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JOINT FIRE RESEARCH ORGANIZATION

REFLECTIVITY AND THE HEAT RESISTANCE OF FOAM

by

P. H. Thomas

Summary

Published data obtained for the heat resistance of protein foams of different expansions and critical shearing strengths are discussed in terms of the suggestion that the variation in heat resistance is due to variation in reflectivity. The data are shown to be not inconsistent with this view.

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Introduction

French has given data [1] for the time to destroy a given volume of foam by heat radiated on to it. It has since been shown that these data can be correlated with the product of expansion and shear strength [2], so that it is possible to regard the heat resistance relative to the amount of heat required to evaporate the water content of the foam as a function of the bubble wall thickness. No physical explanation of this was offered but it is discussed here as a consequence of the variations in absorption or reflectivity of foam resulting from changes in the foam properties.

Theory

Radiation is scattered (reflected and refracted) and absorbed by the liquid in foam. It is assumed that the radiation is scattered equally forward and back. An approximate result can be obtained very simply by regarding the radiation as consisting of two fluxes one forward 'F' and one backward 'B' in a semi-infinite medium.

Let α be the attenuation coefficient,
ω the albedo, i.e. the fraction scattered in an elementary volume. $1-\omega$ is the fraction absorbed.
and x the direction of the radiation normal to the boundary.

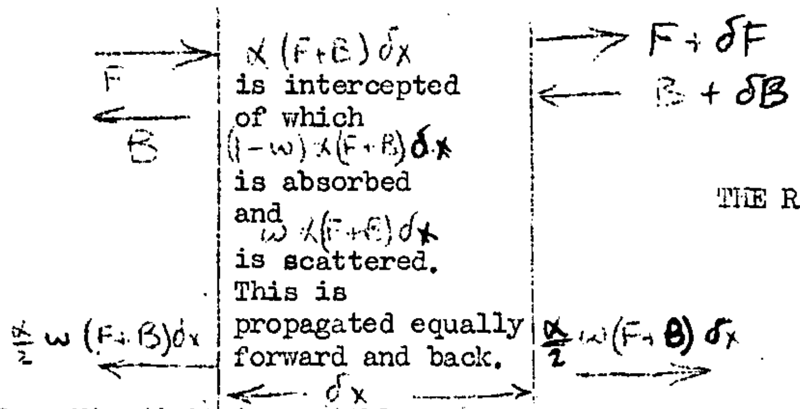

Fig. 1.
THE RADIATION BALANCE

From Fig. 1 it is possible to write

$$\frac{dF}{dx} = -\alpha F + \frac{\alpha\omega}{2}(F+B) \qquad \ldots\ldots (1)$$

$$\frac{dB}{dx} = \alpha B - \frac{\alpha\omega}{2}(F+B) \qquad \ldots\ldots (2)$$

i.e.

$$\frac{d^2F}{dx^2} = \alpha^2(1-\omega)F \qquad \ldots\ldots (3)$$

$$\frac{d^2B}{dx^2} = \alpha^2(1-\omega)B \qquad \ldots\ldots (4)$$

The boundary conditions are

$$F = 1 \quad \text{at } x = 0$$
$$F = 0 \quad \text{at } x = \infty$$

Hence from (3)

$$F = e^{-\alpha(1-\omega)^{1/2} x}$$

$$\frac{dF}{dx} = -\alpha(1-w)^{\frac{1}{2}} \exp —$$
$$\frac{d^2F}{dx^2} = \alpha^2(1-w) \exp —$$

We then can obtain the value of B by inserting the above expression for F into equation 1 from which

$$B = B_o e^{-\alpha(1-\omega)^{1/2} x}$$

$$B_o = \frac{2}{w} - 1 - (1-w)^{\frac{1}{2}}$$

where
$$B_o = \frac{1 - \sqrt{1-\omega}}{1 + \sqrt{1-\omega}} \qquad \ldots\ldots (5)$$

B_o is the reflectivity of the foam.

