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A STIRRED JAR FOR PRODUCTION OF STANDARD FOAM IN THE LABORATORY

by

J.G. CORRIE

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SUMMARY

An 800 ml stirred jar is described. Its foam producing characteristics are recorded to show how 25 per cent drainage time, shear stress, concentration, stirring time, stirring speed and expansion are inter-related. With other variables kept constant, the time for a foam to commence drainage was found to be a linear function of the expansion, which indicates there is a critical bubble wall thickness below which drainage does not occur.

Examples of the use of the apparatus are given.

KEY WORDS: Properties, foam, laboratory, stirred jar, generator, sample

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INTRODUCTION

Many workers have described apparatus for the production of foam in the laboratory. All have various limitations such as failure to produce a uniformly mixed foam, inability to precisely control the expansion, cannot be operated with very small quantities or do not function when insoluble solids are present. No apparatus is generally known for the simple production of small batches of uniform foam of chosen expansion. The apparatus described fulfills this need.

The appratus is based upon the principle that when a cylindrical jar is arranged with its longitudinal axis horizontal, a uniform mix can be obtained filling the entire jar with foam. This is not possible with vertical cylinders.

Foam producing machines can be divided into three groups. In one group, to which this stirred jar apparatus belongs, an energy equilibrium is established, and the stiffness of the foam is determined by the agitator speed and the geometry of the apparatus, and is independent of the concentration of foaming agent above a minimum value.

In a second group the foaming solution and air are subjected to a near instantaneous application of energy and the stiffness of the foam is dependent on the concentration of foaming agent present as well as the level of applied energy. A laboratory apparatus of this type will be described in a subsequent Fire Research Note.

The third group embraces many of the methods now used for foam production in the laboratory and fire suppression field. They are not controlled purely by energy, nor purely by concentration, but a function of both. The relations between concentration and shear stress have various forms and are not readily defined. Figure 1 shows typical relations for apparatus in the three different groups. Laboratory test results are much more enlightening if the apparatus is known to be either energy or concentration controlled. Results from both types of machine are desirable.

DESCRIPTION OF APPARATUS

The apparatus consists essentially of a horizontal Perspex jar in which a stirrer, mounted axially, can be rotated.

It is shown assembled in Fig.2 and the dimensions of the jar and stirrer are shown in Fig.3.

The jar is constructed from 6.35 mm ($\frac{1}{4}$ in) thick Perspex tube. It is of 88 mm internal diameter and 127 mm internal height. The base of the jar is of attached to the base with three set screws and the recess fits into a matching recess in the base. It does not protrude through the base which is retained as a flat surface so that the jar can be stood vertically. The top of the jar is threaded externally with six threads at 3 mm pitch.

The cover is made from brass, 5 mm thick with a rim 23.5 mm outside depth, threaded inside to fit the jar. No jointing is used, the brass cover and the Perspex jar rim making a satisfactory joint. The cover has a simple brass bearing and stuffing box for the agitator shaft. The rim of the cover is etched to a rough surface to grip the supporting cradle.

In the base perimeter of the jar is a 2.5 mm hole with a right angle turn so that liquid from the draining foam will leave the edge of the base plate through a 2.5 mm bore brass tube, 14 mm long. This arrangement accommodates the drainage removal and still retains a flat base plate so the jar can be stood vertically. The drainage tube is fitted with a small rubber stopper which is convenient for frequent removal and replacement.

The jar is arranged to sit in two 25.4 mm wide aluminium cradles, 100 mm apart. The cradles have etched rubber inserts to restrain the jar from turning. The cradles are mounted on an aluminium base plate 400 mm long x 200 mm wide and 12.5 mm thick, which has adjustable supports at each corner for levelling. The base plate has an aluminium support for the motor. The motor[1] is 60 watts capacity with output speed 100-600 r.p.m. The integral speed control is not used and the speed is adjusted by an ADAP Universal[2] Speed Control - not shown in the figure. The Universal speed control has better power characteristics than the integral resistance controller.

The stirrer is mounted on a brass shaft 9.52 mm diameter and 190 mm overall length. One end is squared to fit easily into a matching chuck on the motor output shaft.

There are nine stirrer blades each 82 mm long and 2.4 mm diameter. These blades are of brass wire and are all in the same plane at 17 mm spacing except for the wire at each end which is 8.5 mm from the next wire.

IMPORTANT POINTS IN THE APPARATUS DESIGN

The stirrer is made as a flat comb with all the wires in one plane because it can then be removed from the jar without a large proportion of the foam adhering. The dimensions of the stirrer comb are important. Experiments were made with several wire diameters, different wire spacings and different speeds. If the wires are too fine, foam forms more slowly and does not mix effectively Finer wires produce higher shear stress foams. If the wires are too thick, or too closely spaced, the stirring action is too severe and a layer of unfoamed liquid persists on the periphery.

The apparatus operates effectively with foams having shear stresses up to 70 N/m^2, which covers the range normally used in fire-fighting foams. Expansion of up to 16 can be uses without difficulty and up to 20 with freely foaming liquids such as the synthetic surface active liquids used for the production of high expansion foam.

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1. Type KQPS/29 Griffin & George Ltd
2. J.A.C. Electronics Ltd

The 60 watt motor used in the experimental model had only just sufficient power and it was necessary not to overtighten the stirrer stuffing box. For routine use a 100 watt or $\frac{1}{8}$ h.p. motor, with gear to give a fixed output speed of 510 r.p.m., would be suitable. Very little leakage occurs at the gland providing the rubber cap on the drainage tube is removed when screwing on the jar lid, to avoid creating a slight positive pressure in the jar. Provision of several identical jars is an advantage when experimenting with slow-draining foams. A foam viscometer with sufficient clearance and stem length to the vane, so that shear stress measurements can be made in the 800 ml jar, is advantageous. This permits shear stress and drainage rate to be measured on a single jar of foam.

The diameter of the drainage pipe, 2.5 mm, proved ideal for the protein and synthetic foams, allowing the liquid to drain but not allowing the foam to run out. The brass screw cap for the jar is of substantial design and its weight is effective in preventing the jar from turning when making foam, thus avoiding the necessity of providing a clip to hold the jar.

EXPERIMENTAL PROCEDURE

A protein liquid was used to determine the characteristics of the stirred jar. The liquid had the following properties.

Nitrogen	-	3.55%
Specific gravity	-	1.159
Cylinder expansion	-	1180
Total iron	-	0.023%
pH	-	7.85

Solution of the required concentration was freshly prepared for each test, by dilution with potable water; and the appropriate amount of diluted solution, to give the required expansion, was placed in the jar. The stirrer was positioned and the screw cap tightened. When screwing on the cap it is necessary to remove the rubber plug on the drainage tube to allow air to escape, taking care to keep the jar tilted to avoid loss of liquid. The jar was then placed in the cradles and the shaft slipped into the drive; the motor was started and the time noted.

During the first minute of stirring it was necessary with some combinations of expansion and speed to tilt the machine several times to obtain a full jar of foam.

At the end of the stirring period the motor was stopped and the jar quickly removed. The screw cap was taken off, the stirrer being left in the jar. Any foam in the cap was scraped into the jar which was then placed in a stand, at a slight angle, to drain into a 25 ml measuring cylinder. Drainage time was recorded from the time of stopping the stirrer. The first reading of the drainage volume can be obtained at 90 seconds, which allows a period for any accumulated drainage to flow into the cylinder. Any accumulation of liquid in the base of the jar can be readily observed.

For shear stress measurements, the stirrer was removed and the foam transferred to a 400 ml beaker. Three shear measurements were made and these were completed between 45 and 75 seconds from stopping the stirrer.

EXPERIMENTAL RESULTS

Concentration, expansion, stirring speed, and time were each varied and the measurements of drainage rate and shear stress are shown in Figs 4-11. Table 1 gives the data for 4 proprietary foaming liquids and Fig.12 illustrates one use of the apparatus to determine the effect of pH on the shear stress of a protein foam. Figure 13 gives the time to start of drainage at different expansions.

DISCUSSION

STIRRING TIME

Figure 7 shows the relation between 25 per cent drainage time and critical shear stress with stirring time. A standard stirring time of 6 minutes was selected for routine use. At this period equilibrium has not quite been reached but 6 minutes gave a good compromise to permit economy of experimental time. One of the limiting disadvantages of the stirred jar is that in systems where chemical or physical changes are taking place, such as the precipitation of protein, the time factor is very different from that in commercial apparatus such as branchpipes.

