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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH AND FIRE OFFICES' COMMITTEE
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THE SURFACE APPLICATION OF FOAM TO PETROL FIRES

by

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Summary

A fairly extensive programme of laboratory experiments on the surface application of foam to petrol fires has been carried out. For a criterion of performance of a foam the time of control of the fire to which it was applied was used. This has been defined as the time taken to reduce the total radiation from the fire to one third of its value at the commencement of foam application. The critical rate of application of foam, i.e. the minimum rate at which the fire is likely to be controlled, has been determined for a number of foam compounds. The possibility of scale effects has been investigated and an examination has been made of the influence of expansion factor, critical shearing stress and type of foam compound upon the relationship between the control time and the rate of application. The results of the experiments contained in this report suggest that, when foam is applied at a rate higher than the critical rate, its ability to combat a petrol fire is a function of its water content and of its ability to flow over the petrol surface. The loss of foam due to destruction by the heat radiated from fire appears to be of little importance with most compounds. The fact that there is little to be gained by applying foam to a fire unless the critical rate of application can be exceeded is emphasized. It is thought that the accepted rate of application of 1 gal. per sq. ft. per min. is unnecessarily high for good protein compounds.

Introduction

The development of apparatus, described elsewhere (1), which gives accurate control of foam qualities has permitted a more thorough investigation of the surface application of foam to petrol fires than was possible when Clark, Thornton and Lewis (2) performed their experiments in 1946.

The experiments described in this note were carried out to obtain information under the following headings:-

1) To determine the effect of the size of a petrol fire upon the ease of control of the fire and to see if the results of small-scale tests are applicable to large fires.

2) To compare the performance of a number of different foam compounds and to determine the critical rate of application of branchpipe quality foam made from each compound. The critical rate is defined as the lowest rate of application at which control is likely to occur.

3) To determine the effects of the expansion factor and critical shearing stress of a foam upon its critical rate of application and upon the time of application necessary to control the fire. (The effect of resistance to radiant heat is being examined separately).

Experimental procedure

Three sizes of petrol fires were used having diameters of 25 in., 36 in., and 50 in. The trays in which the petrol was burnt were all constructed of 18 s.w.g. steel sheet and each was 4 in. deep. Each was fitted with a tap in the centre of its base so that liquid draining from the foam could be removed periodically, the level being maintained with fresh petrol. Unleaded pool petrol was used and the depth of fuel in the tray was approximately 2 in.

Five compounds have been examined, namely:-

Compound A - A protein compound in considerable use (Hydrolysed keratin). Brazil.

Compound B - A more recent development of compound A from the same manufacturer. C.S.

Compound C - A protein compound having similar properties and uses to Compound A (Hydrolysed blood).

Compound D - A soap compound apparently inferior to compounds A, B and C as measured by the figure of merit tests but reported to be successfully used in practical fire-fighting. Bersol

Compound E - A wetting agent (not normally used in fire-fighting). Teepol

Compound F - A compound of unknown composition imported from France.

All these compounds had previously been examined in the laboratory to assess their performance in a standard foam-making branchpipe and to determine their petrol figures of merit.[3].

In most of the experiments foam was applied to the surface of the petrol by the method shown in fig. 2A. but for compounds D and E the applicator shown in fig. 2B. was used so that the foam reached the surface without shock. This was considered necessary as it was found that, at high rates of application with these compounds although control of the fire could be obtained, complete extinction was uncertain and flames persisted above the foam blanket due to its contamination with petrol if the application was turbulent. The modified application appreciably lessened this effect and the trouble was experienced to a slight degree only at the highest rate of application used. The size of the foam applicator orifice in all cases was made as nearly proportional to the size of the tray as the use of standard pipe fittings would allow. For the 25 in., 36 in., and 50 in. trays the pipe orifices were 0.63 in., 0.89 in. and 1.41 in. diameter respectively. The special applicators used for compounds D and E were arranged to have similar orifice areas.

The foam was applied through a system of quick-acting change-over valves, placed as close to the applicator as possible, so that samples could be collected for shear strength measurements and application to the fire at the precise moment required could be achieved. The critical shearing stress measurements were made with a rotating vane torsional viscometer, the vane being 3.2 cm square and the rate of shear 13 cm per sec. This instrument was based on that used by Clark [4].

In the majority of the tests foam was applied 30 sec. after the moment of ignition. The fire had by this time reached its peak and in a few tests in which this time was extended to 60 seconds no appreciable change in the results was observed.

At first it was decided to use the time taken to extinguish the fire as a criterion of the performance of a foam, but the results were extremely variable, the end point being rather indeterminate especially when dealing with foams of high critical shearing stress. For this reason it was decided to observe the progress of the fire by measuring the radiation from it, and to obtain a continuous and permanent record for each test. This made it possible to define the control time, which was to be adopted as a criterion of the performance of a foam, as the time taken to reduce the radiation from the fire to some selected fraction of the radiation at the moment when the application of foam was commenced.

The radiation was measured by four radiometers of the gold disc thermocouple type, placed symmetrically at the four corners of a square containing the fire tray. The diagonal distance between the radiometers was made equal to five tray diameters. With the radiometers placed in this manner, variation of the position of the centre of the fire due to movement of the flame could not cause a variation in the total e.m.f. produced by the four radiometers connected in series of more than 5 per cent.

The radiometers consisted of gold discs, $\frac{1}{2}$ in. diameter and 0.004 in. thick, to the receiving surfaces of which copper-constantan thermojunctions of 28 s.w.g. wire were silver-soldered. The receiving surfaces were covered with carbon black from a burning candle. The gold discs were made small to reduce the time of response and time constant of these radiometers under the conditions of the experiments was about 6 sec. Because of their low heat capacity they were somewhat sensitive to draughts; an air velocity of 1 ft. per sec. producing a fall of 15% in the e.m.f. when this was 5 mV. (the maximum recorded in the experiments). However, measurements of draughts carried out in the building in which the smaller tray was used showed that no air velocity exceeding 0.35 ft. per sec. existed in the neighbourhood of the radiometers. This was also true in the building in which the larger trays were used, except on very windy days when intermittent draughts of up to 1ft. per sec. were recorded, though only in the neighbourhood of one or two radiometers at any one time. In general therefore draught effects were not appreciable.

The e.m.f. produced by the four radiometers in series was amplified by means of a D.C. amplifier, the output from which was connected to a recording milliammeter. The layout of this radiation recording apparatus is shown in fig. 1. A device was included in the circuit to enable the observer to make timing marks on the recorder chart by means of a push button. Such marks were made at the moment of ignition, the commencement of application of foam and the extinction of the fire. As a check on the recorder chart speed, which varied from experiment to experiment, an observer also timed the duration of the fire by means of a remotely controlled stopwatch.

Initially the radiometers were connected by copper constantan compensating leads, the cold junction being enclosed in a box which maintained them at a constant temperature for the duration of an experiment. With this arrangement, because of the rise in air temperature during an experiment, the e.m.f. produced was up to 0.5 mV. higher immediately after extinction of the fire than immediately before the fire was ignited, and a correction had to be made for this. It was possible to do this for the smallest tray without causing an error more than 3% in the estimation of the control time. In the case of the two larger trays a similar correction was difficult to make without causing an error of up to 10%. Consequently in the case of most of the experiments with the larger trays the radiometers were modified by placing the cold junctions behind the gold discs so that they were shielded from radiation but were always at the prevailing air temperature.

The four radiometers, connected in series, were calibrated by measuring the e.m.f. produced when placed at various distances from a small radiant panel, at which points the intensity of radiation was known. It was found that, for the purpose of these experiments, the relationship between the e.m.f. and the radiation over the range of temperatures used was closely linear. Consequently, no attempt was made to translate the results obtained into units of radiation and all observations were made directly from the recorder charts.

Reproductions of typical recorder charts are shown in figs. 12 and 13. It will be seen that, at first, the application of foam caused no reduction in radiation but this initial period was followed by a rapid fall in radiation as coverage of the surface was achieved and the fire was brought under control. The fire had then broken up into several small fires, which were extinguished more or less rapidly, resulting in many cases in a long tail to the curve.

This led to the decision to define the control time as the moment at which the radiation was reduced to $\frac{1}{3}$rd of its value at the moment of application of foam. This proportion is much larger than that used by other workers (2) but this is considered justified because:-

1) Once the radiation had fallen to this value the continued application of foam was always found to achieve extinction,

2) Typical experiments were observed by experienced firemen who were asked to state when they considered the fire to be under control. The control time obtained in this way agreed very closely with those obtained from the radiation curve,

3) The point selected lies on a rapidly changing part of the curve where errors in the measurement of the radiation have little effect on the estimation of the control time.

