DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

AND

FIRE OFFICES' COMMITTEE

JOINT FIRE RESEARCH ORGANIZATION

FIRE RESEARCH NOTE

NO. 592

SOOT PRODUCTION BY DIFFUSION FLAMES

PART 3. RATES OF SOOT FORMATION IN FLAMES

by

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March, 1965.

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SUMMARY

An apparatus has been described for the quantitative collection of soot liberated from laminar diffusion flames. This apparatus has been used to measure sooting rates of ethylene diffusion flames under various conditions of dilution.

Plots of sooting rate against ethylene flow have been obtained using nitrogen-oxygen mixtures with oxygen index values over the range 0.135 to 0.405 (13.5 per cent to 40.5 per cent oxygen). Less extensive data have been obtained with 2.8 per cent water vapour present in the nitrogen-oxygen stream. The results have been cross-plotted to show the influence of oxygen index on sooting rate at various fuel flows.

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Introduction and experimental

Part 2[1] of this report dealt with smoke point measurements of laminar ethylene diffusion flames on concentric-tube burners; the effect of varying degrees of dilution with different diluents was described. Part 3 now presents similar, but less extensive, measurements of the sooting rates of these flames at ethylene flows above the smoke points.

The flow system and burner were identical to those described in Part 2[1]. Soot given off by the flames was collected for measured periods of time and weighed on 2.5 cm diameter Whatman GF/A glass fibre discs. The collected soot was determined gravimetrically and the sooting rate was then expressed in terms of mg of soot per minute.

Quantitative collection of the soot was achieved by using the specially designed apparatus shown in Figs 1 and 2. The apparatus was designed to collect eleven replicate samples of smoke in quick succession from a given smoke column by turning the brass ring (A). This ring which was $5\frac{7}{8}$ in in diameter and $1\frac{1}{2}$ in deep, was fitted with a machined central socket. Radial holes (B) drilled in the face of this socket lead to eleven recesses (C) drilled in one face of the brass ring. A glass fibre disc (D), backed with fine metal gauze to act as support, was placed in each recess and held in position by a brass ring (E) which screwed into the recess. Two such disc-holders are shown in the section illustrated in Fig 2. The brass ring (A) was also fitted with a 1 in diameter hole which passed vertically right through it and was situated between two of the recesses; this hole was <u>not</u> joined to the central socket by a radially-bored hole. Smoke passed through this during flame adjustment prior to a sooting-rate determination.

This entire assembly fitted over a machined brass cone (F) which in turn was screwed on to the upper aluminium plate of the burner enclosure. The cone and socket were held together by a spring-loaded ring (G) which screwed down on top of the disc assembly. This clamping ring was fitted with a P.T.F.E. gasket (H).

The brass cone was bored out centrally and was fitted with a radial hole which could be aligned with any of the radial holes of the disc assembly by means of the indexing rod (I) and stop (J). The rod (I) could be fitted into twelve holes (K) in the disc assembly ring, corresponding to the eleven collection positions and the flame adjustment position. The central hole of the brass cone led to a vacuum system (Fig 2) fitted with a water cooled condenser. A vacuum was applied (Fig 2) during soot collection. The differential pressure across the disc and its support amounted to about 15 cm of Hg.

After leaving the burner enclosure the soot was contained as a thin column in a 1 in diameter pyrex tube (L) supported centrally about $\frac{1}{8}$ in below the rim of the exhaust hole. The position of this tube was fairly critical. If it projected too far below the exhaust hole there was extensive recirculation of exhaust gases inside the burner enclosure; on the other hand, loss of soot occurred if the tube was too short. The above arrangement enabled a series of duplicate determinations to be carried out consecutively. At high sooting rates the filter discs were filled in less than 5 secs and under these conditions total collection times of 15 secs or more were achieved by using a number of discs for each determination; there was no appreciable loss of soot during the fraction of a second required to select a fresh disc. Total collection times varied from

4 mins to 15 secs and the soot collected generally weighed between 0.5 mg and 4.0 mg. Reproducibility of results generally lay within ± 0.05 mg.

There was no visible change in flame size or structure during collection or during changeover of the discs.