The heat resistance h relative to unit water content is inversely proportional to the absorption of the foam i.e.

$$h = \frac{1}{A}$$

where
$$A = 1 - B_o$$

i.e. from equation 5

$$h = \frac{1}{2}\left(1 + \frac{1}{\sqrt{1-\omega}}\right) \qquad \ldots\ldots (6)$$

It is now necessary to calculate ω in terms of the foam properties.

<u>The calculation of ω</u>

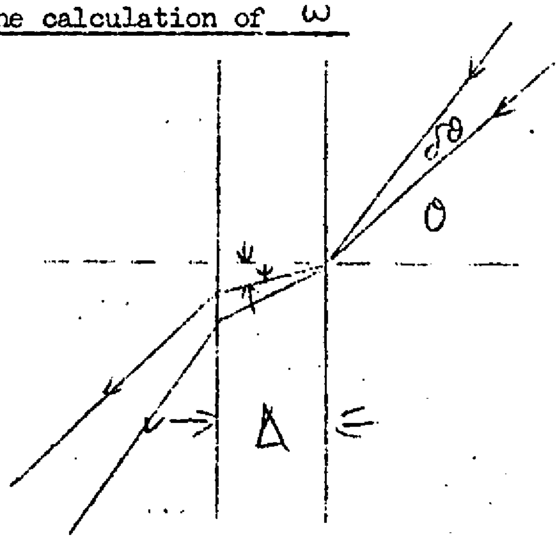

Fig. 2.
TRANSMISSION THROUGH BUBBLE WALL

A pencil of radiation making θ with the normal to a layer of liquid has a path length $\Delta \sec \psi$ where Δ is the thickness of the liquid layer and ψ the angle of refraction (see Fig. 2). The fraction transmitted is therefore $\mu\ \Delta \sec \psi$ where μ is the absorption coefficient. The radiation is assumed to be isotropic so that the same relations hold for all orientations of the liquid layer. The fraction in the elementary cone $d\theta$ is $\sin\theta\ d\theta$ and the mean fraction absorbed is therefore

$$1 - \omega = \int_0^{90} \left(1 - e^{-\mu \Delta \sec \psi}\right) \sin\theta\, d\theta$$

Since $\int_0^{90} \sin\theta\, d\theta$ is unity we have

$$\omega = \int_0^{90} e^{-\mu \Delta \sec \psi} \sin\theta\, d\theta \quad \text{......} \ (7)$$

We have the refractive index

$$\frac{\sin\theta}{\sin\psi} = 1.33$$

ω is found as a function of $\mu\Delta$ by numerical integration. It is then possible to compute A in terms of $\mu\Delta$ and this is shown in Fig. 3.

We have also
$$\Delta = \frac{2}{ES} \quad \text{......} \ (8)$$

where E = expansion
S = specific surface $\quad cm^{-1}$

Clarke (3) gives the relation

$$2aS = q_c$$

where q_c is critical shearing stress
and a is a constant for any one foam liquid and of dimensions dyne/cm.

Hence from equation 8
$$\Delta = \frac{4a}{E q_c} \quad \text{......} \ (9)$$

A value for a of 3 dynes/cm is given for hydrolised keratin foam by Clark (3) and this value is assumed for the foam used in these experiments.

Computation and results

From equations 6, 7 and 9 the heat resistance h has been formally obtained in terms of μ the absorption coefficient and the product Eq_c. However, the dependence of h on μ means that a mean absorption must be calculated to allow for the spectrum of the incident radiation. This has been assumed to be characteristic of a black body at 1,100°K. The actual heat resistance has been calculated from the mean absorption $\bar{A}$ by

$$\frac{1}{h} = \bar{A} = \int_0^{\infty} A\, f(\lambda)\, d\lambda$$

where $f(\lambda)d\lambda$ is the fraction of the total radiation between wavelengths λ & $\lambda + d\lambda$

For any one value of Eq_c, Δ is calculated from equation 9 and with values of μ for water, obtained from the International Critical Tables and values of $f(\lambda)$, k was obtained from equation 10 and Fig. 3. The result of the computation is shown in Fig. 4 together with the experimental data. The results which appear to be anomalous (2) in terms of a single correlation between k and Eq_c are excluded here.