Details of experiments carried out

Using compounds A, D and E tests were carried out on each of the three sizes of tray to determine the relationship between the control time and the rate of application of liquid, maintaining the foam qualities constant. The rate of application was lowered until a point was reached at which the fire could not be controlled, so that an estimate of the critical rate could be obtained. The critical rate was defined as the minimum rate of application of the liquid content of the foam at which control was likely to be obtained and was taken as the asymptote to the curve of control time against rate of application of liquid.

Further experiments were made with compounds B, C and F with the 25 in. tray to find the control time - rate of application relationship and the critical rates for these three compounds.

For all these experiments the foam was arranged to have physical characteristics, expansion factor, and critical shearing stress, similar to those of foam produced by the standard foam-making branchpipe.

Experiments were then performed using compound A and the 25 in. tray, to determine the effect of (a) expansion factor (keeping the shearing stress constant) and (b) shearing stress (keeping the expansion constant) upon the control time - rate of application relationship and also upon the critical rate of application.

Using compound A only, tests were made with the 36 in. tray to ascertain the relationship between control time and critical shearing stress for each of four expansion factors. The rate of application of liquid was maintained at 0.07 gal. per sq. ft. per min. for all these tests. Similar tests were carried out with the 50 in. tray for each of two expansion factors.

Throughout this investigation each individual experiment was performed twice and the average of the two results was used. Generally good agreement was obtained between members of each pair of experiments, except where the critical rate was being approached; at this latter stage some divergence of results occurred.

Experimental results

The results of these investigations are shown graphically in fig. 3 to 11.

Fig. 7 is derived from fig. 5 and shows the relationship between the rate of application of liquid and the total quantity of liquid required to achieve control of the fire.

The three recorder charts reproduced in figs. 12 to 14 represent three experiments using compound A in which the rate of application was about 5 times the critical rate (fig. 12), the rate of application was only 40% above the critical rate (fig. 13) and the rate of application was not sufficient to control the fire (fig. 14).

Discussion of results

1) Scale effects

From figs. 3, 4 and 5 it is seen that no appreciable or significant scale effect over the range of sizes of fire occurred. The ratio of minimum to maximum area was, of course, only 1 to 4 and it might be advisable to fill in the gap between these sizes and the practical size of fire before saying that the results are directly applicable to the practical case. Experiments have been carried out by other workers on larger fires. Clark (2), using a 9 ft. diameter tray and compound A, obtained a critical rate of approximately 0.035 gal. of liquid per sq. ft. per min. as compared with 0.028 gal. per sq. ft. per min. obtained from the tests described here. Navarin and Malcolm (5) performed tests on a fire 25 ft. by 30 ft. using $\frac{1}{2}$ in. depth of petrol on water; foam was produced by the fog foam method from a protein compound and a critical rate of about 0.045 gal. of liquid per sq. ft. per min. was obtained. There is, therefore, some evidence that the results of the experiments described here are to some degree applicable to larger fires.

2) Comparison of compounds

From fig. 6 the critical rate of application for branchpipe quality foams produced from each of the six compounds have been estimated and the figures are shown in Table 1.

Table 1

Compound Identification	Critical rate of application
	gal. of liquid per sq. ft. per min.
A	0.028
B	0.020
C	0.025
D	0.055
E	0.055
F	0.065

There is a 2.3 to 1 range in the values of the critical rate obtained but the results of the experiment indicate that, when foam is being applied at rates well above the critical rate, the selection of compound is of no great importance as far as the control of the fire is concerned. Compounds D and E would normally be considered poor compounds (figures of merit 35 and 15 respectively as compared with 200 for compound B) but their performance in these experiments was surprisingly good. It should be stated, however, that these compounds have poor post extinction stability, being rapidly broken down by hot petrol. This was of no great importance in these experiments but might well be of major importance if there were large masses of hot metal in the fire area or if there were danger of flash-backs from other areas of fire.

The derived curves in fig. 7 indicate that the greatest economy in material necessary to achieve control is obtained by using rates of application only slightly above the critical rate. This effect tends to be cancelled out by the fact that at rates of application only slightly above critical the time taken to obtain final extinction is generally very long. Consequently it is generally best to use rates of application of the order of twice the critical rate (as given in Table 1). The generally accepted figure of 1 gal. of foam per sq. ft. per min. (about 0.14 gal. of liquid per sq. ft. per min.) is unnecessarily high for the protein compounds in general use; for these compounds $\frac{1}{2}$ gal. of foam cu. sq. ft. per min. should be adequate.

3) Effect of expansion factor

It is seen from figs. 8 and 9 that, over the range of critical shearing stresses used in practice (300 to 700 dyne per sq. cm.), the expansion factor has no measurable effect upon the control time. At critical shearing stresses above 700 dyne per sq. cm. the expansion factor begins to influence the control time and at higher shear stresses the control time appears to tend to a limit inversely proportional to the expansion factor (for expansion factors between 5 and 13.5). This effect may be due to the applicator, rather than the expansion factor and critical shearing stress, controlling the thickness of the foam blanket.

Figure 10 shows that with compound A, for the normal level of critical shearing stress, the expansion factor has no effect upon the control time - rate of application relationship.

4) Effect of critical shearing stress

It is evident from figs. 8 and 9 that for foams which have critical shearing stresses of the order of that obtained with the standard foam-making branchpipe (300 to 700 dyne per sq. cm.) the control time is approximately proportional to the critical shearing stress or in other words the ability of the foam to cover the surface, this being largely controlled by the critical shearing stress. Fig. 11 shows that, above the critical rate of application, the control time increases with increase in shearing stress, probably also because of the influence of critical shearing stress on the rate of coverage. Critical shearing stress has little effect upon the critical rate of application.

Conclusions

The gernal conclusion of a practical nature to be drawn from these experiments is that the performance of a foam in combating a petrol fire is a function of its water content and its ability to flow over the petrol surface, while with most compounds the loss of foam due to destruction by this fire is small, particularly when applied at rates well above the critical rate. These conclusions support those of Amsel (6) and Clark (2). The resistance of the foam to breakdown on hot petrol may be of considerable importance particularly as far as maintaining coverage of the surface after the fire has been extinguished is concerned. This factor may be of more importance than the ability of a foam to withstand the effects of radiation.

A point of importance demonstrated by these experiments is that it is a waste of materials to attempt to deal with a petrol fire if foam cannot be applied at a rate greater than the critical rate. This point is borne out by fig. 16 which shows the effect upon a fire where the rate of application of foam was only 80% of the critical rate and in which there was only a slight and temporary reduction in radiation, the fire rapidly returning to its peak. This means that, whenever possible, if sufficient equipment is not initially available it is advisable to attempt to build up resources so that the critical rate can be exceeded before fire-fighting operations are commenced and the initial operations should be confined to preventing the spread of the fire. In cases where there is a known risk the wisest procedure is obviously to ensure that permanent equipment is installed on such a scale as to make it possible to apply foam with the minimum of delay at a rate well above the critical rate for the largest area of fire ever likely to occur: this would amount to about $\frac{1}{2}$ gal./sq. ft./min. for a good protein compound.

