Fire Research Note No. 652

MOVEMENT OF SMOKE ON ESCAPE ROUTES

PART 2. EFFECT OF DOOR GAPS ON MOVEMENT OF SMOKE

by

H. L. MALHOTRA

FIRE
RESEARCH
STATION

JANUARY, 1967.

Fire Research Station,
Borehamwood,
Herts.
ELStree 1341

F. R. Note No. 652
January, 1967.

MOVEMENT OF SMOKE ON ESCAPE ROUTES

PART 2. EFFECT OF DOOR GAPS ON MOVEMENT OF SMOKE

by

H. L. Malhotra

MINISTRY OF TECHNOLOGY AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

F. R. Note No. 652
January, 1967.

MOVEMENT OF SMOKE ON ESCAPE ROUTES
PART 2. EFFECT OF DOOR GAPS ON MOVEMENT OF SMOKE

by

H. L. Malhotra

Introduction

During the early stages of a fire in a compartment large quantities of smoke are usually produced. Whilst walls and floors can be designed to be imperforate to the passage of smoke, doors can be a source of weakness. A door is designed to provide access to and from a compartment and in its simplest form of construction consists of a panel hinged along a vertical edge and moving freely in a frame. Clearances exist between the edge of the panel and its frame for freedom of movement, clearances which if excessive are unable to prevent the passage of smoke.

Residential buildings such as flats, hotels etc. have specified areas designated as escape routes which the occupants can use for normal access purposes, and for means of escape in case of a fire. These routes would have doors leading to and from them which if not effective barriers to the passage of smoke could seriously impair the usefulness of these routes.

Experience has shown that well built hinged doors when shut can be an effective barrier to the penetration of smoke but no quantitative data are, however, available on their specification as satisfactory smoke stop doors. It is therefore necessary to have a knowledge of the part the gaps between the door and the frame play and the amount of smoke that can penetrate through them. The present investigation was undertaken to obtain quantitative data on the passage of smoke through door gaps of various sizes.

Experimental technique

An experimental building[1] consisting of a smoke chamber representing a room and an escape lobby was available for experiments on the movement of smoke and it was proposed to separate the two by a door specially designed for these experiments. The door was a typical single swing flush door of 45 mm thickness measuring 66 x 190 cm. The frame of the door was specially constructed as shown in Figure 1 to permit independent adjustment of the gaps at the rebate from zero to 6.4 mm along all the edges. With the gaps set at a maximum the area available for the passage of smoke was 322 cm^2.

With the door between the lobby and the smoke chamber in a closed position, a smoke generator was put in action and the other doors and shutters in the lobby closed. Measurements of smoke were made using meters and techniques described in F.R. Note No. 652 on "Movement of Smoke on Escape Routes". When the results of the tests were examined it appeared that the flow of smoke through the door did not provide a coherent picture and the results were being affected by extraneous influences. With the door gaps at maximum width of 6.4 mm the smoke density in the lobby varied by nearly 60 per cent between tests. Similarly with other gaps variable performances were obtained in repeat tests depending upon the prevailing wind conditions. As the lobby was not completely air tight, its internal pressure varied with respect to the smoke chamber depending upon the direction and speed of the wind and hence the smoke penetration through the door did not follow a consistent pattern. It was considered that for experimental purposes tests on the doors should be carried out under still air conditions.

For this purpose a 6.7 x 2.3 metre timber framed shell was erected inside a large laboratory and provided with an intermediate partition with the experimental door as shown in Figure 2. Three smoke density meters were used in the positions shown, two at eye level at a height of 1.6 metres and the third at a height of 0.9 metres. The smoke generator was placed in the other compartment, the door gaps adjusted and measurements taken of smoke penetration for a period of 30 minutes.

It was realised at the outset that it would be necessary to obtain some indication of the smoke conditions that are likely to be encountered in actual fires. The amount of smoke that is produced in a fire and consequently the quantity able to penetrate through a door would be governed by a number of factors, an important one being the rate at which the fire develops. Without extensive experimental work full data on the rate of production of smoke in fires could not be obtained and for the purpose of this investigation it was only possible to make a tentative comparison. For this purpose use was made of a test (No. 7) conducted to determine the behaviour of a proprietary door under conditions of actual fire in the experimental building used for the first part of these tests.

In this test, conducted in the experimental building, the door was mounted to separate the smoke/fire chamber from the lobby and fuel in shape of timber cribs and wall linings was provided. In the lobby area smoke meters were installed in four positions to measure continuously the penetration of smoke during the test. As the primary purpose of the test was to measure the fire resistance of the door, the experimental conditions were so arranged that a rapidly developing fire took place.

The door was of solid timber construction with a glazed panel and of approximately the same overall dimensions as the door used in the main investigations. The gaps were measured between the door and the frame and found to vary between 0.7 and 5.0 mm, the average value being 2.5 mm.

Results of tests

Seven tests, including the ad hoc fire test, were performed with various sizes of gaps as shown in Table 1 below. Gap 'A' (Fig. 3) was the clearance between the edge of the door and the frame, whilst gap 'B' was that measured between the door face and the doorstop. In test No. 6 there were no gaps between the door and the frame; instead two equal sized rectangular holes were provided in the upper and the lower half of the door to give an area of 322 cm^2, equal to that provided by the gaps in test No. 3.

Table 1. Size of door gaps for different tests

Test No.	Gap 'A'	Gap 'B'
1	Nil	Nil
2	3.2 mm	3.2 mm
3	6.4 mm	6.4 mm
4	6.4 mm	3.2 mm
5	6.4 mm	Nil
6	322 cm^2 opening in door	
7	Average gap 2.5 mm	

The results of the tests are plotted in Figures 4 to 10 showing the optical density/metre as measured by the smoke meters together with the mean value of the smoke density in the compartment. In Figure 11 mean smoke densities of the various tests, excluding No. 6, are plotted to compare the rate of smoke penetration through the doors. In Figure 12 the average visibility in the rooms is shown using the mean smoke density curves.

It is clear from Figure 10 that in the ad hoc fire test the rate of penetration through the door fluctuated between wide limits. The initial very high rate of smoke penetration occurred during the first few minutes when fire in the chamber was not fully developed and large quantities of smoke were produced. On the further development of fire and emission of flames from the window of the fire chamber, the penetration of smoke was quickly reduced to a low level, thereafter increasing steadily for the next 12 minutes. During this time the door would have deformed due to heat thus increasing the clearance between the face and the stop. Flaming of the door face occurred at 21 minutes on the fire side and shortly afterwards the severity of fire in the chamber started to decrease with only small quantities of smoke being produced at this stage by the fire itself. Most of the smoke which came through the door at this stage was probably being produced by the combustion of the door itself. Considerable charring of the door would have occurred during this period and whilst the door was still standing at 30 minutes, it collapsed 6 minutes after the end of the experiment.

Discussion of results. General

When two rooms are separated by a door, and a fire starts on one side, generation of heat leads to an increase in pressure compared with the other room. This pressure differential is the motivating force responsible for the passage of smoke through the available gaps and clearances. The quantity of smoke that is likely to pass through the gaps will be influenced by pressure differential, rate of smoke generation, and the gap dimensions. In a hinged type of door with a rebated frame smoke in its travel changes its direction through 90 degrees before its emission on the other side. Width of a gap is likely to be an important factor in determining the quantity of smoke that can penetrate under given conditions of pressure difference; the length of the path may also have to be taken into account as it would influence the resistance to flow of smoke.

The timber door used in the experiments with the smoke generator represented a construction of normal workmanship and the adjustable stops used were also made of wood. When the gaps were set nominally at zero, some leakage of smoke occurred indicating that the fit was not absolutely perfect.

The smoke density curves show that stratification of smoke occurred in the compartment with the smoke meter nearest the door at high level giving generally higher readings followed by the high level distant meter before the smoke reached the area close to the floor. In the ad hoc fire test, a similar pattern was observed although when smoke was penetrating at high rates the differences between the maximum and the minimum densities in the lobby was greater.

Smoke generator tests

Mean smoke density curves for various tests are plotted in Figure 11 to enable a comparison to be made between different tests. In tests Nos. 1, 2 and 3 during the first six minutes only small amounts of smoke penetrated, presumably because the smoke chamber was filling during this period and the pressure differential across the door was not fully developed to its maximum value. Smoke penetrated at a very high rate in test No. 3 with a 6.4 mm gap for the remainder of the test period. The difference between smoke conditions in tests Nos. 1 and 2 was not large over the whole period. It would seem that a path length of 70 mm with a right angle bend in it offered much greater resistance to the passage of smoke with a 3.2 mm gap width than with a width of 6.4 mm. This may have also been responsible for greater flow of smoke in test No. 4 than in test No. 2 as in the former the gap width of 6.4 mm existed for only part of the path length.