STIRRER SPEED

Figure 5 shows the effect of stirrer speed on the 25 per cent drainage time and the shear stress. Both increase linearly with stirrer speed over the range investigated. It is possible that both lines have a slight curvature and considerably more data would be required to determine this.

If the angular velocity of the liquid in the jar is such that the centrifugal force exceeds the force of gravity, which acts to keep the liquid in the base of the jar, the liquid will rotate around the periphery. The critical speed at which this will occur can be calculated by equating the centrifugal force to the force of gravity which gives the equation

$$\text{Critical speed (r.p.m.)} = \frac{60}{2\pi} \sqrt{\frac{g}{v}}$$

$g = 980 \text{ cm/s}^2$

v = radius cm

Using the radius of the stirrer wires, the critical speed is 147 r.p.m. The jar operates well, without liquid separation at 3-4 times the critical speed because the foam does not rotate at the same speed as the stirrer.

CONCENTRATION

Figure 9 shows that the shear stress of the stirred jar foam is independent of concentration from 2 per cent to 10 per cent, and it is not therefore possible to distinguish between samples whose only difference is their concentration. This is a very important practical point, since different batches of the same product, which may differ appreciably in concentration of active constituents, cannot be differentiated in the apparatus. A different type of apparatus which is sensitive to changes in concentration must be used.

Figure 9 shows that the 25 per cent drainage time increases with concentration up to 6 per cent and thereafter shows little change. This suggests that drainage rate rather than shear stress may be the best guide to the optimum concentration at which a foam liquid should be used.

EXPANSION

Figure 10 shows that the 25 per cent drainage time is directly proportional to the expansion. It also reveals that at an expansion of 6.9 the 25 per cent drainage time is zero. These observations can be examined in another interesting manner by plotting the time required for drainage to commence against the expansion. This is shown in Figure 13. Again a linear relation is found which gives zero time for drainage to commence when the expansion is 8.9.

MECHANISM OF DRAINAGE

The following hypothesis of the mechanism of drainage of these types of foam is consistent with the observations.

Liquid will drain almost instantaneously from the foam until the bubble wall thickness is reduced to a critical value, after which drainage will proceed at a rate depending on the rupture of bubbles.

If a foam is formed at sufficiently high expansion, or with sufficiently small bubbles, the bubble film will be below the critical thickness and there will be no initial drainage, liquid liberated by the collapse of bubbles being incorporated in the adjacent bubble walls, increasing their thickness. After a period, sufficient bubbles will have collapsed to increase the wall thickness to the critical value, and drainage will commence.

There are thus two types of foam which may be described as 'fully foamed' or 'partially foamed' liquid.

On this basis, both the drainage rate in $ml/m^2/s$ for the first 25 per cent, and the 25 per cent drainage time will have little meaning for partially foamed liquids, because they depend upon the proportion of initial excess liquid.

In fully foamed liquids the drainage rate in $ml/m^2/s$ for the first 25 per cent will be proportional to the depth of foam while the 25 per cent drainage time will be substantially independent of the foam depth. The 25 per cent drainage times recorded in this apparatus, in which the jar is 127 mm tall, providing we are examining a fully-foamed liquid, should therefore be similar to those obtained in the 50 mm deep tray frequently used in fire foam work, and should also be similar to those in layers of about 25 mm, frequently arising in fire tests.

It has not yet been possible to investigate the effect of bubble size with this apparatus, but a preliminary observation is that the bubbles are of uniform size of about 0.02 mm diameter. If the uniformity of the bubbles can be confirmed, the apparatus will be of great interest in the study of the physical properties of foams.

USE OF THE APPARATUS - PRACTICAL EXAMPLES

Figure 12 shows the effect of pH on the shear stress of a protein foam. Of particular value is the small effort required to obtain this data using the in half a day. Several man-days would be required to obtain the same data from branchpipe tests, with lower accuracy and much greater expenditure of material. Only 100 ml of protein foam liquid were used.

This test was made using protein foam liquid containing no iron salts to see whether the pH effect was dependent upon the presence of iron salts. It clearly is not.

This example shows how changes in the nature of the foam liquid can be measured, although the apparatus would not distinguish between 4 per cent and 8 per cent concentration.

Table 2 gives data obtained to discover whether pH has any effect on the shear stress of the foam from a proprietary synthetic foam liquid. It has no significant effect over a wide range of values and is very different from protein foam in this respect.

Table 1 gives data for 4 proprietary foam liquids. Significant differences in the shear stresses and 25 per cent drainage times of the various foams are evident. These differences must be attributable to the nature of the foam liquids because the stirred jar will not show differences resulting from different concentrations.

A potential use of the stirred jar is to permit assessments that have hitherto been difficult because no standard foam liquid is available as a reference standard. If, for example, it was necessary to measure the efficiency of a branchpipe, this could be done by comparing the shear stress of the branchpipe foam with that of foam produced in the stirred jar, using the same compound at the same concentration and expansion.

CONCLUSIONS

Uniform samples of foam can be produced in the horizontal stirred jar. There are limitations to the range of foam properties but these do permit the production of foams with the characteristics which are usual in fire fighting applications.

After a stirring period of 6 minutes, an equilibrium is approached. The stiffness of the foam depends on the geometry of the apparatus, the agitator speed, and the expansion: it is independent of concentration above a minimum value.

The drainage rate patterns found in the experimental tests can be explained on the basis of a critical bubble wall thickness below which foam will not drain as it collapses, but will absorb liquid from collapsing film into surviving film, thus increasing the thickness of the surviving film.

Foams can be classified into fully-foamed, or partially foamed liquids, according to whether the bubble wall thickness is below or above the critical value.

Twenty-five per cent drainage times for partially-foamed liquids have little meaning.

The results indicate that for fully foamed liquids 25 per cent drainage times should be substantially independent of the depth of foam at the depths of several centimetres normally employed in laboratory sampling apparatus.

The stirred jar enables knowledge of some of the properties of a foam liquid to be obtained with minimum effort, and using small quantities of foam liquid.

ACKNOWLEDGEMENT

Mr A. Wiltshire gave valuable assistance in the design of the apparatus.

Table 1

Shear stresses and drainage rates for various proprietary foam liquids

Stirrer - 9 x 2.4 mm wires
Expansion - 8
Stirring time - 6 min
Speed - 510 r.p.m.

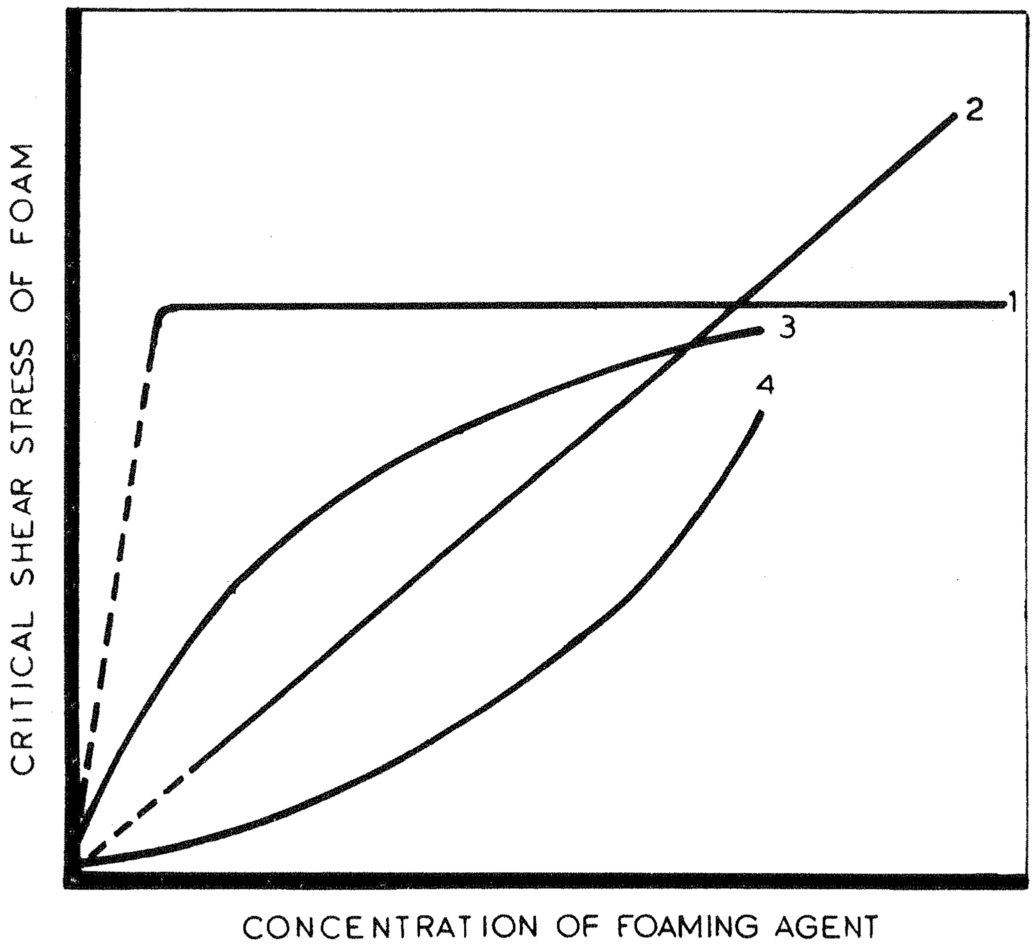
Foam liquid	Shear stress N/m^2	25 per cent drainage time min - s
4% protein foam liquid A	26.0	2 - 15
4% protein foam liquid B	35.4	3 - 50
6% light water 194	6.35	4 - 55
4% synthetic high expansion foam liquid	12.0	7 - 50