Acknowledgement

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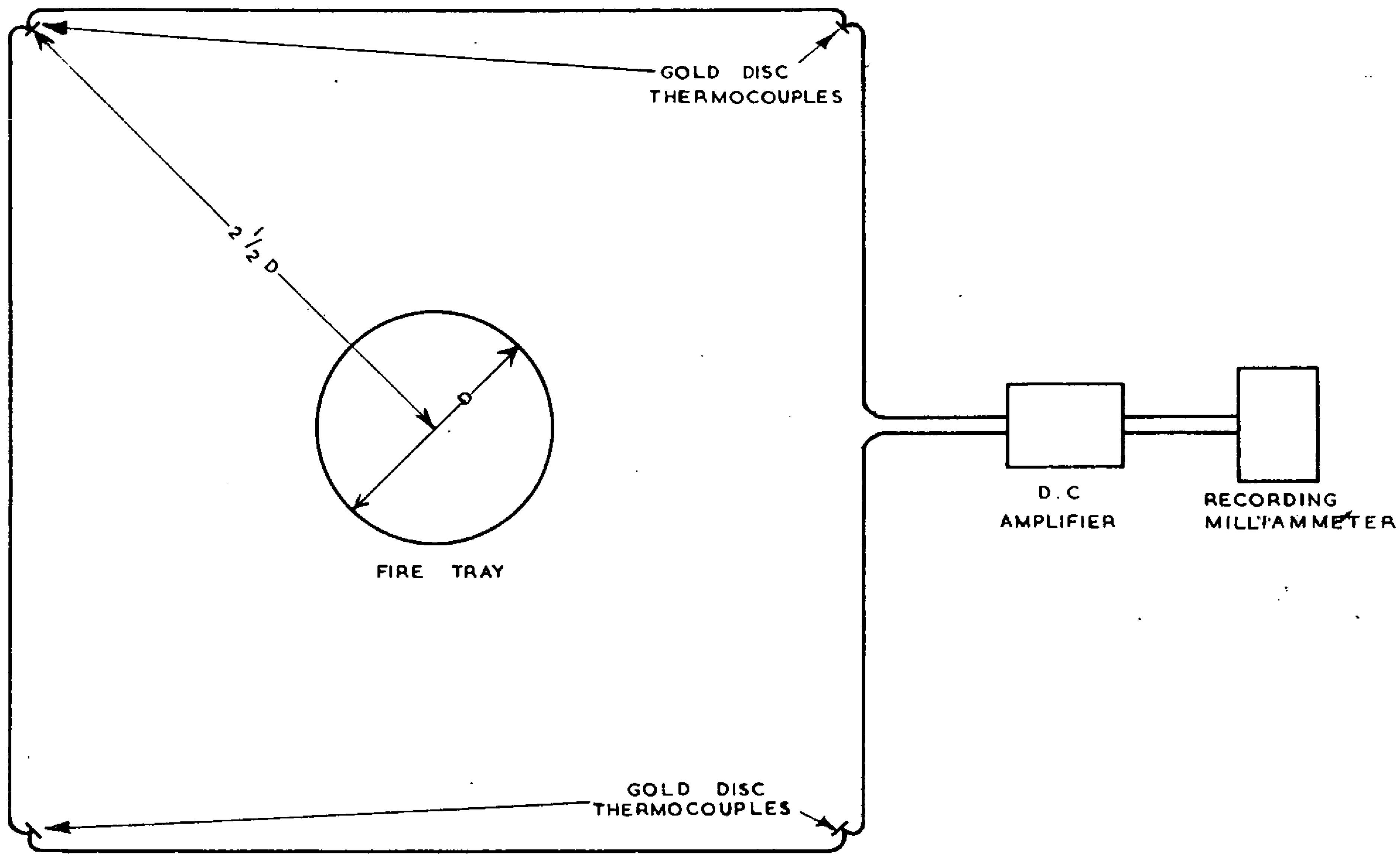

FIG. 1. DIAGRAMATIC ARRANGEMENT OF RADIATION RECORDING APPARATUS.

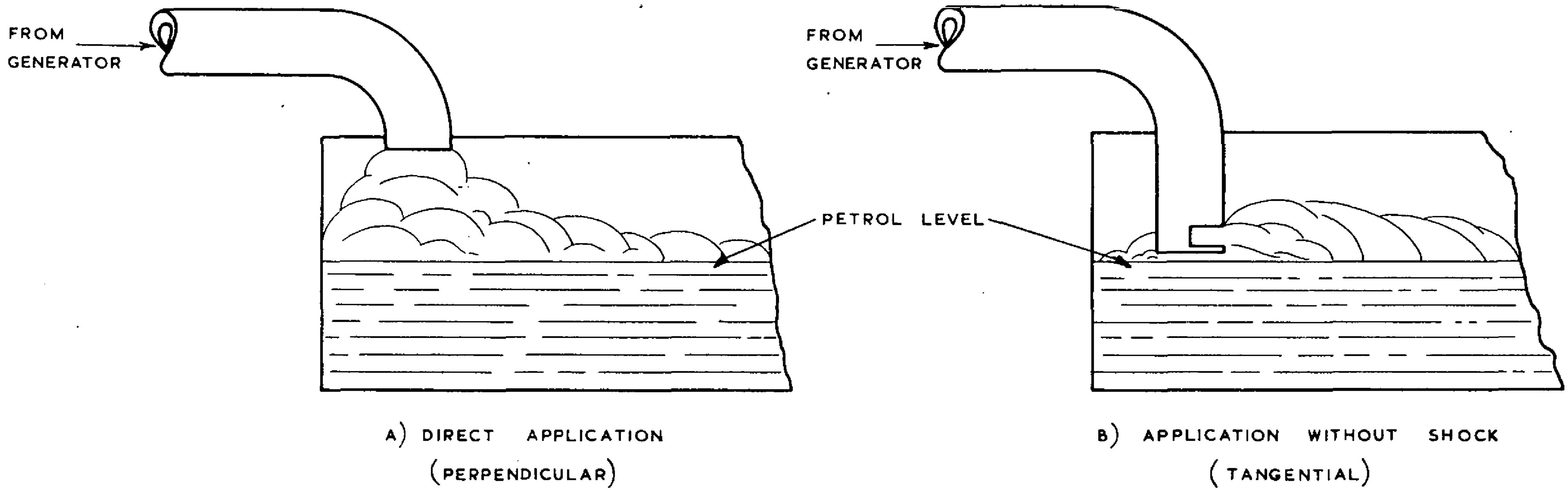

FIG. 2. METHOD OF FOAM APPLICATION.

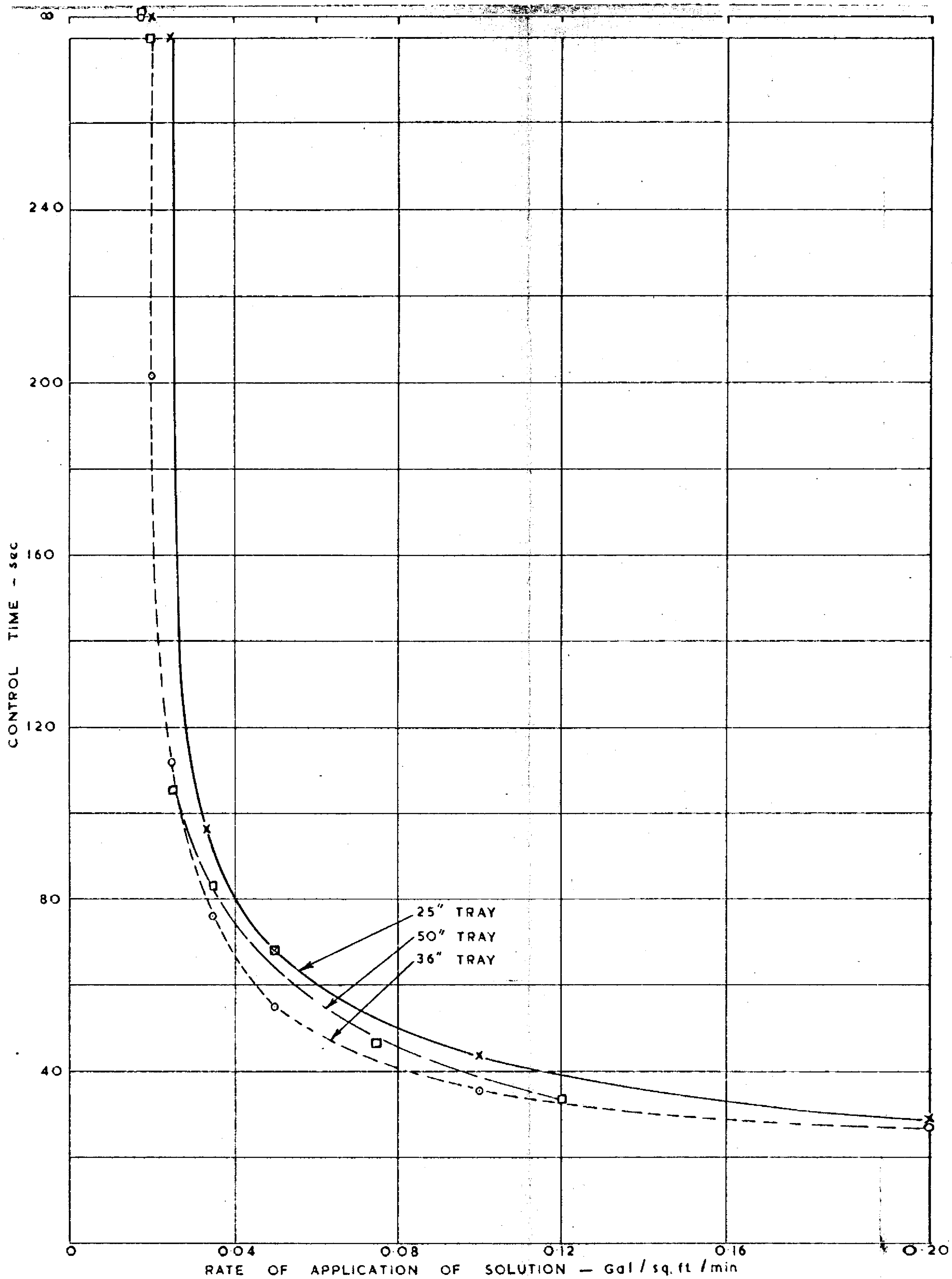

FIG. 3. EFFECT OF RATE OF APPLICATION OF SOLUTION ON CONTROL TIME FOR THREE SIZES OF TRAY.
COMPOUND A. BRANCHPIPE QUALITY FOAM. EXPANSION FACTOR = 7·5.
CRITICAL SHEARING STRESS = 430 dyne/cm².