On the other hand, results of tests Nos. 1 and 5, both with Gap 'B' having nil value are identical until 24 minutes when slightly greater amounts managed to pass through in the latter test.

Data from test No. 6 (Fig. 9) confirm the effect of path resistance on flow of smoke; with the same area for flow available compared with test No. 3, the flow of smoke was considerably greater with the two rectangular openings which provided a minimum of path resistance.

In Figure 12 the mean curves for various experiments are plotted in terms of visibility based on the data given in Part 1. In tests Nos. 1, 2 and 5 visibility remained very good, never falling below 9 metres, whilst in test No. 4 it was reduced to about 7 metres at 15 minutes but by the end had improved to 8 metres. In none of these tests was the visibility reduced to a dangerous level. With 6.4 mm door gaps in test No. 3, however, the visibility was reduced to 5 metres just after 15 minutes and continued to drop at a rapid rate so that at the end of 30 minutes it reached a low value of 1.5 metres. The amount of smoke that was able to pass through a gap of this size would have created a serious hazard to escape after 15 minutes.

Ad hoc fire test (No. 7)

In this test although the door gaps at the start were on an average only 2.5 mm there was considerable penetration of smoke during the first 6 minutes when the fire was rapidly developing in the chamber. At this stage, before the fire had been able to vent itself through the window of the fire chamber by damaging the glazing the pressure differential across the door was likely to be markedly greater than at any time in the tests with the smoke generator.

The reduction in smoke density between 6 and 9 minutes occurred when the fire was burning freely in the fire chamber and the increase in smoke density after 9 minutes may have been accompanied by deformation of the door and consequential increase in the size of the gaps. Ignoring the initial sudden ingress of smoke, the visibility was reduced to 5 metres at $17\frac{1}{2}$ minutes i.e. about 2 minutes later than that obtained with 6.4 mm gap in the smoke generator test.

The results of tests using the smoke generator and the ad hoc fire test are not directly comparable. In the ad hoc test smoke was generated at variable rates, the pressure differential across the door is considered to have fluctuated and the door is assumed to have deformed under the action of heat; after 21 minutes it was actually flaming on the fire side. These are the conditions which would be present in actual fires when the fire occurs on one side of the door, and which would be difficult to standardize. In a building a door to a compartment or a room may have to withstand the effects of fire and act as a smoke barrier at the same time but the position of the majority of doors on escape routes would be such that they would be remote from the seat of fire and therefore unlikely to be exposed to the same conditions as in the ad hoc test.

For the majority of situations in practice the tests with the smoke generator are therefore likely to provide a useful guide to what would usually happen on escape routes. There is, however, still need to determine from actual fires or ad hoc tests the conditions to which a door on an escape route would be exposed. This would provide a more realistic assessment of the time scale used in the smoke generator tests.

Effect of gap sizes

To make a comparison of the effect of door gaps the average curves for the various tests are plotted in Figure 11 and areas computed to obtain the total quantity of smoke in each case. The integrated values for the 10, 20 and 30 minute periods have been adjusted by scaling test No. 1 to unity, and given in Table 2, and plotted in Figure 13.

Table 2. Integrated values of smoke density

Test No.	Door gap	0–10 min	0–20 min	0–30 min
1	nil	1	1	1
2	3.2 mm	2.50	2.39	1.96
3	6.4 mm	3.20	7.45	7.53
4	3.2 mm	4.90	5.20	3.48
5	nil	1.40	1.11	1.20
7	2.5 mm (at start of test)	41.7	14.35	8.92

An examination of the curves shows that up to 10 minutes the differences between the 3.2 and 6.4 mm gaps are not well defined but after this time, the larger gap permitted 3 times more smoke to penetrate while the gap sizes are in the ratio of 1 : 2. The results of test No. 4 do not fit into the pattern in view of the non-uniform nature of the gap. In the ad hoc test the quantity of smoke during the first 10 minutes was 13 times that with 6.4 mm gap, but nearly the same at the end of 30 minutes.

Conclusions

The tests performed for this investigation were not comprehensive enough to provide complete data for evaluating smoke penetration through doors. There is need for further work to establish the relative importance of gap width and path resistance and their effect on smoke flow as well as to determine the conditions to which doors would be exposed on the escape routes when not directly involved in a fire.

Some tentative conclusion can, however, be drawn in assessing the capabilities of doors as smoke barriers.

Hinged doors in rebated frames can act as smoke barriers when the fit of the door in the frame is such that gaps do not exceed 3.0 mm. Gaps in excess of 3 mm can result in penetration of smoke in sufficient quantities to reduce visibility to 5 metres or less in under 20 minutes.

Although no tests were conducted specifically to establish the effect of deformation of door on penetration of smoke, this could have an important influence on the performance of doors as smoke barriers. In this case the clearance between the door edge and the frame would be of critical importance as this would be unaffected by deformation of the door and would control the flow of smoke.

By inference, doors which do not have rebated frames such as double swing doors, would not be very effective as smoke barriers.

There is need for a standard method to determine the capabilities of doors as smoke barriers. The method used in these experiments can form the basis of such a test.

