusions of these small scale tests were that a fire could not be extinguished with certainty if the foam contamination exceeded 10 to 12 volume of petrol per 100 volume of liquid at the surface and that this would probably be exceeded for foams of expansion greater than 4.

(4) Fire tests - the role of stirring

Control in a given time can be obtained with base injection at an appreciably lower rate of application than with surface application. This difference was thought to be caused by the stirring of the petrol by the foam (2) and some experiments were carried out injecting air alone into the tank. The third curve in Figure 7 shows the effect of this stirring action on the control time and it can be seen that it must play an appreciable part in the process of base injection. The curve was plotted by taking an equivalent rate of application of liquid as the rate of injection of air divided by the expansion of 4 used in the foam injection experiments. Figure 8 shows a radiation curve for a typical air-stirring experiment.

IV Large scale experiments

(1) Measurement of petrol pick-up

The first series of large scale experiments was carried out, using the same compound in the same concentration for the same range of expansion factors as had been used with the 2 ft. tank, to find out how the scale affected the contamination of the foam. A similar relationship between expansion factor and pick-up was found through the actual values of the pick-up tended to be slightly higher than with the smaller tank.

Further determinations of the amount of petrol picked up were then made with the large tank concentrating on expansion factors in the range $2\frac{1}{2}$ to 4. During these experiments it was noted that the amount of the petrol pick-up was varying with the particular drum of compound used. This meant that even if extinction were possible with a given batch of this compound this variation might be sufficient to make the method unreliable. During these tests measurements of the drainage rates of some of the foams were measured, by the method used by Tuve and Peterson (3). An analysis of the result obtained shows that for the given critical shearing stress and expansion factor the pick-up increases with increasing rate of drainage.

From Figure 9 it may be seen that the petrol picked up by foams of the lower expansions in the larger tank is approximately twice that picked up by comparable foams in the smaller tank. The effect of increasing the concentration of the solution to 10 per cent was investigated and was found to result in an increase in the petrol pick-up of about 50 per cent.

Figure 10 gives the relationship between petrol pick-up and critical shearing stress for an expansion factor of 3 for the large scale tank.

(2) Large scale fire tests

Two fire tests were then carried out on the large tank with foams of expansion 3 and 4 made from a 3 per cent solution of compound A. The rate of injection was 0·063 gal. of liquid per sq. ft. per min. and the critical shearing stress was 250 dyne per sq. cm.; in neither case was the fire extinguished. With the foam of the lower expansion the petrol surface was covered completely and the petrol in the foam did not burn but an edge fire developed which could not be extinguished by base injection. With the higher expansion foam coverage and control were obtained in about 50 seconds. There was no edge fire but, as had happened with some unsuccessful small scale tests an uncontrollable foam fire developed as the major flames collapsed. A few more fire tests were carried out on the large scale and in no case was extinction obtained, although the fire was usually reduced to very small flames over the foam surface and a slight edge fire. In general, the course of the fire followed the pattern already noted on the small scale.

It was evident from these tests that the extinguishing of a fire in the larger tank was more difficult than in the smaller tank and would be unlikely with compound A as used in these tests. Consideration was therefore given to reducing the petrol pick-up on overcoming its effect by the addition of an extinguishing agent to the foam.

V Examination of methods of reducing petrol pick-up or its adverse effects

(1) Effect of injecting foam into water at the bottom of the tank

A previous small scale test, in which the level of the liquid drained from the foam had accidently been allowed to rise high enough to cover the base injection inlet, gave an abnormally low petrol pick-up and to verify this effect a second test with dyed petrol was carried out with the base injection inlet submerged in water. The number of globules of petrol in the foam was estimated to have been reduced by about 75 per cent. A similar test was carried out on the large tank in which the foam was injected into one foot of water and the petrol pick-up measured, but no significant reduction was found. It thus appears that the effect is confined to shallow depths of petrol.

(2) The addition of extinguishing agents to the foam

Attempts were made to extinguish the foam fire by the addition of extinguishing agents to the foam before it was injected. The addition of carbon tetrachloride to petrol in various proportions showed that at 50/50 mixture of the two was necessary to prevent combustion and it was therefore estimated that it would be necessary to get at least as much carbon tetrachloride to the surface as the amount of petrol picked up if this method was to be successful.

Experiments were carried out with the small scale tank using foam having an expansion of 6. When carbon tetrachloride was injected into the mixing chamber of the foam generator at a rate equal to one-third of the foaming liquid flow rate, the foam arriving at the surface of the petrol contained a mixture of carbon tetrachloride and petrol in the ratio of 7 to 3. The addition of carbon tetrachloride resulted in the proportion of foaming liquid reaching the surface being approximately halved. In a fire test extinction was achieved shortly after the surface was covered.

Chlorobromomethane was tried as an alternative extinguishing agent. This was more effective than carbon tetrachloride and the addition of 10 volumes to every 100 volumes of foaming liquid resulted in the extinction of the fire shortly after the surface was covered. The resulting foam blanket appeared to be more persistant than that containing carbon tetrachloride.

One test was carried out on the large tank using foam with an expansion of 3 to which carbon tetrachloride was added at a rate equal to 30 per cent of the foaming liquid flow rate of 0·05 gal. per sq. ft. per min. The carbon tetrachloride - petrol mixture contained in the foam at the surface was found to be in the proportions of 6 to 4 but only 45 per cent of the foaming liquid reached the surface. In a fire test carried out under these conditions it was not possible to cover the petrol surface, presumably owing to the deterioration of the foam caused by the carbon tetrachloride; this had been observed to some extent, on the small tank. Success may have been possible with chlorobromomethane but this line of investigation was not continued as the use of another foam compound was proving hopeful. The additional expense and complication of using extinguishing agents is obviously not warranted if foam alone can be made to work reliably.

(3) Examination of foam compounds

The petrol pick-up was determined for a number of foam compounds and mixtures of foam compound and wetting agents. Foam was made in a simple foam generator shown in Figure 1. The liquid flow was adjusted to 22 cc. per min. and the expansion set to about 5. A sample of the foam from the generator was first collected in a beaker of known volume and its expansion factor determined. Foam was then injected into petrol contained in a 6 cm. diameter glass tube as shown in Figure 12. The foam overflowing the top of the tube was collected in a beaker of known volume and its petrol content was determined.

In order to allow for the variations in the actual expansion factor, it was assumed that, over the small range of expansion factors involved, the pick-up was proportional to the air volume factor and petrol pick-up index was defined as

$$\frac{\text{petrol pick-up in volume per 100 volume of liquid at surface}}{\text{air volume factor}}$$

TABLE 1

Petrol pick-up of foams formed from various foaming agents

Foaming agent	Expansion factor	Petrol pick-up per 100 volume solution arriving at surface	Petrol pick-up index	mean
A Hydrolysed keratin 3%	5·2 5·0 5·2	10·6 9·8 10·6	2·5 2·5 2·5	2·5
B Experimental hydrolysed keratin 3%	4·7 4·7 6·1	7·9 7·5 11·2	2·1 2·0 2·2	2·1
C Hydrolysed blood 3%	5·0 4·9	11·9 10·9	3·0 2·8	2·9
D Soap solution 3% (in tap water)	5·3 4·9 4·9 5·0	15·4 9·2 10·6 11·9	3·6 2·3 2·7 3·0	2·9
E Wetting agent (detergent) 3%	4·7 5·0 4·9	18·7 36 33	5·0 9·0 8·5	7·3
G Hydrolysed protein (Australian 3%)	5·0 4·4	12·0 10·0	3·0 2·9	3·0
K Hydrolysed blood 3%	5·3 4·9	14·5 15·1	3·4 3·9	3·7
3% (A) + 3% wetting agent (E) (sludge filtered off)	4·7	47	13	13
1½% (A) + 1½% wetting agent (E) (sludge filtered off)	4·9	33	8·5	8·5
3% (A) + 0·3% (by weight) wetting agent (1)	4·5	42	12	12
3% (A) + 0·1% wetting agent (2)	4·5	38	11	11

The results are given in Table 1 from which it can be seen that the foam produced from the wetting agent has a high petrol pick-up and that the wetting agents conferred this property onto foams produced from wetting agent protein compound mixtures. The experimental compound (B) had a pick-up lower than any other compound investigated and it was decided to include this compound in the large scale experiments.

VI Large scale tests with an experimental compound

Large scale tests with foam produced from a different batch of compound B gave pick-up figures which were lower than the very small scale tests had indicated they might be. The first fire tests were made with the foam generator set as it had been for earlier tests. Under these conditions the fire could not be extinguished but the foam fire was reduced to little more than flickers of flame. It was subsequently discovered that by arranging the foam generator so that more energy was put into the production of the foam, a more homogeneous foam resulted with but little increase in critical shearing stress. This foam was found to drain more slowly than the less homogeneous one previously used. The petrol picked up with this foam was found to be 4 to 5 volumes per 100 volumes of foaming liquid, only 30 to 50 per cent of that obtained with standard protein compound used for the earlier unsuccessful tests. Up to 75 per cent of the liquid injected reached the surface. Plate 4 shows this foam rising to the petrol surface and Plate 5 shows the blanket formed.

A fire test was carried out with a foam of expansion factor 3·5 produced in the above manner. This foam had a critical shearing stress of 130 dynes per sq. cm and took more than 3·0 min. to lose 25 per cent of its liquid content. The rate of injection of liquid was 0·075 gal. per sq.ft. per min. and foam injection was commenced 2 minutes after the ignition of the petrol. The fire was extinguished in 3·3 minutes almost as soon as the coverage of the surface was complete. There was no burning of the petrol in the foam at any stage and it was evident that the quantity of petrol picked up was not sufficient to cause a foam fire. A second test carried out under generally similar conditions but with a preburn time of 3·5 minutes gave very similar results with extinction in 3·8 minutes. A further increase in the preburn time to 9 minutes had no apparent effect and extinction was obtained in 3·3 minutes.

After these experiments more petrol was pumped into the tank and the new level was such that the reinforcing members at the top of the tank were partially submerged. A fire test with the same foam and the same rate of injection and with a preburn time of 5·0 minutes resulted in extinction of the main fire almost as soon as the surface was covered after 3·3 minutes but flames persisted around the reinforcing members and for about 1 ft. each side of them. These flames went out after a further 4·7 minutes injection. This additional time was probably occupied by the cooling of the metal to a temperature below the ignition temperature of the petrol.

A fifth test was then carried out, with the petrol at the lower level and a preburn time of 8·0 minutes was allowed. Records of temperatures during this test indicated that the main plates reached a maximum temperature of 500 to 540°C in the first 3 to 3½ minutes while the centre of the cross reached about 700°C. This fire was also extinguished in 3·3 minutes. Thus the four tests with the petrol at the lower level had given consistent results.

It was then decided to investigate the effect of a considerably longer preburn time. In the final test with these foam properties the fire was allowed to burn for 30·5 minutes before injection was commenced. For the major part of this time the tank temperature was kept down to below 400°C by intermittent cooling but no cooling was applied during the last 4·0 minutes and the temperature of the tank plates again rose to 500°C. This test was carried out with the petrol at the higher level and the main fire was extinguished in 5·0 minutes but small flames around one of the reinforcing members lasted for a further 3·0 minutes.

The quantity of liquid required for extinction was 0·25 gal./sq.ft. when the fire was put out in 3·3 minutes and 0·60 gal./sq.ft. if the reinforcing members were submerged when extinction took 8 minutes.

An experiment with the same compound but with the expansion factor increased to 4·3 just failed to achieve extinction but the final flickers of flame were so small that one person was able to blow them out. It is consequently thought that 4·3 is very near to the upper limit of expansion factor for this compound.

Plates 6 - 8 show stages in one of these successful experiments and are typical of the pattern of all of them. Plate 6 shows the fire at its height just before foam was injected and Plate 7 the fire after foam had been injected for about 2 minutes. It is seen that at this stage, although an appreciable area of the petrol is still uncovered, the fire is well under control; the considerable reduction in fire is probably due partly to the stirring action of the foam. After another minute the surface was covered except for the hole caused by turbulence over the foam inlet, as shown in Plate 8, and after approximately a further $\frac{1}{2}$ minute, the blanket was sealed and the fire was out. These photographs show the complete absence of any foam fire.