Table 2

Shear stress of a synthetic foam at various pH values

Stirrer - 9 x 2.4 mm wires
Expansion - 8.0
Speed - 510 r.p.m.
Concentration - 2% vol/vol

pH	Shear stress - N/m^2
12.0	10.9
8.5	9.6
7.8	10.2
6.3	9.6
4.5	9.6
3.5	9.6



1 Energy controlled (stirred jar)
2 Concentration controlled (wire stirrer)
3 Compound characteristic (packed column)
4 Compound characteristic (turbine)

FIG. 1 CHARACTERISTICS OF DIFFERENT DESIGN OF FOAM PRODUCING APPARATUS

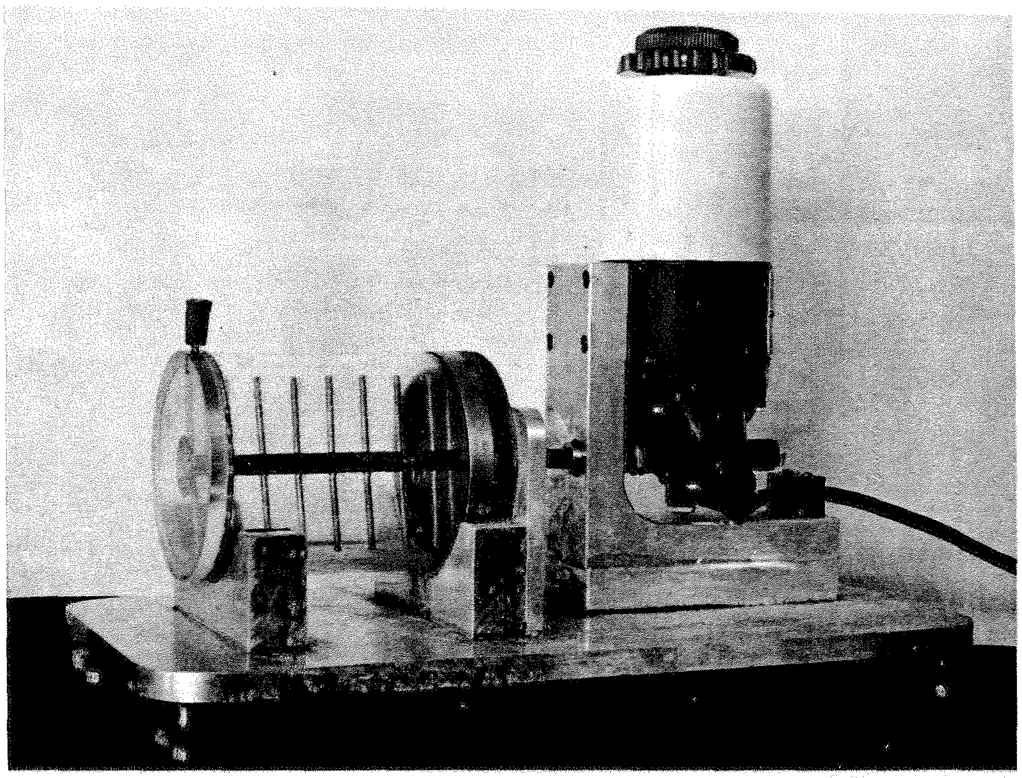


FIG. 2. STIRRED JAR ASSEMBLED FOR OPERATION

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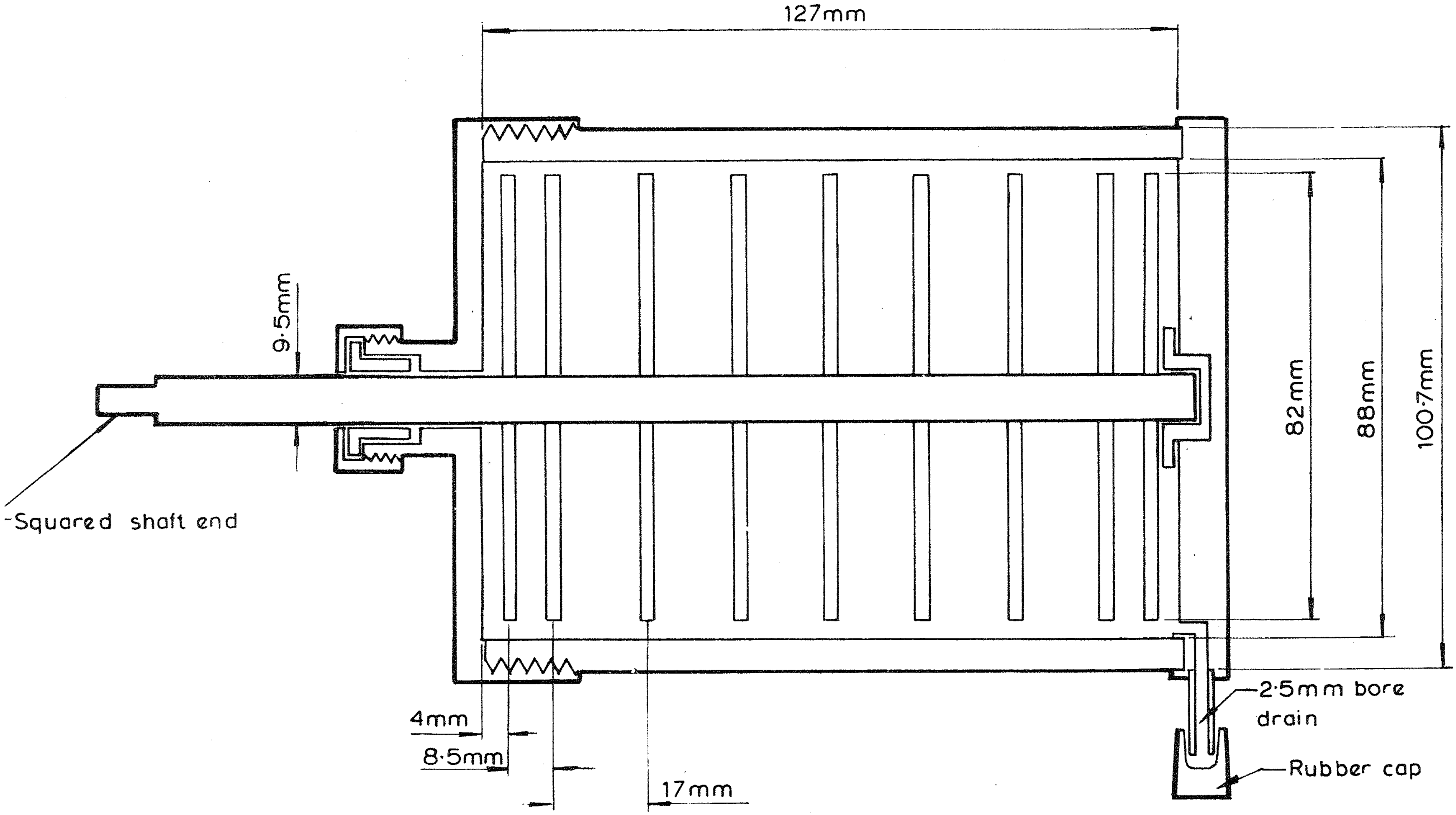
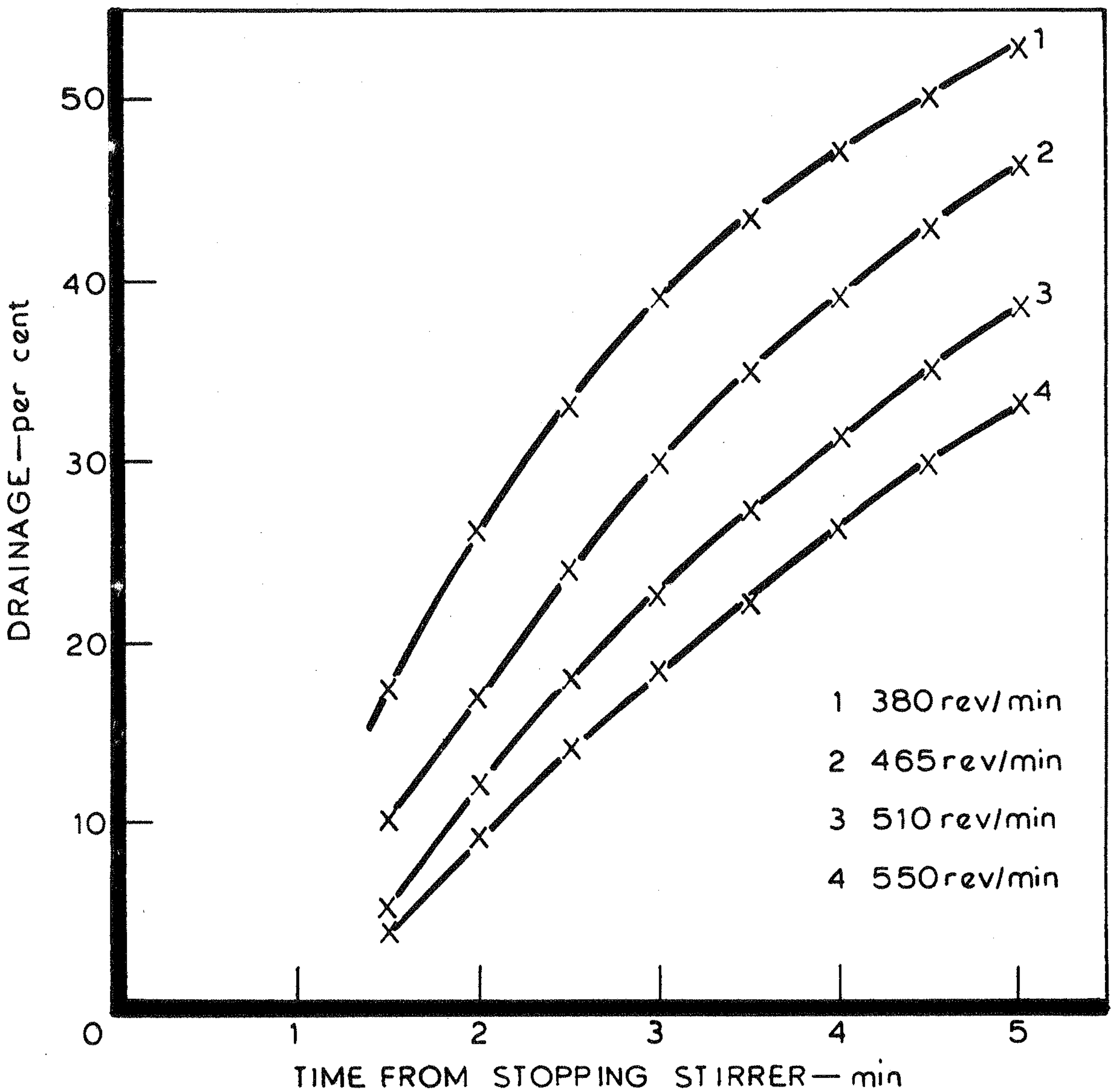


FIG.3 CROSS SECTION OF JAR AND STIRRER



Stirrer – 9 x 2·4mm wires

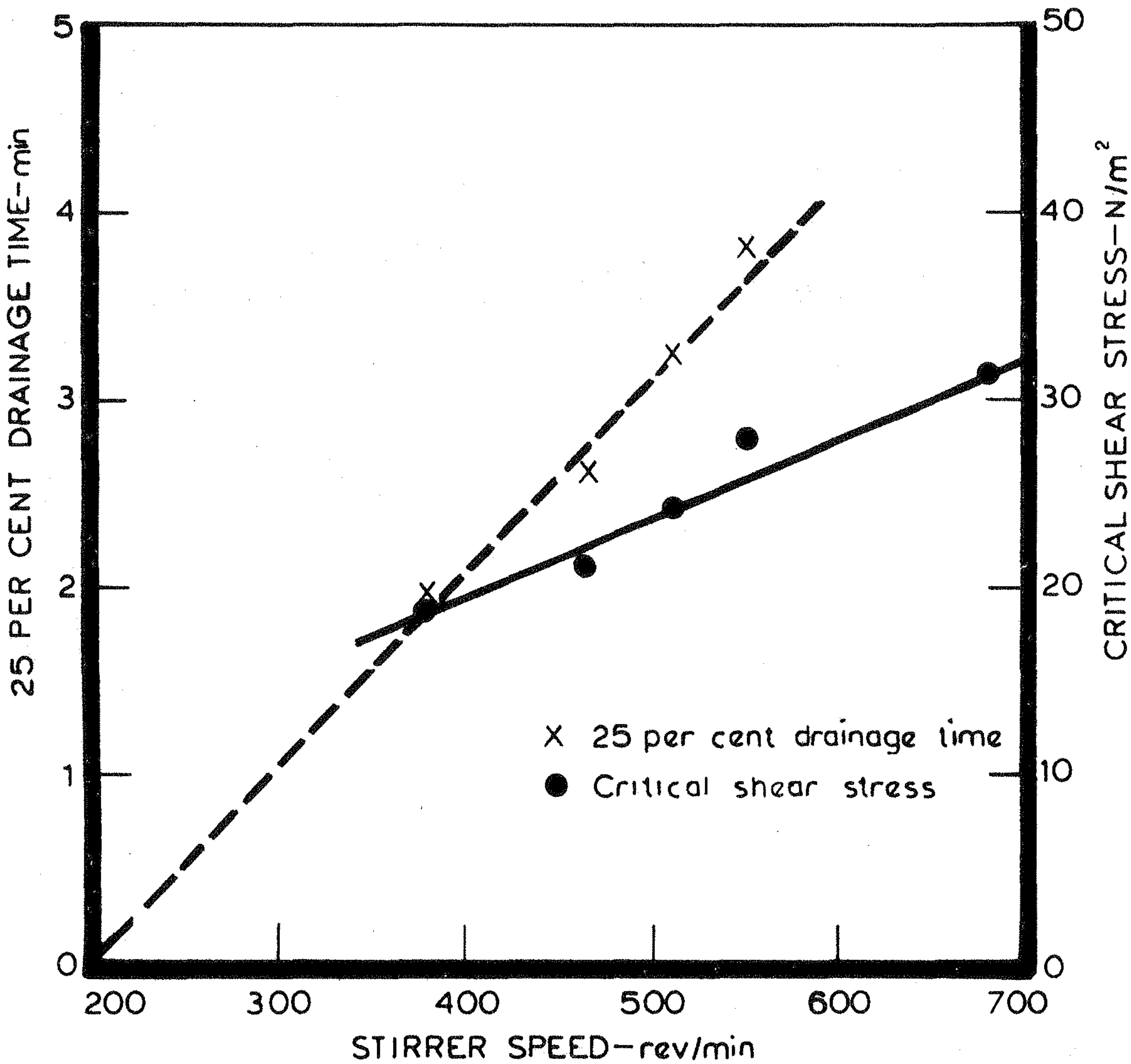
Expansion – 8:1 (100 mℓ)