Reference

1. Fire Research 1962.

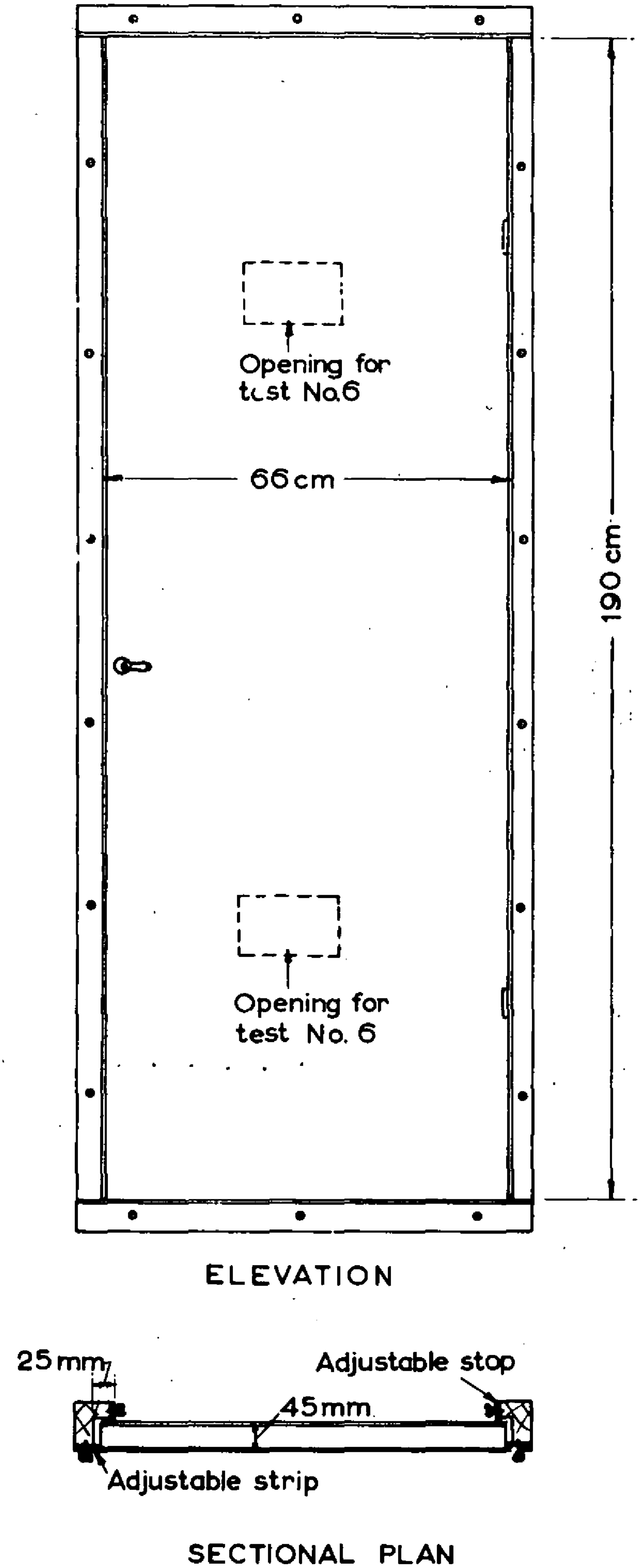

FIG. 1. EXPERIMENTAL DOOR

1/7342 F.R.652

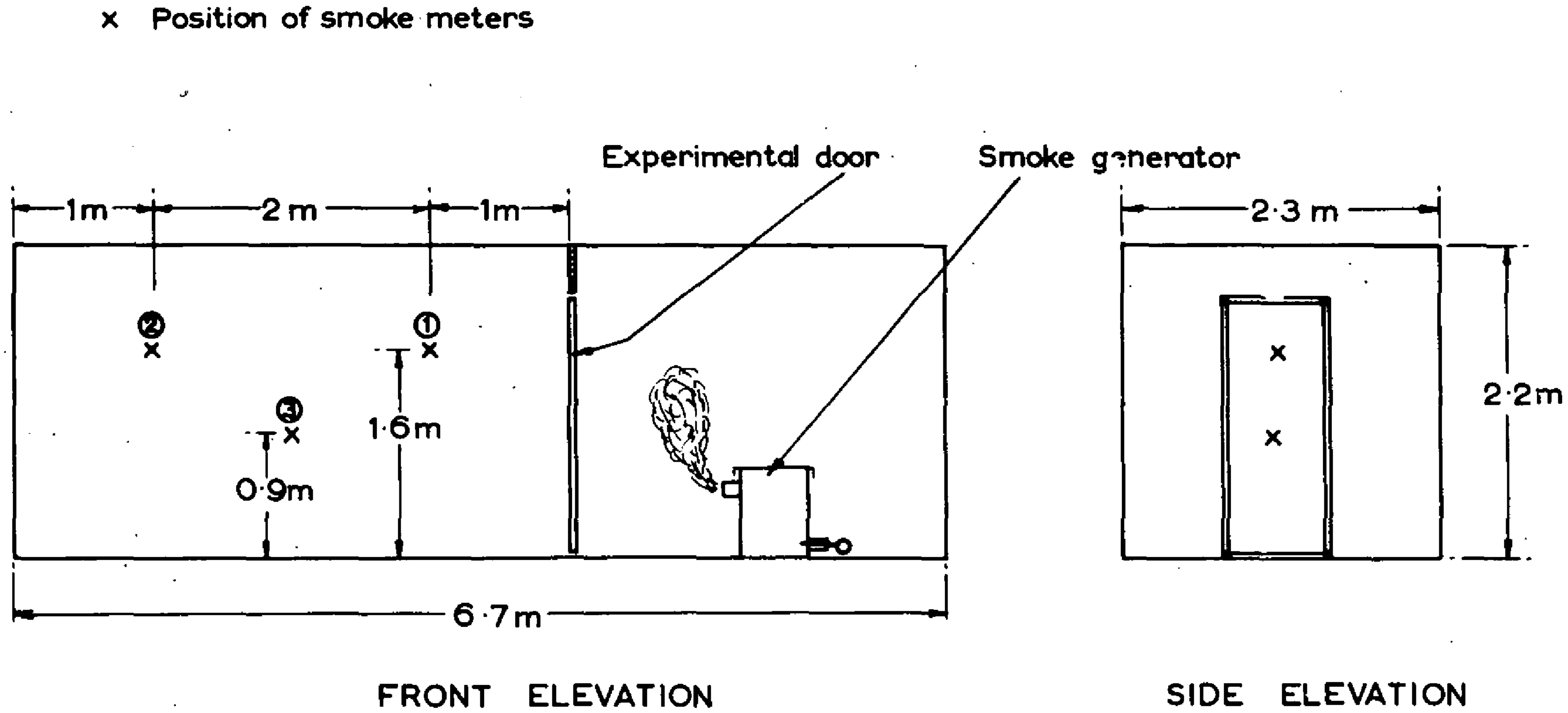

FIG. 2. TIMBER BUILDING USED FOR SMOKE TESTS

