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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

A METHOD FOR CLASSIFYING THE FIRE HAZARD OF INTERNAL LININGS AND THEIR TREATMENTS

by

D. Hird and G. C. Karas

SUMMARY

Experimental work on the fire hazard of internal linings showed that the tests available do not give sufficient scope for recommendations to be made on the use of internal linings in any situation. This paper describes a test to do this and suggests that it might replace the surface spread of flame test of B.S. 476.

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Fire Research Station,
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Herts.

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INTRODUCTION

The main hazard associated with the use of combustible materials in buildings is where large areas are used as internal linings for walls and ceilings. This hazard does not only depend on the nature of the linings themselves but also on the nature and amount of other combustible materials in the building. Full-scale tests (1) carried out by the Building Research Station and the Joint Fire Research Organization on furnished living rooms showed that under certain conditions a fire would develop slowly in a room lined with an incombustible material and very rapidly in a room lined with certain types of combustible material. In similar tests (2) at the U.S. Forest Products Laboratory where the arrangements of the combustibles was such as to enable an initial fire in the furniture to develop rapidly, the difference between the combustible and noncombustible linings was small.

To make a full assessment of the fire hazard of different linings it is necessary to know how they will affect the growth of fire under a complete range of conditions, and those selected for the full-scale tests at the Joint Fire Research Organization are those likely to show up differences in the whole range of materials from the most **flammable** to noncombustible (and these are representative of the conditions in many modern dwellings and offices.) The development of a technique whereby small-scale models could be used to simulate the growth of fire in a room enabled the performance of a variety of materials to be studied under such conditions (3). The relation between the large and small-scale results was such that the results of the small-scale tests could be used with confidence in a comparison of the effects of different internal linings on the growth of fire. The criterion chosen to make this comparison was the time taken for the room to become fully involved in fire (time to flash-over) when walls and ceilings were lined with the material. The time taken for the fire to reach this stage would govern the time available for escape for occupants in other parts of the building.

The results of a suitable test for internal linings should be capable of correlation with the actual fire performance of the tested materials under a variety of different conditions. It was considered that if the results of any test could be correlated with those obtained from the model rooms, they would furnish sufficient scope for recommendations on the use of internal linings in any situation.

Many tests have been designed to assess the fire hazard of internal linings and the best known in this country is the surface spread of flame test of B.S. 476 [4]. It was found that this test classified in one group, materials which could have a wide range of performances under fire conditions[3], and that this could not be overcome by any regrouping. Of the other tests in existence, only the Tunnel test of the Underwriters' Laboratories appeared to have a range which would allow a correlation with the results obtained using model rooms. This test is however very cumbersome, requiring a specimen 25 ft long and 20 in. wide[5].

It was decided therefore to develop a suitable test based on the following assumptions:-

1) The most important hazard to be assessed is the ability of a material, when used as an internal lining, to accelerate the growth of fires. The test should also show which materials can be ignited by a small flame and will easily cause a continuous fire.

2) The combustible content of the material is only important in so far as it accelerates this growth; any contribution to the fire load is likely to be small compared with that of the floor and contents.

3) The smoke conditions in a building are likely to depend much more on the degree of ventilation than the nature of the lining material.

4) The test should, if possible, be a simple one which manufacturers could use in the development of products.

It was considered that a satisfactory test could be evolved by a suitable assessment of three factors:-

(a) The ease of ignition of the lining by a small flame.

(b) The ease of ignition of the lining by a larger source of heat.

(c) The rate of liberation of heat after ignition of the lining together with a measure of the total amount of heat liberated.

THE TEST

For ease of control it was decided that the main source of heat should be electrical, but practical considerations necessitated the use of small gas flames for the small igniting source. It was considered that the rate of liberation of heat could best be assessed by measuring the temperature of the flue gases when the specimen was heated in an enclosure. These considerations governed the form of the test and left a number of variables, the two most important being the rate of heating of the specimen and the ventilation to the enclosure. The final test conditions and criteria chosen and described in this paper were those which enabled a good correlation to be made between the performance of a range of materials on the test and their performance when used as linings in the model room experiments (Table 1).

GENERAL DESCRIPTION

A panel of the material is used as a vertical wall of a small incombustible enclosure, a chimney is incorporated in the roof of this enclosure and a slit for ventilation is cut in the bottom of the vertical wall opposite the specimen (Figs 1, 2, 3). Inside the box are two pencil type electric fire elements and a small battery of gas jets. The gas jets simulate a small source of ignition and later supporting radiation is supplied from the electric elements at a constant rate. A pair of thermocouples in the chimney record the rise in temperature of the flue gases. The temperature/time curve obtained is related to that resulting when a prescribed incombustible material replaces the specimen. These relations are used as criteria to classify the material. A detailed description is given in Appendix I.

PROCEDURE

The specimen to be tested is pressed up as indicated (Appendix I), the gas is ignited and the flames impinge on the sample. Three minutes later the elements are switched on and the power controlled to 1500 watts, i.e. 750 watts per element. The experiment is continued for 20 minutes after the ignition of the gas and a continuous temperature/time record is taken, this is compared with that obtained using a prescribed incombustible specimen which is $\frac{3}{8}$-in thick asbestos wood.

RESULTS AND CRITERIA

The materials shown in Table 1 were tested with the exception of impregnated hardboard, which was unobtainable at the specific salt retention:

in addition, a sample of fibre insulating board impregnated with monammonium phosphate to 19 per cent salt retention was tested though no model room tests had been carried out on this material. Three samples of each specimen were investigated and representative temperature/time curves are plotted in Figs 4, 5, 6, 7. All specimens were conditioned at 20°C and 56 per cent relative humidity. The repeatability of the apparatus was found to be good and Figs 8 and 9, give an indication of this. The results when plotted fall into several general patterns and Figs 4, 5, 6, 7, 10 show that criteria of classification can be inferred from these patterns, which will give an order of hazard similar to that obtained in the model rooms. The factors considered are firstly the time taken to exceed the temperature θ, attained with the incombustible material, by 50°C and secondly the time for which this excess is maintained (the excess denoted by $> (\theta + 50)$). The classification is given in Table 2 and diagrammatically in Fig. 11. Class A being the highest classification.

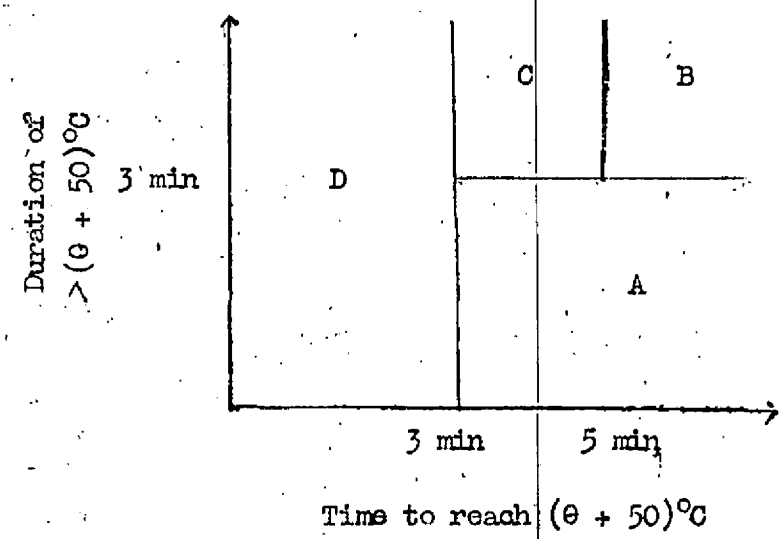

FIG. 11. DIAGRAM OF CLASSIFICATION

Class D can be considered separately from the other classes, and indicates materials which can be ignited by a small source, irrespective of any contribution they may make to a fire. In the other three classes the contribution to the fire is taken as the most important criterion, and a subdivision is made to give Classes B and C by consideration of the time to ignition. It can be seen from Fig. 11 that it is possible to move from any class to Class A without going through the intermediate classes by, in some materials (Class D), increasing the time for ignition or in others (Classes B & C reducing the period over which the materials evolve heat.