Results

Sooting rates were determined using nitrogen as diluent. As described in Part 2[1] nitrogen and oxygen flows were metered separately and mixed before being supplied to the outer tube of the burner. All flows refer to conditions of 761 mm pressure Hg, and 22 ± 2°C. The oxygen flow was held constant at 210 cm^3/min and the nitrogen flow was varied to give oxygen indices over the range 0.135 to 0.405. As in Part 2, oxygen index = oxygen flow/(oxygen + nitrogen) flow. All experiments were carried out on Burner A, the dimensions of which are given in Part 2.

Plots of sooting rate (mg/min) against ethylene flow were obtained for a selection of oxygen index values. These results are presented in Figs 3-4. Sooting rates were also measured for an oxygen index value of 0.135, but these values were not all reproducible. This latter effect is probably due to the flame "lift-off" which occurs[1] about this value of oxygen index. The "lift-off" was not entirely reproducible, but is probably associated with some pre-mixing of fuel and oxygen and a consequent decrease in sooting rate; such a decrease in sooting rate appeared to result from the lifting of the flame.

The results of Figs 3 and 4 were cross-plotted to show the influence of oxygen index on sooting rate for various fuel flows (Fig 5).

In a further series of determinations water vapour (2.8 per cent) was added to the nitrogen-oxygen stream. Sooting rates were measured for three oxygen index values (Figs 6 and 7).

Discussion

Extrapolation of the sooting rate against ethylene flow curves to zero sooting rate gives smoke point curves (Fig 8) similar in shape to those obtained in Part 2[1]. The maximum and minimum in the water-free curve occur at different oxygen index values to those obtained from visual smoke-point measurements[1], but the agreement is reasonable.

The shape of the curves in Fig 5, and its dependence on fuel flow, cannot be explained with the information available. Any explanation must be expected to depend on factors such as those outlined in Part 2[1].

Water vapour is once again found to increase smoke points and decrease sooting rates. It is interesting to note that, in the presence of added water vapour, sooting rate increases less rapidly with ethylene flow (Fig 6) than in its absence (Fig 3).

References

(1) McLintock and Rasbash, Part 2 of this Report, J.F.R.O. Fire Research Note No. 582.