11/1343 F.R. 652

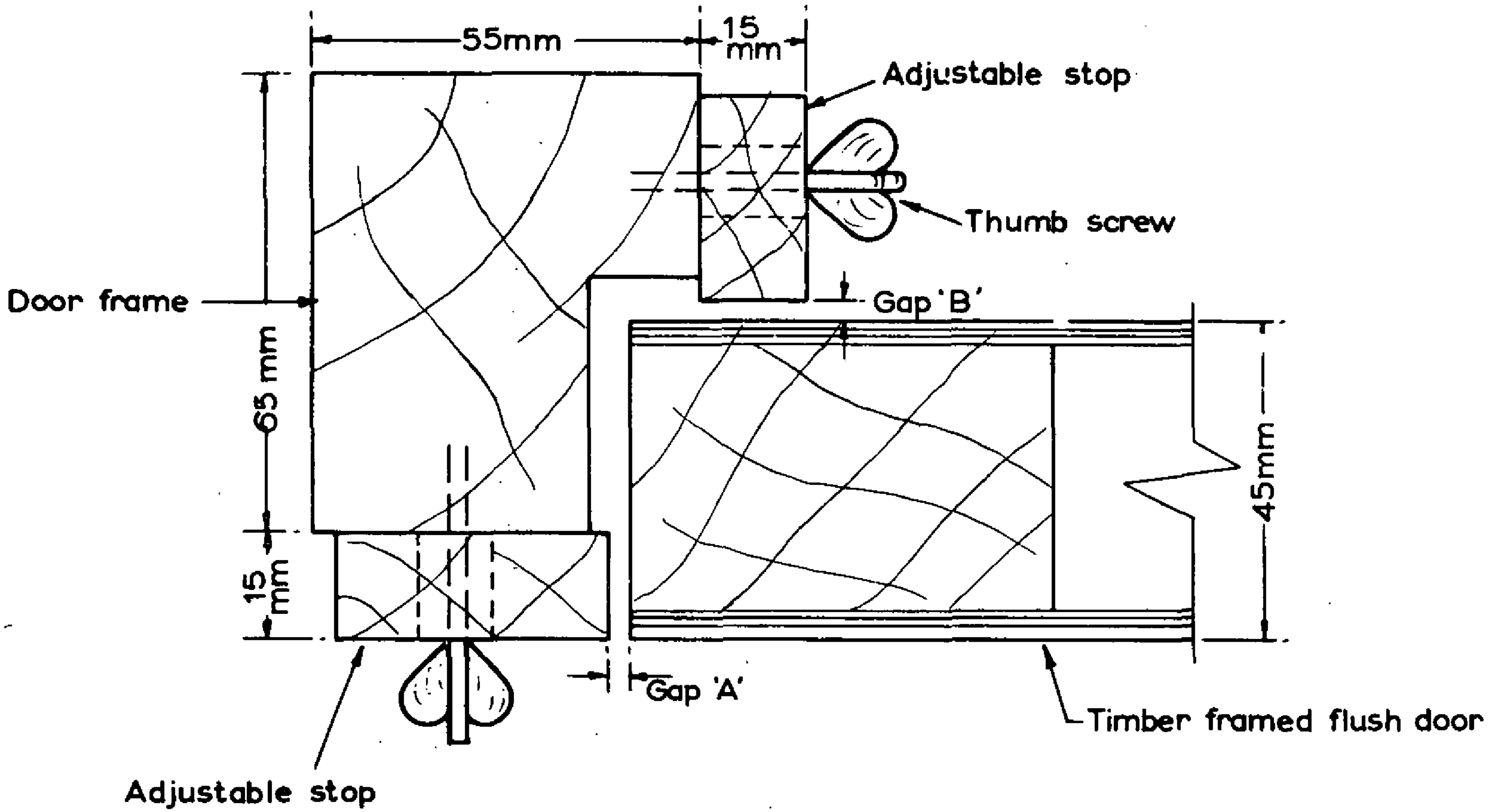

FIG. 3. DETAILS OF ADJUSTABLE DOOR FRAME

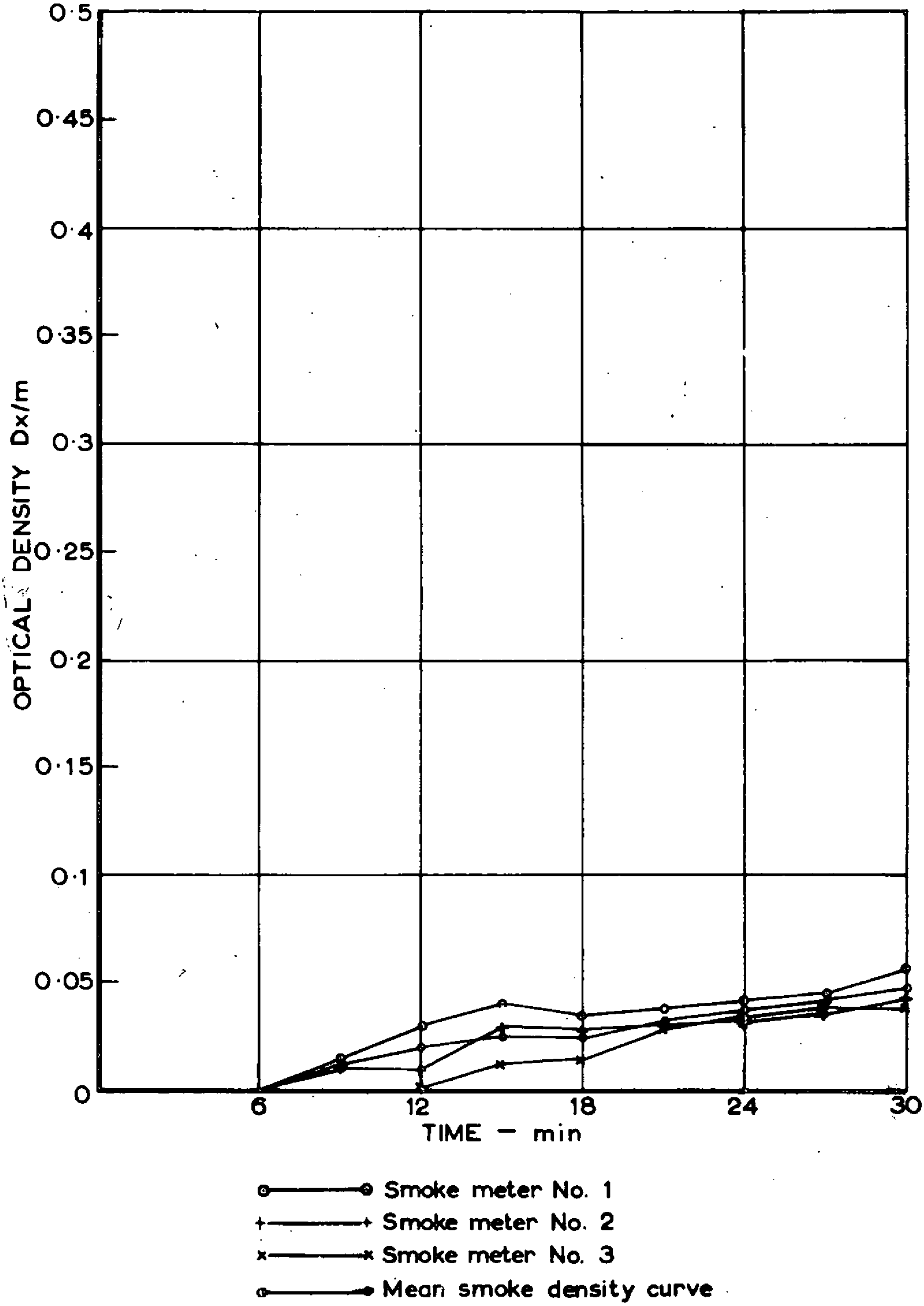

FIG. 4. SMOKE DENSITY CURVES—TEST No. I.