TABLE 2

PROPOSED CLASSIFICATION OF BUILDING BOARDS

Class	Criteria
Class A	Reaches $(\theta+50)^{\circ}C$ in more than 3 min and remains $>(\theta+50)^{\circ}C$ for less than 3 min
Class B	Reaches $(\theta+50)^{\circ}C$ in more than 5 min and remains $>(\theta+50)^{\circ}C$ for more than 3 min
Class C	Reaches $(\theta+50)^{\circ}C$ between 3 and 5 min and remains $>(\theta+50)^{\circ}C$ for more than 3 min
Class D	Reaches $(\theta+50)^{\circ}C$ in less than 3 min

Table 3 indicates how each specimen falls into the proposed classification and compares these with the results given in Table 1. Table 4 and Figs 8 and 9 show the variation obtained in the results.

DISCUSSION OF RESULTS

The fact that variation in the thermal properties of the specimen can make slight differences to the temperature of the flue gases before ignition of the specimen (Appendix II), makes this test unsuitable for the determination of the contribution made by materials to a fire, if this contribution is small; hence the test could not replace the present combustibility test.

CONCLUSIONS

The test described permits the grading of a complete range of materials in relation to their performance under practical fire conditions. Though the relative importance of internal linings and furnishings in the development of a fire will vary under different conditions, the order of hazard indicated by the test will remain the same, the time scale only varying.

The test should therefore furnish sufficient scope for recommendations on the use of internal linings in any situation.

APPENDIX I

DETAILED DESCRIPTION OF TEST

Figs 1, 2 and 3 are detailed dimensional drawings of the apparatus. Plates 1 and 2 give a general view of the front and rear. The apparatus is made of $\frac{1}{2}$-in. asbestos wood of thermal conductivity not exceeding 5.12×10^{-4}

C.G.S. units. The whole is maintained rigid by means of a metal frame of 20 s.w.g. mild steel. A small mica window is inserted for observation purposes.

Two electric fire elements, maximum rating 1000 watts, wound with nickel chromium wire 26 s.w.g., at 24 turns per inch on a $\frac{1}{2}$-in. diameter refractory former to 53 ohms resistance cold, are inserted, and connected to a variable voltage source and the power adjusted to 1500 watts throughout the test. A horizontal gas burner is mounted $\frac{1}{8}$ in. away from the specimen to play 14 small flames onto the panel. The holes are $^1/_{16}$-in. diameter and town gas, calorific value stated to be approximately 490 B.t.u./ft^3 (4.45 cal/cm^3) is supplied at a rate of 0.063 ft^3/min (1.77 l./min).

Fig. 2 gives a detailed drawing of the chimney. This is of 20 s.w.g. sheet iron. Two 26 s.w.g. chromel alumel thermocouples are inserted in the positions shown. In order to obtain an average the thermocouples are connected in series.

The backing of the specimens consists of one sheet of $\frac{3}{8}$-in. asbestos wood and a 2-in. slab of cement fondu and vermiculite in ratio 1 to 4 by volume. It was found that a good seal was necessary to prevent leaks from the box. The method used was to press the specimen and the asbestos wood together against the gap by means of metal angles (Plate 2) and to back these with the vermiculite held tightly against them.

APPENDIX II

The effect of the thermal properties of different specimens on the heat losses from the box and consequently the flue gas temperatures, is discussed and a number of comments on other features of the test are made.

INCOMBUSTIBLES AND SPECIMENS BEFORE IGNITION

The temperatures in the chimney are a measure of the difference between the heat supplied by the electric and gas heaters and that lost by conduction through the board and the box.

If a constant flux of heat Q is assumed to fall on the surface and an amount H θ_1 is lost from the surface, then assuming the specimen to behave as a semi-infinite slab for a time τ then at an instant t, where $t < \tau$ the heat conducted to the interior of the sample (q) is given by [(6)]:-

$$q = Q\, e^{h^2 kt}\, \mathrm{erfc}\, h\sqrt{kt} \qquad (1)$$

where

$$h = \frac{H}{K}$$

$$k = \frac{K}{\rho s}$$

K = thermal conductivity

ρ = density

s = specific heat

H = cooling coefficient

Writing $h^2kt = \frac{H^2t}{K\rho s} = A$ and considering different $K\rho s$ values, the difference in chimney temperatures for two materials for any instant t is given by:-

$$\theta_1 - \theta_2 \propto e^{A_2^2} \operatorname{erfc} A_2 - e^{A_1^2} \operatorname{erfc} A_1 \qquad (2)$$

From equation (2) it is possible to derive the difference in temperature between that obtained using asbestos wood and that which would be obtained with a perfectly insulating material $\left(K\rho s = 0 \text{ i.e. } e^{A^2} \operatorname{erfc} A = 0 \right)$

$$\frac{\theta_M - \theta_S}{\theta_O - \theta_S} = \frac{e^{A_S^2} \operatorname{erfc} A_S - e^{A_M^2} \operatorname{erfc} A_M}{e^{A_S^2} \operatorname{erfc} A_S} \qquad (3)$$

where the suffixes M, S, O, refer to any material, asbestos wood and the hypothetical material respectively.

If $\phi = \theta_M - \theta_S$ and $\phi_O = \theta_O - \theta_S$

then

$$\phi_O = \frac{\phi \, e^{A_S^2} \operatorname{erfc} A_S}{e^{A_S^2} \operatorname{erfc} A_S - e^{A_M^2} \operatorname{erfc} A_M} \qquad (4)$$

Using values of ϕ obtained experimentally with fibre glass having $K\rho s = 3.2 \times 10^{-6}$ C.G.S. units gives a value of $\phi_O = 35°C$ for a perfectly insulating material.

This means that although incombustible materials with a low $K\rho s$ value will give flue temperatures above that for asbestos wood, they will not result in a misclassification of incombustible materials. This is borne out by the results for a number of materials covering a wide range of $K\rho s$ values (Fig. 12).

AFTER IGNITION OF THE SPECIMEN

The temperature of the face of the specimen can be considered constant after ignition, and although the heat losses by conduction will depend on the thermal properties of both specimen and lagging, their effect on the flue gas temperature will be small compared with the contribution from the test sample.

GENERAL COMMENTS

The time for which the flue gas temperature is more than 50°C above the time-temperature curve obtained with the incombustible material was chosen as the simplest method of classification. The area between the time-temperature curve of a specimen and that of the standard incombustible material should give a better indication of the contribution the material makes to a fire.

It was found necessary to brush the thermocouples after each test to prevent an accumulation of soot.

ACKNOWLEDGEMENTS

The authors are indebted to Mr. D. I. Lawson for suggestions on the form of the test, and to Dr. P. H. Thomas, Mr. H. G. Wraight and Mr. C. F. Fischl all of whom have been connected with the work.

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TABLE 1

PARTICULARS AND RESULTS OF BOARDS TESTED IN FULLY-LINED MODEL ROOMS

Particulars of linings	Classification on spread of flame test of B.S. 476	Mean time for all rooms to become involved in fires min	sec
Incombustible		17	10
Fibre insulating board with 3/16-in. skim plaster coat	Class 1	17	45
Woodwool	Class 1	16	45
Plasterboard	Class 1	16	35
Hardboard impregnated with mon-ammonium phosphate (Retention of salt stated to be 17-18% by weight)	Class 1	15	45
Hardboard with surface treatment of Paint* A (30 g/ft²)	Class 1	13	30
Fibre insulating board with surface treatment of paint A* (30 g/ft²)	Class 1	10	35
Asbestos paper faced fibre insulating board	Class 1	10	30
Fibre insulating board with surface treatment of paint A* (15 g/ft²)	Class 1	9	25
Fibre insulating board with surface treatment of silicate paint	(Class 2-3 (Borderline)	7	45
Fibre insulating board with 2 coats of distemper	Class 3	6	00
Untreated hardboard	Class 3	6	15
Compressed straw slabs	Class 3	5	45
Untreated fibre insulating board	Class 4	5	00

* An intumescent fire-retardant paint

TABLE 3

RESULTS AND CLASSIFICATIONS OBTAINED

Particulars of linings	Mean time to reach (θ+50)°C min	sec	Minimum duration of (θ+50)°C min	sec	Maximum duration of (θ+50)°C min,	sec	Resulting classification	Times in model rooms min	sec
Incombustible	Never		Nil		Nil		Class A	17	10
Fibre insulating board with 3/16-in. skim plaster coat	13	45	0	15	5	30	Class A	17	15
Wood wool	Never		Nil		Nil		Class A	16	45
Plasterboard	5	35	0	30	2	00	Class A	16	35
Hardboard impregnated with mon-ammonium phosphate (Retention of salt stated to be 17-18% by weight	Samples not availble at this impregnation							15	45
Fibre insulating board with mon-ammonium phosphate (Retention of salt stated to be 19% by weight	7	0	6	0+	6	0+	Class B	Not Tested	
Hardboard with surface treatment of paint A* (30g/ft²).	5	25	6	15	7	00	Class B	13	30
Fibre insulating board with surface treatment of paint A* (30 g/ft²)	6	50	8	00	8	30	Class B	10	35
Asbestos paper faced fibre insulating board	6	50	9	30	12	45	Class B	10	30
Fibre insulating board with surface treatment of paint A* (15 g/ft²)	5	15	7	45	10	15	Class B	9	25
Fibre insulating board with silicate paint coat	4	0	7	0	7	0+	Class C	7	45
Fibre insulating board with 2 coats of distemper	4	05	9	00	11	30	Class C	6	00
Untreated hardboard	2	25	7	45	9	45	Class D	6	15
Compressed straw slabs	1	10	18	45	19	00	Class D	5	45
Untreated fibre insulating board	0	40	12	30	13	15	Class D	5	00