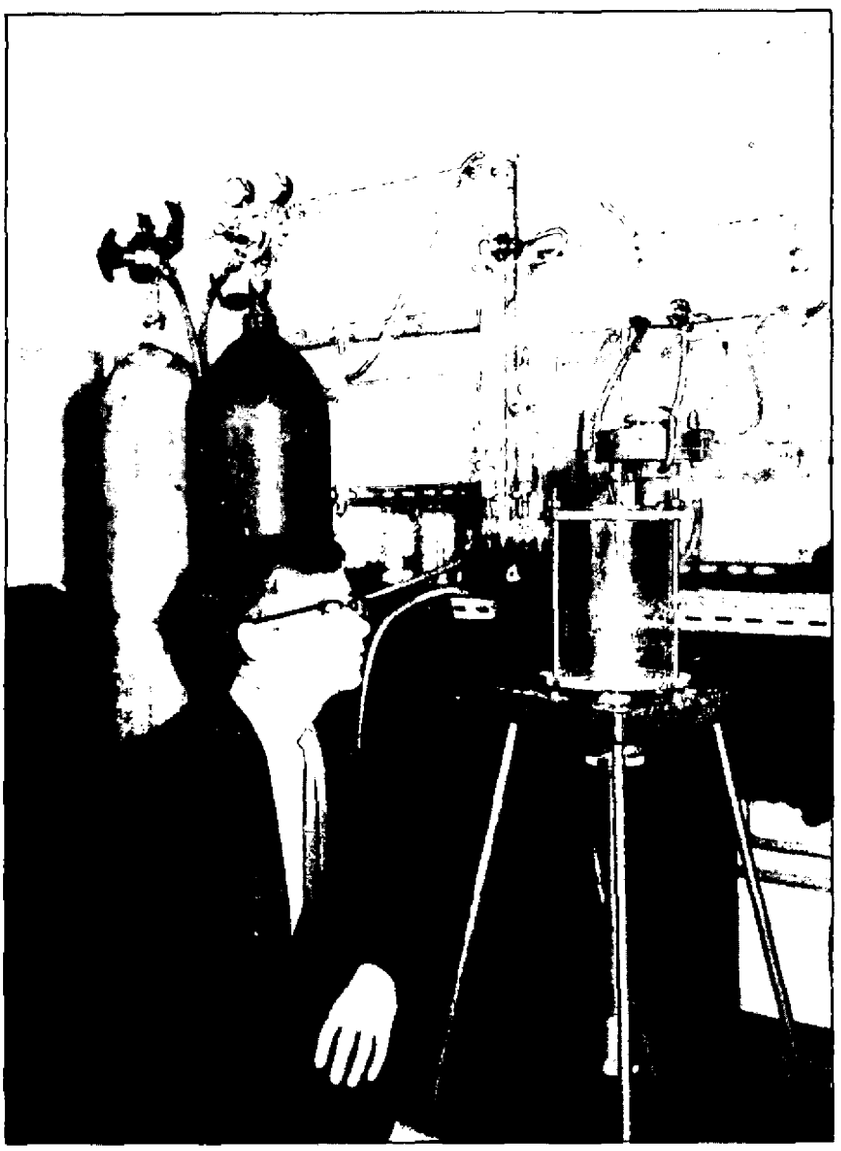


FIG. 1. APPARATUS FOR MEASURING SMOKE FORMATION FROM