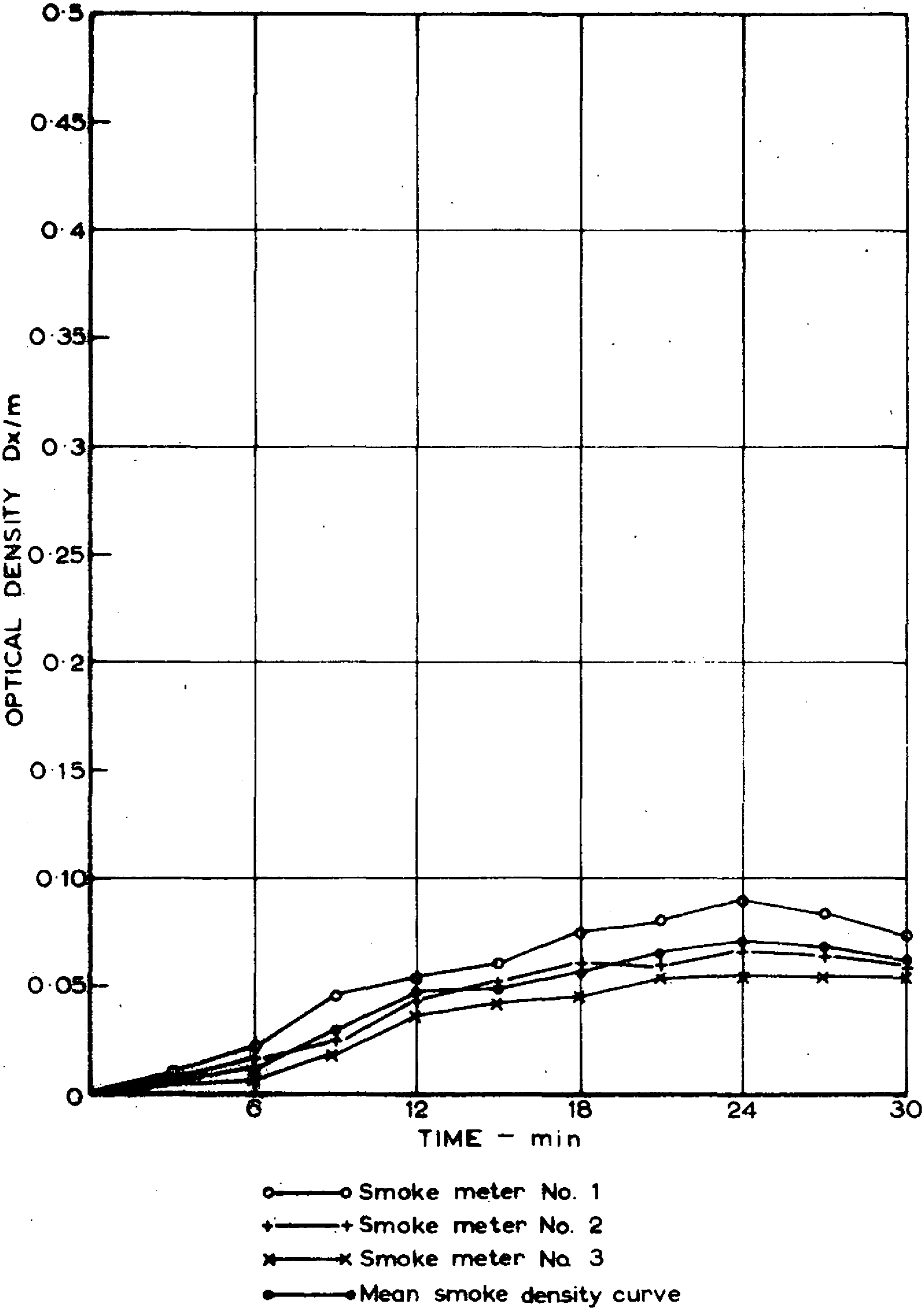

FIG. 5. SMOKE DENSITY CURVES – TEST No. 2

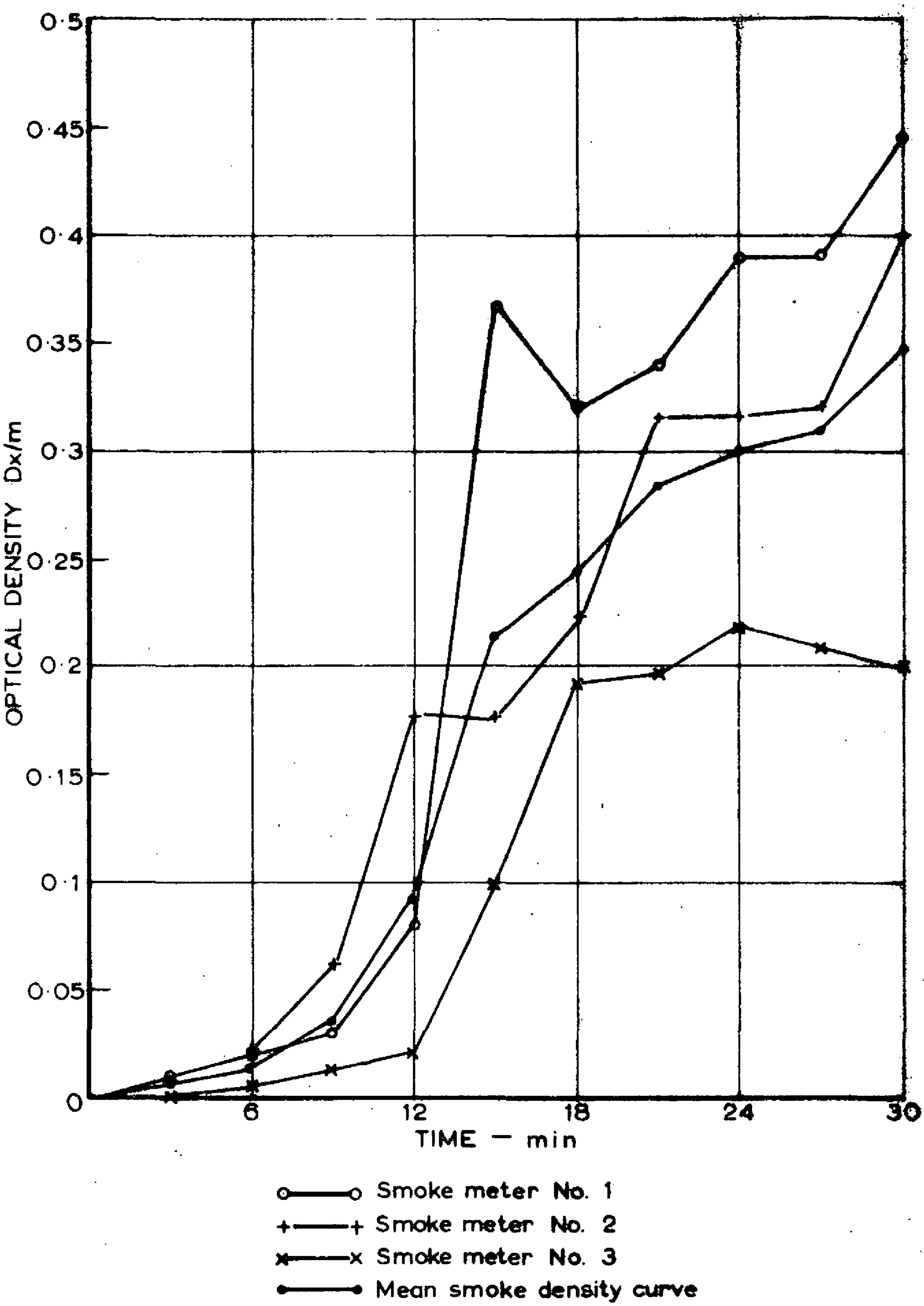

FIG. 6. SMOKE DENSITY CURVES – TEST No. 3.