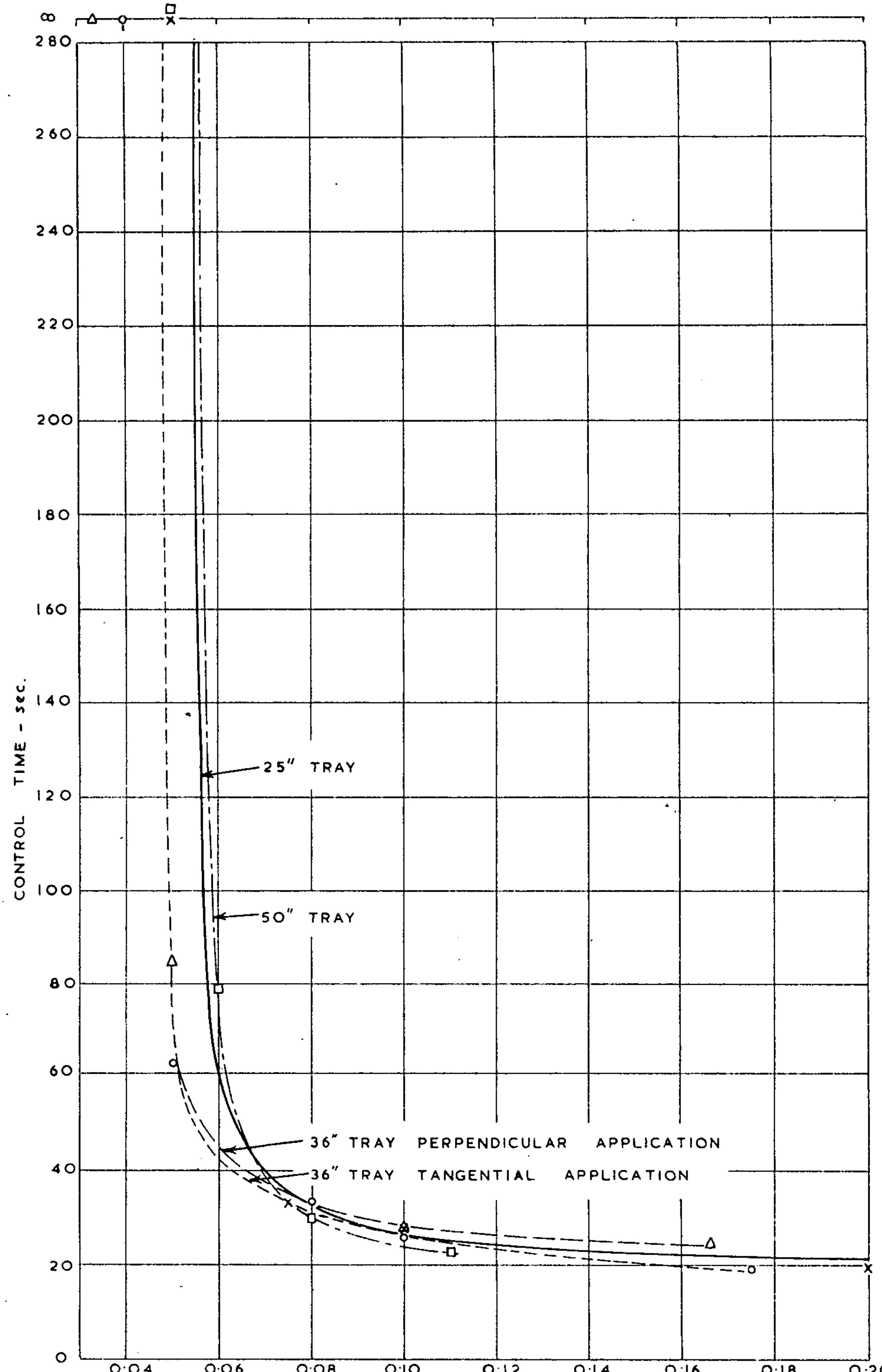

FIG. 4. EFFECT OF RATE OF APPLICATION OF SOLUTION ON CONTROL TIME FOR THREE SIZES OF TRAY.

COMPOUND D. BRANCHPIPE QUALITY FOAM. EXPANSION FACTOR = 11. CRITICAL SHEARING STRESS = 80 dyne / cm².

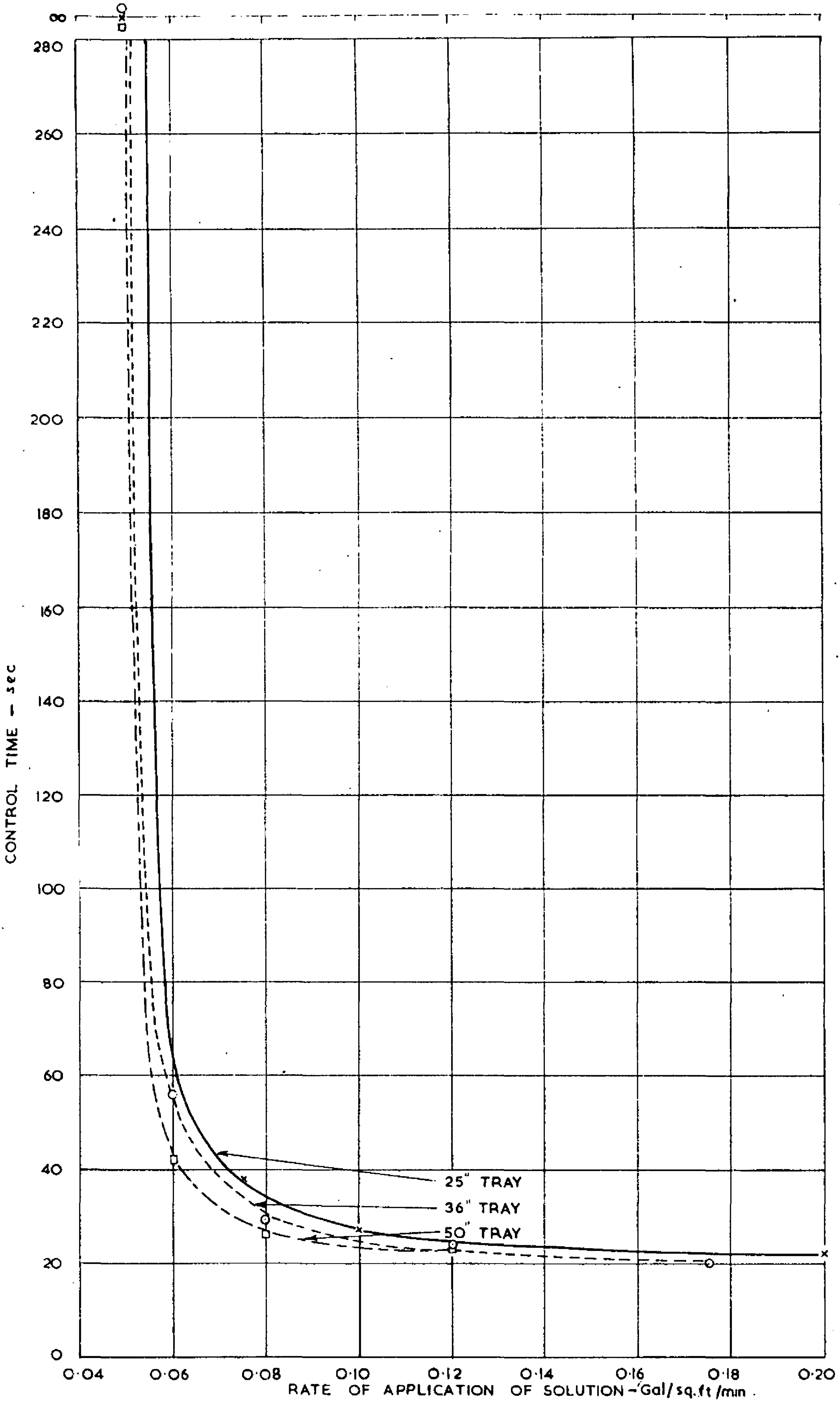

FIG. 5. EFFECT OF RATE OF APPLICATION OF SOLUTION ON CONTROL TIME FOR THREE SIZES OF TRAY. COMPOUND E. BRANCHPIPE QUALITY FOAM. EXPANSION FACTOR = 11. CRITICAL SHEARING STRESS = 70 dyne/cm².