DIFFUSION FLAMES

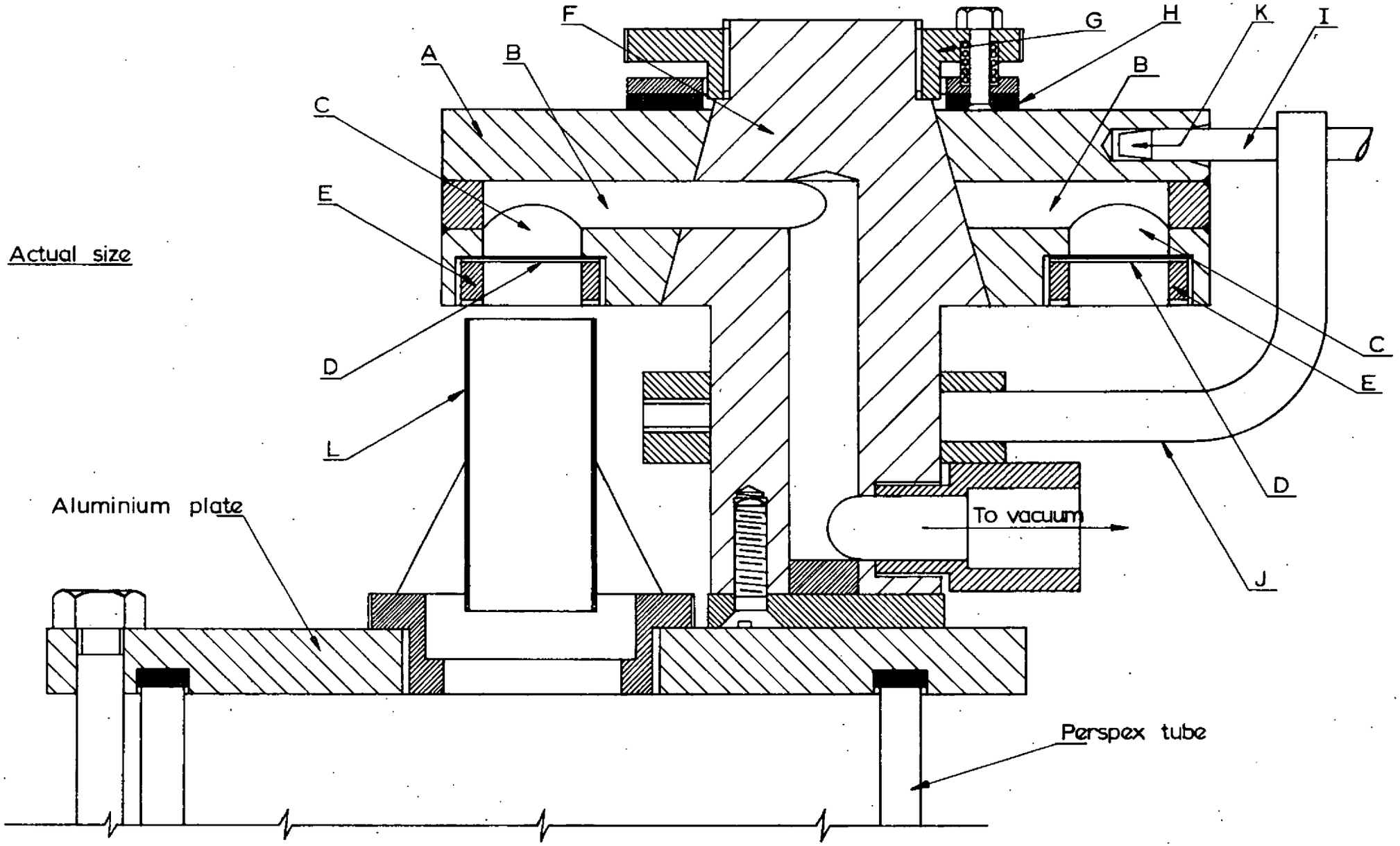
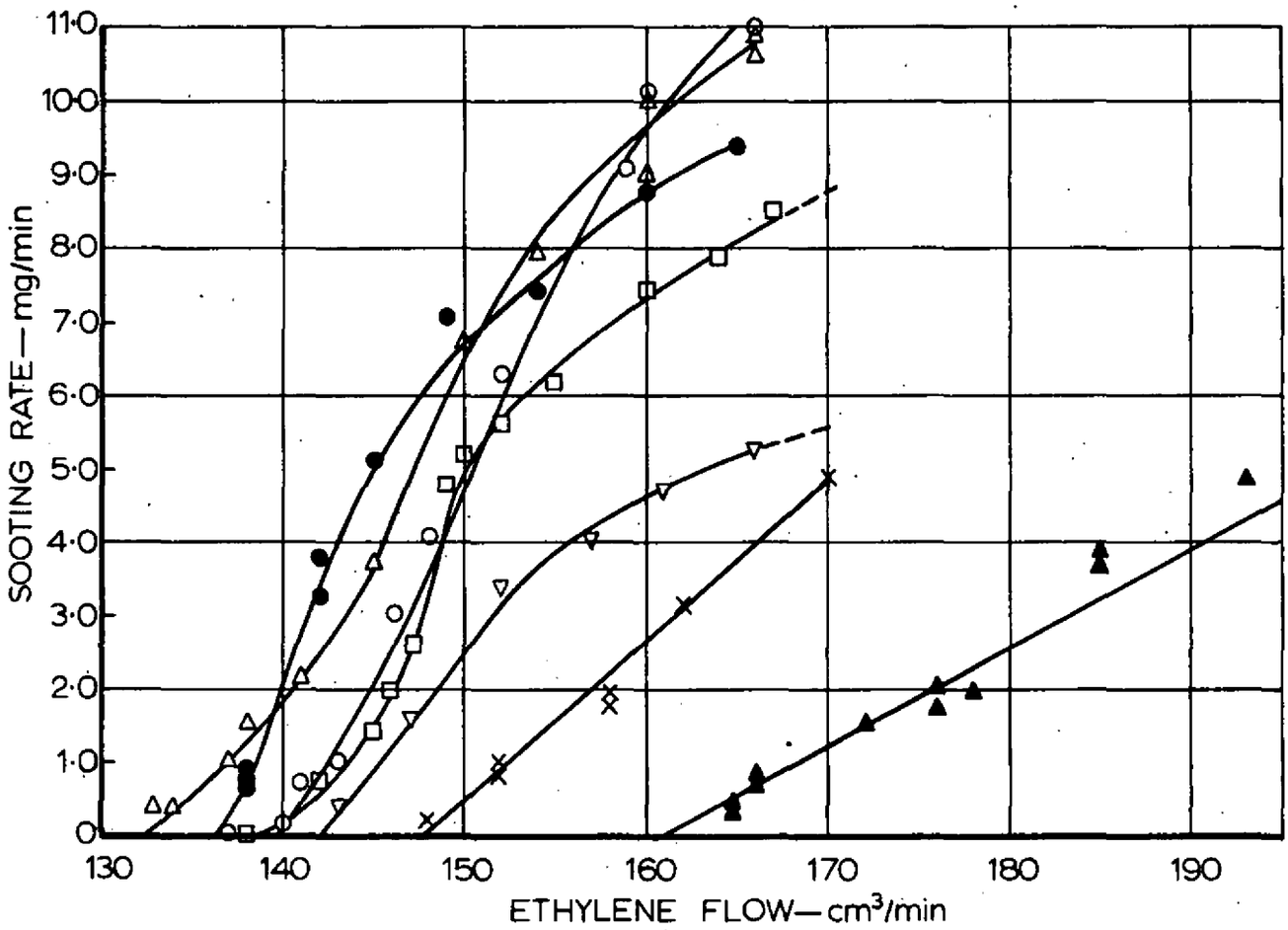