* Paint "A" an intumescent paint
\+ Only one sample tested

Table 4 and Figs 8 and 9 show the variations obtained in the results

TABLE 4

VARIATIONS OBTAINED FOR THREE SAMPLES OF EACH SPECIMEN

Particulars of linings	Times to reach(θ+50)°C min	secs	Duration of (θ+50)°C min.	secs.
Incombustible	Never		Nil	
Fibre insulating board with 3/16-in. skim plaster coat	15 15	00 00	0 0	15 15
Woodwool	Never		Nil	
Plasterboard	5 5 5	30 30 15	2 1 0	00 00 30
Fibre insulating board with mon-ammonium phosphate (Retention of salt stated to be 19% by weight	7	0	6	0*
Hardboard with surface treatment of paint A+ (30 g/ft²)	5 5 5	30 30 15	7 6 6	00 30 15
Fibre insulating board with surface treatment paint A+ (30 g/ft²)	6 7 7	00 15 15	8 8 8	00 30 30
Asbestos paper faced fibre insulating board	7 7 6	00 00 30	12 9 10	45 30 45
Fibre insulating board with surface treatment of paint A+ (15 g/ft²)	5 5 5	15 15 15	7 10 10	45 15 15
Fibre insulating board with coat of silicate paint	4	0	7	0*
Fibre insulating board with 2 coats of distemper	4 4 4	00 00 15	10 9 11	00 00 30
Untreated hardboard	2 2 2	30 30 15	9 9 7	45 15 45
Compressed straw slabs	1 1 1	15 00 15	18 19 18	45 00 45
Untreated fibre insulating board	0 0 0	45 30 45	12 13 12	30 15 45