Discussion

It is seen that in the region of large values of Eq_c, where drainage can be disregarded as a factor responsible for lowering the heat resistance (and in fact giving values less than unity for $Eq_c < 6000$) the calculated line is below the actual results and appears to have a less steep slope. The data on the absorption of water that has been used is by no means adequate for this purpose and the value of α is an assumed value. A smaller value of this property would have the effect of shortening the scale of Eq_c i.e. of raising and steepening the calculated line.

On the other hand it must be said that the theoretical model is subject to two principal errors. By neglecting side scattering it overestimates the value of k. Equating the forward and back scattering instead of taking into account the greater value of the forward scattering also affects the value of α. The magnitude of these effects cannot be readily ascertained without a more detailed analysis.

It is not possible to be certain that all the observed variation in heat resistance is a result of changes in reflectivity but the calculations show that there are reasonable grounds for thinking so.

References

(1) "The resistance of fire-fighting foams to destruction by radiant heat". FRENCH, R. J. J. App. Chem. 2, 1952, 60.

(2) "A note on the resistance of foam to radiant heat". THOMAS, P. H. F.R. Note 173/55.

(3) "A study of mechanically produced foams for combating petrol fires". CLARK, N. O. H.M.S.O. 1947.

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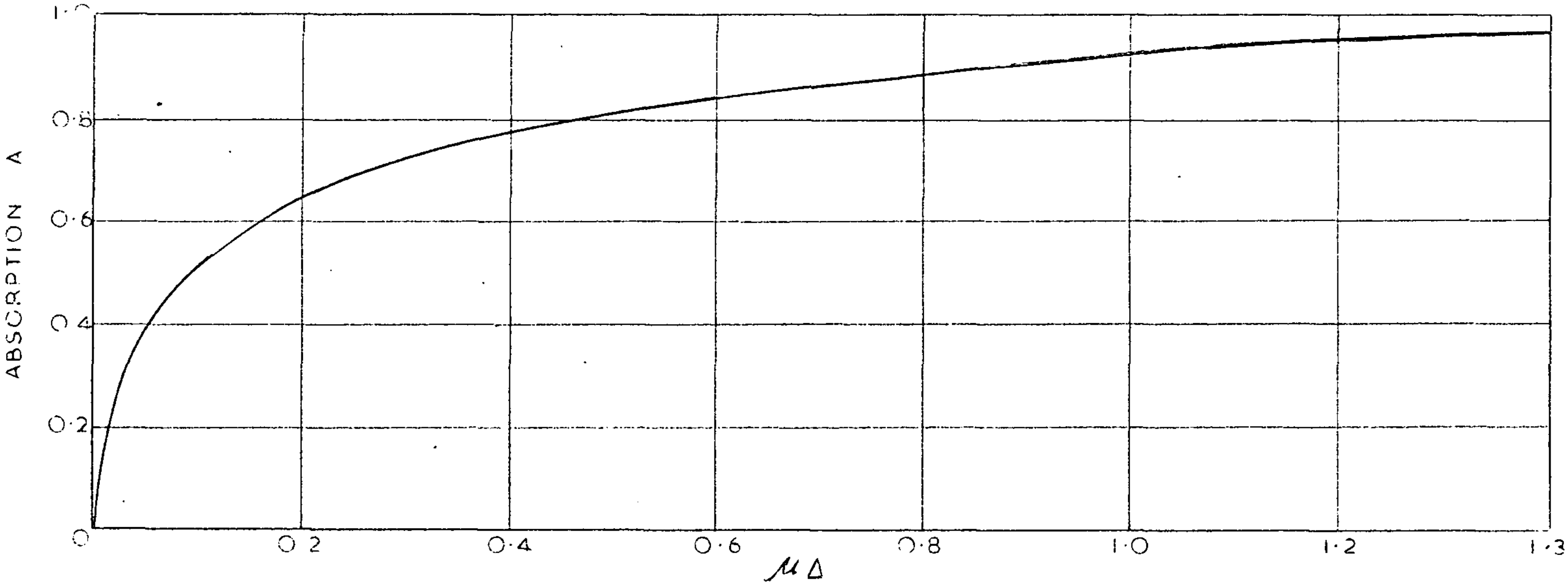

