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SOME ELECTRICAL PROPERTIES OF HIGH EXPANSION FOAM

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SUMMARY

The electrical resistance of foams has been measured as a function of expansion using simple conductivity cells which can also be used as expansion meters. The electrical shock hazard of medium and high expansion foam when used on fires involving live electrical equipment is assessed.

KEY WORDS: Foam, high expansion, electrical shock, expansion, measurement.

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INTRODUCTION

Knowledge of the electrical properties of foam is desirable from two points of view. Firstly, being a water-based extinguishing agent, foam may present an electrical shock hazard to personnel. This is particularly the case with high expansion and medium expansion foams, when these are used to fill compartments containing live electrical equipment and when personnel may be partially or totally immersed in the foam. Much is known of the hazard of plain water when used as jets or sprays and this information has been reviewed by O'Dogherty[1]. Secondly, a problem often exists with the measurement of foam expansion particularly with high expansion foam in full scale tests. A knowledge of the variation of electrical resistance of foam with expansion would enable expansion to be measured using a simple conductivity cell. This note describes the use of such a cell and measurements of foam resistance made with it.

THEORY

The current flowing through a conductor is given by the relationship

$$I = V \frac{A}{rL} \qquad \ldots. \ (1)$$

where I = current flowing (amps)
V = voltage applied across conductor (volts)
A = cross sectional area of conductor (cm^2)
L = length of conductor (cm)
r = specific resistance of conductor (ohm cm)
(specific conductance = $\frac{1}{r}$ mho cm^{-1})

In order to calculate the current flowing through a sample of foam, it is necessary to know the path length (L), the cross sectional area (A), and the specific resistance of the foam (r).

Safe values of I for human exposure have been discussed by O'Dogherty[1]. A value of 1 mA is generally regarded as the current that is just perceptible.

Safe values for continual exposure may be taken as high as 5 mA. The lower limit for fatal shock is said to be 50 mA. For fire fighting purposes, a safe level of current is generally taken to be that which is just perceptible, i.e. 1 mA although 3 mA has often been used. Ballas[4] considers a current of less than 10 mA, the current sufficient to prevent voluntary muscle movement, to be 'reasonably safe'.

There may be some difficulty in deciding the value of A. If the foam is in the form of a jet, e.g. low expansion foam used from a portable fire extinguisher, then A is the cross-sectional area of the jet. High expansion foam used to fill a compartment in which live electrical equipment is situated presents a different situation. If a person is partially or wholly immersed in the foam, then the choice of a value for A is not at all obvious. The surface area of the live equipment and the surface area of the skin of the person in contact with foam may not be known. An extreme case would be that in which A was taken to be the largest projected area of a man of average size, the area of the live equipment being assumed to be at least as large as this.

The specific resistance of foam (r_f) has been related to the specific resistance of the diluted foam solutions from which it is made (r_s) and the expansion (E) by Blackman[2]. Based on a dielectric analogy his expression is

$$\frac{r_f}{r_s} = R = E\left(\frac{3}{3-f}\right) - \frac{f}{3-f} \qquad \ldots . (2)$$

where f is a numerical factor.

Blackman suggested that for low expansion foams in which bubbles were in intimate contact, a value of $f = 1.5$ gave the best correlation. As expansion increased he suggested that from dielectric considerations f might approach unity.

PREVIOUS WORK

It is of interest to note values of specific resistance for various water supplies and diluted foam solutions (r_s) which have been published for various foam liquids. These are shown in Table 1.

Clark[3], using a conductivity cell containing 15 mm x 40 mm platinum electrodes spaced 20 mm apart measured the specific conductivities of five different foam solutions and foams made from these solutions at expansions up to

20. His results are summarised graphically in Fig.1. Also plotted on Fig.1 is the theoretical correlation of Blackman for $f = 1.5$.