VII Analysis and discussion of results

From an analysis of the results of the investigations described here the following general conclusions have been drawn.

1) The amount of petrol picked up by a foam increases rapidly with increasing expansion factor (see Figure 9) and it is estimated that a fire cannot be extinguished if the pick-up exceeds 10 to 12 volumes per 100 volumes of foaming liquid reaching the surface.

2) The proportion of the injected liquid reaching the surface increases with increasing expansion factor. No significant relationship between this factor and any other property of a foam was found (see Figure 13).

3) The variation of the rate of injection, over the small range used, had no significant effect on the petrol pick-up.

4) Increasing the concentration of the foaming liquid from 3 per cent to 10 per cent appears to increase the petrol pick-up by about 50 per cent.

5) For a given expansion factor the petrol pick-up increases with the critical shearing stress (see Figure 10).

6) For a given expansion factor and critical shearing stress, the petrol pick-up decreases as the drainage rate of a foam decreases.

7) Raising the temperature of the petrol greatly increases the amount of petrol picked up by a foam (see Figure 4).

8) The amount of petrol picked up on the small scale by foams of low expansion factor was of the order of half that obtained on the large scale which suggests that the pick-up increases with increasing depth of petrol.

9) The petrol pick-up may vary from one batch to another of the same compound; a variation as high as 2 to 1 was found in these experiments.

Figures 14 and 15 give comparative curves for extinction of fire at various rates of surface application and base injection. From these it is seen that on a small scale base injection is a little more efficient than surface application in that at a given rate of injection or application the former method gives extinction in less time and consequently with less liquid than does the latter method. There is, however, evidence of scale effect with base injection whereas little such effect was apparent in the surface application experiments. In the large tank test more than twice as much liquid was required to achieve extinction than was the case with the smaller tank, and when hot metal was present considerably more liquid was needed. A test on a full size tank 93 ft. in diameter has been carried out in America (3) using, however, only a 10 in. layer of petrol floating on 19 ft. of crude oil; approximately 0·85 gal. of liquid per sq. ft. was used to extinguish the fire when applied at 0·097 gal. per sq. ft. per min. through two inlets. This scale effect may be partly due to the effect of turbulence tending to drive the foam to the side of the tank with more force on the larger size than on the smaller size of tank and building up a relatively thicker layer of foam so that it takes longer to cover the surface. It is thought that coverage may only be obtained on large tanks, as was the case in the American test, by turning off the foam and allowing it to flow back to fill in the centre of the blanket.

VIII Suggested requirements for practical applications

From these investigations the following requirements for a base injection installation can be suggested. The foam compound used must be of such a type that a homogeneous foam (i.e. even bubble size, and low drainage rate) with an expansion factor of 3 to 4 can be produced having at the same time a low critical shearing stress (less than 130 dyne per sq. cm). Compounds at present in general use in this country do not fulfil these requirements. The successful experimental compound (B) used could be used in a 3 per cent solution to produce consistently a foam having those properties which took more than 3 minutes to lose 25 per cent of its liquid. (With the protein compound (A) used previously it was not possible to improve on a 25 per cent drainage time of 2·5 minutes and this required a foam having the high critical shearing stress of 300-350 dynes per sq. cm., resulting in too high a petrol pick-up).

It is not thought that it will be possible to produce the type of foam required using compound B or a similar compound in normal practical equipment, except possibly from a foam pump, as the energy required to make such a homogeneous foam is comparatively high and may be outside the possibilities of any self-aspirating type of generator. It is possible that the design of suitable equipment may prove necessary if existing equipment cannot easily be modified to give the necessary foam properties.

It is estimated that the rate of base injection will have to be at a minimum of 0·05 gal. of foaming liquid per sq. ft. of surface per min. to ensure that the amount reaching the surface exceeds 0·03 gal. per sq. ft. per min. as below this it will be seen that the total quantity of liquid required increases considerably (Figure 15). As there is evidence of scale effect for base injection it is difficult to estimate the total quantity of liquid that will be needed to achieve extinction but it will almost certainly be as high as 1 gal. per sq. ft., and may reach 2 gal. per sq. ft. particularly if the petrol surface is broken up by any metal reinforcing members around which small but persistent fires may develop. On this basis a 100 ft. diameter tank might well require 8000 to 16000 gals. of foaming liquid injected at a minimum rate of 400 gal. per min. for certain extinction. This would require 240 to 480 gal. of foam compound.

In the experiments described here the inlet velocities of the foam were comparatively low (1·5 ft. per second for the successful large scale experiments) and the authors have not accumulated sufficient results to say what the limits for large scale application should be. Tuve and Peterson (3) report that using a 22½ in. diameter tank the inlet velocity may be as high as 20 to 30 ft. per second but it is not known whether this figure is subject to scale effects. In the larger scale American test, mentioned above, with a single foam inlet and a velocity of 9·2 ft. per second extinction was not achieved whereas with two inlets and half the velocity it was successful. It should be remembered that the foam was first injected into crude oil on which there was a 10 in. deep layer of petrol.

To be more certain of the minimum requirements it is felt that a large scale test with a tank of say 40 to 50 ft. diameter is needed to gain more information about the effects of scale, especially with regard to the maximum permissible inlet velocity.

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(3) TUVE, R. L. and PETERSON, H. B. A study of some mechanical foams and their use for extinguishing tank fires. U.S. Naval Research Laboratory Report No. 3725. August, 1950.

(4) BURGOYNE, J. H., KATAN, L. L. and RICHARDSON, J. F. The application of air foam to oils burning in bulk. Journal of the Institute of Petroleum, 1949, 35, (312) 795-814.

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Appendix A

Determination of the petrol content of a foam sample

The first method adopted for the estimation of the petrol content of a foam sample was to add a measured volume of iso-propyl alcohol approximately equal to the volume of the liquid content of the foam. This rapidly broke down the foam completely and the volume of the resulting liquid was measured. This was allowed to stand in a measuring funnel for more than five minutes so that the petrol contained in the mixture rose to the surface and could be drawn off and measured. This method led to very low values of the amount of petrol picked up as it was subsequently discovered that if the amount of iso-propyl alcohol used exceeded 50 per cent of the volume of the liquid content of the foam sample some of the petrol would dissolve in the solution alcohol mixture. If smaller quantities of iso-propyl alcohol, were used the sludge formed by reaction between the alcohol and the foaming solution made measurement of the petrol volume very inaccurate.

It was found that by centrifuging the mixture obtained by breaking the foam down for about five minutes the petrol could be easily separated from the sludge and it was not necessary to use a volume of iso-propyl alcohol exceeding 50 per cent of the liquid content of the foam sample. There was a slight difficulty in using this smaller quantity of iso-propyl alcohol in that it did not completely break the foam down but the quantity of liquid contained in the remaining froth was not more than 3 per cent of the total liquid.

Other anti-foaming agents for breaking down the foam were tried. Tributyl phosphate and silicone "Antifoam A" which are not soluble in water, did not completely break down the foam of small bubble size produced by the laboratory generator though they were effective on foams of larger bubble sizes.

Higher alcohols (n - octyl alcohol and sec - octyl alcohol) were found to be very efficient in breaking down foams which did not contain petrol but the presence of petrol greatly reduced their efficiency as the alcohol dissolved in it. However, in several cases n - octyl alcohol was substituted for the iso-propyl alcohol and there was no significant difference in the results obtained.

The procedure finally adopted was to break down the foam by adding a volume of iso-propyl alcohol equal to approximately 40-50 per cent of the volume of the liquid content of the foam and to measure the volume of the resulting liquid. 140 cc. of this was poured into four tubes and centrifuged for 5 minutes at 3,000 r.p.m. A cake of brown sludge formed between the petrol and the alcohol-solution mixture and occasionally a white gel formed in the petrol layer making its volume difficult to measure. This could often be removed by acidifying with sulphuric acid and centrifuging for a further two minutes. The volume of the petrol was obtained by measuring its depth in the tubes. As the petrol was an addition to the foam all values of petrol pick-up have been calculated as volumes of petrol per 100 volumes of foaming liquid.

Both methods were used on some occasions to determine the amount of petrol pick-up. Analysis of the results has shown that a reasonable correction for the errors in the first method can be made by assuming that each of the results was too small by 5 volumes of petrol per 100 volumes of liquid.

The determination of the proportion of the injected liquid reaching the surface

In order to calculate the percentage of the injected liquid reaching the surface it was assumed that the mass of the air contained in the foam was the same at the surface as when it was injected.

Then the percentage of liquid arriving at the surface is given by

$$\frac{E_s - 1}{E_i - 1} \times 100$$

where E_i is the expansion factor of the injected foam

E_s is the expansion factor of the foam at the surface

and is given by $\dfrac{\text{volume of sample of foam - volume of petrol}}{\text{volume of solution contained in sample}}$

PC.

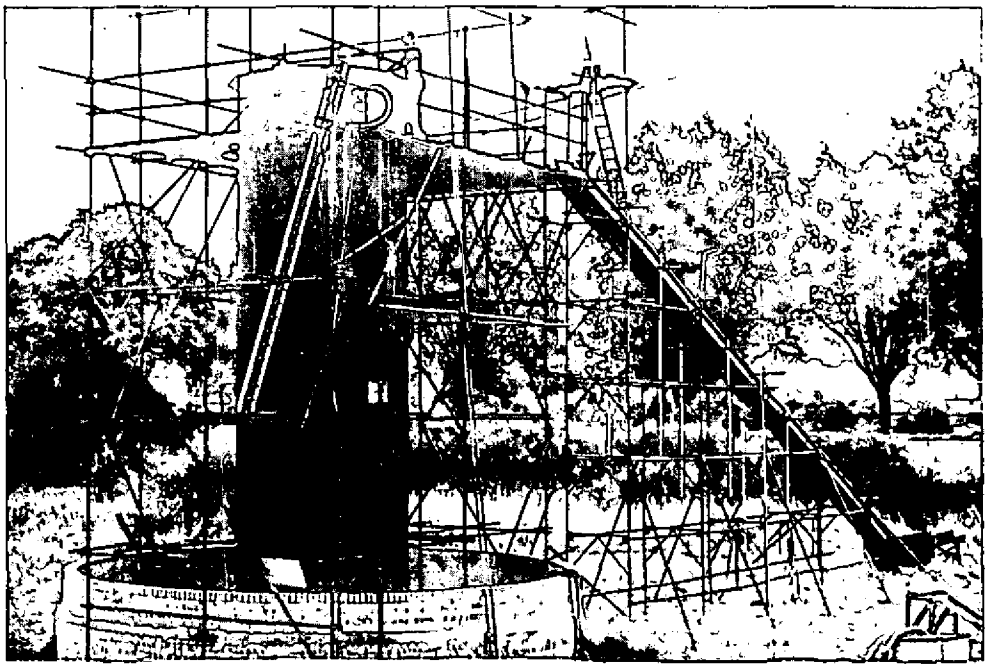

Plate I. General view of 9 ft by 30 ft tank.