Stirring time — 10 min

Foam liquid – Protein without iron at pH 7·85

Concentration — 4 per cent vol/vol

FIG.4 PERCENTAGE DRAINAGE IN RELATION TO TIME FROM STOPPING STIRRER – VARIOUS STIRRER SPEEDS



Stirrer — 9 x 2·4mm wires

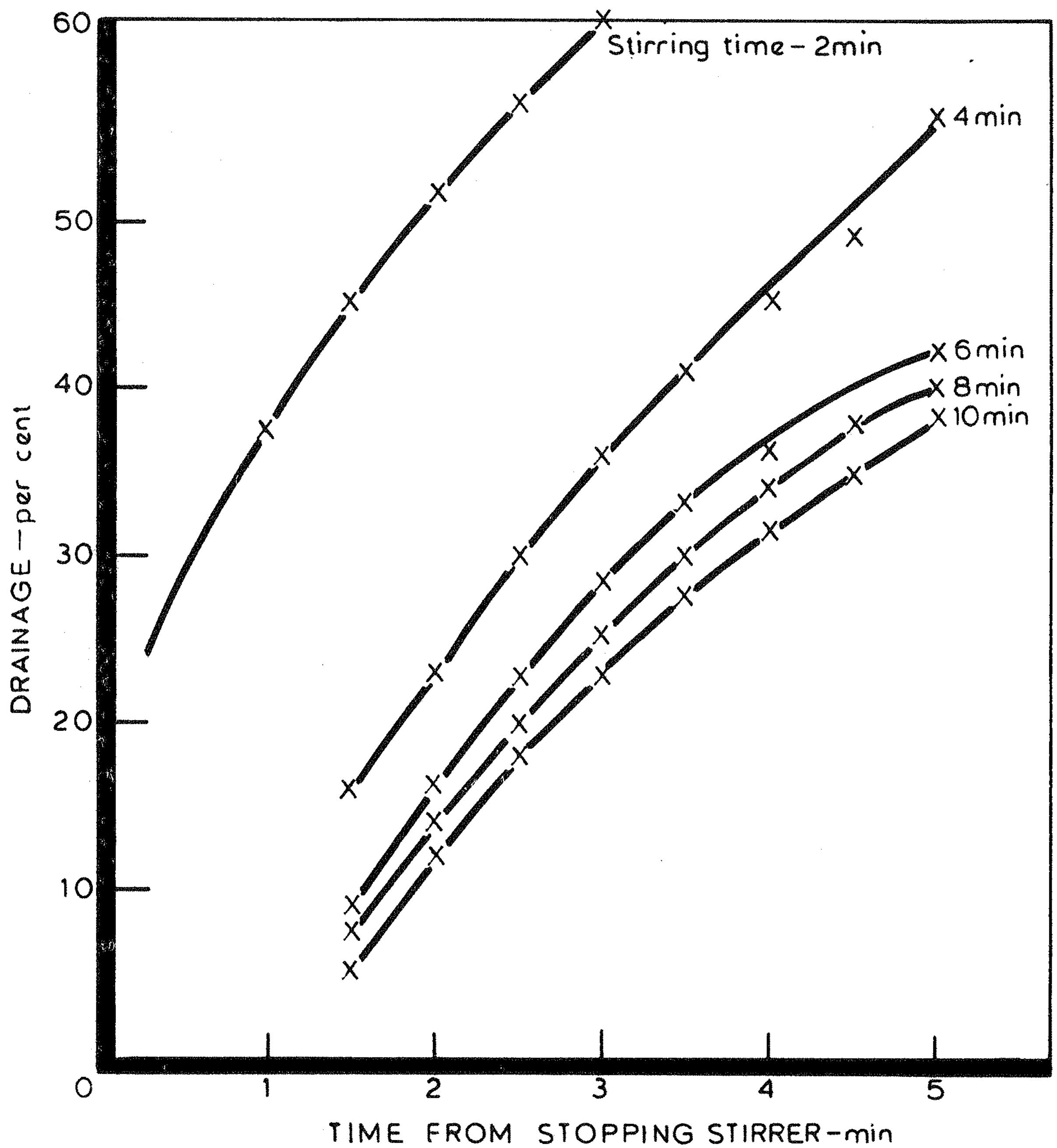
Expansion — 8 : 1

Stirring time–10 min / drainage 6 min / shear

Foam liquid—Protein without iron pH 7·85

Concentration–4 per cent vol / vol

FIG. 5 25 PER CENT DRAINAGE TIME AND CRITICAL SHEAR STRESS IN RELATION TO STIRRER SPEED



Stirrer – 9 x 2·4mm wires

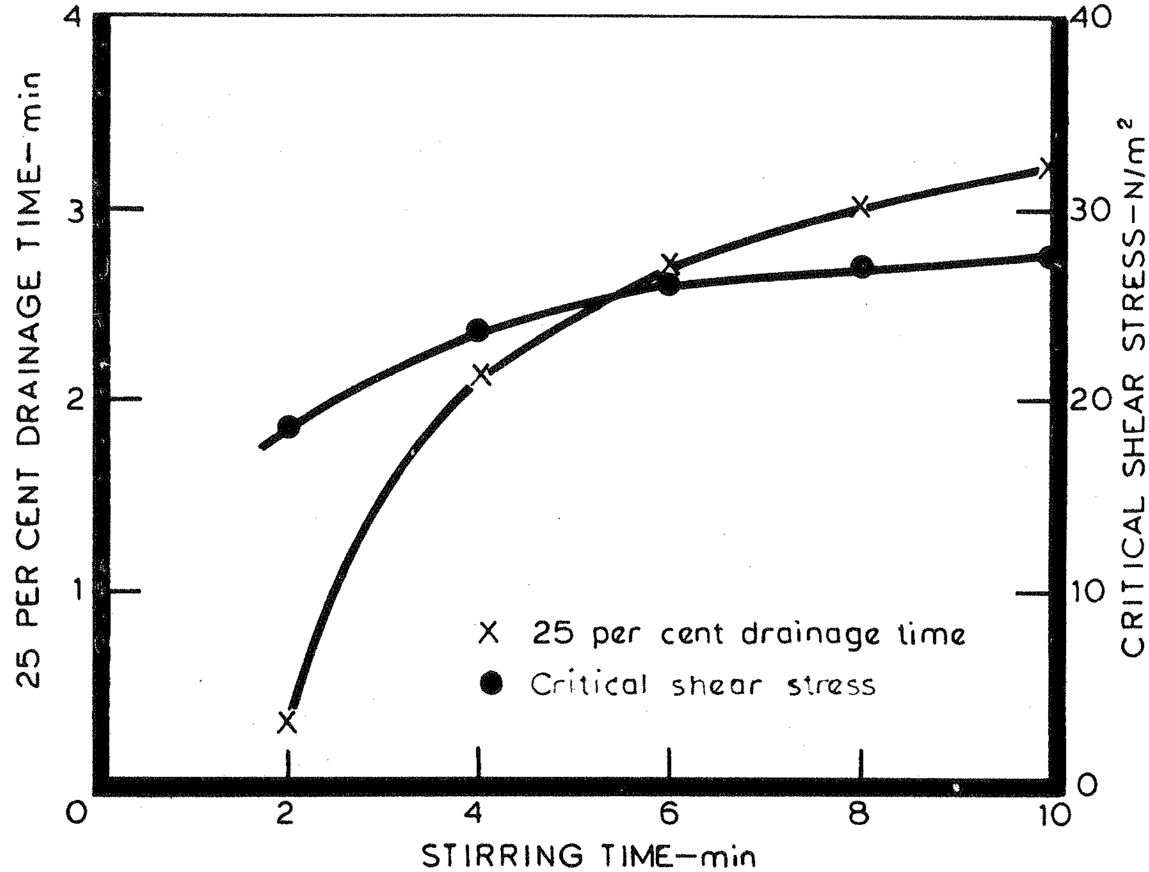
Expansion – 8 : 1 (100 mℓ)