Ballas[4] has made a study of electrical shock hazard of high expansion foam, using two synthetic foam liquids, one specially formulated to reduce electrical conductivity. With a full-size mannequin electrode and a live switch box of unspecified dimensions, the current flowing at an applied voltage of 440 volts AC, was measured for foams of expansion 500 at various electrode separation distances. The results of this work are summarised in Fig.4. The results for demineralised and fresh water based foam do not extend beyond a separation of 60 cm (approx. 2 ft). Calculation of the cross-sectional area of the current path from these results for demineralised and fresh water based foams assuming equation (1) holds shows that A increases almost linearly with L from about 100 cm^2 at $L = 2$ cm to 1250 cm^2 at $L = 50$ cm for fresh water foams and from 200 cm^2 at $L = 2$ cm to 2000 cm^2 at $L = 50$ cm for demineralised water foams. Over the same range of L, A for sea water foams is fairly constant at about 150 cm^2. Ballas's results would indicate, therefore, that A is a function of both L and r_f.

Alquier[5] reports that high expansion foam (expansion not stated) has a specific resistance of 14×10^6 ohm cm, whilst Achilles[6] reports a value of 1.28×10^6 ohm cm for foam of expansion 1000 made from a solution, the specific resistance of which is given in Table 1.

Savkov[7] reports that foam of expansion in the range 200 to 500 is safe with respect to a voltage of 6 kV and a separation distance of 3 m.

Alquier[5] and Spencer[8] have reported that electrical equipment of all kinds, motors, electronic equipment etc remains working satisfactorily with a minimum of damage when immersed in high expansion foam.

EXPERIMENTAL

An investigation has been made of the conductivities of diluted solutions of a synthetic foam liquid used for generating high expansion foam and the conductivities of samples of foam, over a wide range of expansion, made from these solutions. The concentration of foam liquid in this diluted foam solution was 1.5 per cent by volume.

The conductivity of the diluted foam solutions was measured using a conductivity cell containing two 5 mm x 6 mm platinum electrodes spaced 11 mm apart (Griffin and George type 575-915/005). This conductivity cell was also used to measure the conductivity of some foam samples at expansions of up to 30.

A special conductivity cell was constructed for measuring the conductivity of foam samples of expansions of up to 1330. This consisted of two square copper plates, 500 cm^2 in area, 1.2 mm thick fixed parallel to each other at a separation of 25 cm by attaching each plate at its centre point to opposite ends of a 12 mm diameter insulating rod of the appropriate length. This cell was used in conjunction with the conductivity bridge described above. Some measurements were made with a similar cell made from aluminium plates. Expansion was measured directly by weighing a known volume of foam. Foam was made using a number of different proprietary and experimental foam generators and branchpipes.

Cell constants for the three electrodes were measured using solutions of potassium chloride, in 'conductivity' water, of known concentration, the conductivity being calculated from published data. The experimental values of cell constant are shown in Figs 2 and 3.

RESULTS

Results obtained for foam of expansions up to 1330 using all three electrodes are shown, together with Clark's[3] results and Blackman's[2] prediction (with $f = 1.5$) in Fig.1. The values of K were calculated by:

$$K = \frac{r_f}{r_s} = \frac{R_S\ C_S}{R_F\ C_F}$$

where R is the conductivity bridge reading

C is the cell constant at that reading (from Fig.2 or 3)

S,F refer to diluted foam solution and foam respectively.

DISCUSSION

The measurements of K made using the Griffin conductivity cell for foam of expansions up to 20 are correlated well by Blackman's[2] theoretical prediction with a value of 1.5 for f, which was reported to have given the best correlation with Clark's[3] results. The theoretical prediction correlates Clark's results less well than it does the present measurements. The results for K using the large cells are higher than those obtained using the Griffin cell by a factor of 1.25 (at expansion 10) to 1.5 (at expansion 1000). Blackman predicted that at high expansion, $f = 1.0$, which would result in a greater divergence. Clearly the present measurements with the large cells do not bear out Blackman's prediction. The reason for this is not known but there may be some systematic error in the measurements. The results obtained in these preliminary experiments, as seen in Fig.1 are not adequately precise to form an accurate calibration for the large cells in their present form. The design of the cells can be improved, particularly by incorporating a 'guard ring' around one electrode. This would reduce any 'bulging' of the current path (due to edge effects) between the electrodes. Despite the present lack of precision in the measurements, it is clear that the technique of foam expansion measurements by electrical means can be extended to foams of expansions of the order of 1000.