* Only one sample tested

\+ Paint "A" is an intumescent paint

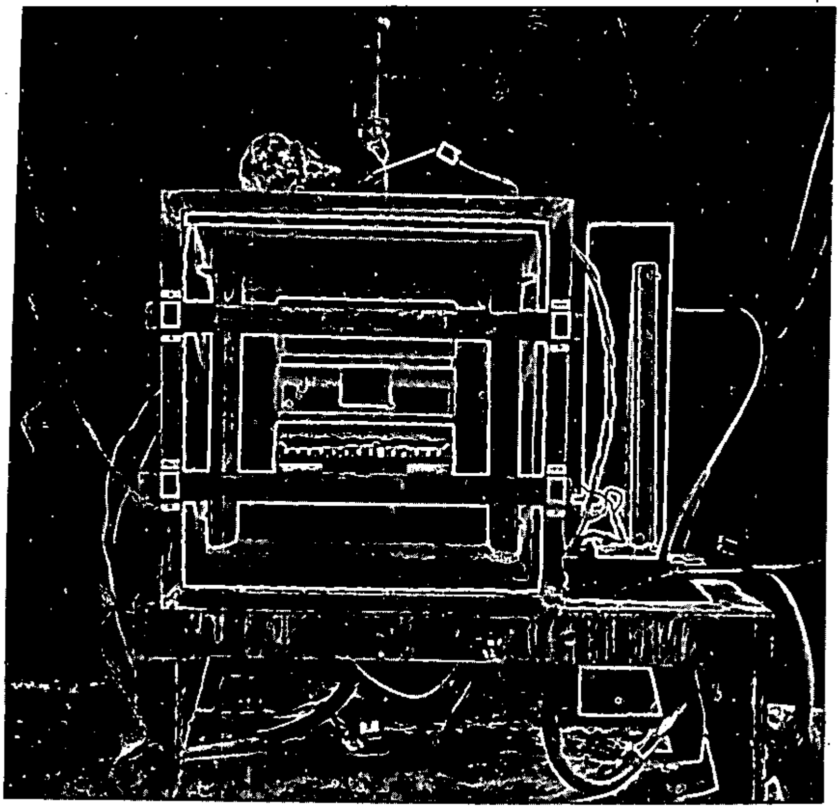

PLATE. 1. FRONT VIEW OF APPARATUS

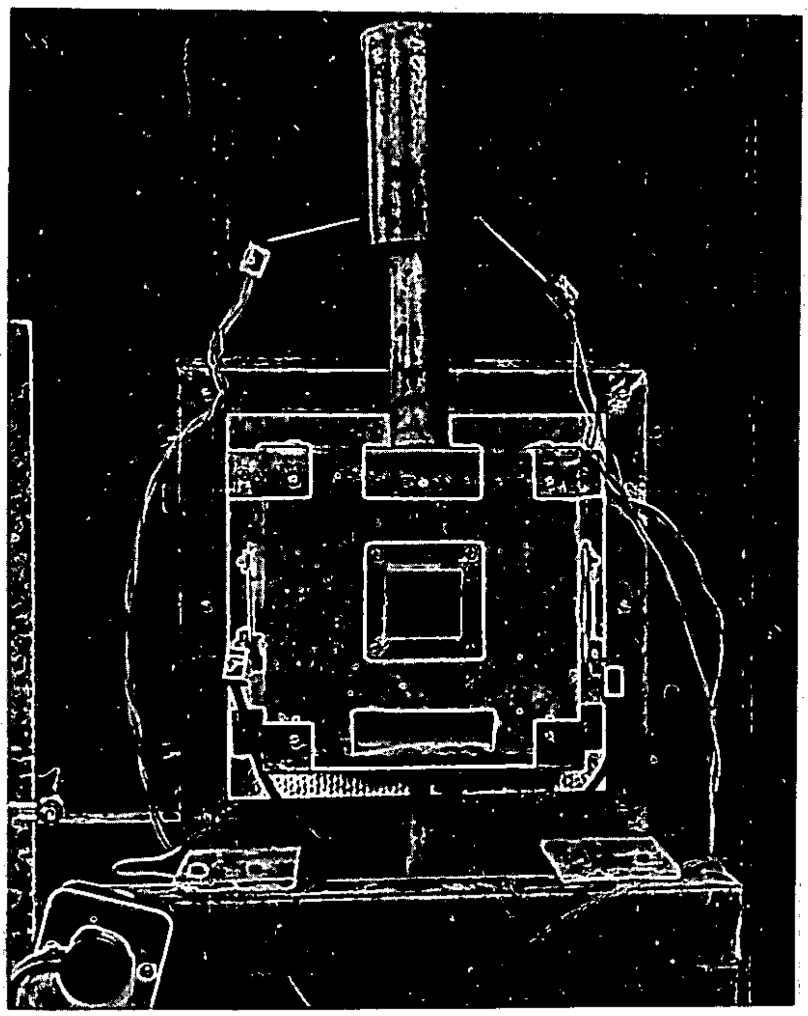

PLATE. 2. REAR VIEW OF APPARATUS

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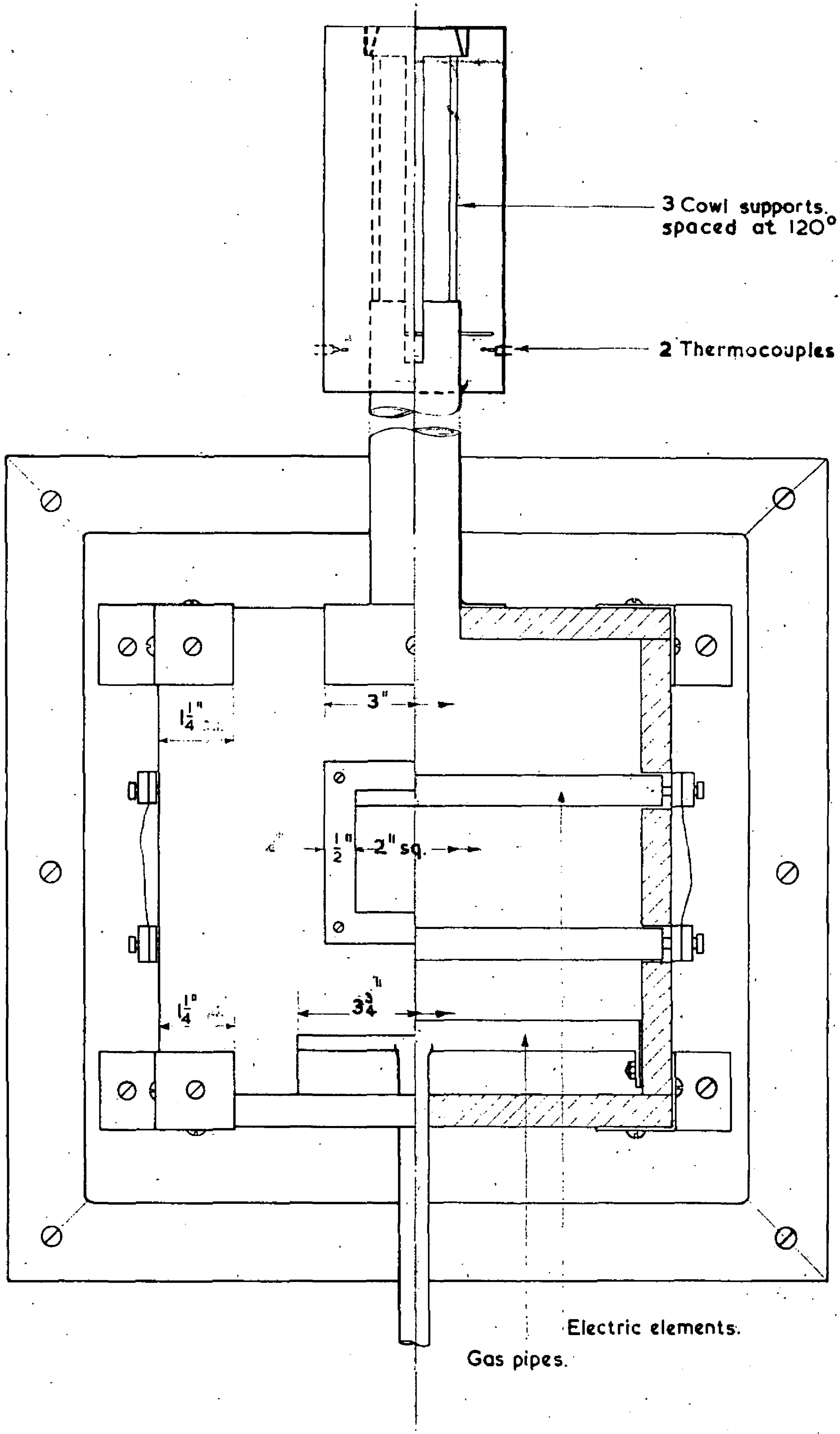

FIG. 1. FRONT VIEW.

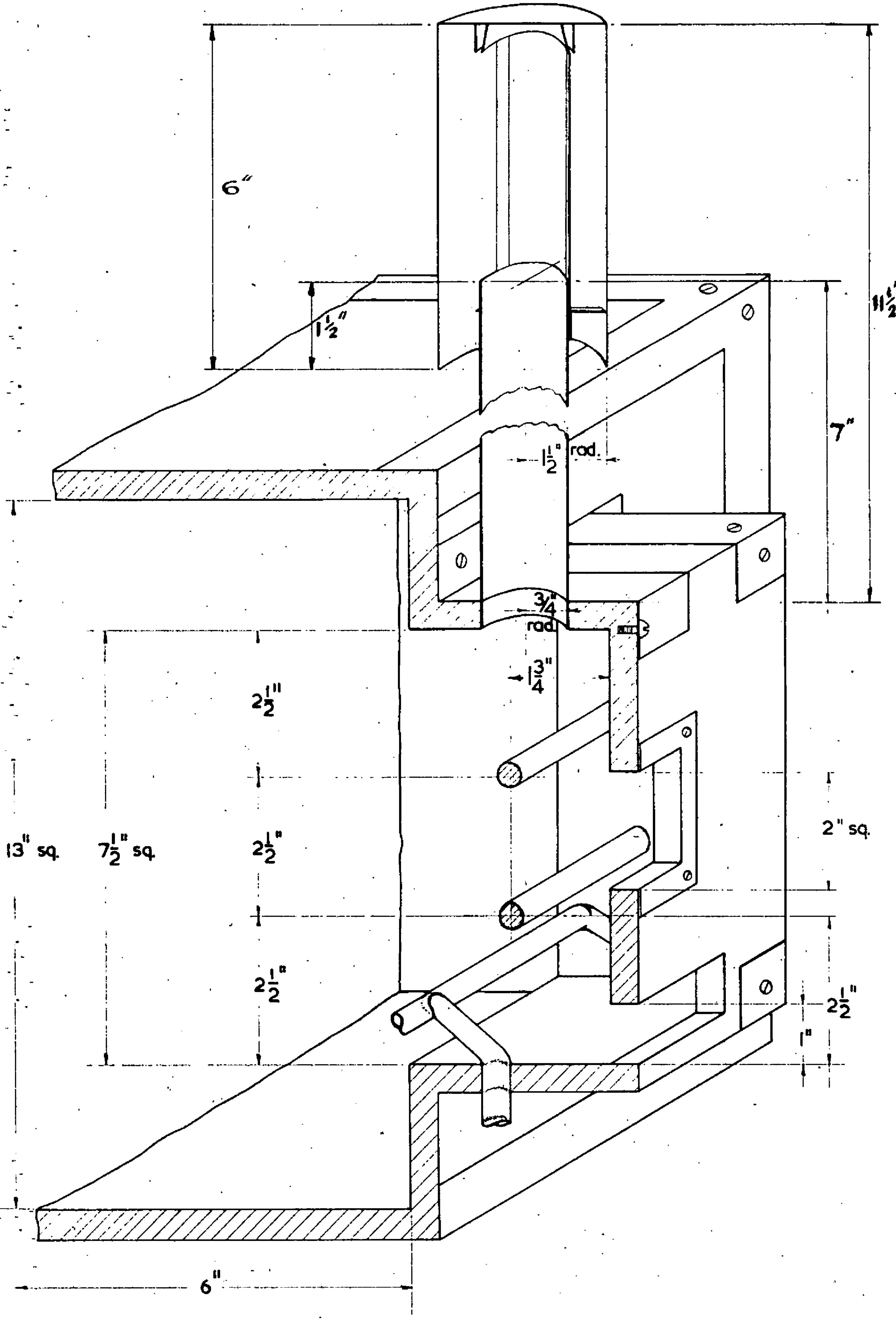

FIG. 2.