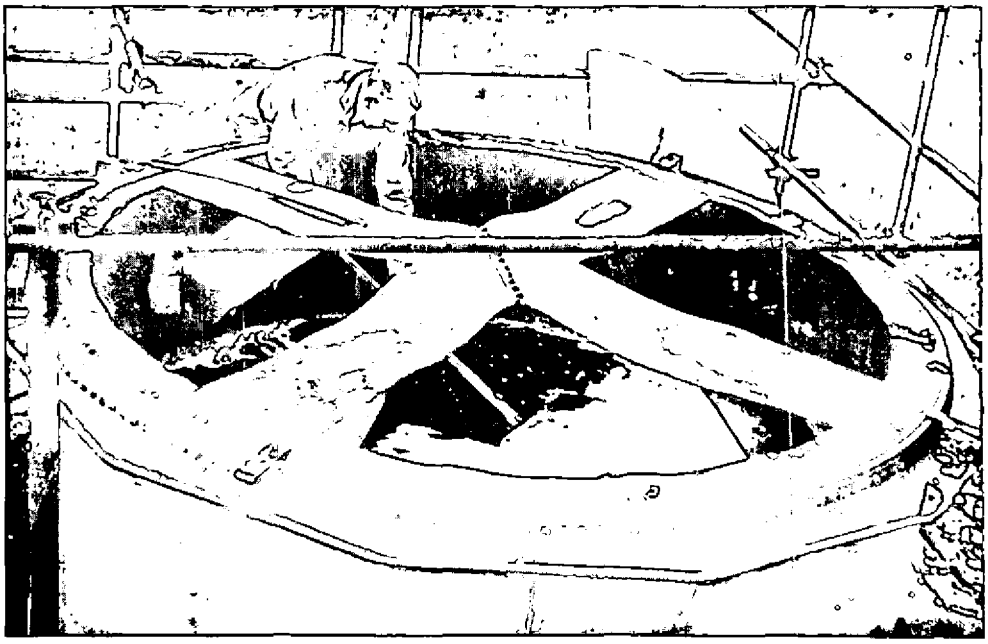

Plate 2. View of top of tank.

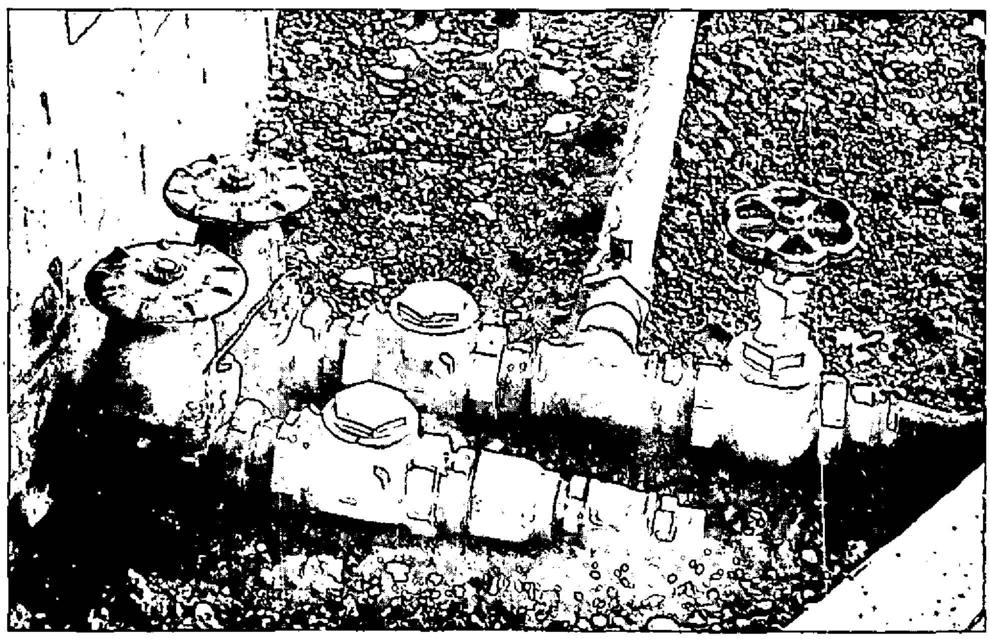

Plate 3. Arrangement of valves at bottom of tank.

Plate 4. Foam rising to petrol surface.

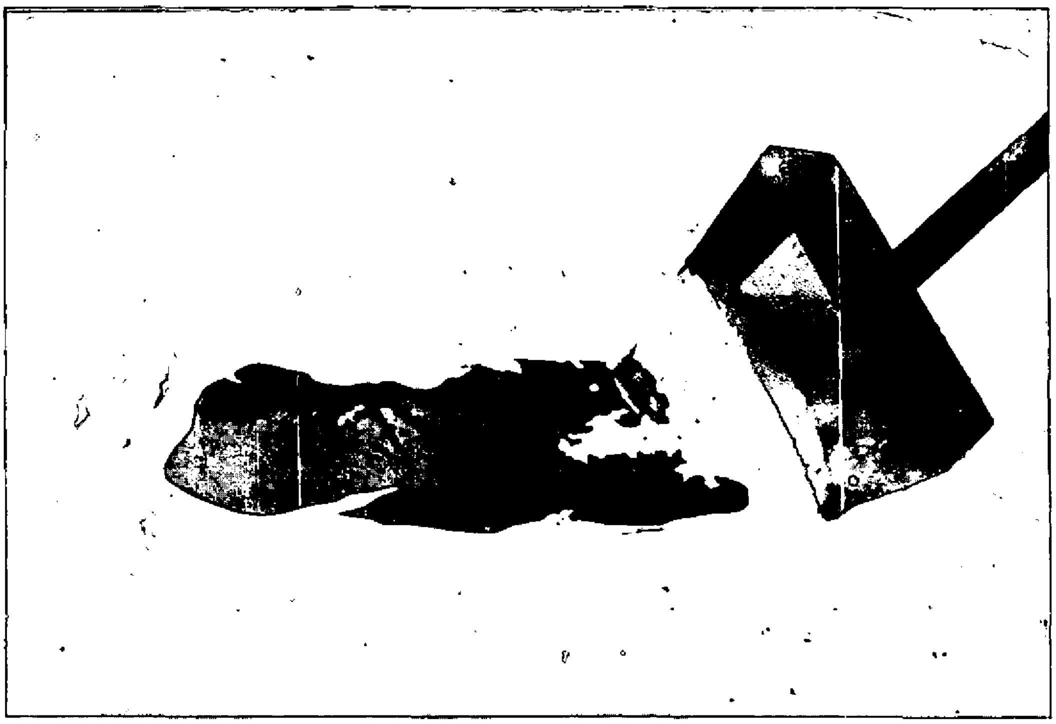

Plate 5. Foam blanket at petrol surface.

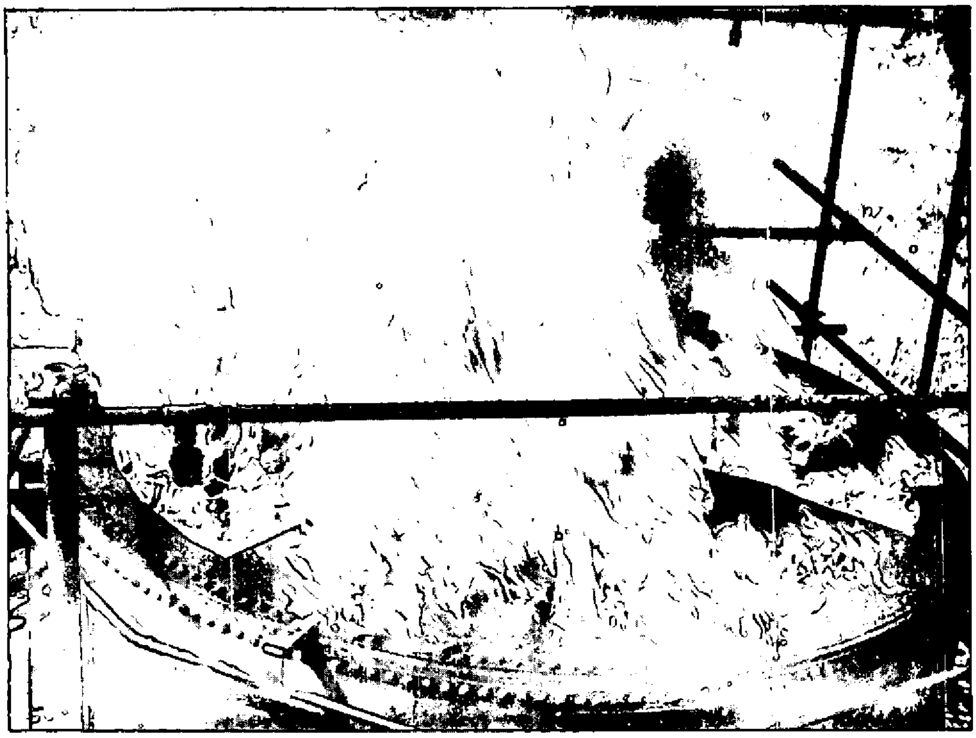

Plate 6. Fire at commencement of foam injection.

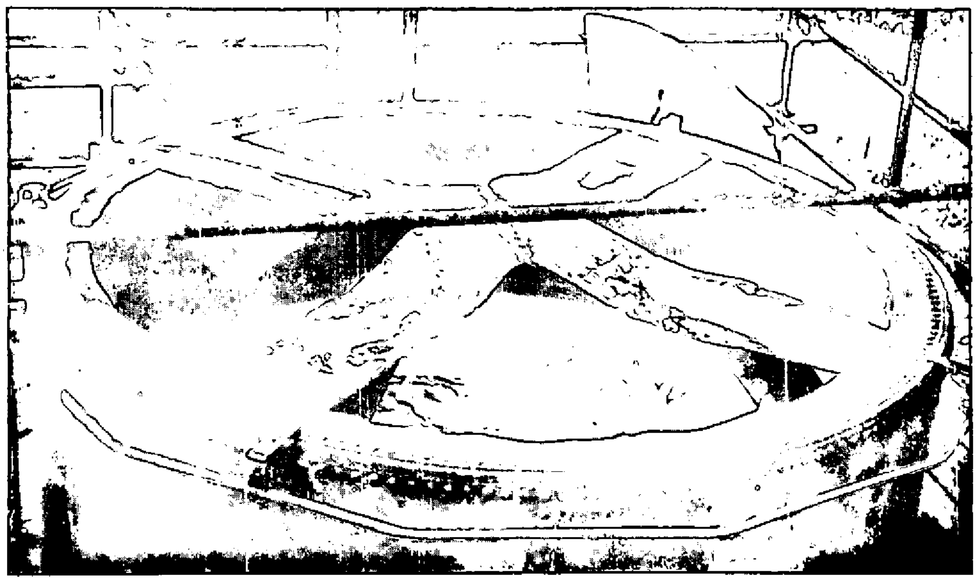

Plate 7. Fire after 2 min of foam injection.

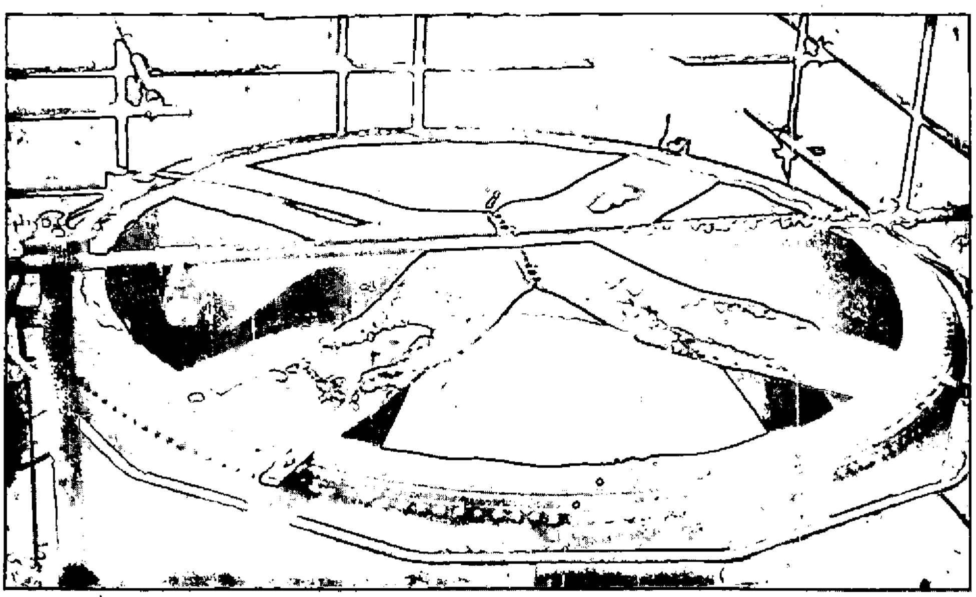

Plate 8. Fire after 3 min of foam injection.