Large conductivity cells of the type described made from copper plates have been used to give an indication of the variation of foam expansion with time at four different heights, up to 6 m (20 ft), above ground level in a series of full scale tests on the extinction of fires in racked goods by high expansion foam. Typical results have been published[9].

During these tests, screens were used to form a barrier against any foam overspill. The screens consisted of 2 m (6 ft) x 1 m (3 ft) asbestos panels bolted to a metal frame, somewhat smaller than the panels and mounted on nylon wheels, which were thus insulated from the floor. The screens were placed edge to edge but did not themselves form a continuous current path, the metal frames being separated by a gap of about 5 cm. During one test, when foam overspilled but was held back by the screens which were therefore in contact with the foam, it was noticed the metal of the screens was 'live'. Investigation showed that the foam overspill had also come into contact with a live 13 amp socket a few feet from the end of the row of screens. The foam had formed an electrically-conducting bridge between one screen and the next, and the presence of the screens had therefore considerably extended the distance over which a perceptible current flowed. Generally therefore, in a practical fire-fighting situation, the introduction of high (or medium) expansion foam into a compartment may connect a number of metal structures or fittings, not normally in electrical contact, into a continuous conducting path of resistance very much lower than that of an equivalent length of foam.

Although the specific resistance of foam may be known, the life hazard to personnel in contact with foam itself in contact with live electrical equipment cannot be reliably estimated because:

a) as discussed above, it is difficult to quantify A, the current cross-sectional area;

b) the normal process of liquid drainage in the foam will decrease the expansion (and therefore lower the resistance) of the lower levels of foam, i.e. at ground level where personnel are standing, and also collect on the floor forming an additional current path which may offer less resistance than the foam;

c) the presence of unearthed metal objects in the foam will reduce the effective resistance of the foam.

CONCLUSIONS

The electrical shock hazard when using medium or high expansion foam for filling compartments containing 'live' electrical equipment is greater than that arising from the use of plain water in the form of jets or sprays in a similar situation. In the latter case the electrical equipment will often be visible and steps can be taken to maintain a "safe distance"[1] from it. When the compartment is filled with foam, objects immersed in the foam cannot be seen and this, coupled with the points (a) to (c) outlined above, results in an unknown and unpredictable situation. Before personnel enter a foam-filled compartment it is essential that <u>all</u> electrical equipment in contact with foam be isolated.

Table 1

Published values of specific resistance (ohm cm) for various water supplies and diluted foam solutions

	Specific resistance (ohm cm)	Ref.
Various public water supplies	0.5×10^3 to 5×10^3	1
Sea water	20	
'Tap' water	2.48×10^3	6
1.5 per cent synthetic foam solution	1.15×10^3	
'Demineralised' water	384×10^3	4
'Fresh' water	6×10^3	
'Sea' water	24	
Synthetic foam liquid 'A' (specially formulated)	4.2×10^3	
Synthetic foam liquid 'B'	95	
2.0 per cent A in 'demineralised' water	9.5×10^3	
2.0 per cent A in 'fresh' water	4.9×10^3	
2.0 per cent A in 'sea' water	24	
2.0 per cent B in 'demineralised' water	1.15×10^3	
2.0 per cent B in 'fresh' water	0.85×10^3	
2.0 per cent B in 'sea' water	24	

REFERENCES

1. O'DOGHERTY, M. J. "The shock hazard associated with the extinction of fires involving electrical equipment". Fire Research Technical Paper No.13. HMSO 1965.

2. BLACKMAN, M. "The electrical resistance of foams". Home Office Civil Defence Research Committee, Sub-committee FRC(F) 121 July 1945.