1/7346 FR. 662

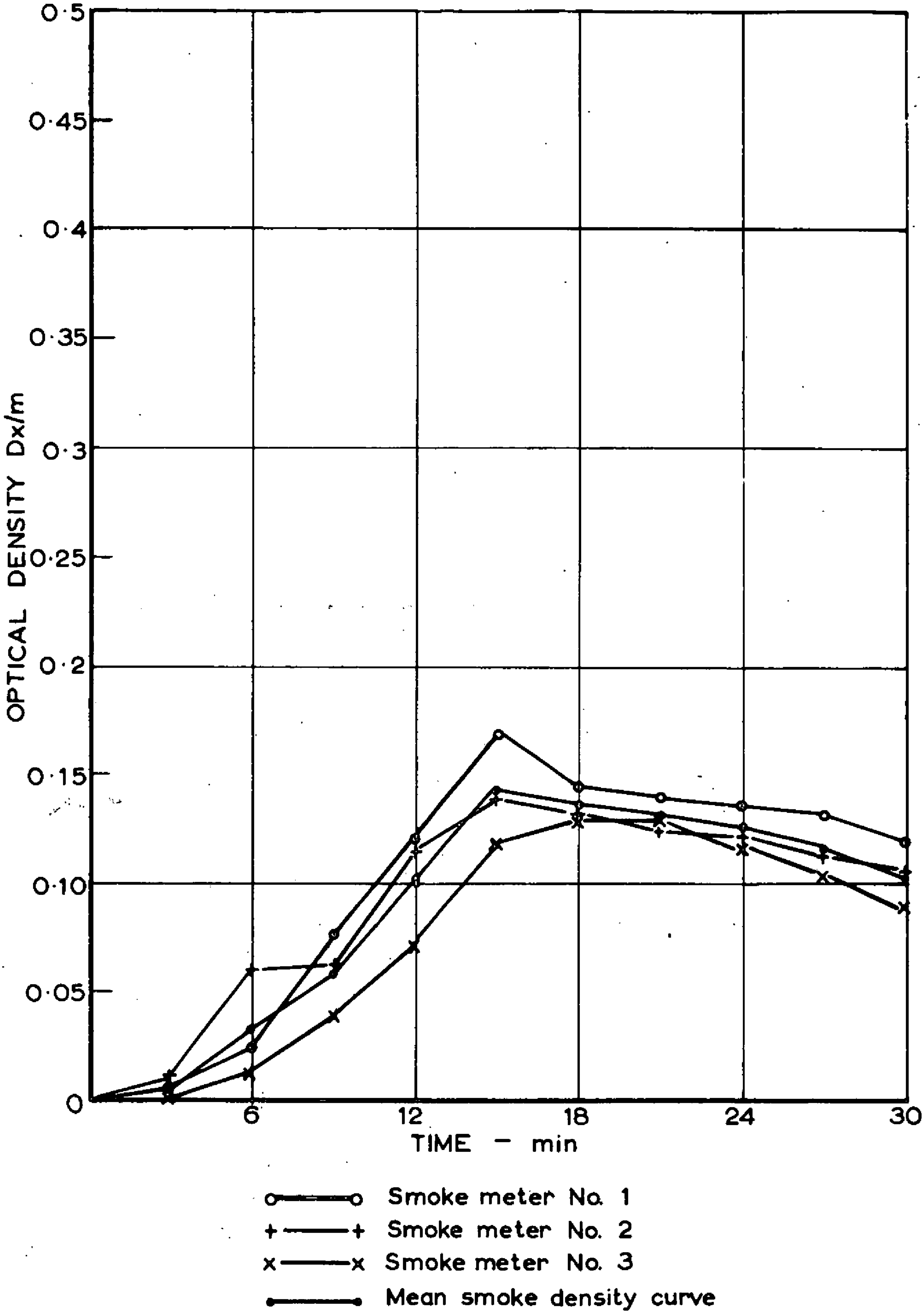

FIG. 7. SMOKE DENSITY CURVES – TEST No. 4

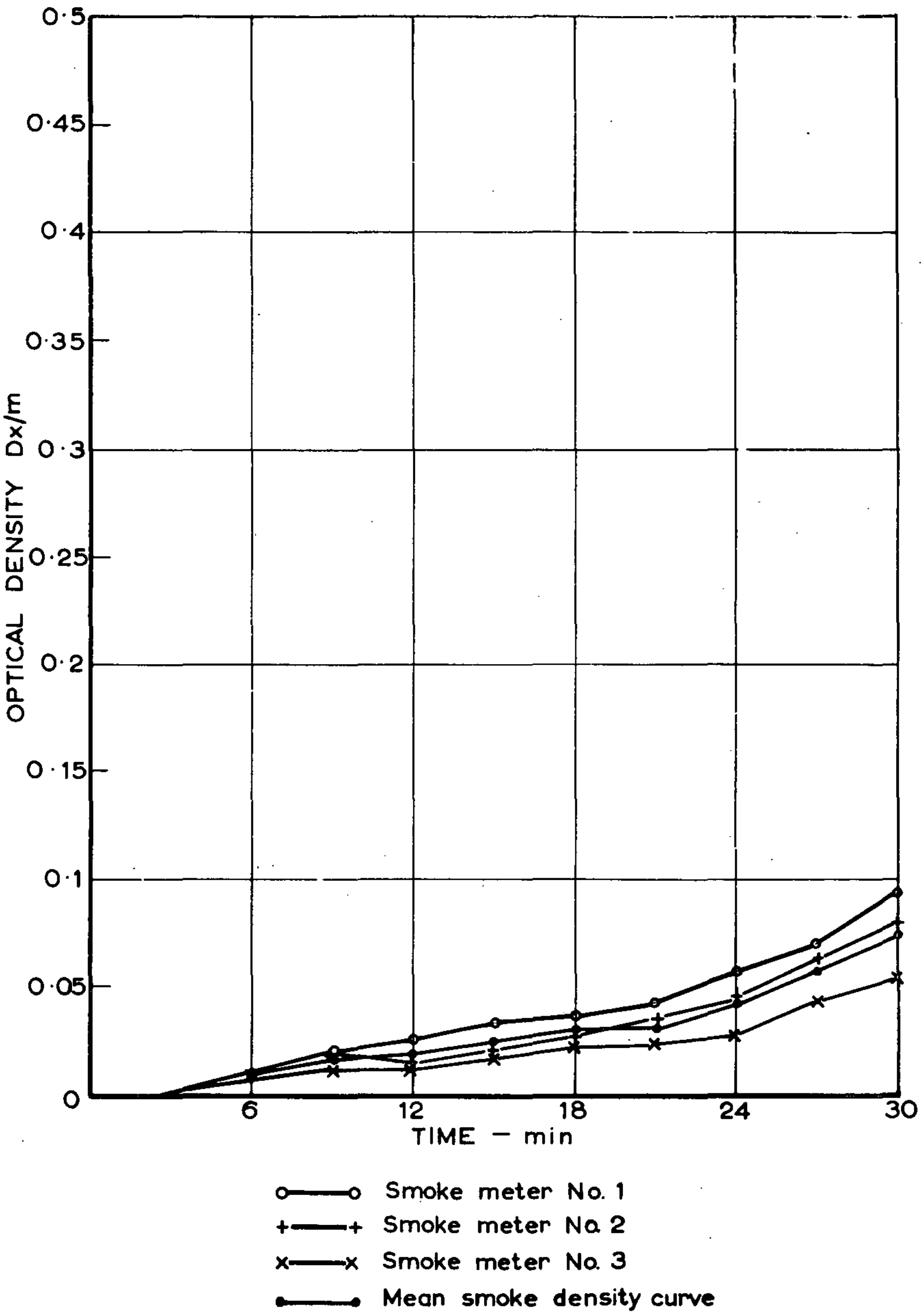

FIG. 8. SMOKE DENSITY CURVES – TEST No. 5

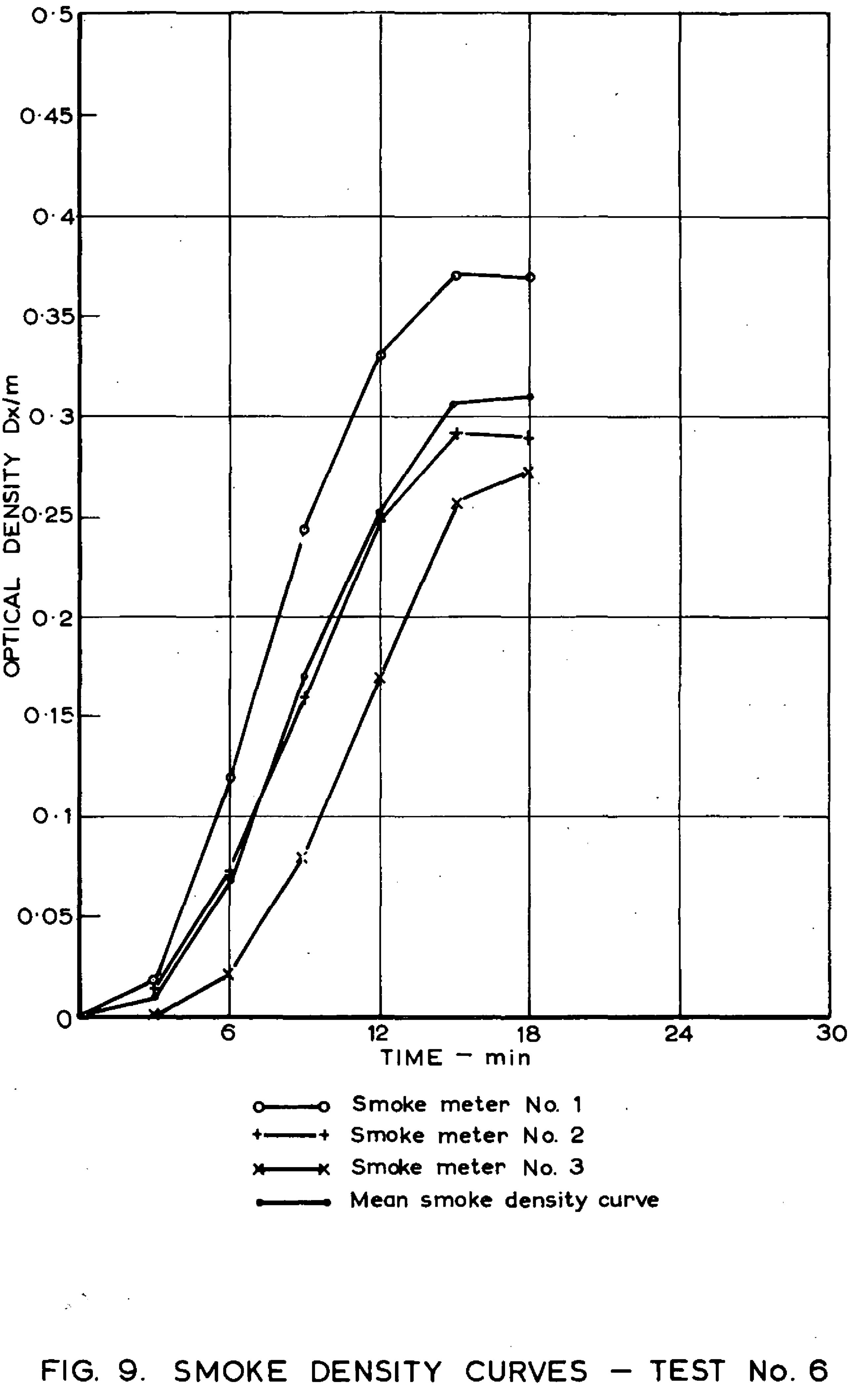

FIG. 9. SMOKE DENSITY CURVES — TEST No. 6