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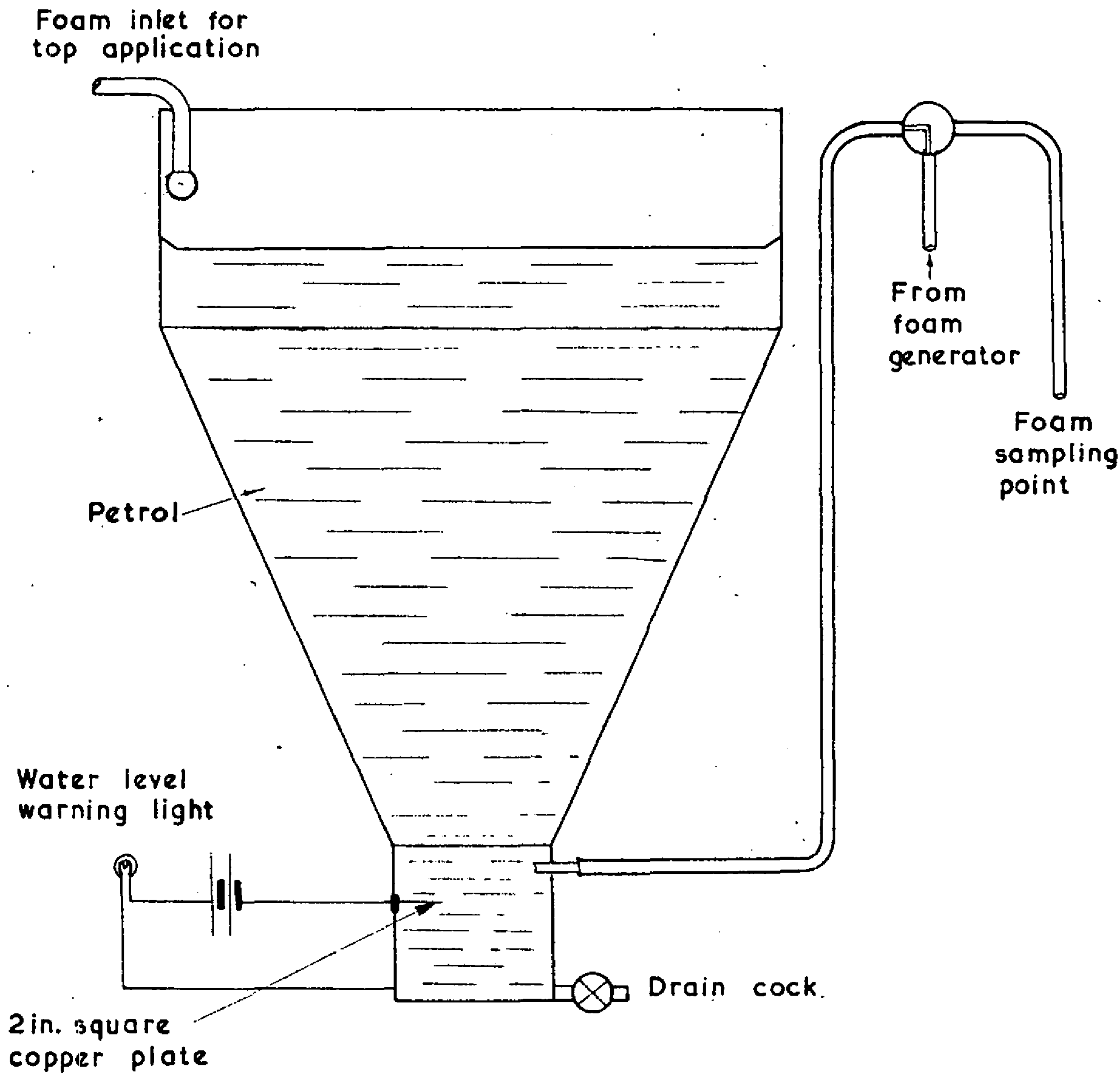
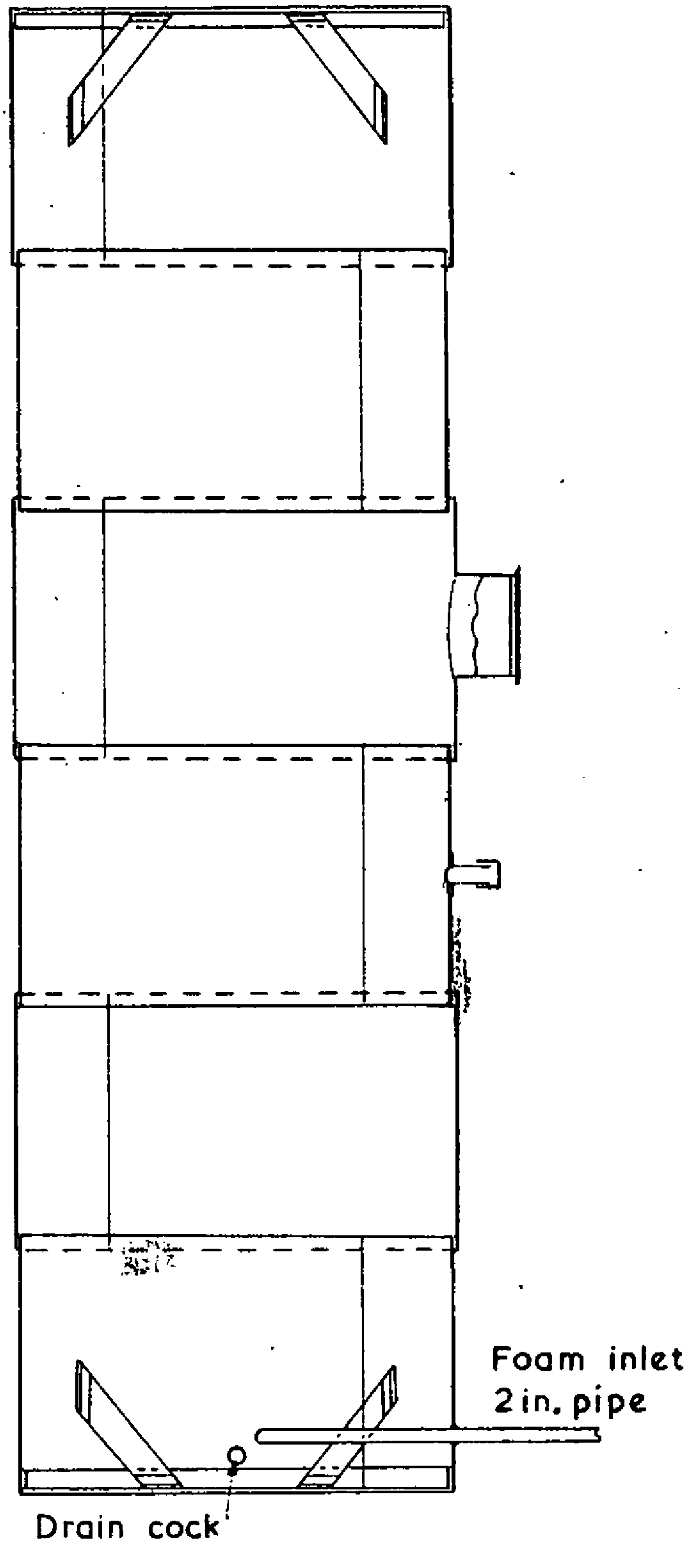


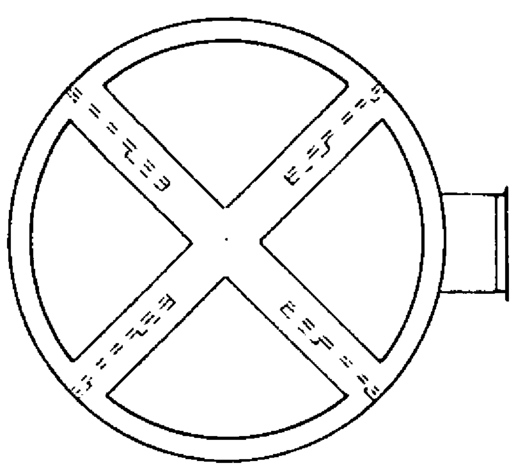
APPROXIMATE SCALE 2in.= 1ft

FIG.1. TANK USED IN SMALL SCALE EXPERIMENTS

F.R. Inc.



LONGITUDINAL SECTION



PLAN OF TOP

SCALE 1/4 in. = 1 ft

FIG. 2. TANK USED IN LARGE SCALE EXPERIMENTS

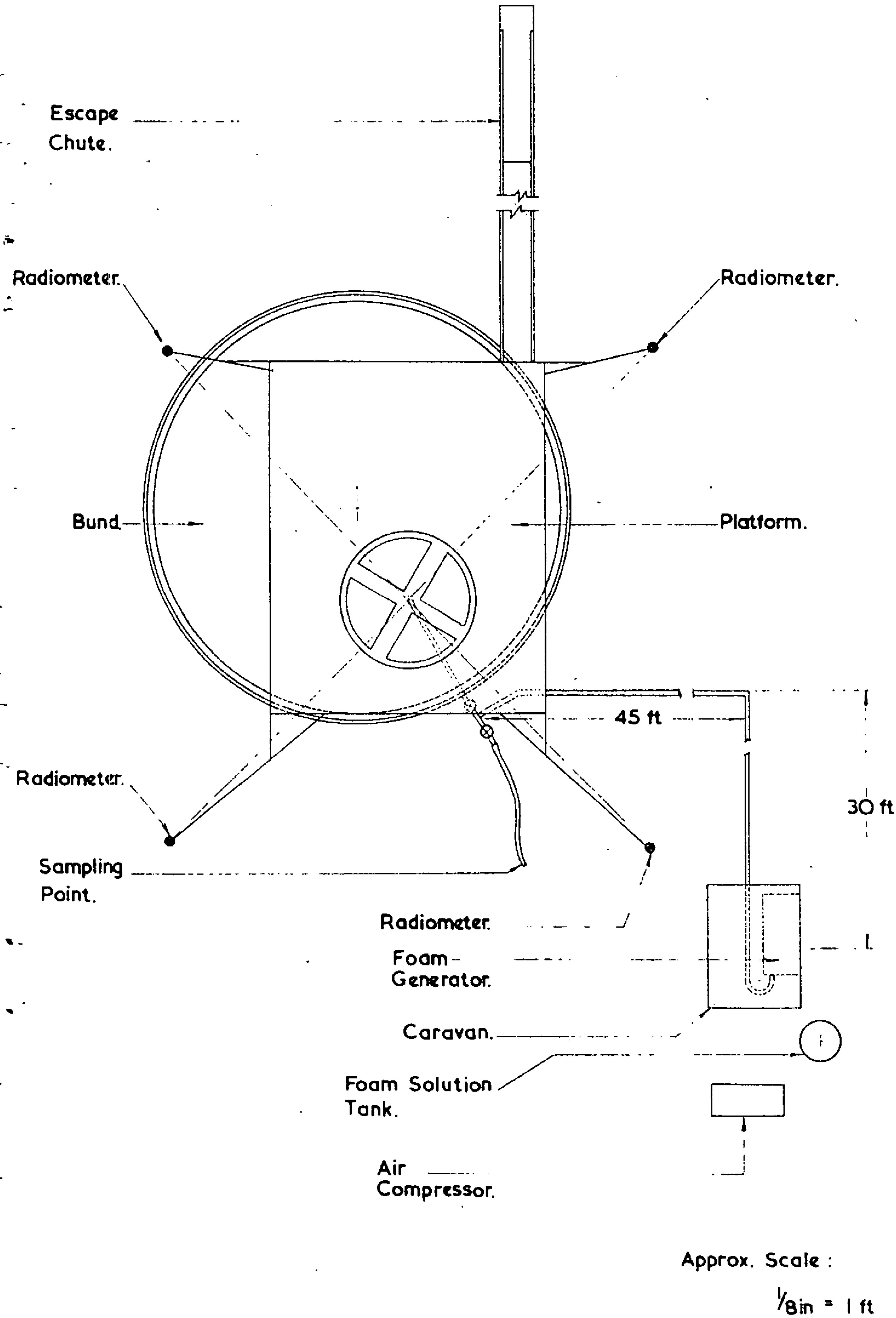


FIG. 3. GENERAL ARRANGEMENT OF APPARATUS FOR LARGE SCALE TESTS.