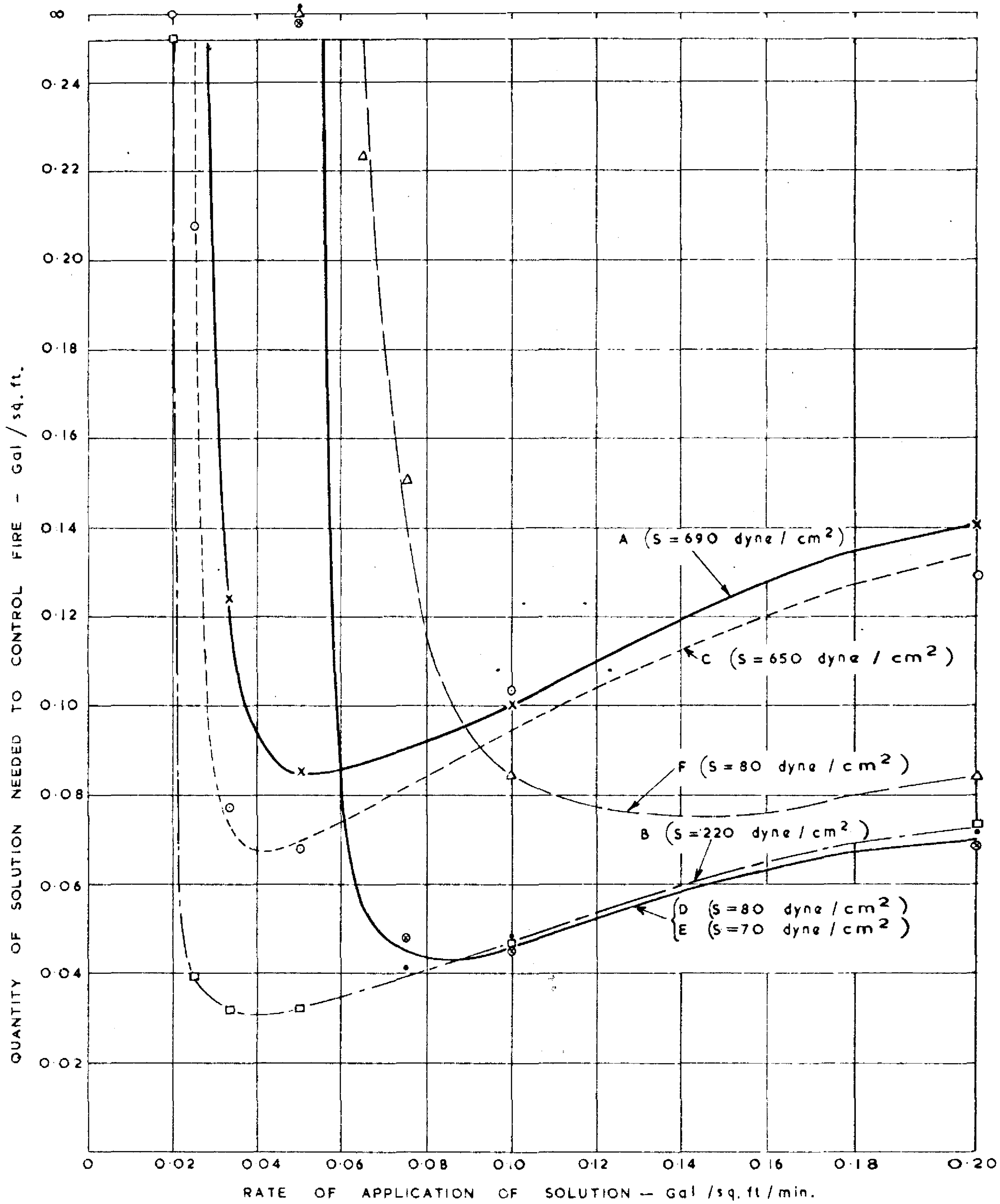

FIG. 7 EFFECT OF RATE OF APPLICATION OF SOLUTION ON QUANTITY OF SOLUTION NECESSARY TO CONTROL THE FIRE.

FOAMS AS PRODUCED BY No 2 BRANCHPIPE. 3% SOLUTION. 25" DIA. TRAY.

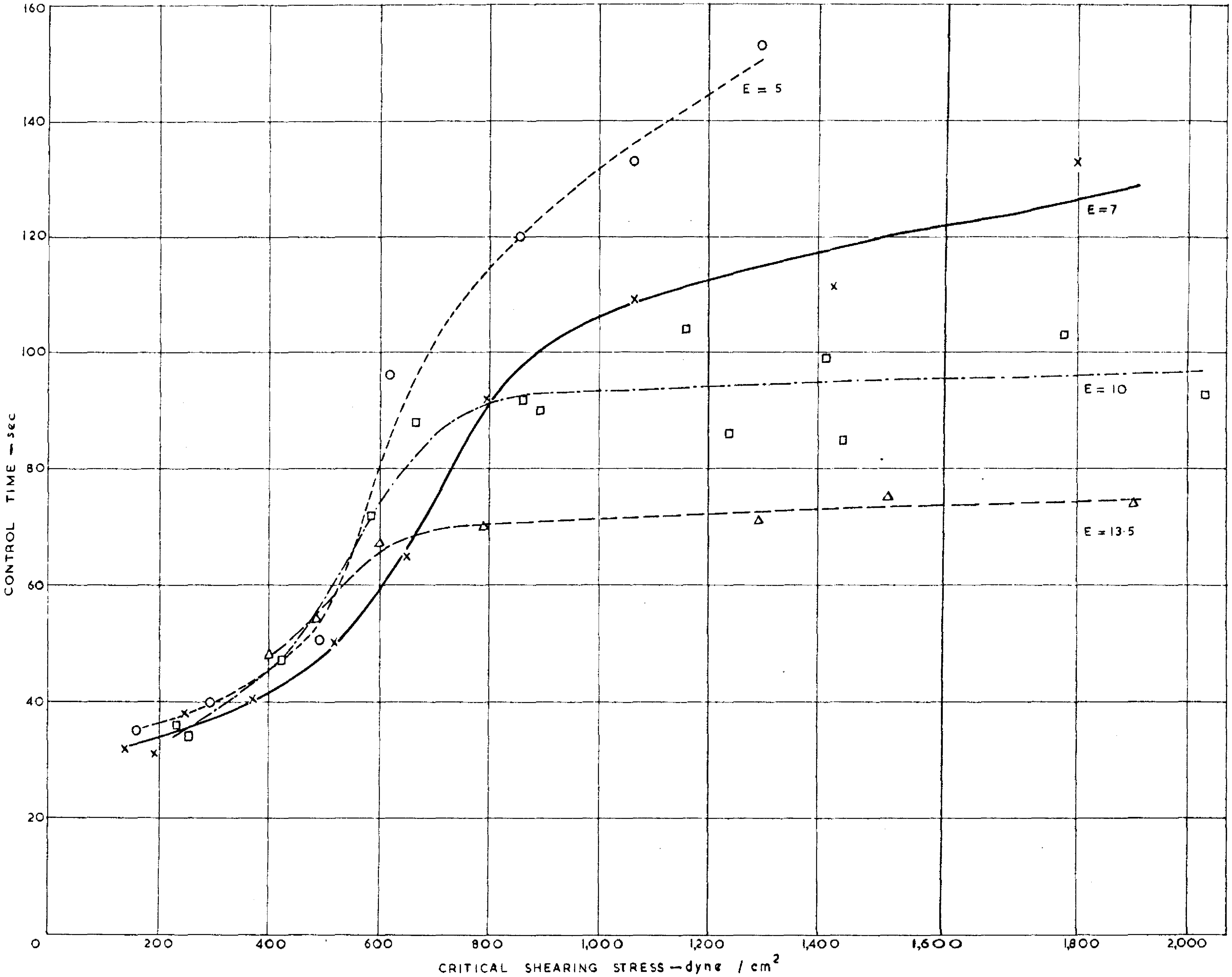

FIG. 8. EFFECT OF CRITICAL SHEARING STRESS ON CONTROL TIME AT FOUR EXPANSION FACTORS.
RATE OF APPLICATION OF LIQUID CONSTANT AT 1/14 Gal/sq.ft/min. 36" DIAMETER TRAY. COMPOUND A.