FIG. 3. ABSORPTION OF FOAM AS A FUNCTION OF $\mu\Delta$

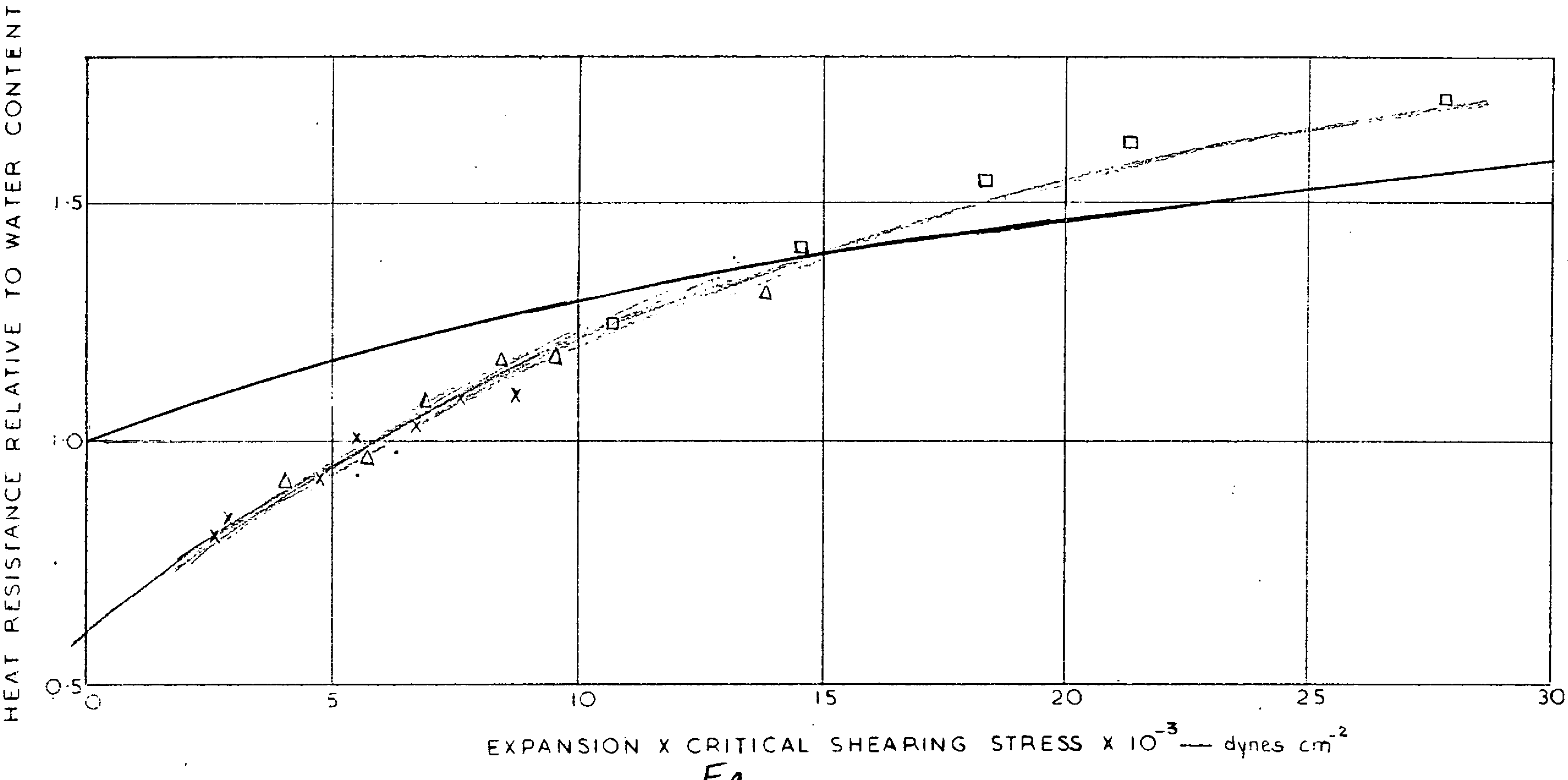

FIG 4 THE HEAT RESISTANCE OF FOAM OF DIFFERENT SHEAR STRENGTH AND EXPANSION