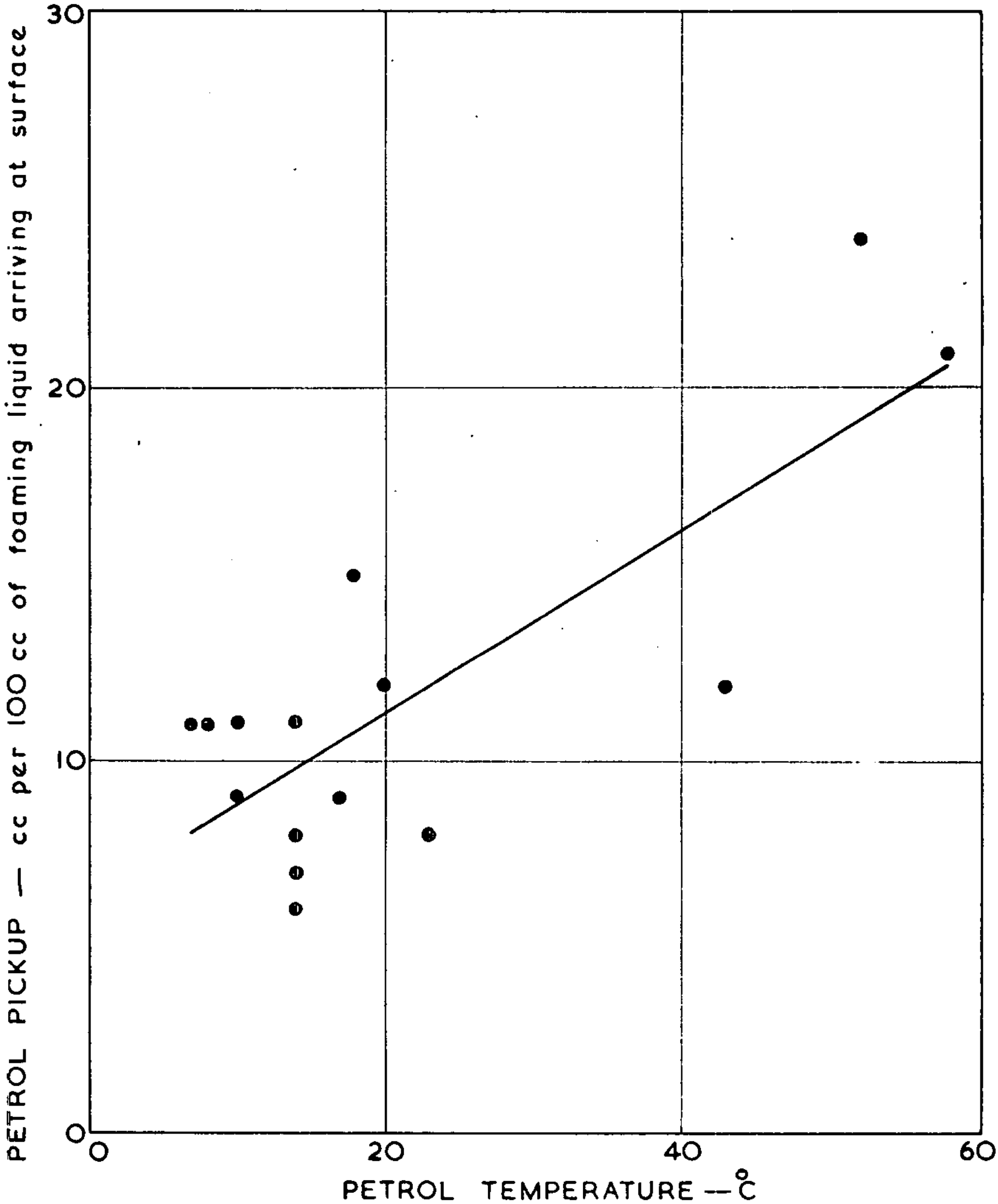


FIG. 4. EFFECT OF TEMPERATURE OF THE PETROL ON THE QUANTITY PICKED UP

(Small scale tank. Critical shearing stress = 300 dyne/cm^2 Expansion factor = 4).

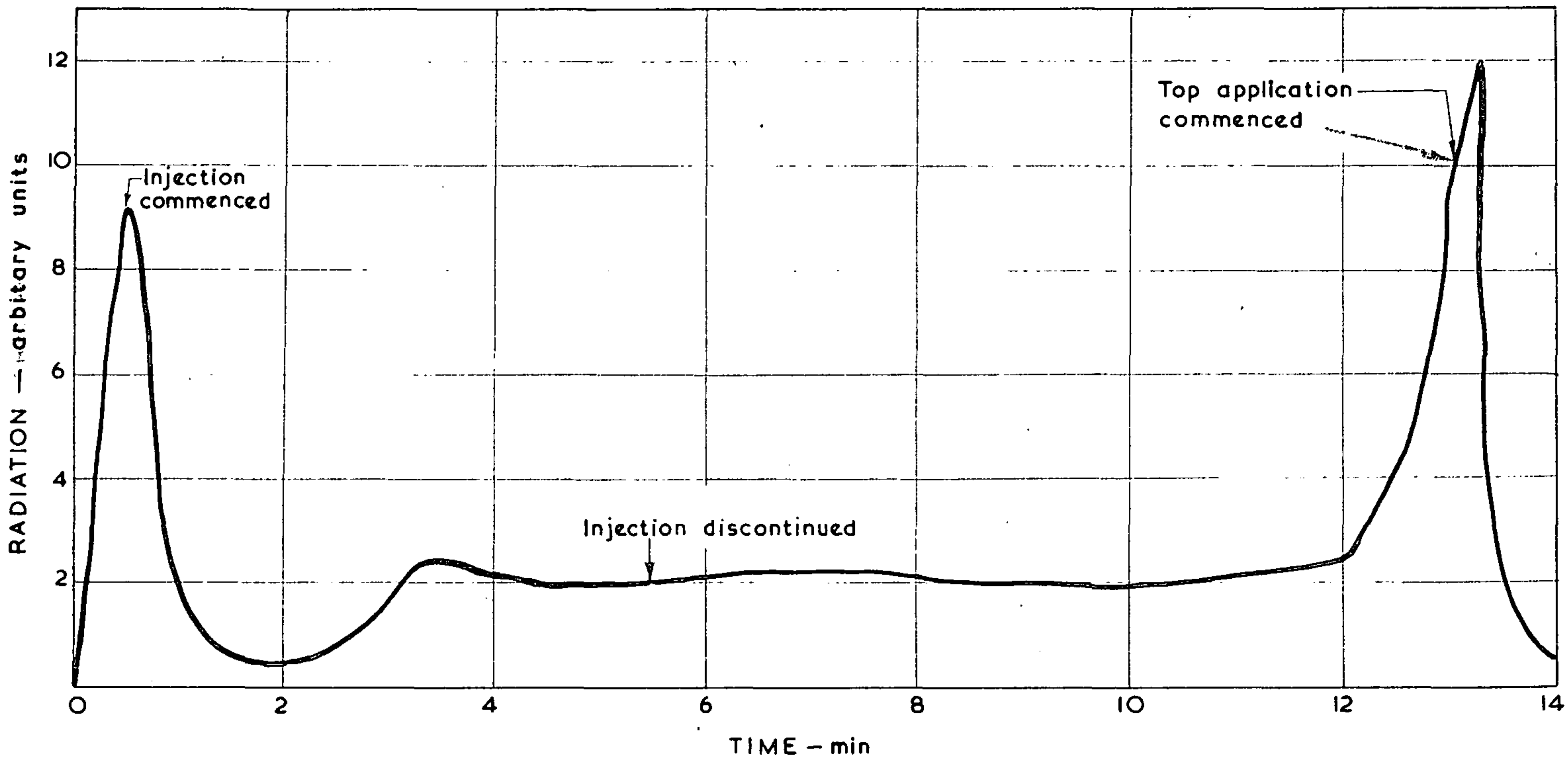


FIG. 5. RECORD OF E.M.F. OF RADIOMETERS (PROPORTIONAL TO RADIATION) DURING A SMALL SCALE FIRE WHICH WAS NOT EXTINGUISHED BY BASE INJECTION