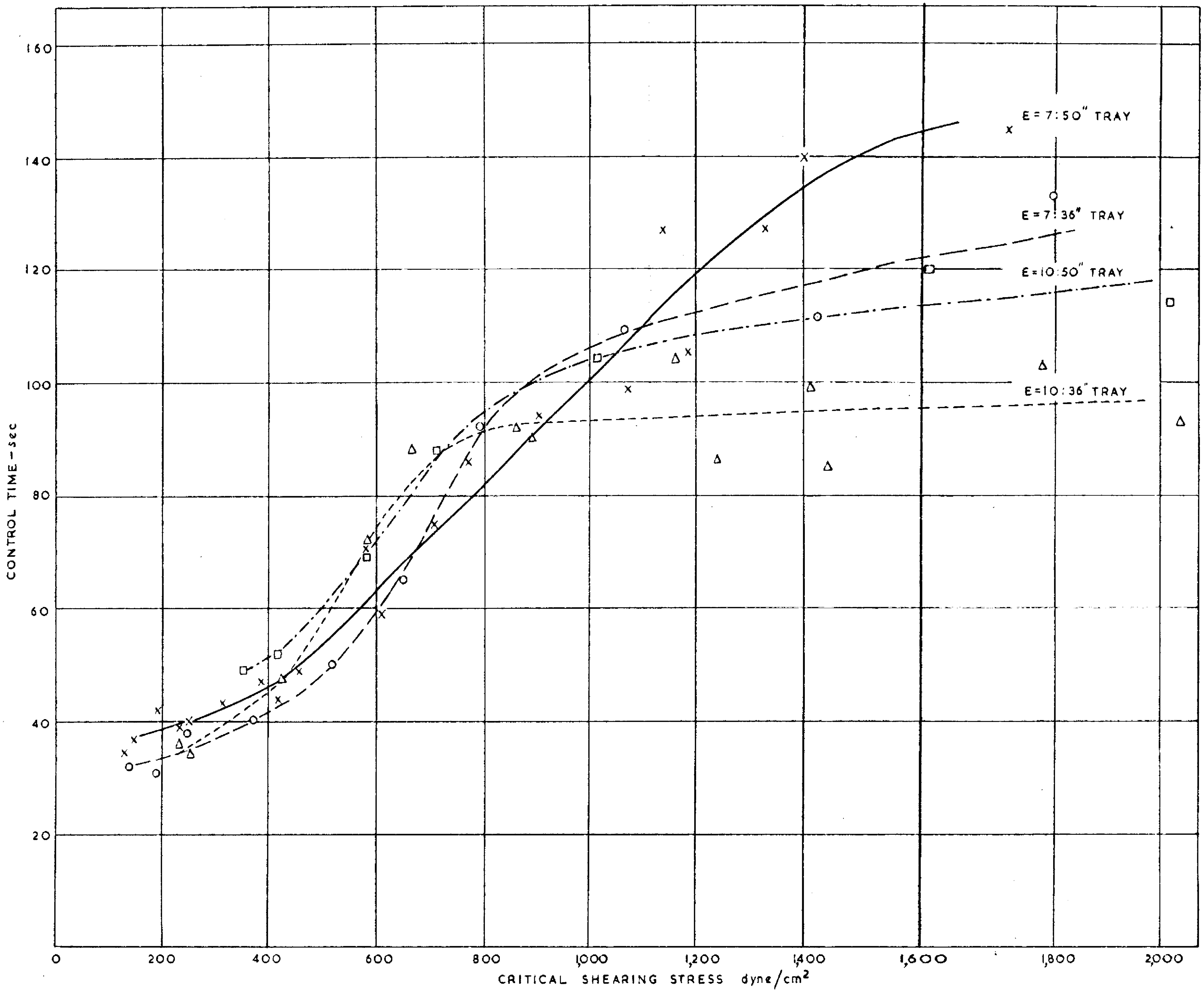

FIG. 9. EFFECT OF CRITICAL SHEARING STRESS ON CONTROL TIME FOR TWO SIZES OF TRAY AT TWO EXPANSION FACTORS.
RATE OF APPLICATION OF LIQUID CONSTANT AT 1/14 gal/sq.ft/min. COMPOUND A.

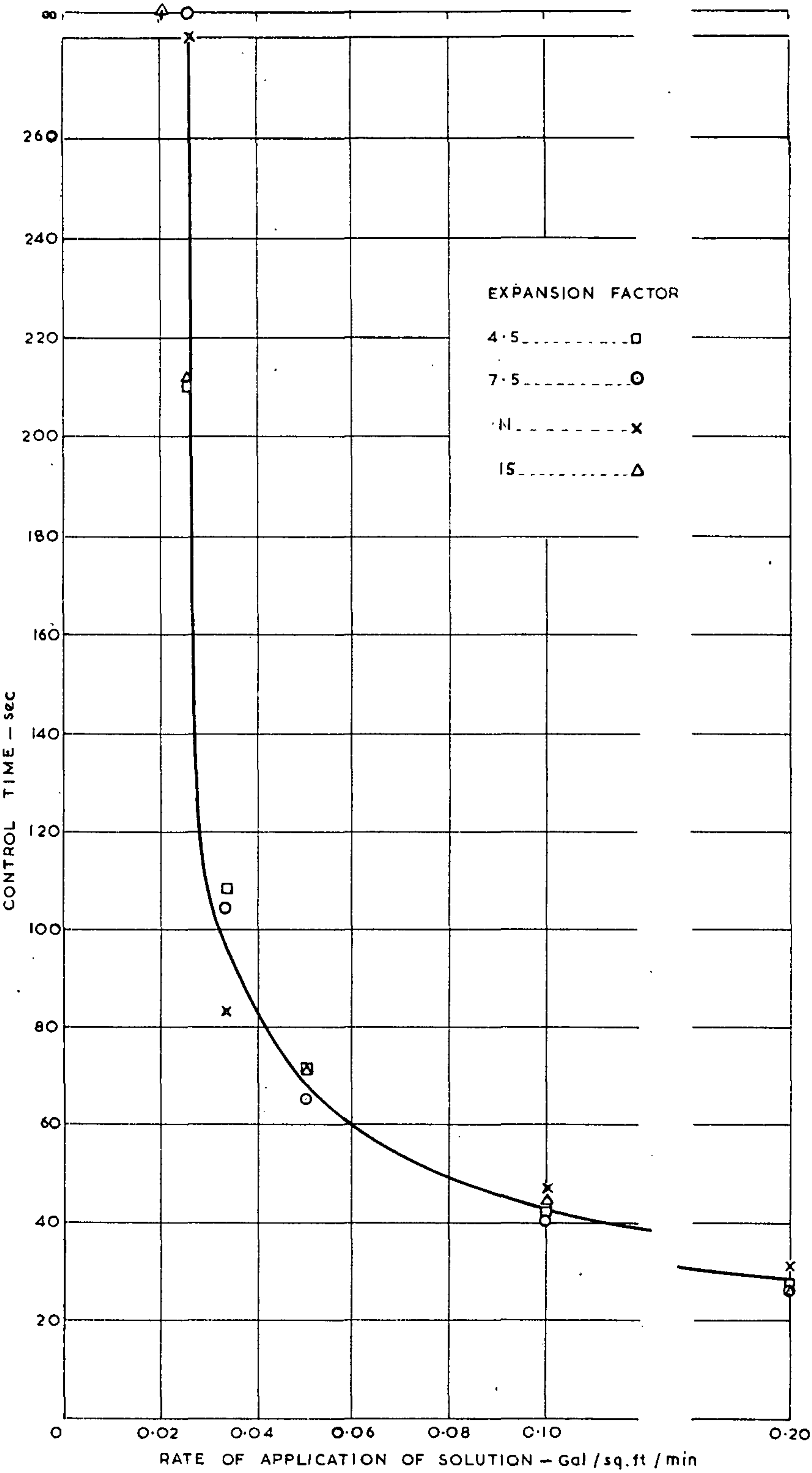

FIG. 10. EFFECT OF RATE OF APPLICATION OF SOLUTION ON CONTROL TIME AT FOUR EXPANSION FACTORS.