Foam liquid – Protein without iron pH 7·85

Stirrer speed – 510 rev / min

Concentration – 4 per cent vol / vol

FIG. 6 PERCENTAGE DRAINAGE IN RELATION TO TIME FROM STOPPING STIRRER – VARIOUS STIRRING TIMES



Stirrer — 9 x 2·4 mm wires

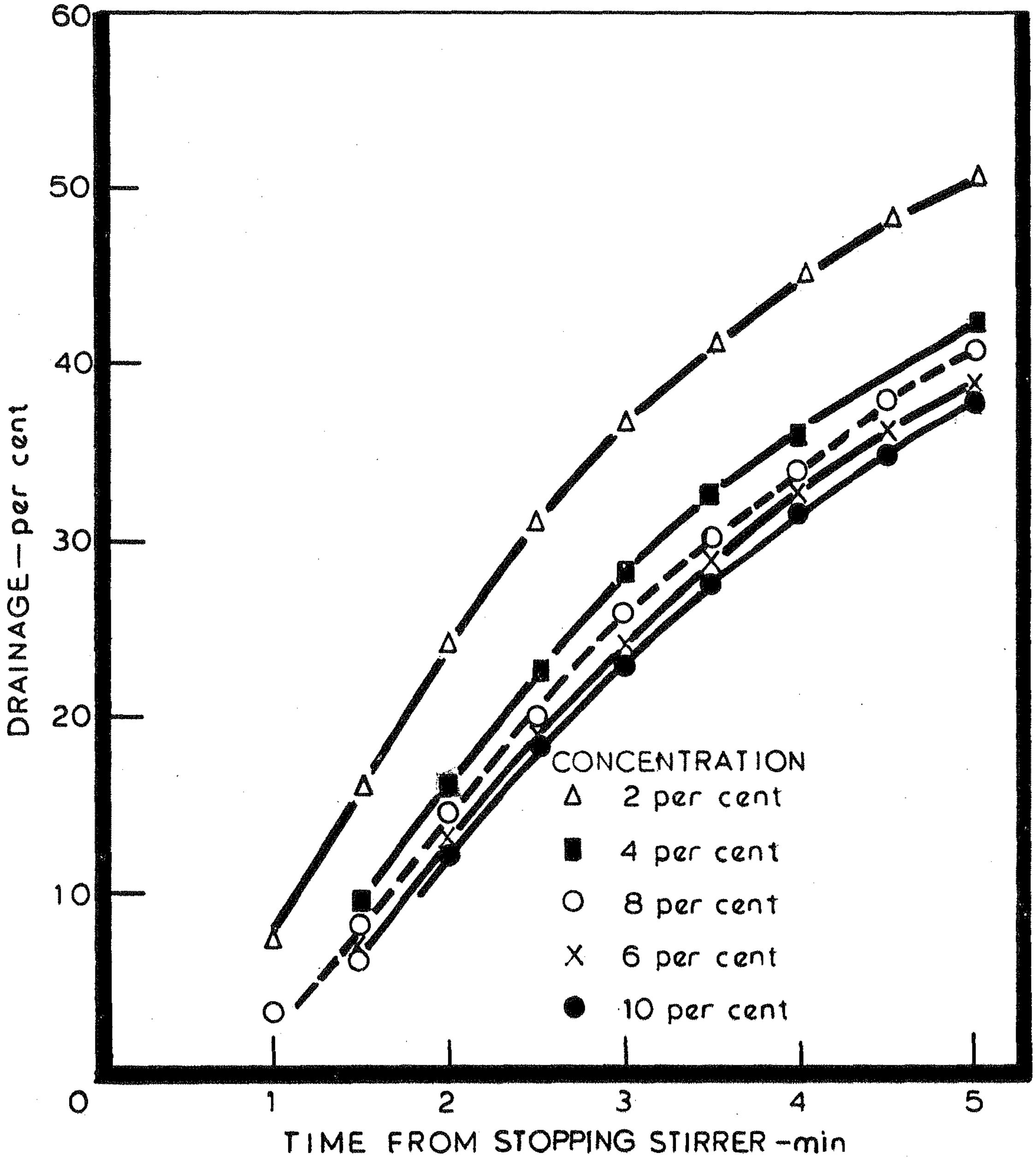
Expansion — 8 : 1

Speed — 510 rev/min

Foam liquid — Protein without iron pH 7·85

Concentration — 4 per cent vol/vol

FIG.7 25 PER CENT DRAINAGE TIME AND CRITICAL SHEAR STRESS IN RELATION TO STIRRING TIME



Stirrer — 9 x 2·4 mm wires

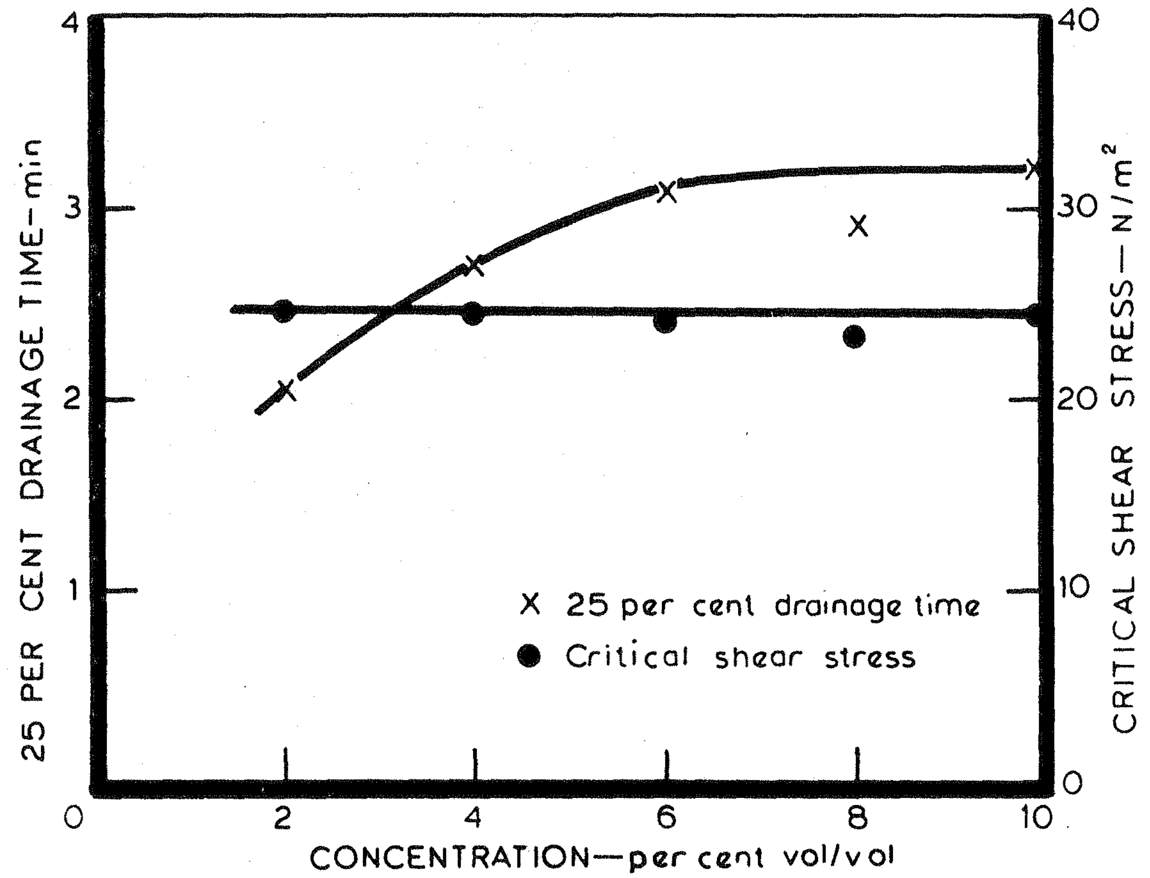
Expansion — 8:1 (100 mℓ)