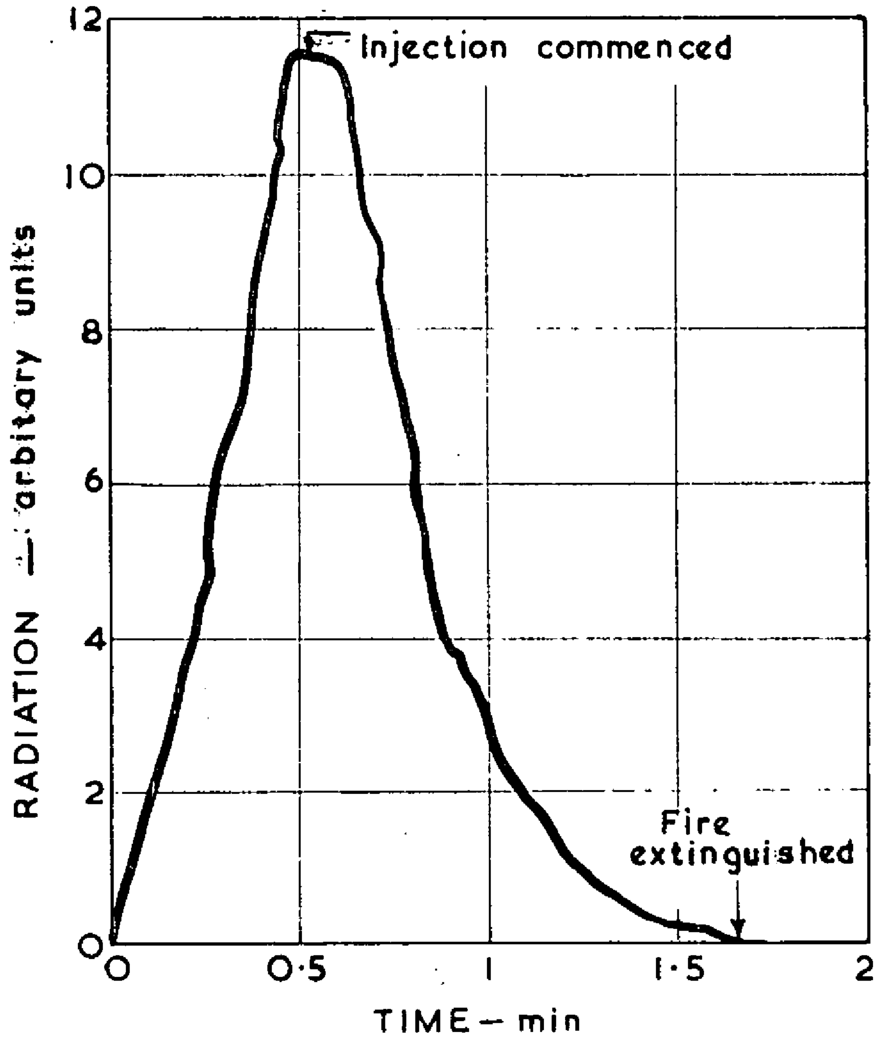


FIG.6. RECORD OF RADIATION DURING A SMALL SCALE FIRE WHICH WAS RAPIDLY EXTINGUISHED

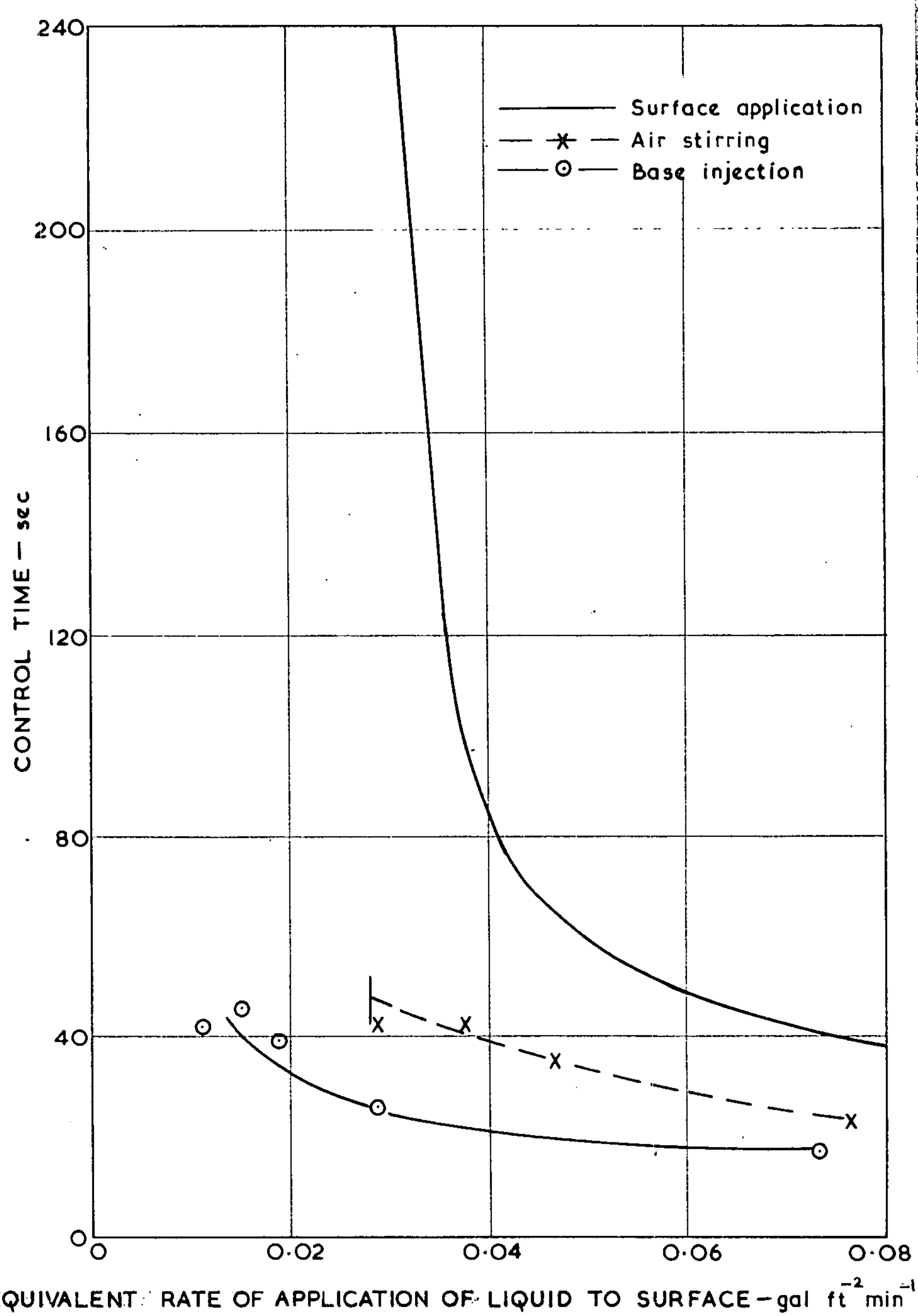


FIG.7. COMPARISON OF EFFECT OF SURFACE APPLICATION, BASE INJECTION AND AIR STIRRING AT DIFFERENT RATES ON CONTROL TIME (SMALL SCALE)