CRITICAL SHEARING STRESS = 430 dyne/cm². COMPOUND A. 25" DIA. TRAY.

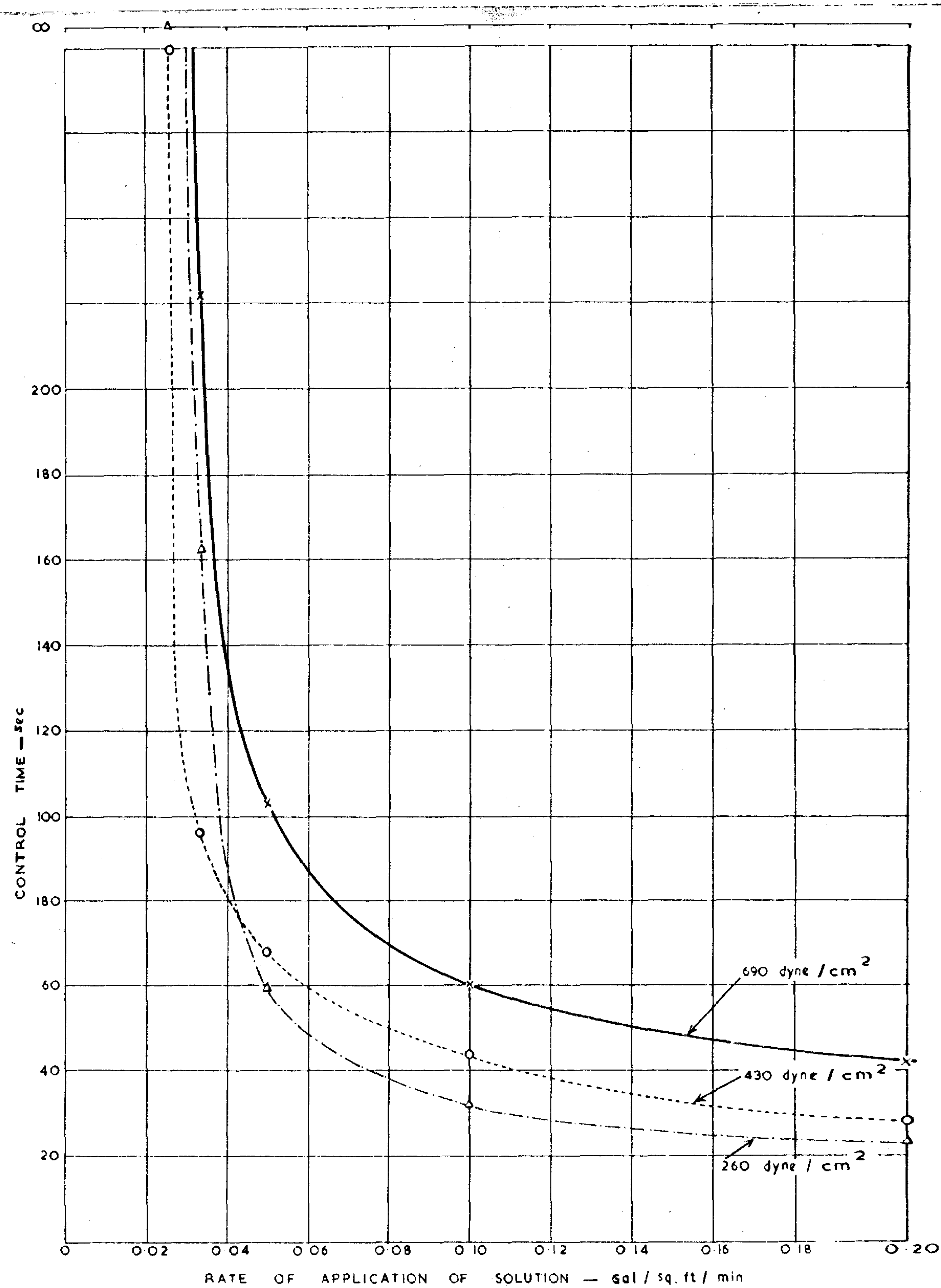

FIG. 11. EFFECT OF RATE OF APPLICATION OF SOLUTION ON CONTROL TIME FOR THREE VALUES OF CRITICAL SHEARING STRESS. COMPOUND A. 25" DIAMETER TRAY.
EXPANSION FACTOR = 7·5 EXCEPT FOR 430 dyne / cm² CURVE WHICH IS MEAN OF FOUR VALUES (SEE FIG. 10)

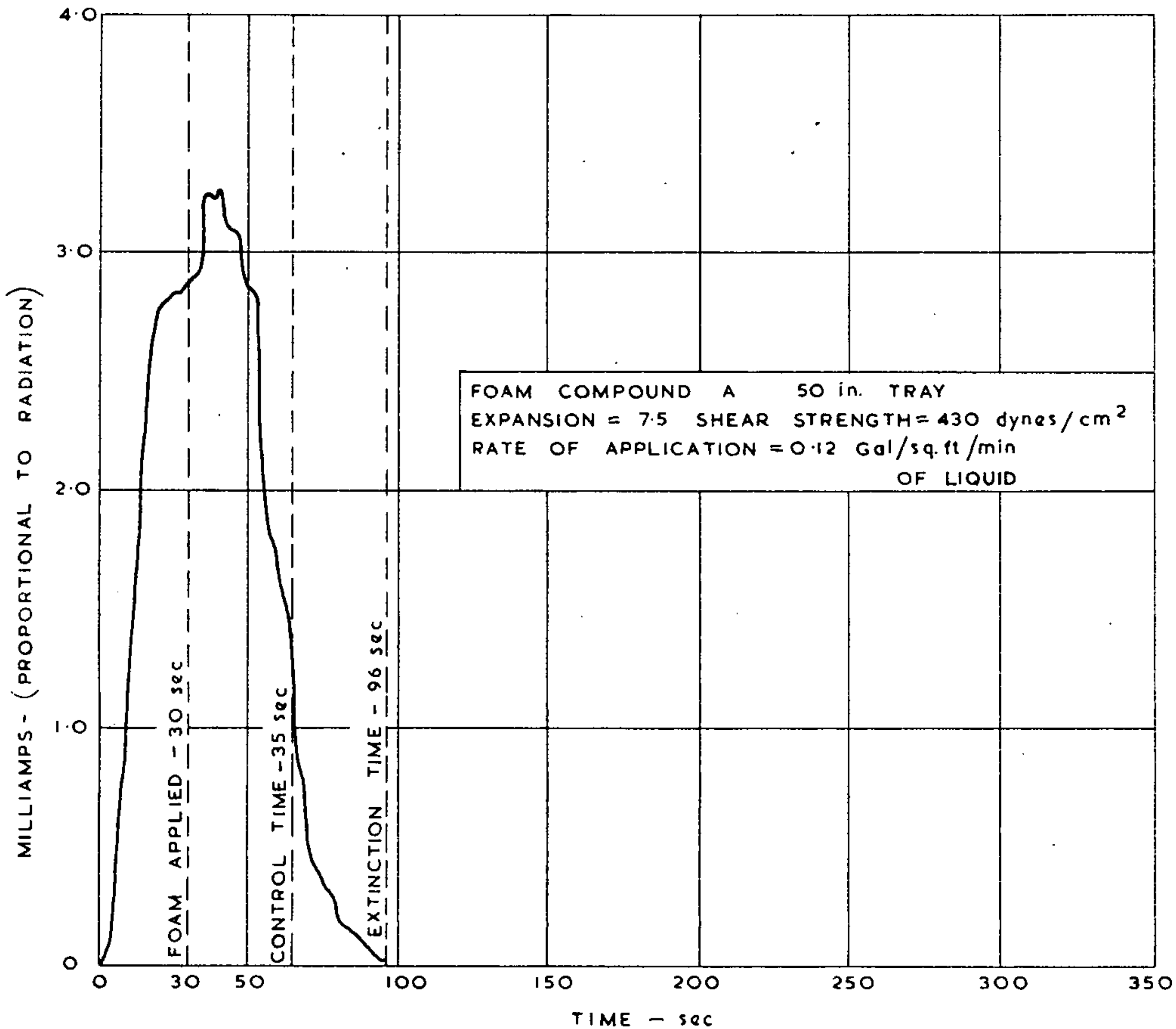

FIG. 12. REPRODUCTION OF RECORDER CHART – TEST No 211.