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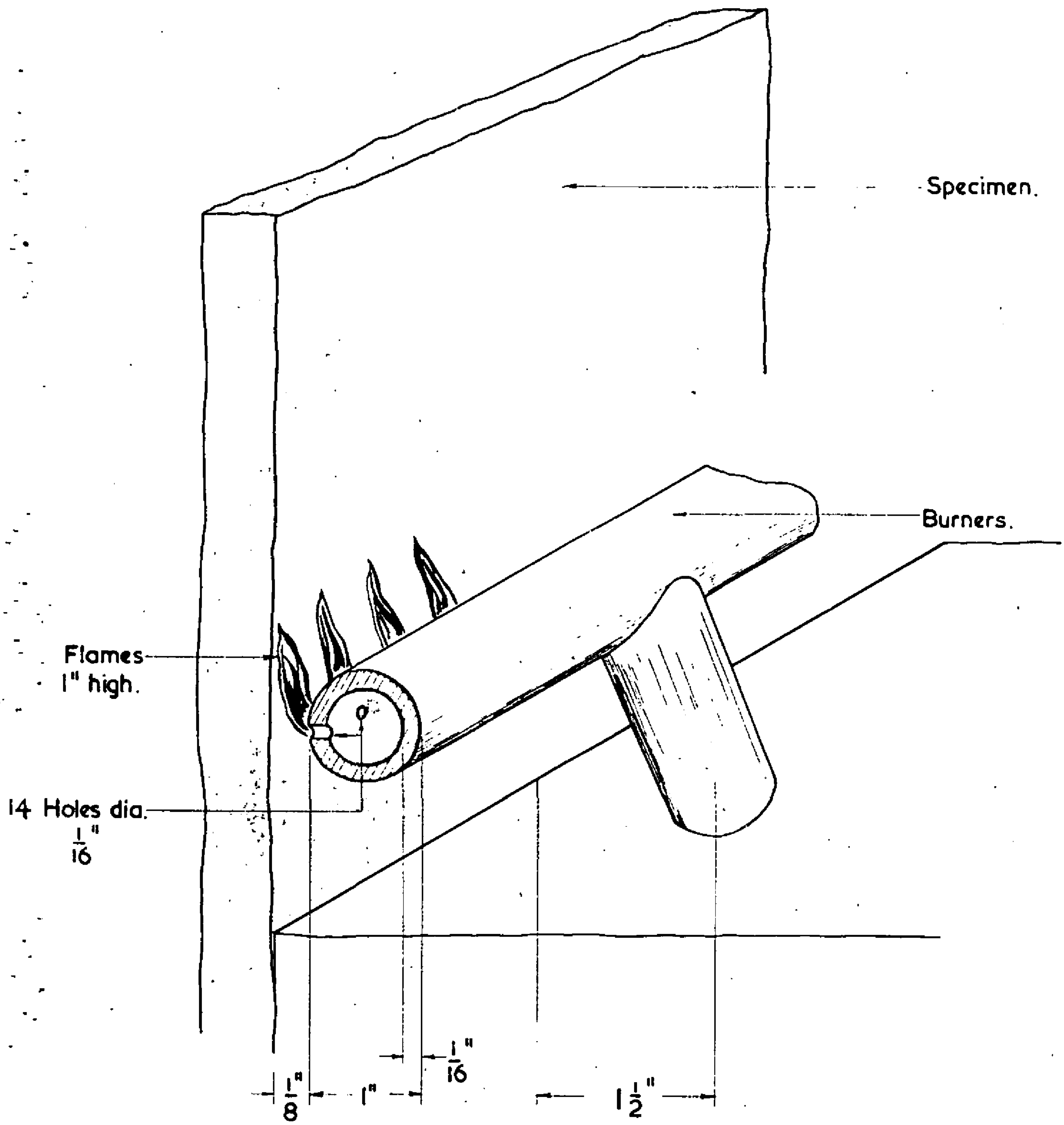

FIG. 3. RELATION OF BURNER TO SPECIMEN.

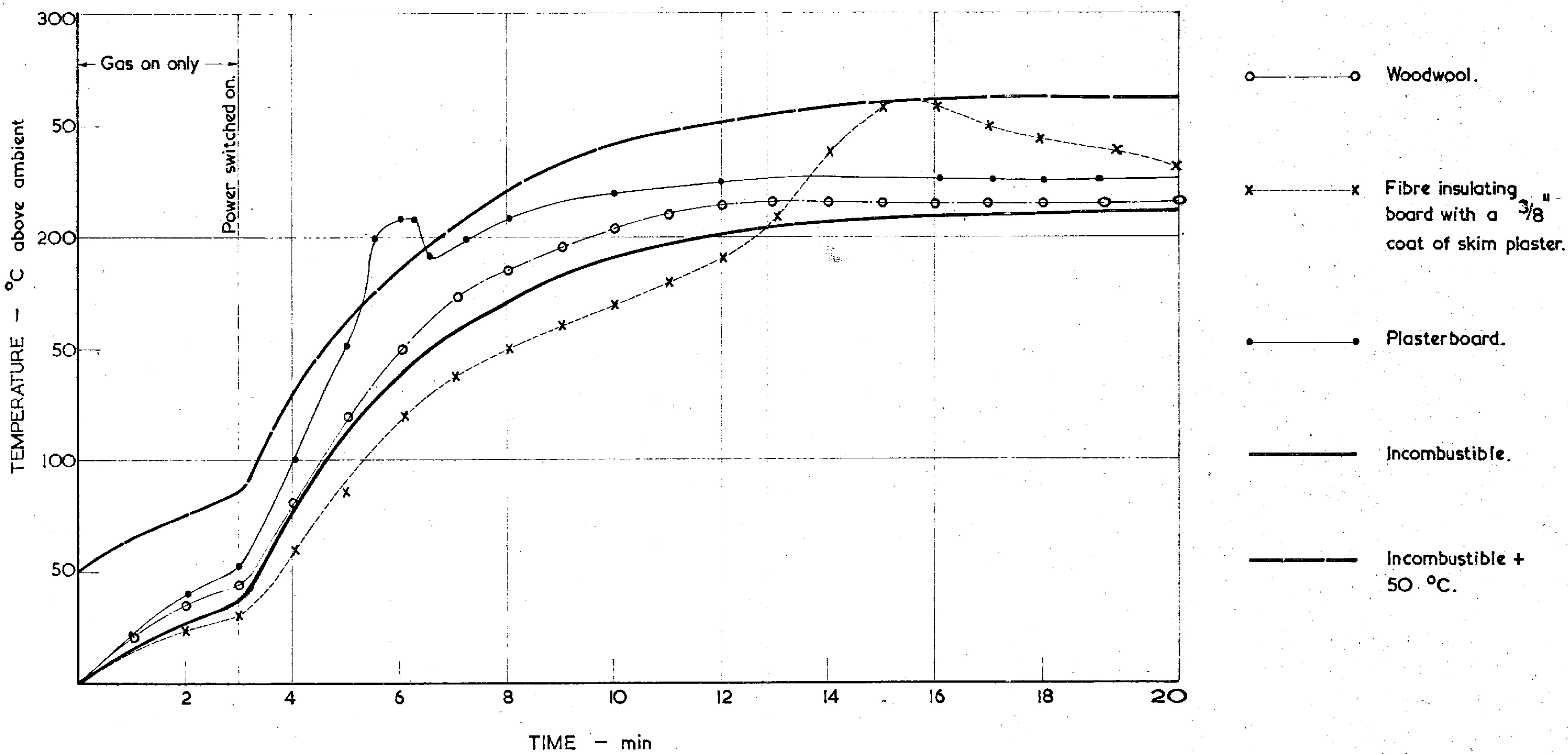

FIG. 4. REPRESENTATIVE CURVES FOR PROPOSED CLASS A.