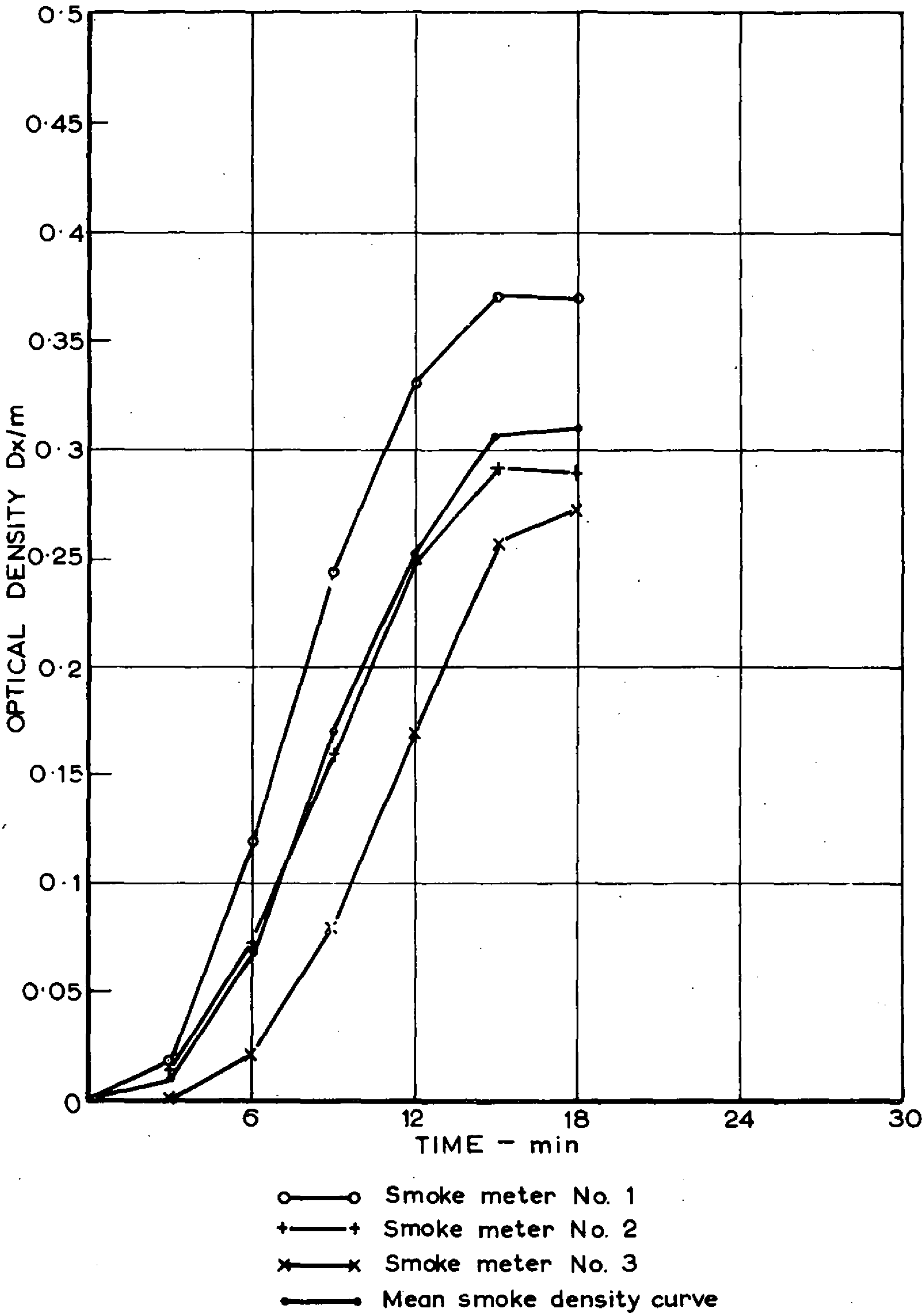

FIG. 9. SMOKE DENSITY CURVES – TEST No. 6

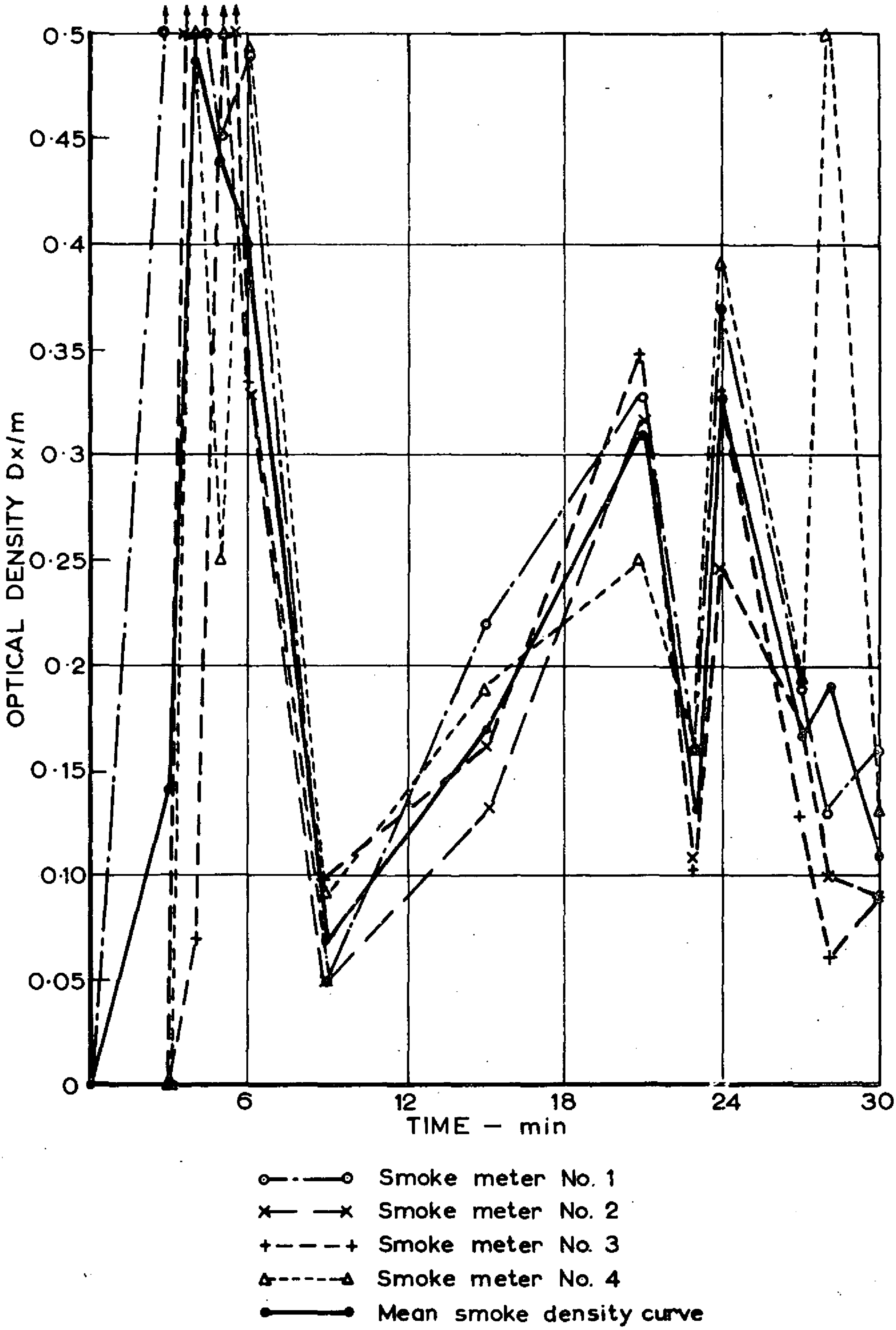

FIG. 10. SMOKE PENETRATION THROUGH A DOOR IN AN AD HOC FIRE – TEST No. 7

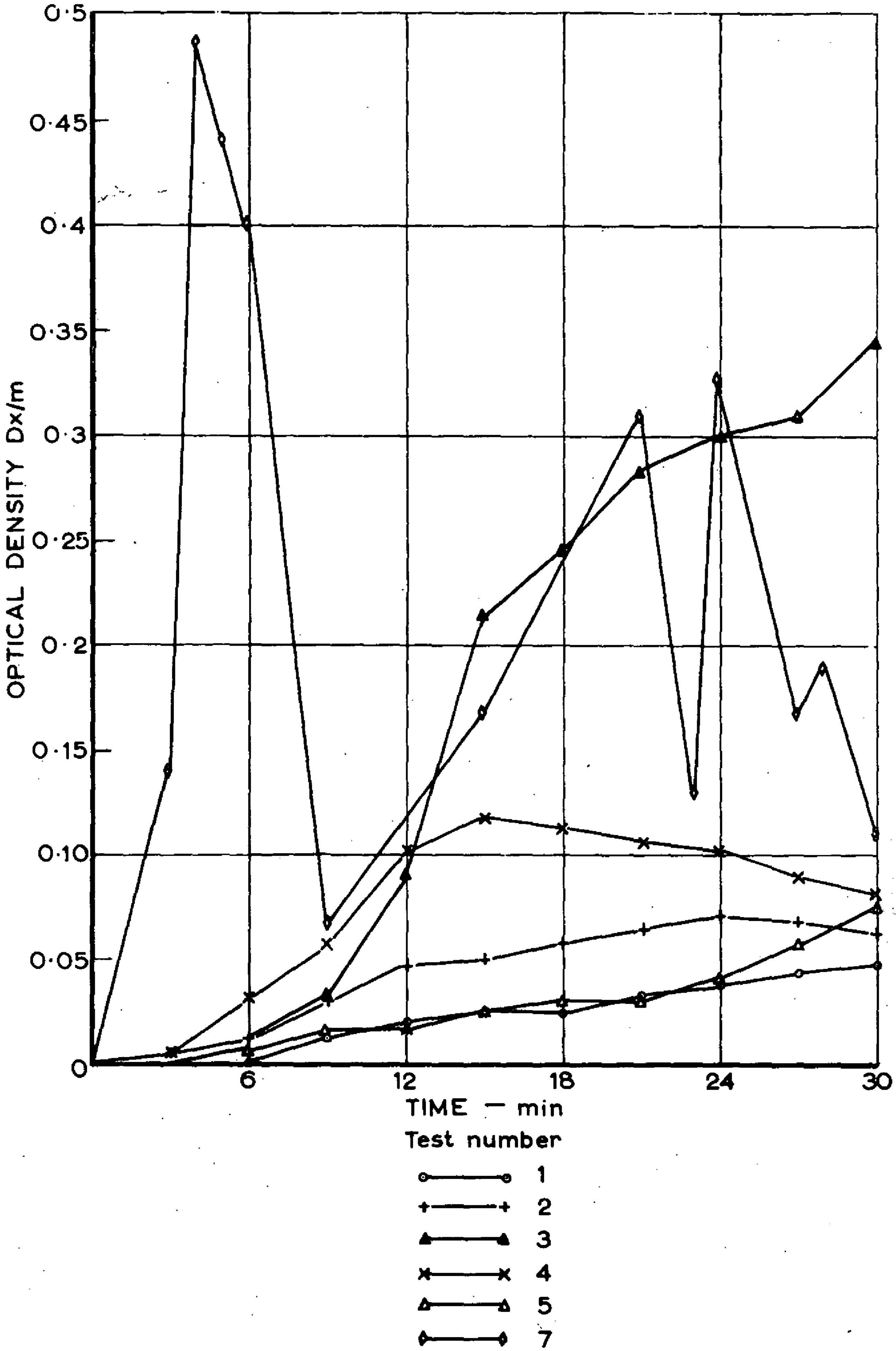