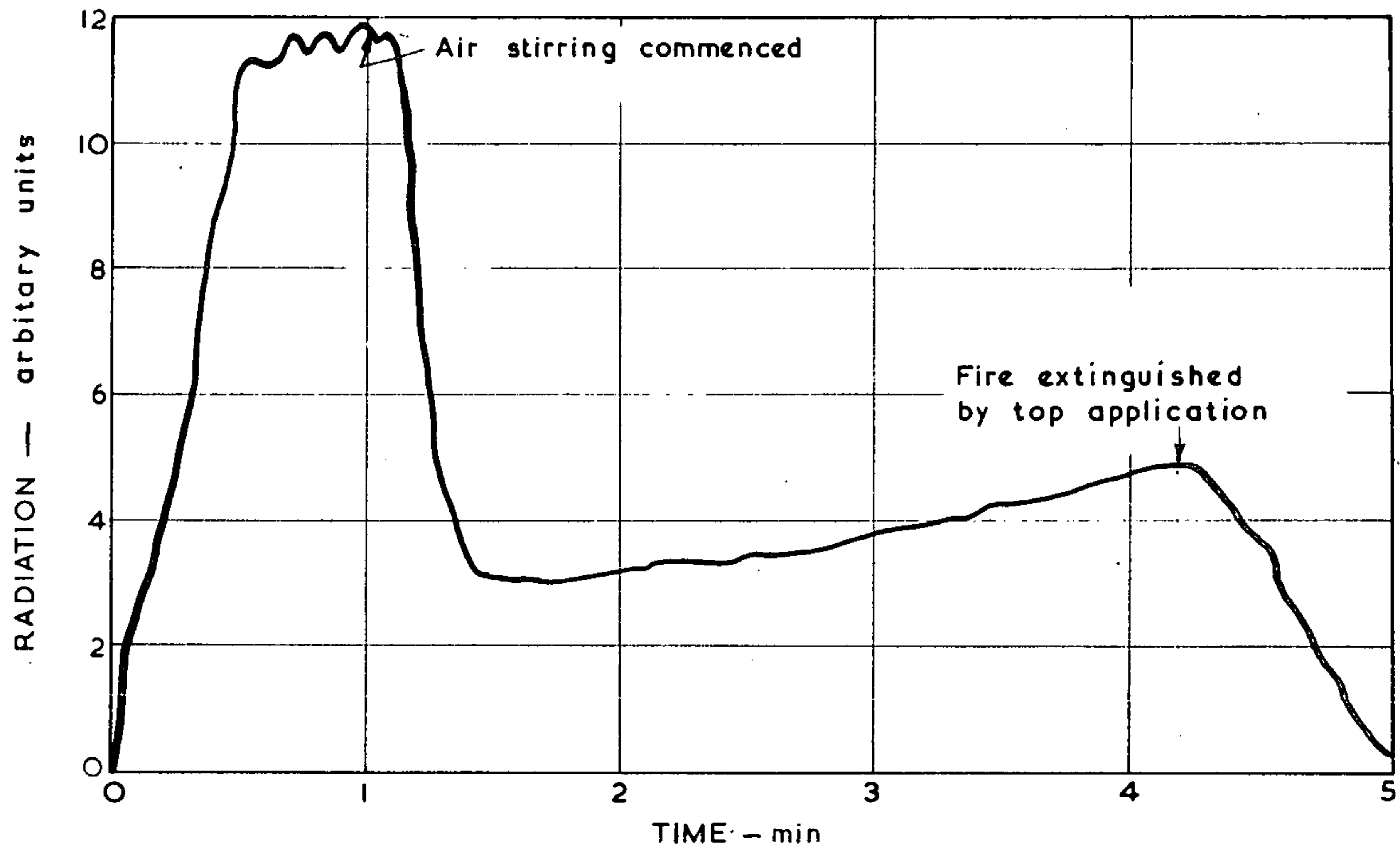


FIG.8. RECORD OF RADIATION DURING A TYPICAL SMALL SCALE AIR STIRRING EXPERIMENT

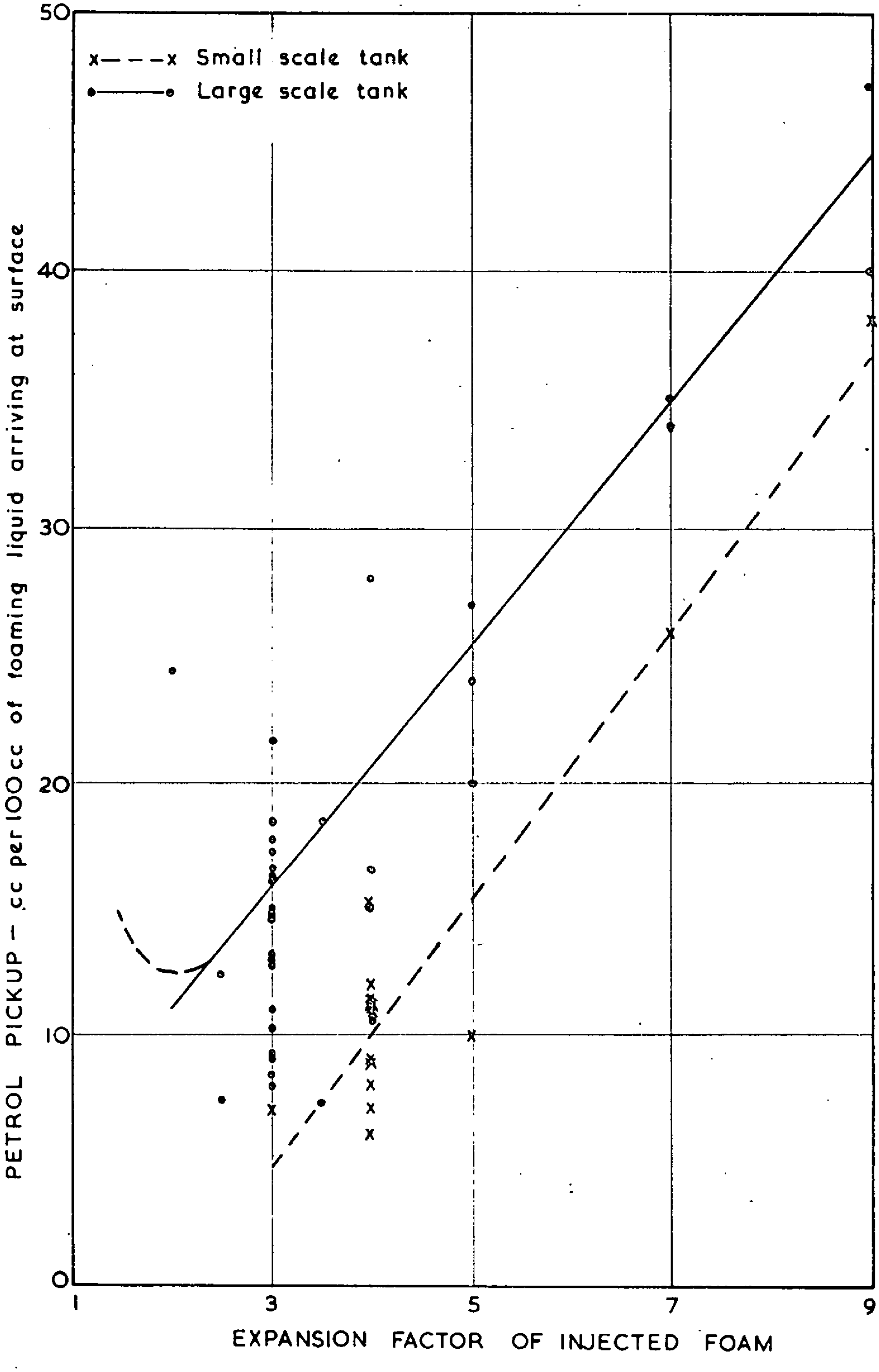


FIG.9. THE EFFECT OF EXPANSION FACTOR ON PETROL PICKUP FOR BOTH LARGE AND SMALL SCALE TANKS

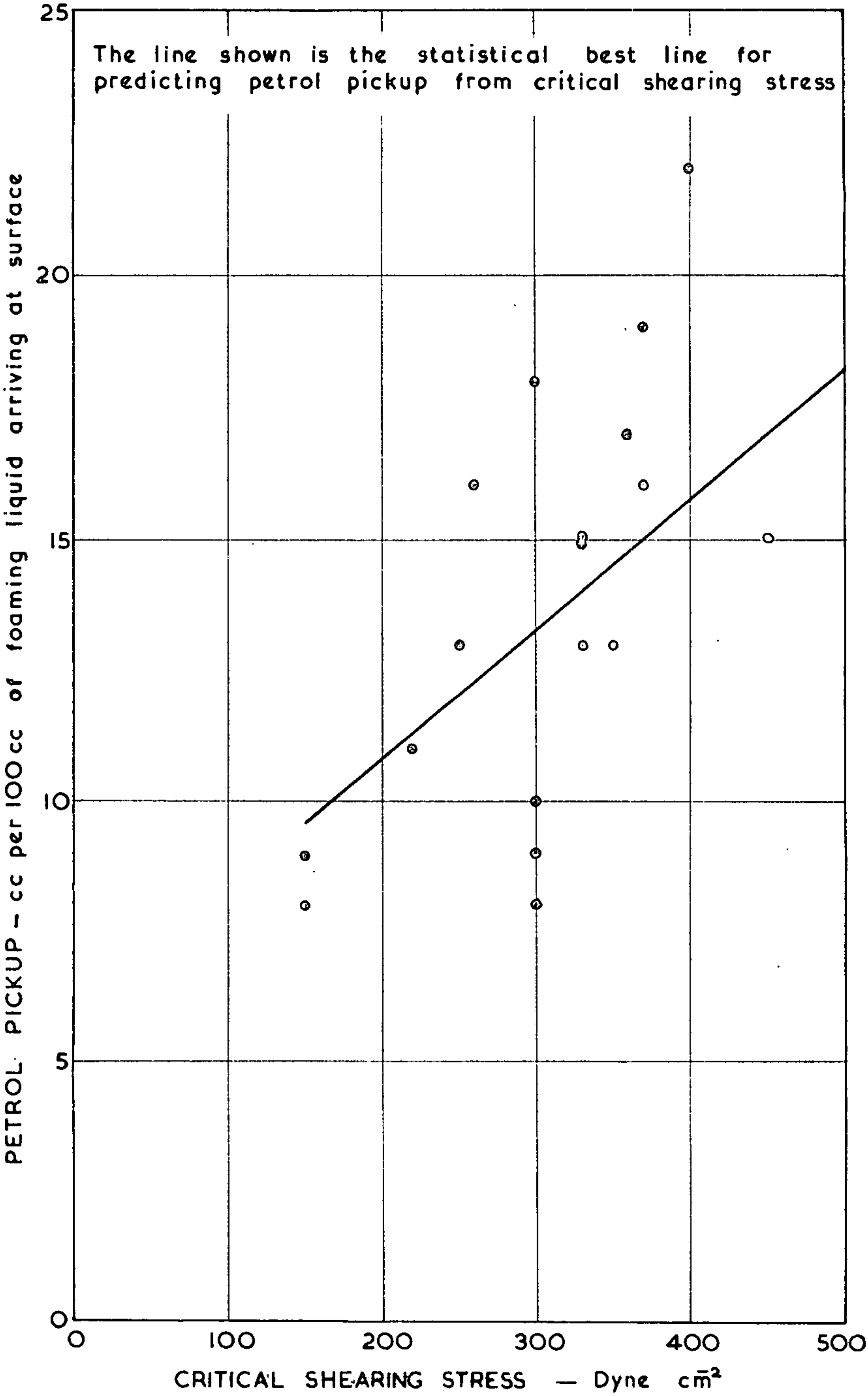
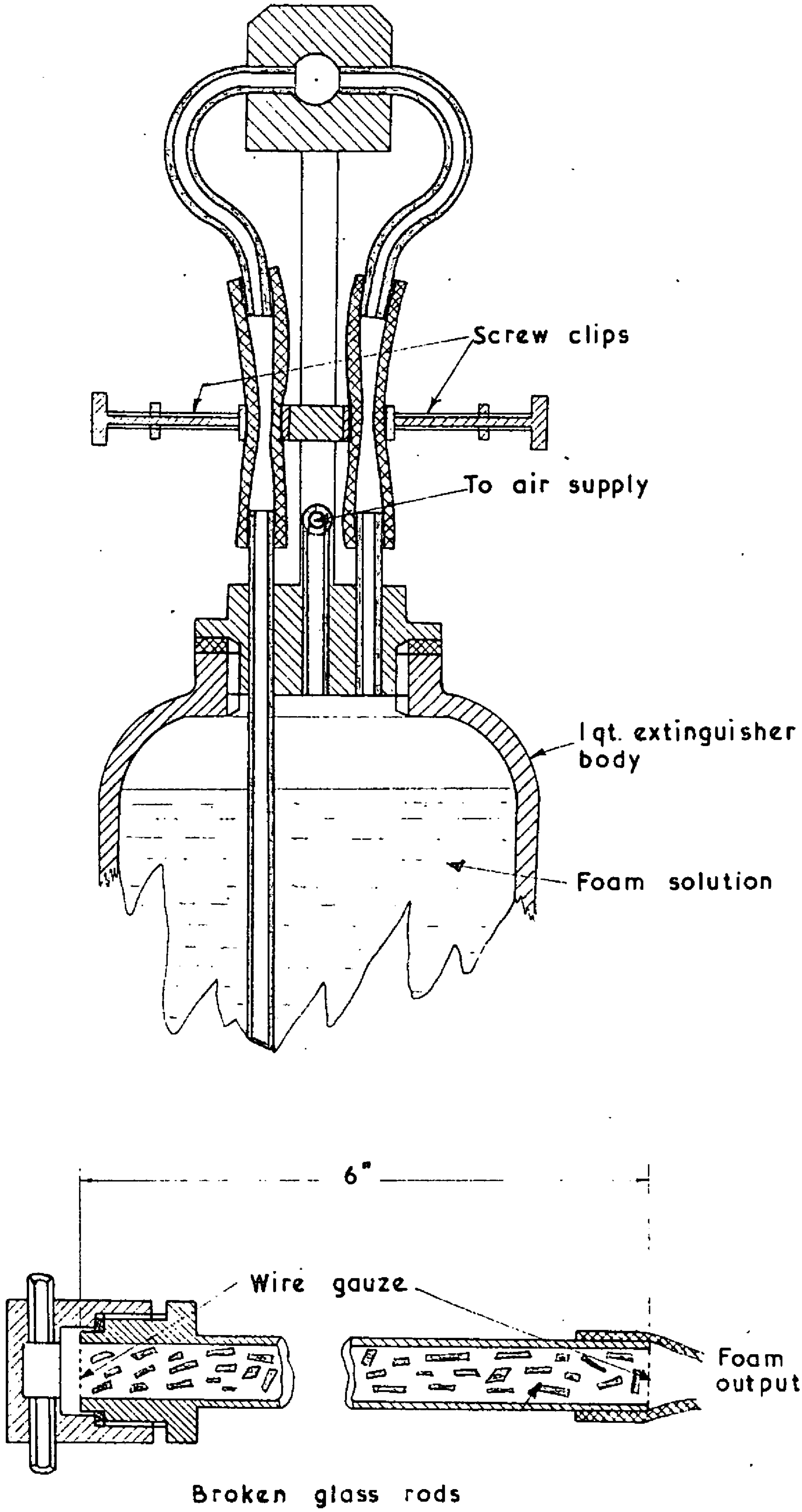


FIG. 10. EFFECT OF CRITICAL SHEARING STRESS ON PETROL PICKUP. (Large scale tank expansion factor of injected foam = 3)