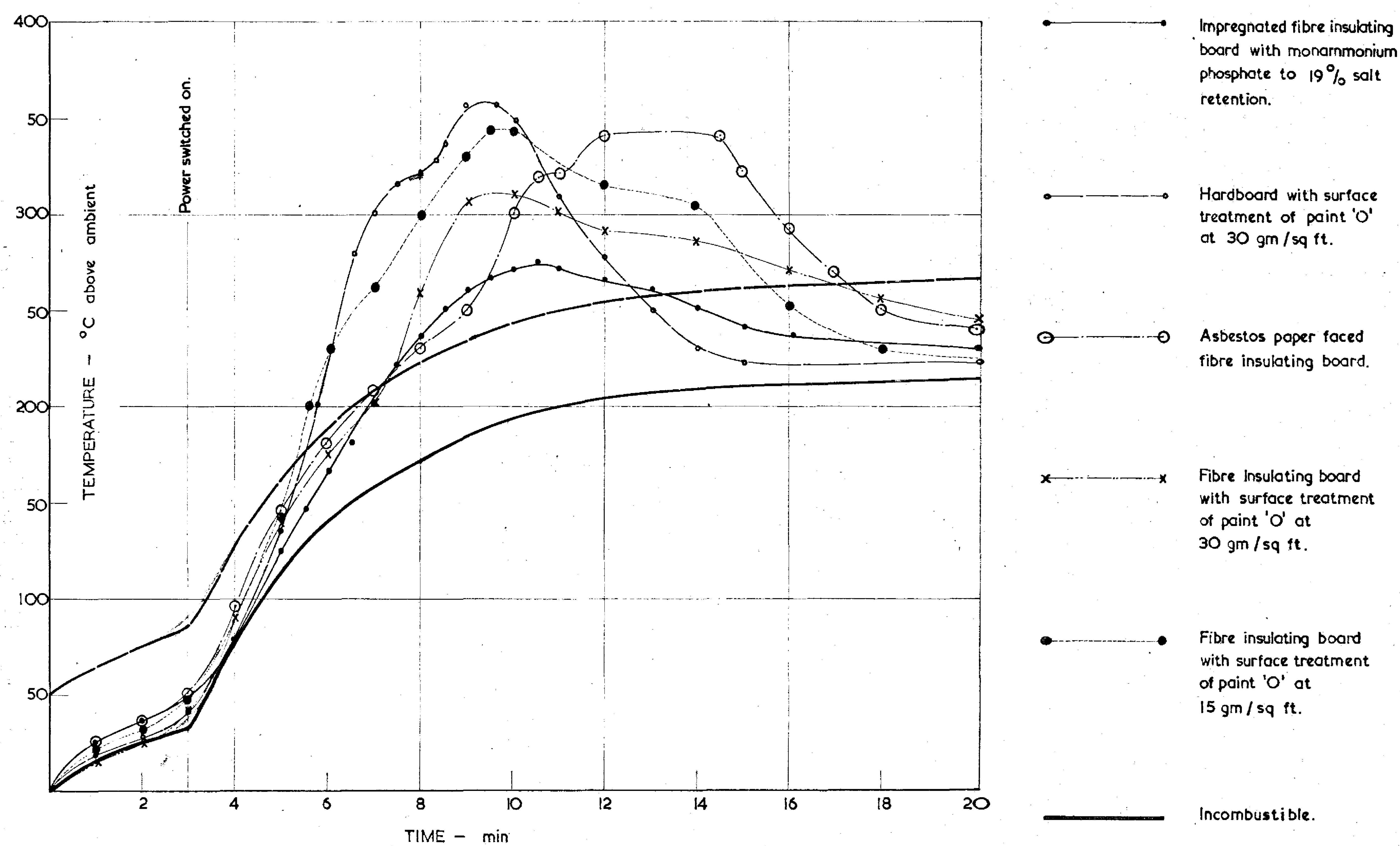

FIG. 5. REPRESENTATIVE CURVES FOR PROPOSED CLASS B.

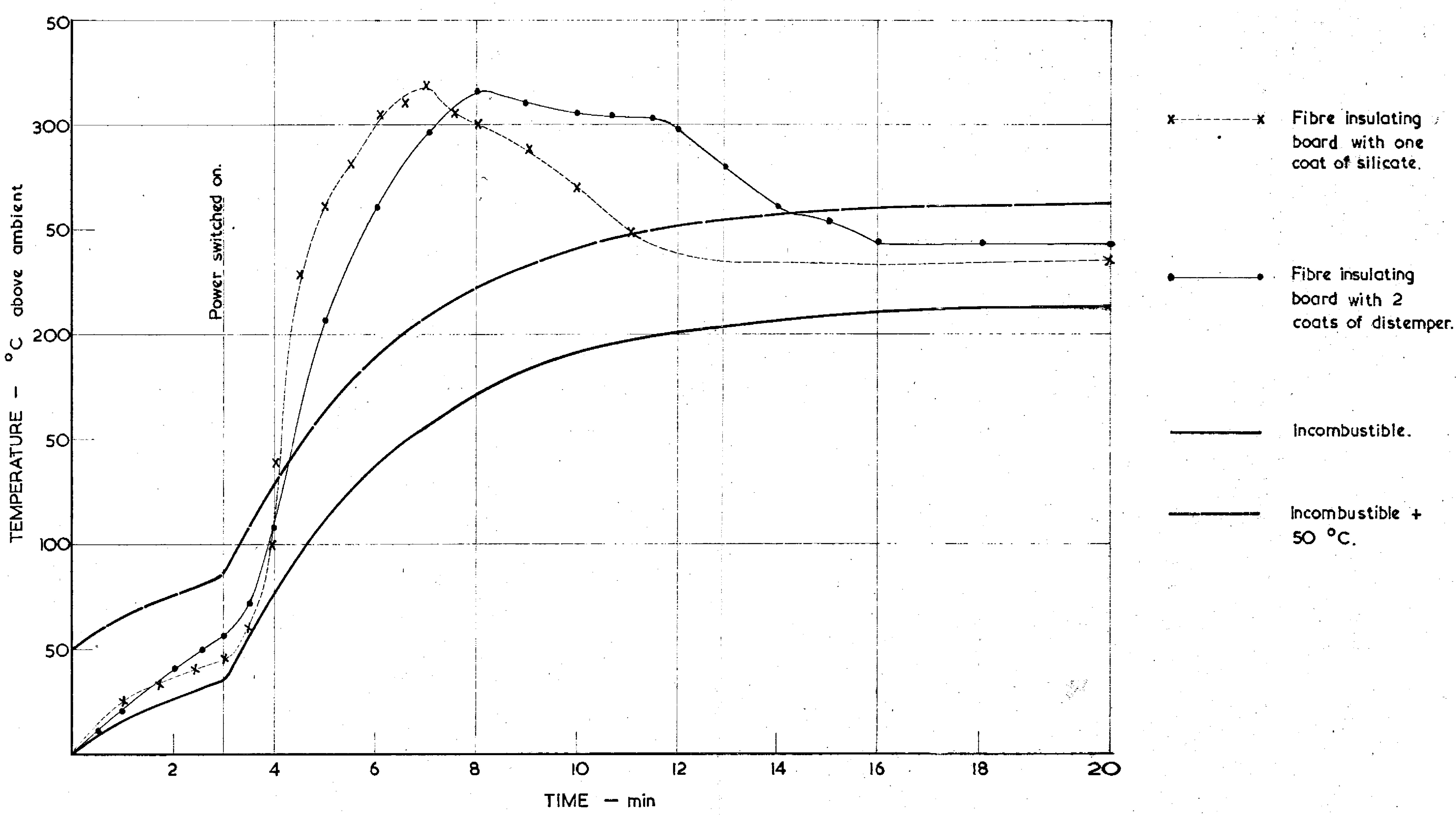

FIG. 6. REPRESENTATIVE CURVES FOR PROPOSED CLASS C.

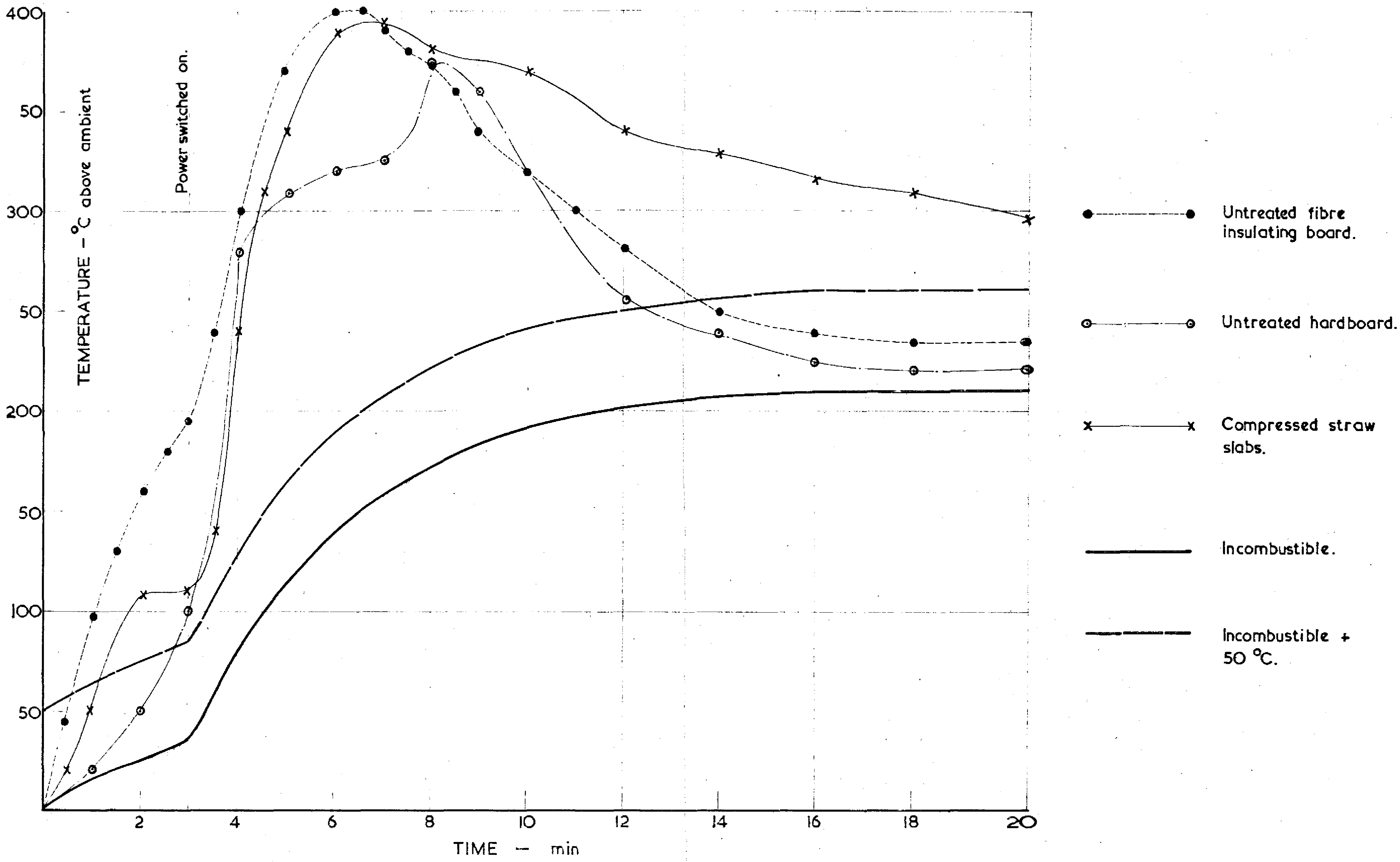

FIG. 7. REPRESENTATIVE CURVES FOR PROPOSED CLASS D.