3. CLARK, N. O. "The electrical conductivity of foam". Trans. Farad. Soc. 44 (302) (Parts 1 and 2) 13-15.

4. BALLAS, T. "Electric shock hazard studies of high expansion foam". Fire Technology 5 (1) 38 1969.

5. ALQUIER, J. "La mousse a grande expansion". Prot. Civile et Securité Indust. No.148 (1966) p.17.

6. ACHILLES, E. "Erfahrungen bei der verwendung von leichschaum". Z.V.F.D.B. 3/66 p.77.

7. SAVKOV, E. P. and VASILERON. "Highly expanded foam - an effective means of putting out fires". Booklet published in Moscow by publishers for Building Literature 1965, pp 48. NLL translation RTS 3755 (1967).

8. SPENCER, E. W. "The use of high expansion fire extinguishing foam on operating electronic equipment". M.I.T. Lincoln Laboratory Report A646 also reported in ASSE Journal Sept. 1964.

9. NASH, P., BRIDGE, N. W. and YOUNG, R. A. "The extinction of fires in storages of racked goods using high expansion foam". Fire Research Note 857 (1971).

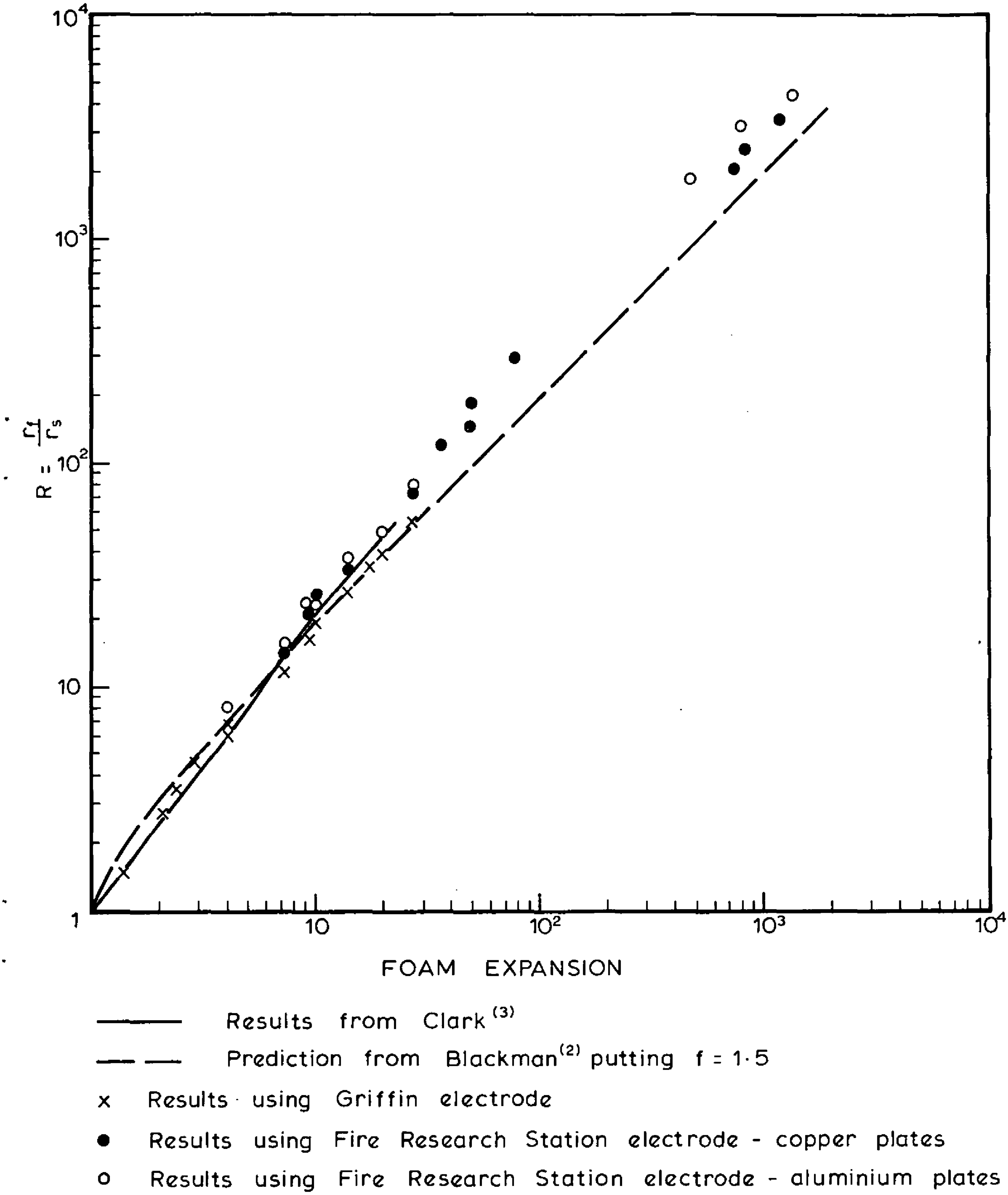

FIG. 1. VARIATION OF FOAM RESISTANCE WITH EXPANSION

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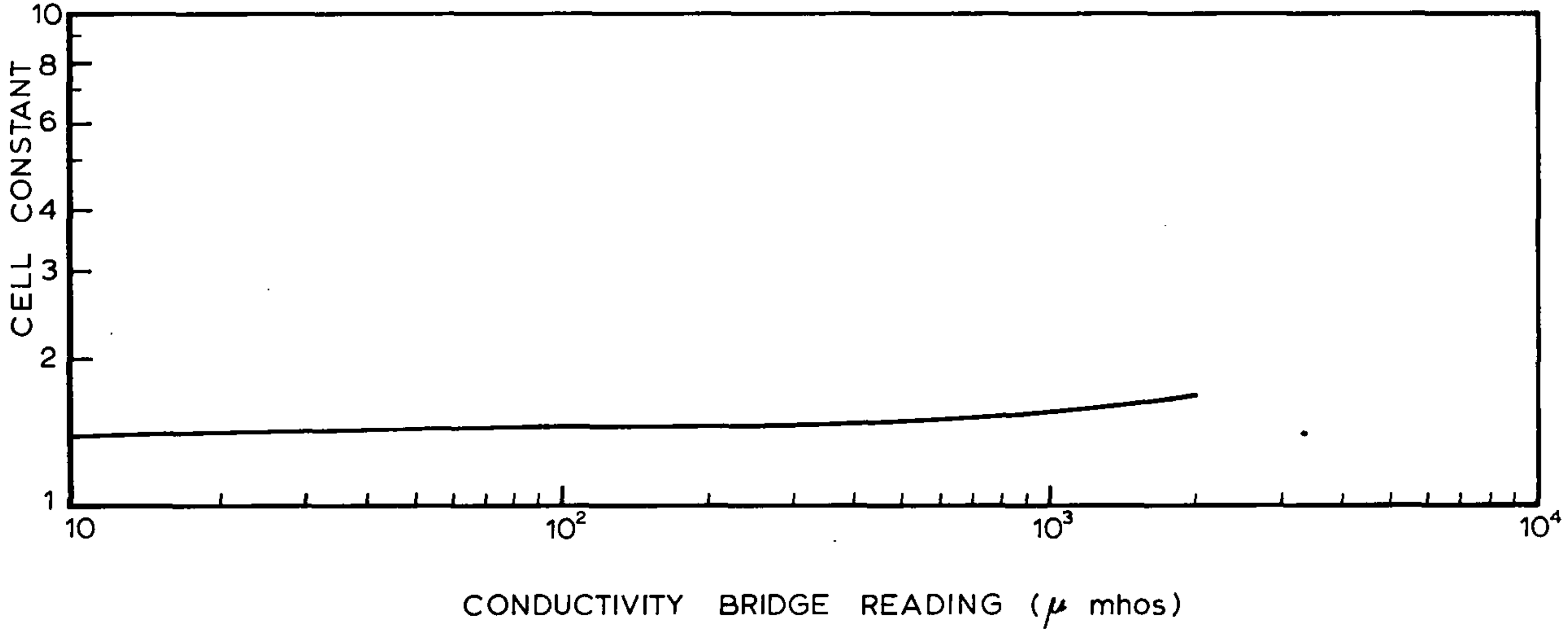