FIG. 11. MEAN SMOKE DENSITY IN TESTS

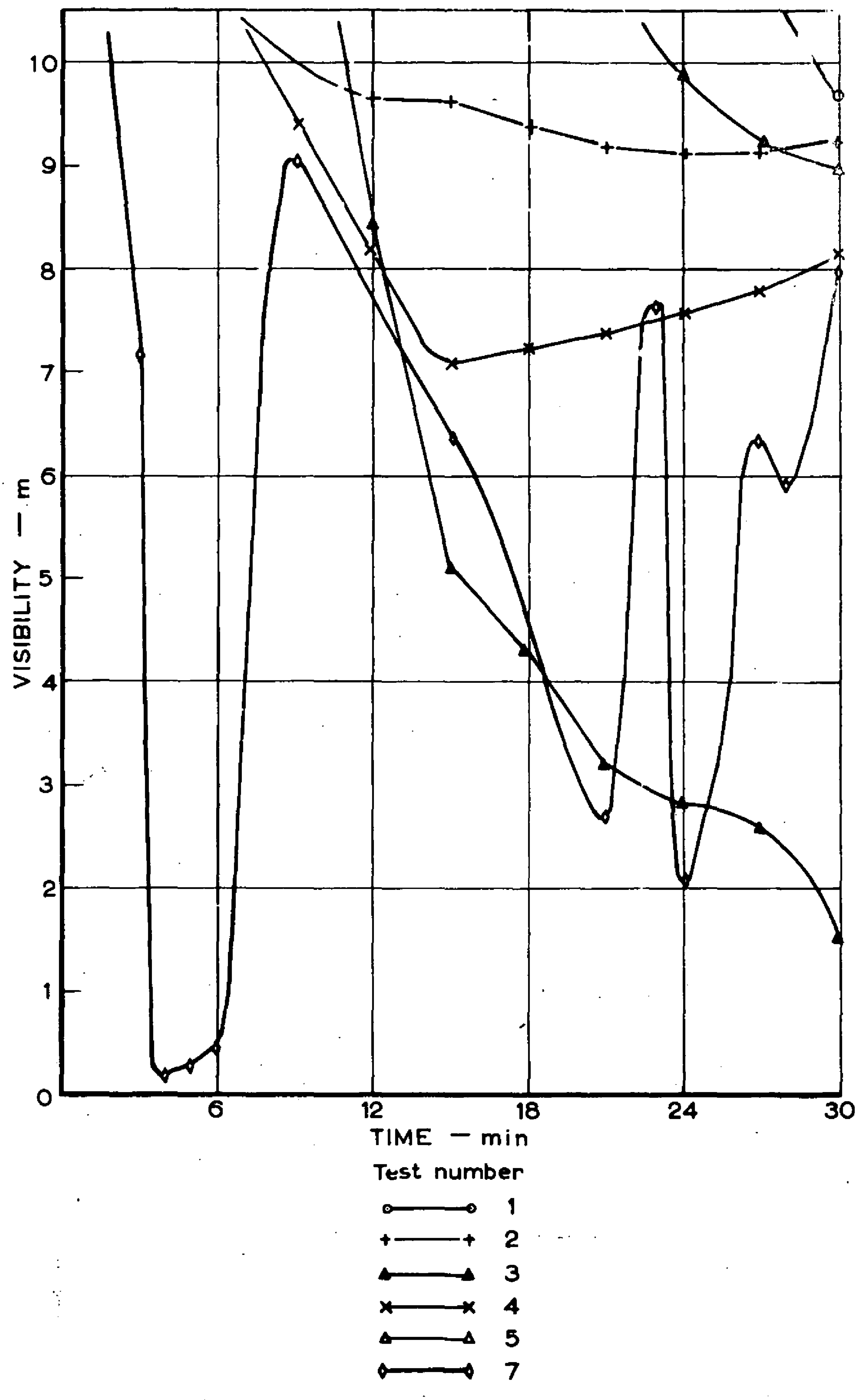

FIG. 12. EFFECT OF DOOR GAPS ON VISIBILITY

1/7351 F.R. 652

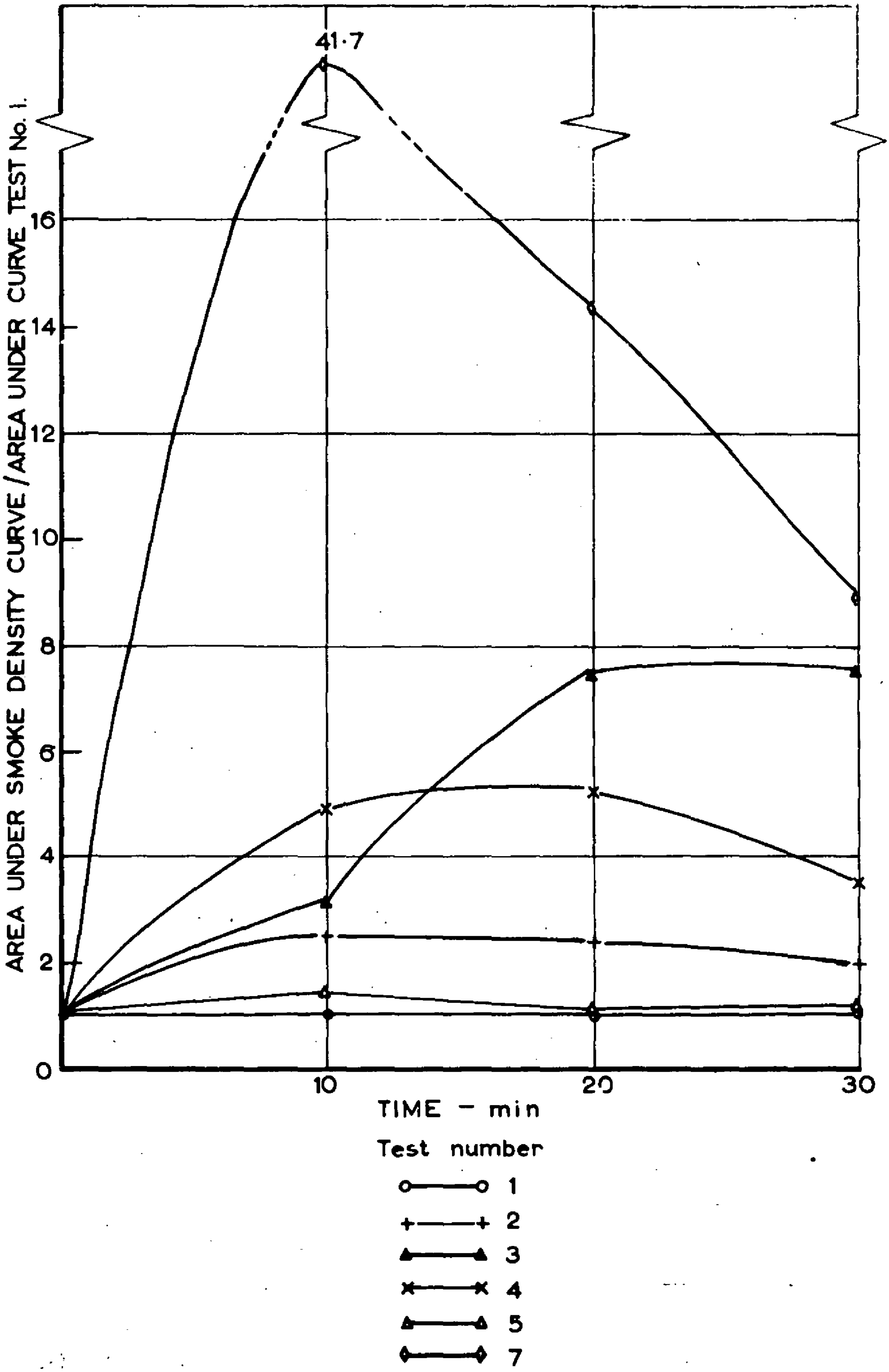

FIG. 13. COMPARISON OF SMOKE PENETRATION IN DIFFERENT TESTS