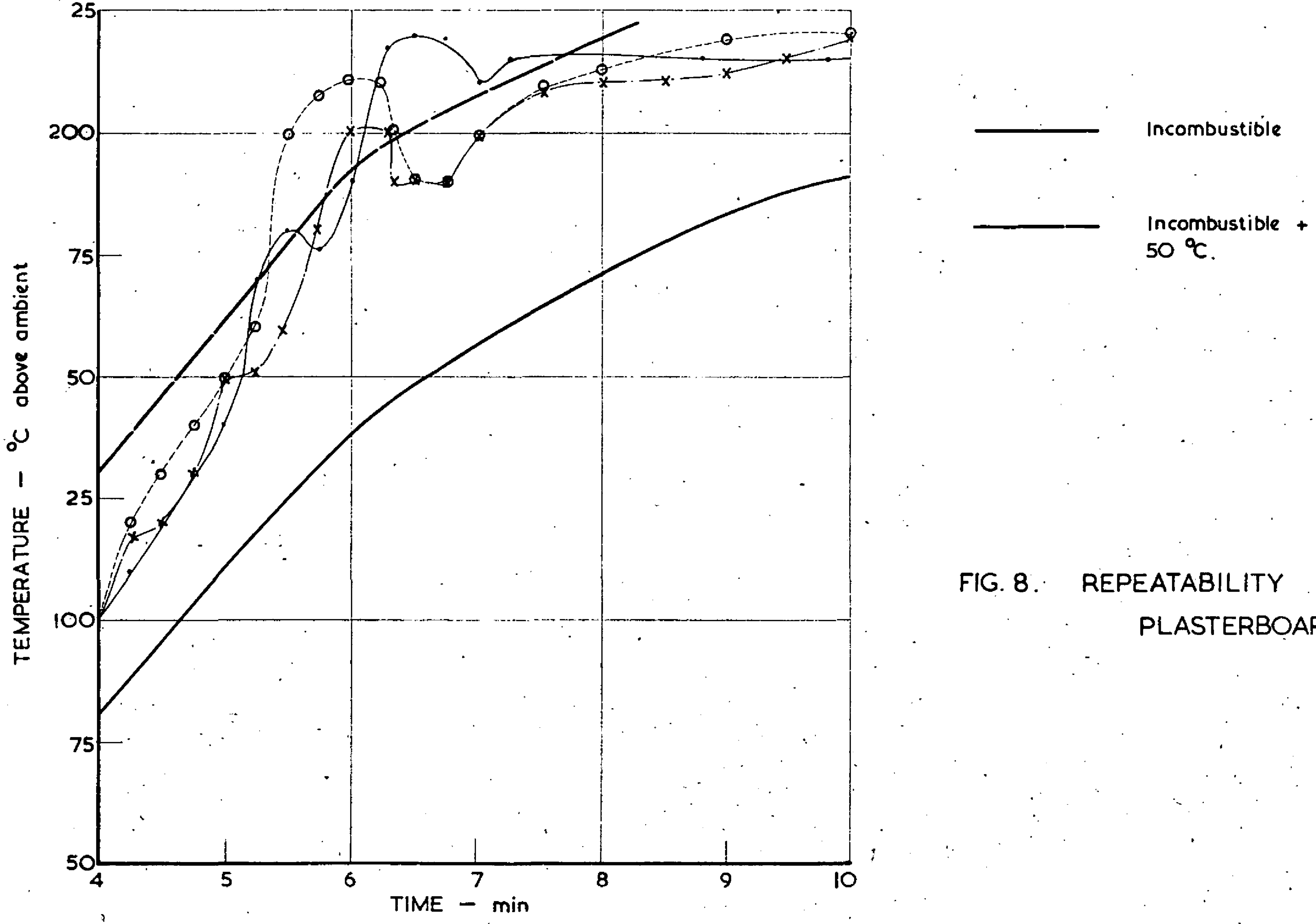

FIG. 8. REPEATABILITY OF PLASTERBOARD.

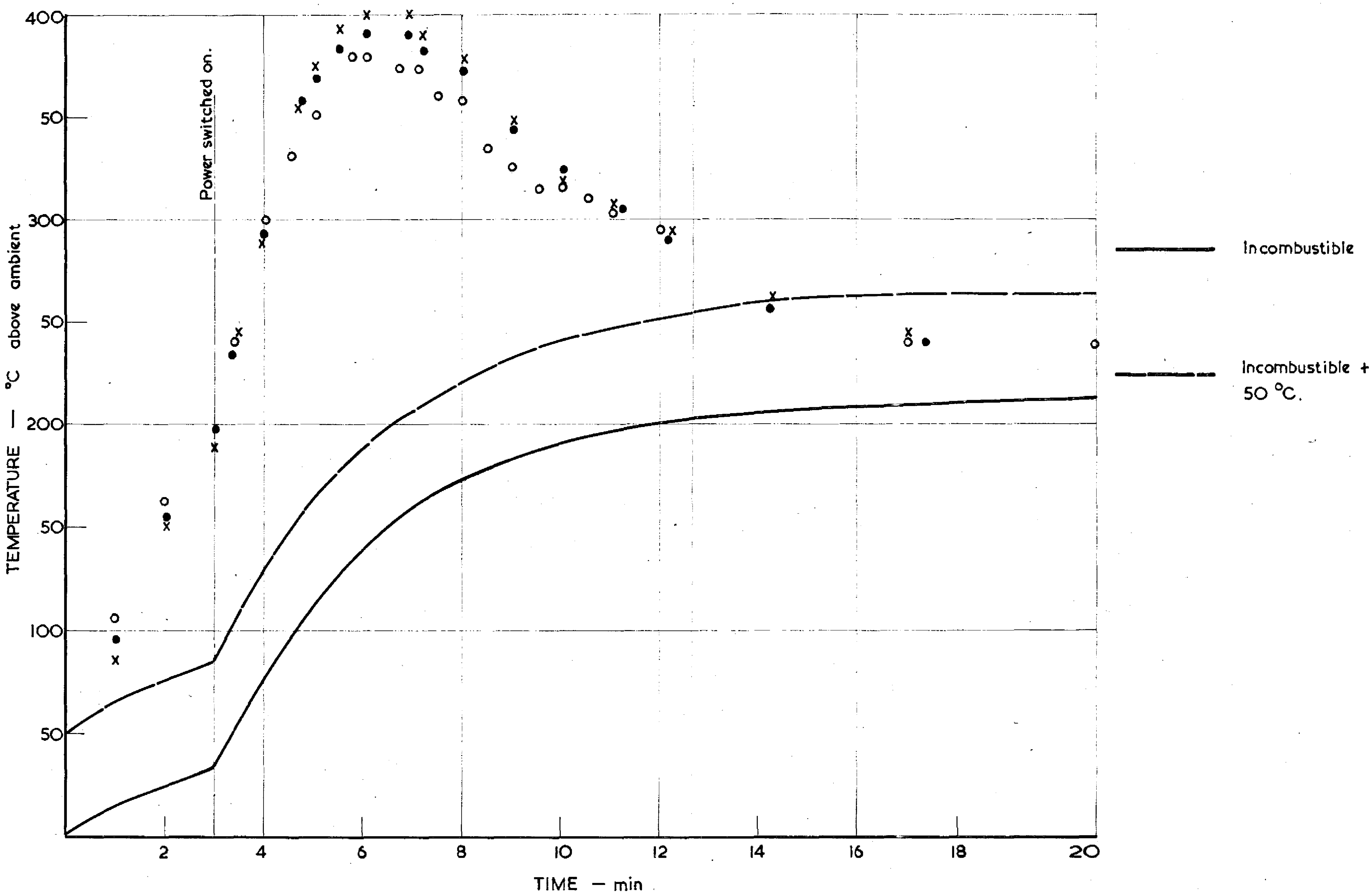

FIG. 9. FIBRE INSULATING BOARD UNTREATED (REPEATABILITY)