Stirring time — 6 min

Foam liquid — Protein without iron pH 7·85

Speed — 510 rev/min

FIG. 8 PERCENTAGE DRAINAGE IN RELATION TO TIME FROM STOPPING STIRRER — VARIOUS CONCENTRATIONS



Stirrer– 9 x 2·4 mm wires

Expansion – 8:0

Stirring time – 6 min

Foam liquid – Protein without iron pH 7·85

Speed – 510 rev/min

FIG.9 25 PER CENT DRAINAGE TIME AND CRITICAL SHEAR STRESS IN RELATION TO CONCENTRATION

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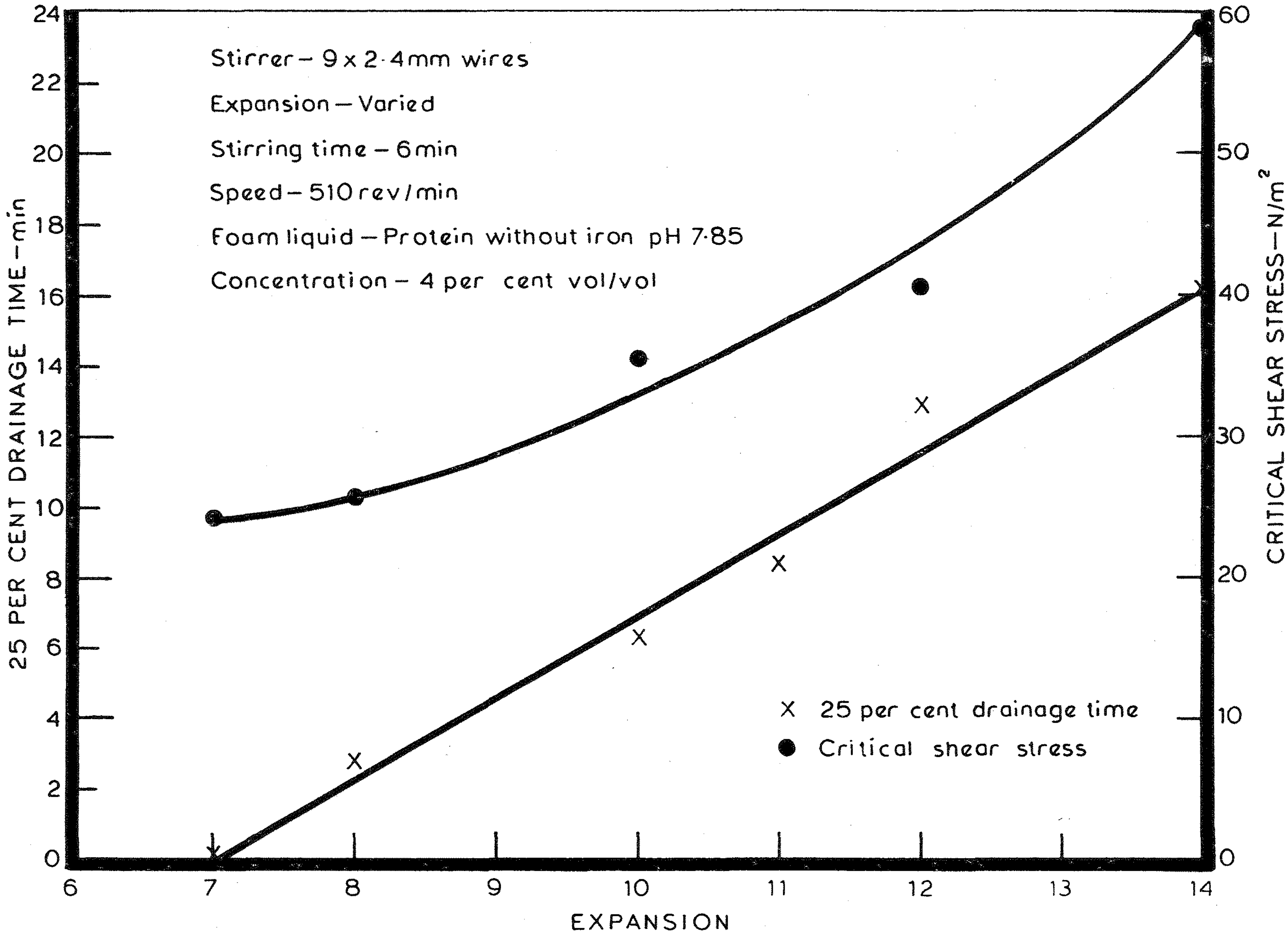
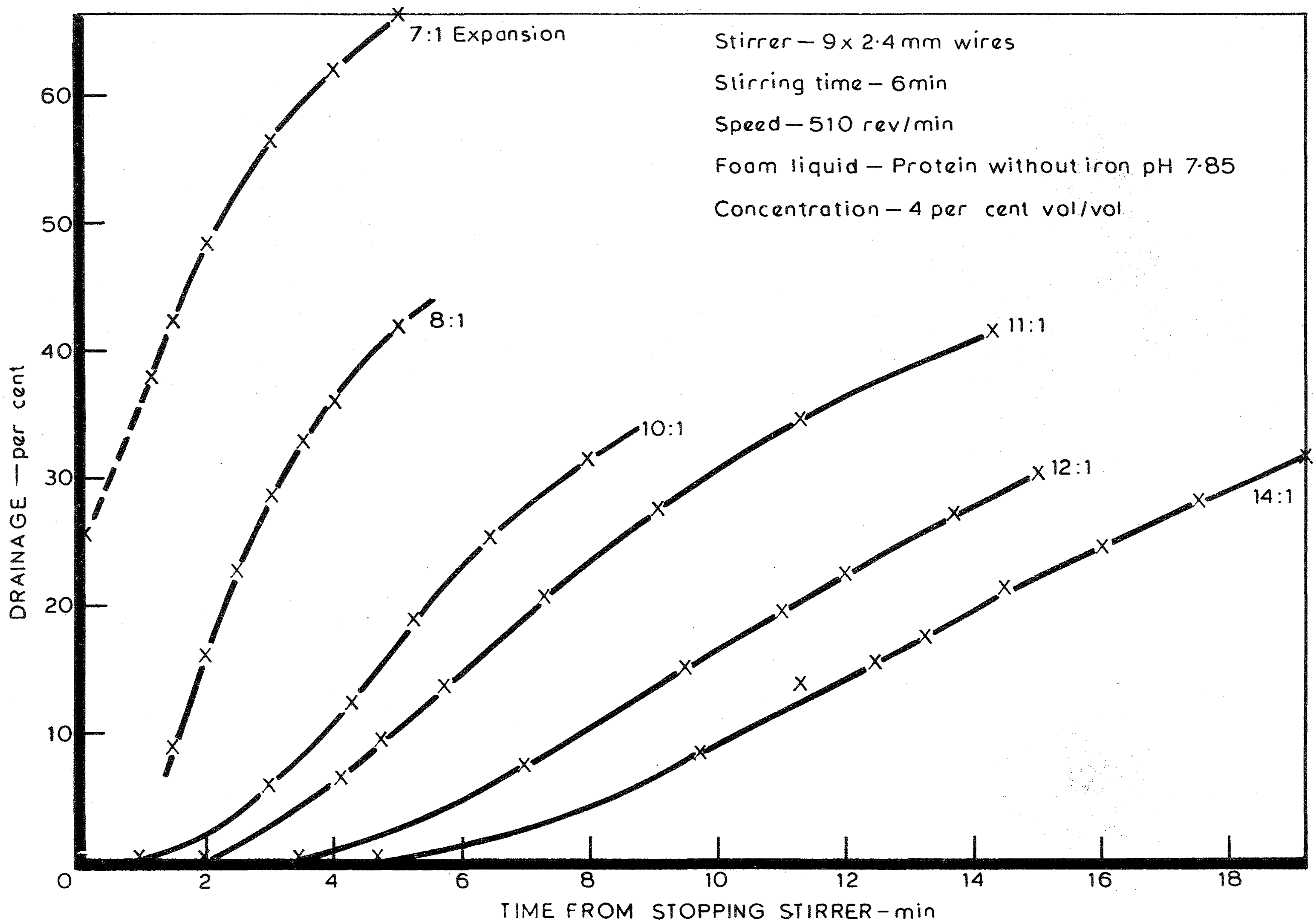
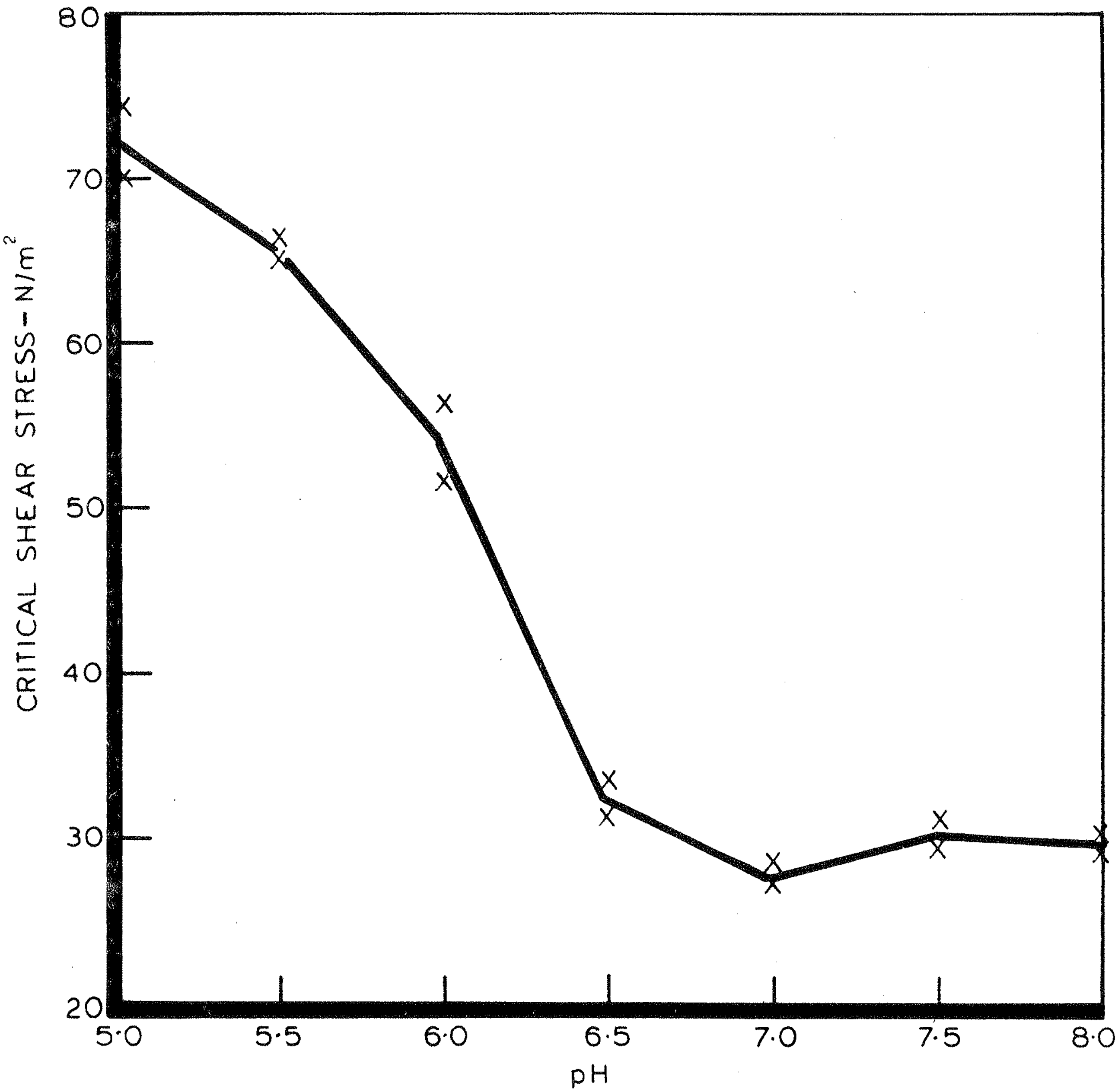