SECTION OF MIXING CHAMBER AND IMPROVER

FIG. 11. MINIATURE FOAM GENERATOR

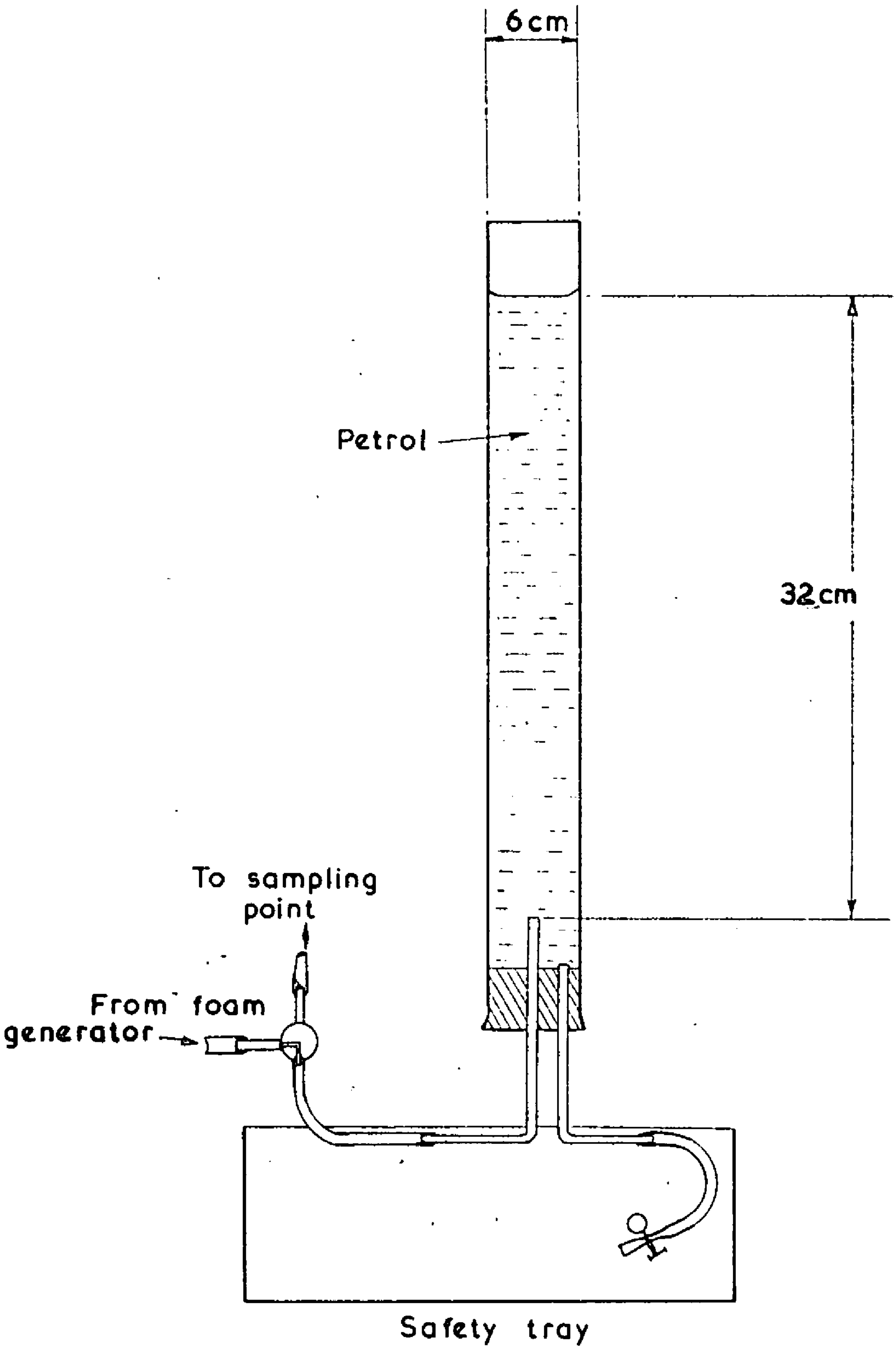


FIG. 12. APPARATUS USED FOR COMPARISON OF PETROL PICKUP OF VARIOUS FOAMING AGENTS

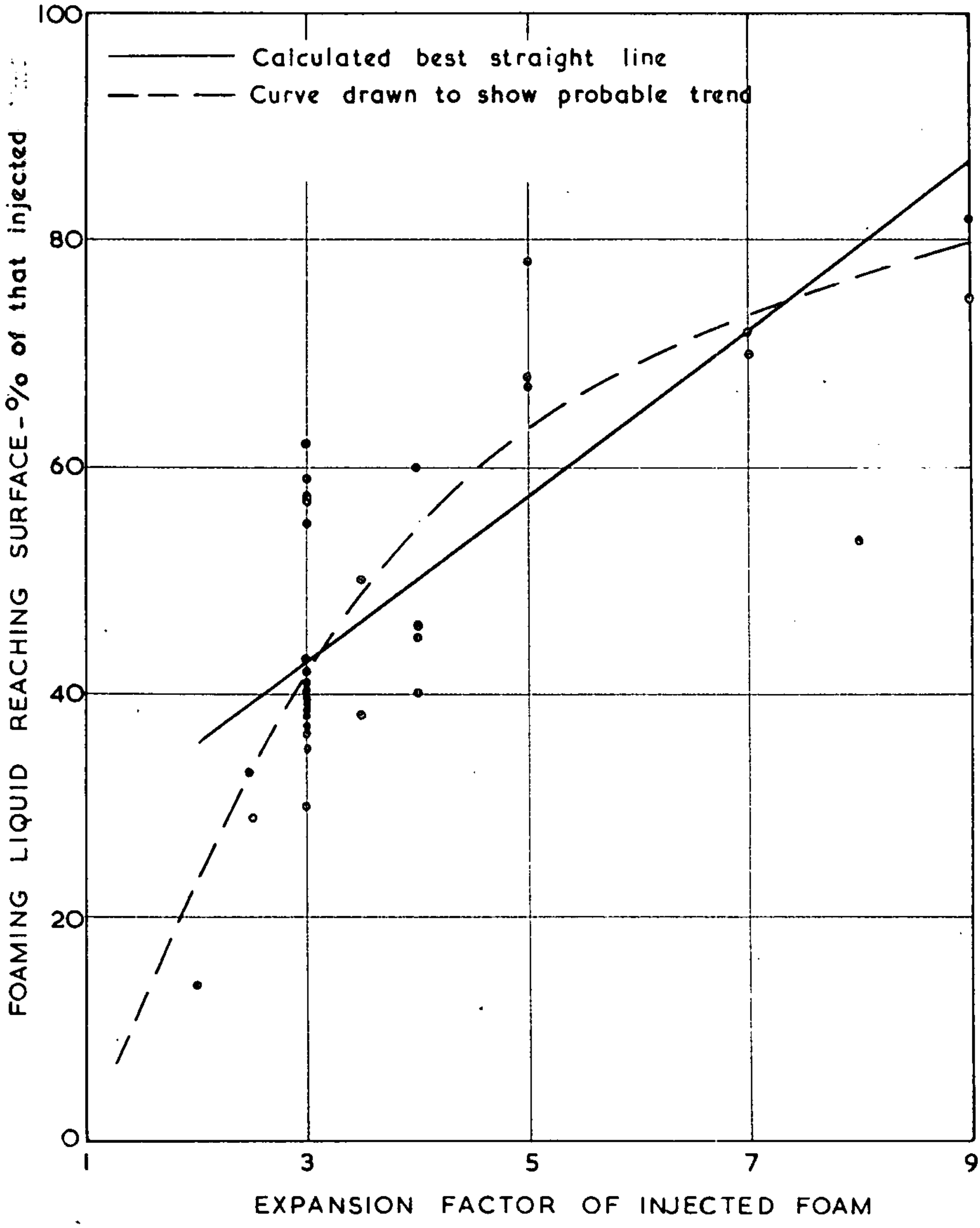


FIG. 13. EFFECT OF EXPANSION FACTOR ON QUANTITY OF FOAMING LIQUID REACHING SURFACE. (large scale tank)

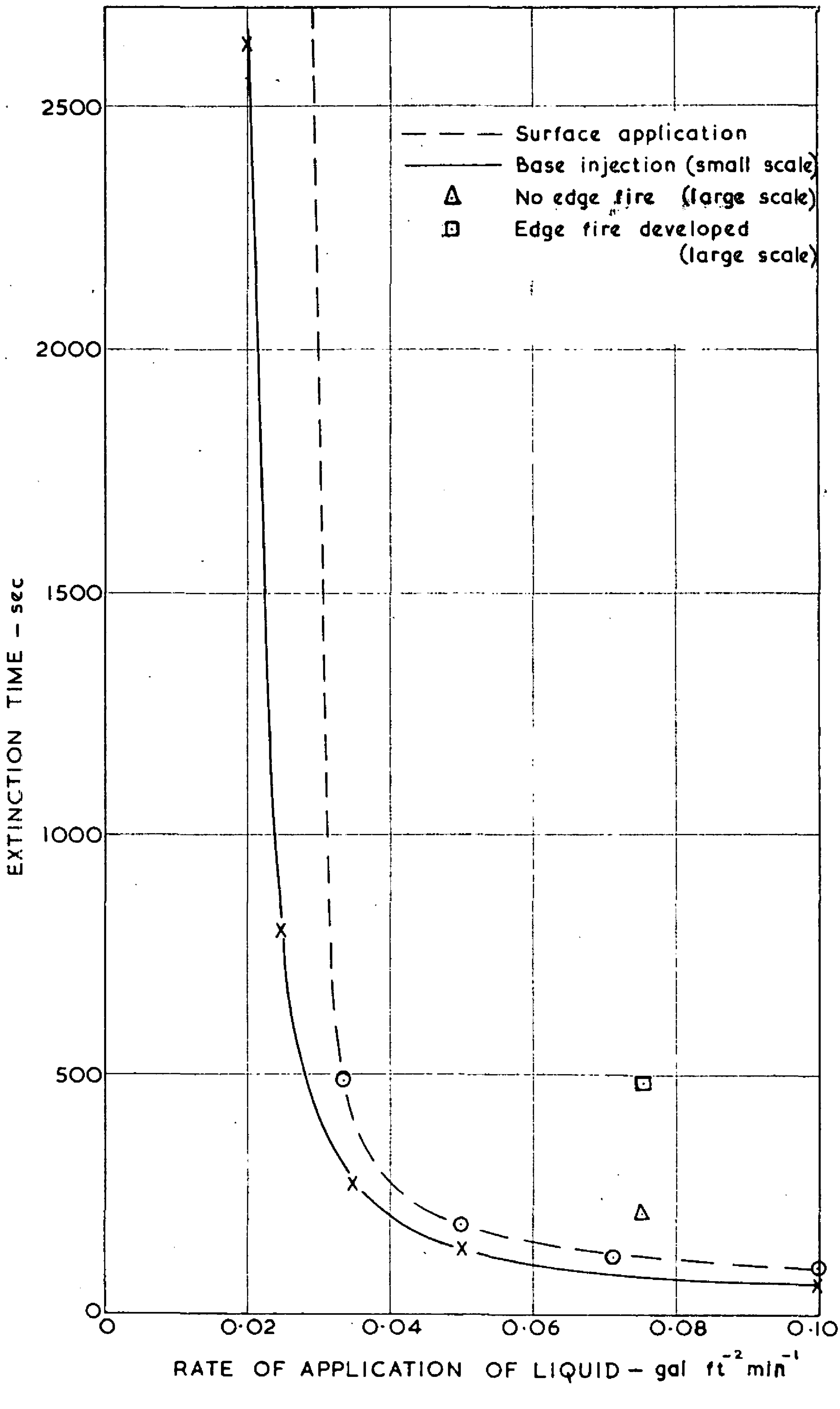


FIG. 14. EXTINCTION TIMES OF FIRES AS A FUNCTION OF RATE OF APPLICATION OF LIQUID

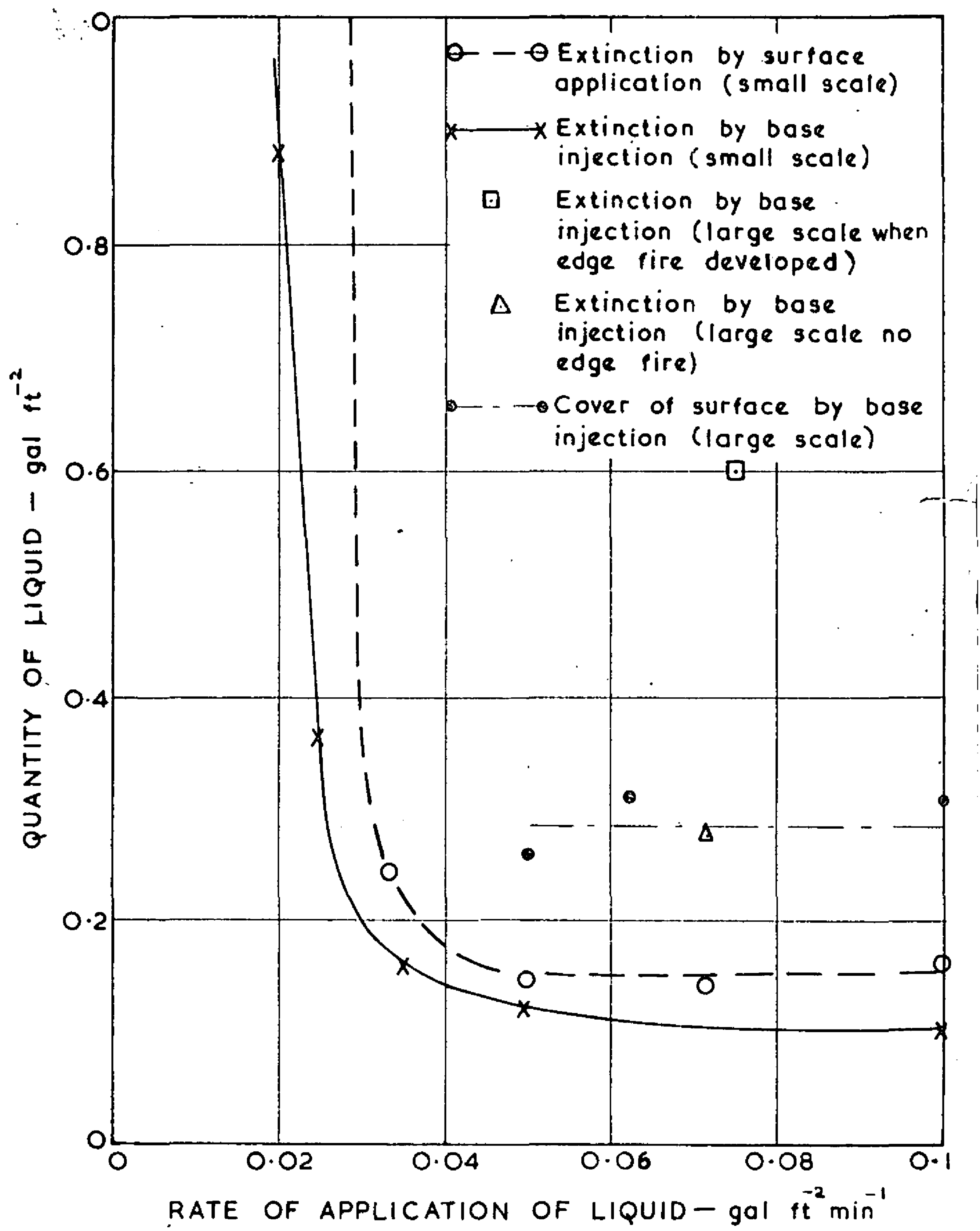


FIG. 15. QUANTITY OF LIQUID REQUIRED TO EXTINGUISH FIRES ON THE LARGE AND SMALL SCALE AS A FUNCTION OF RATE OF APPLICATION WHEN FOAM WAS APPLIED BY BASE INJECTION AND TOP APPLICATION