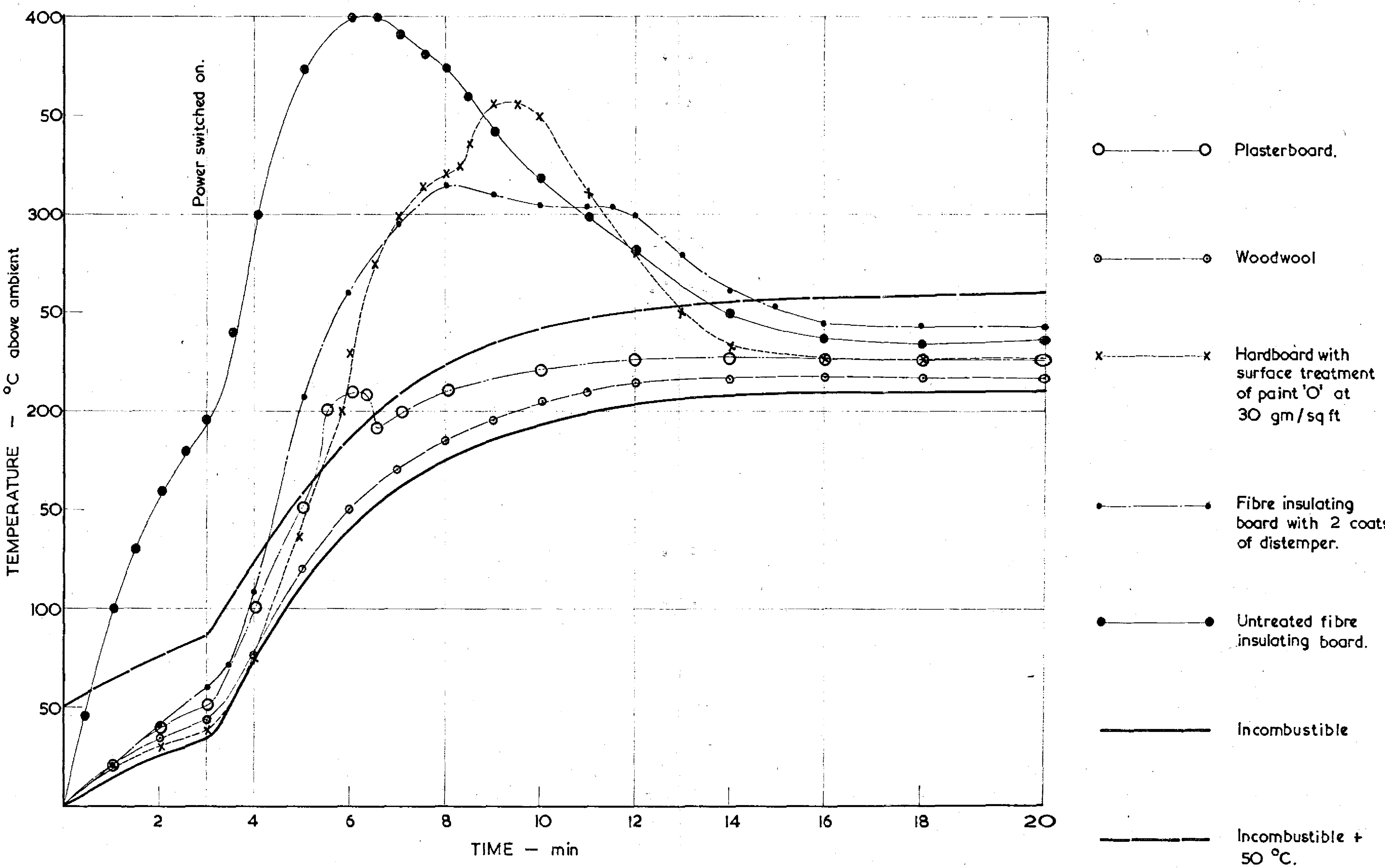

FIG. 10. REPRESENTATIVE CURVES FROM ALL CLASSES ALSO PLASTERBOARD.

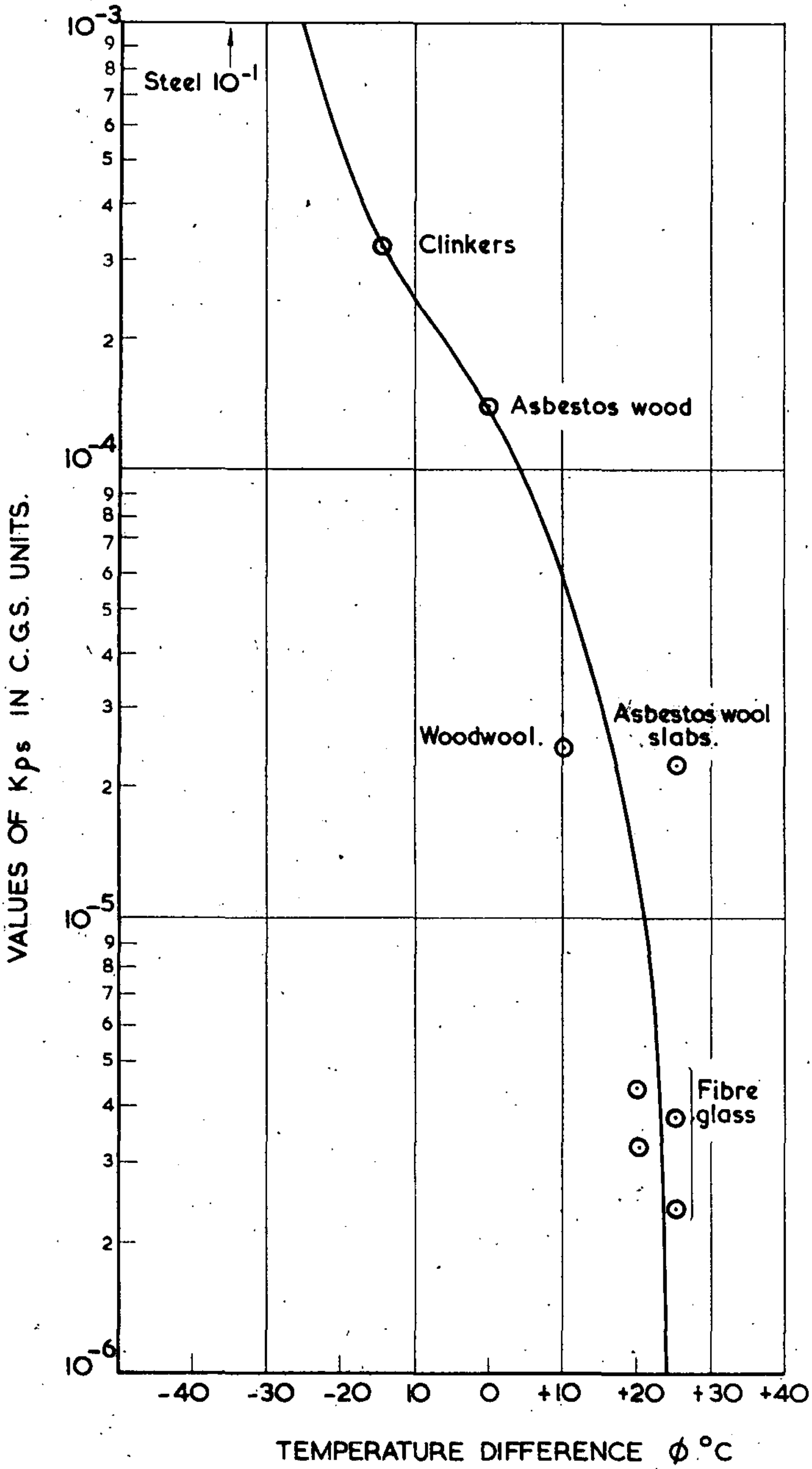

FIG.12. TEMPERATURE DIFFERENCE OBTAINED FOR VARIOUS VALUES OF K_{ps} AT 8 MINUTES RELATED TO ASBESTOS WOOD.