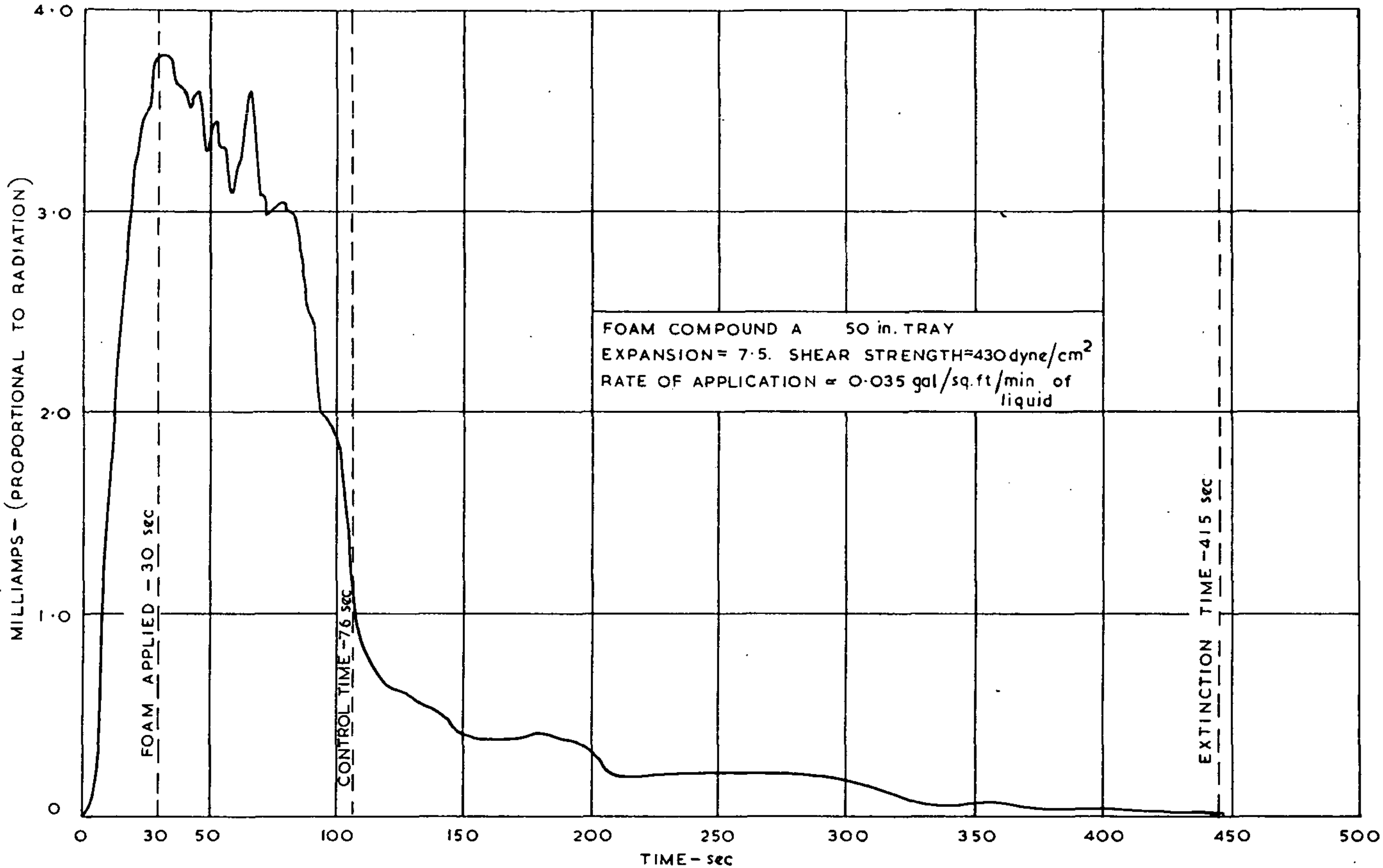

FIG. 13. REPRODUCTION OF RECORD CHART – TEST N° 214.

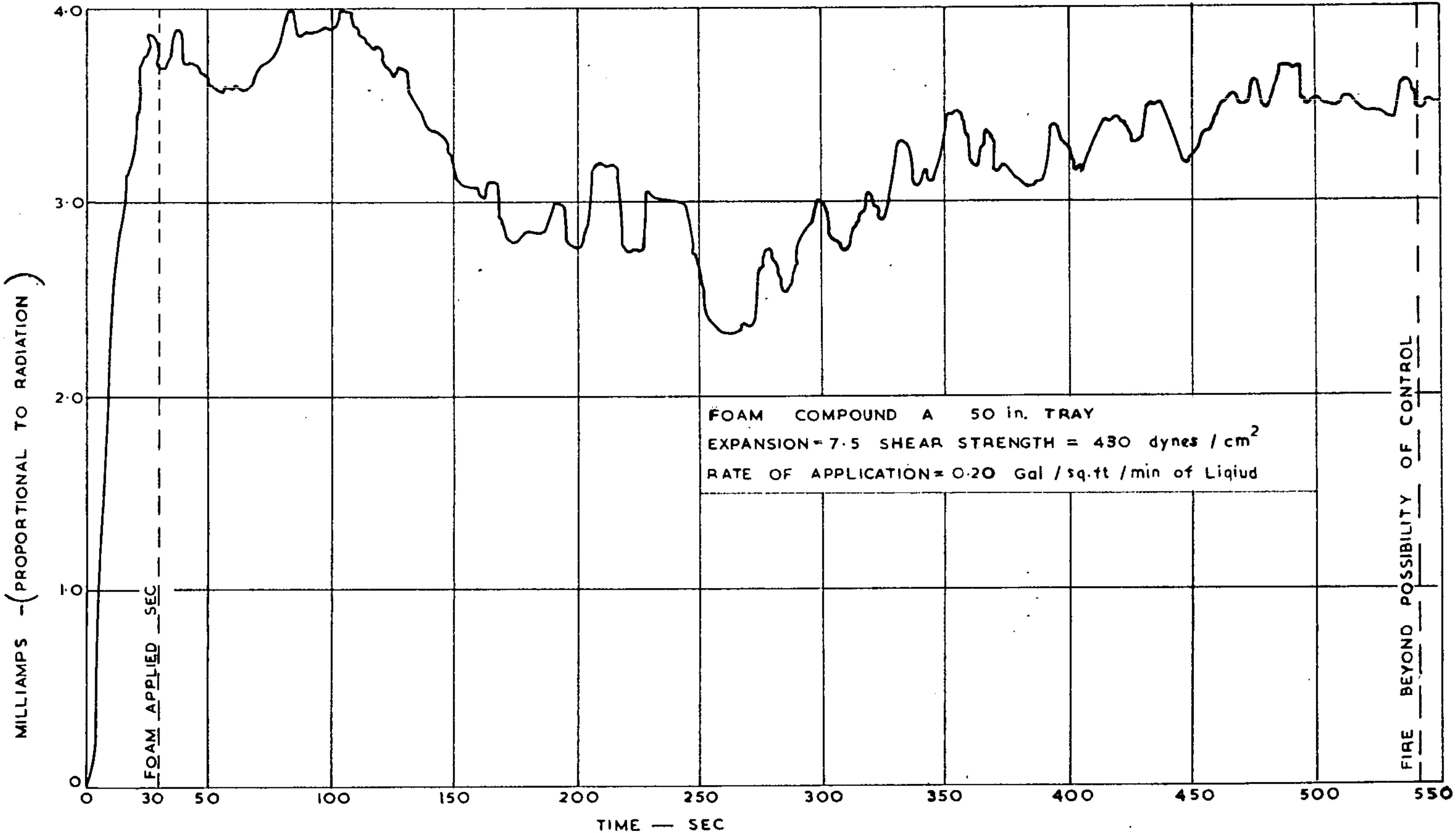

FIG. 14. REPRODUCTION OF RECORDER CHART TEST No 217.