FIG. 2. EXPERIMENTAL CELL CONSTANT FOR GRIFFIN CONDUCTIVITY CELL

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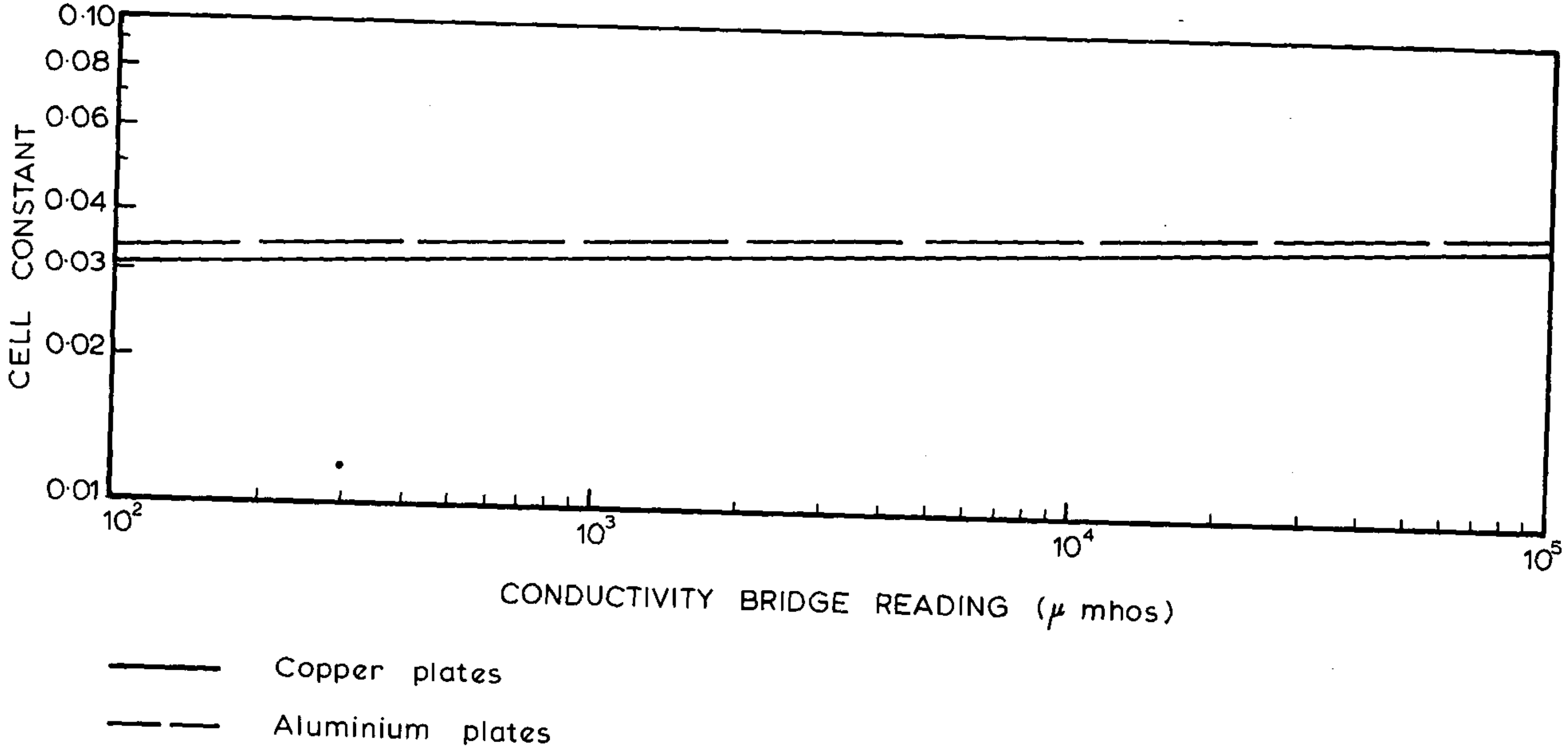