.10 25 PER CENT DRAINAGE TIME AND CRITICAL SHEAR STRESS IN RELATION TO EXPANSION



1 PERCENTAGE DRAINAGE IN RELATION TO TIME FROM STOPPING STIRRER — VARIOUS EXPANSION RATIOS



Stirrer — 9 x 2·4mm wires

Expansion — 8 : 1

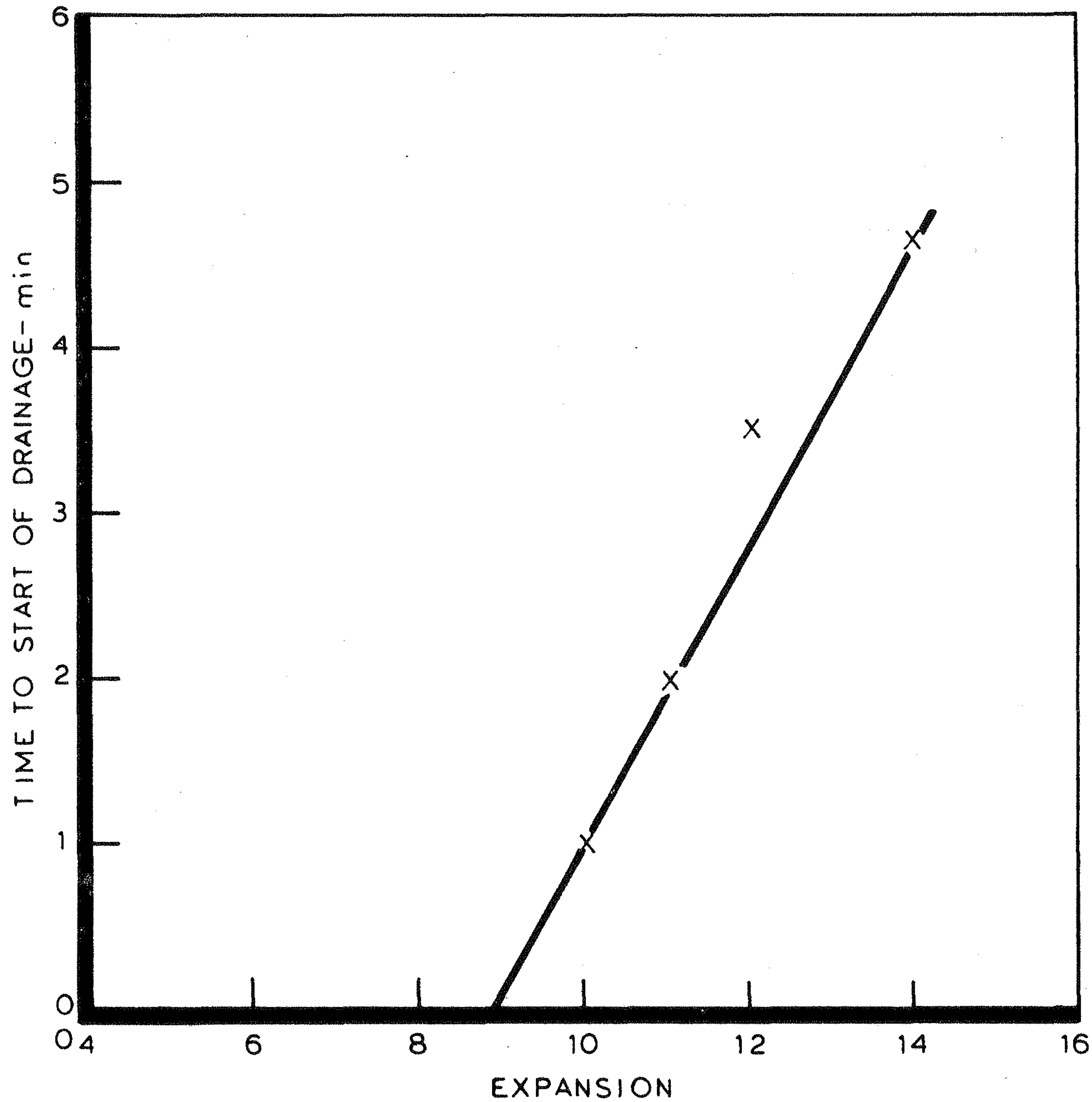
Stirring time – 6min

Speed – 680 rev/min

Foam liquid – Protein without iron (pH varied)

Concentration—4 per cent vol/vol

FIG.12 RELATIONSHIP BETWEEN CRITICAL SHEAR STRESS AND pH



Stirrer — 9 x 2·4 mm wires

Stirring time — 6 min

Speed — 510 rev/min

Foam liquid — Protein without iron pH 8·0

Concentration — 4 per cent vol/vol

FIG.13 RELATIONSHIP BETWEEN START OF DRAINAGE AND EXPANSION