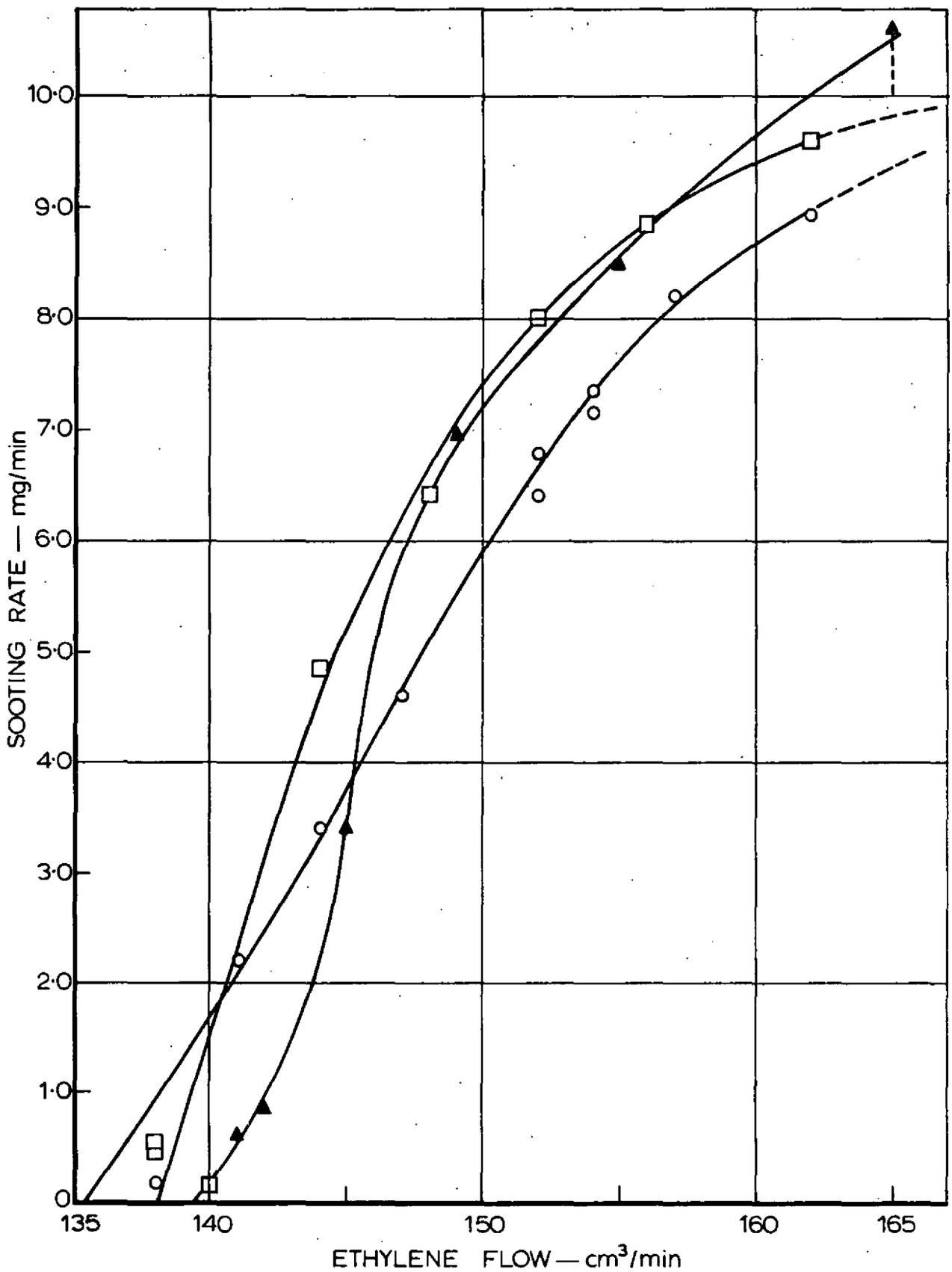
FIG. 2. SMOKE SAMPLING APPARATUS



Nitrogen as diluent
Oxygen flow constant at 210 cm^3/min
Nitrogen flow varying

Oxygen index	Symbol
0·405	△
0·345	●
0·296	o
0·210	□
0·189	▽
0·171	×
0·149	▲