FIG. 3. EXPERIMENTAL CELL CONSTANTS FOR FIRE RESEARCH STATION CONDUCTIVITY CELL

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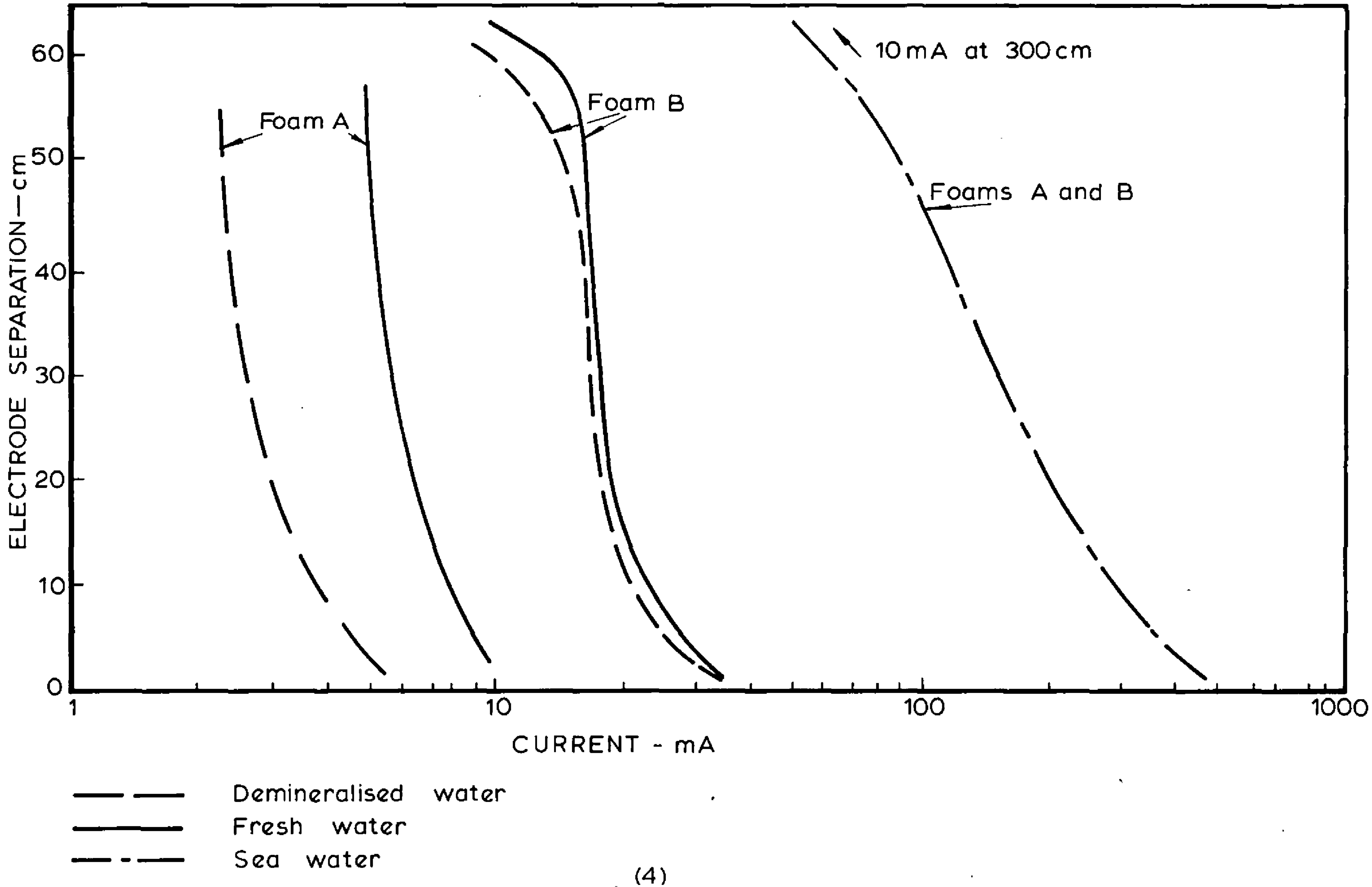

FIG. 4. DATA OBTAINED BY BALLAS(4) FOR FOAM OF EXPANSION 500 USING ELECTRODES FORMED BY A SWITCHBOX AND A METAL MANNEQUIN