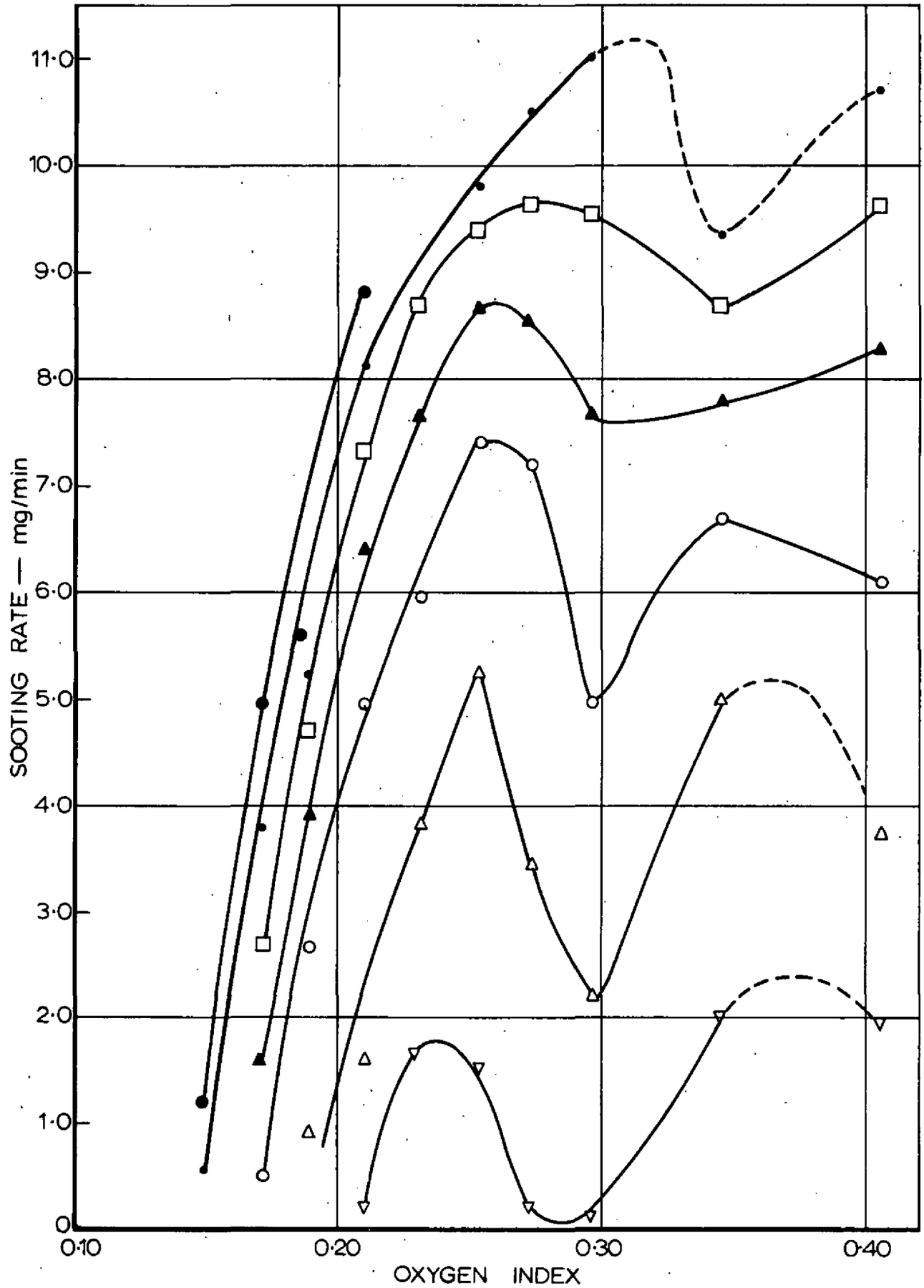
FIG. 3. SOOTING RATE VERSUS FUEL FLOW



Nitrogen as diluent
Oxygen flow constant at 210 cm³/min
Nitrogen flow varying

Oxygen index	Symbol
0·253	□
0·273	▲
0·231	o

FIG. 4. SOOTING RATE VERSUS FUEL FLOW



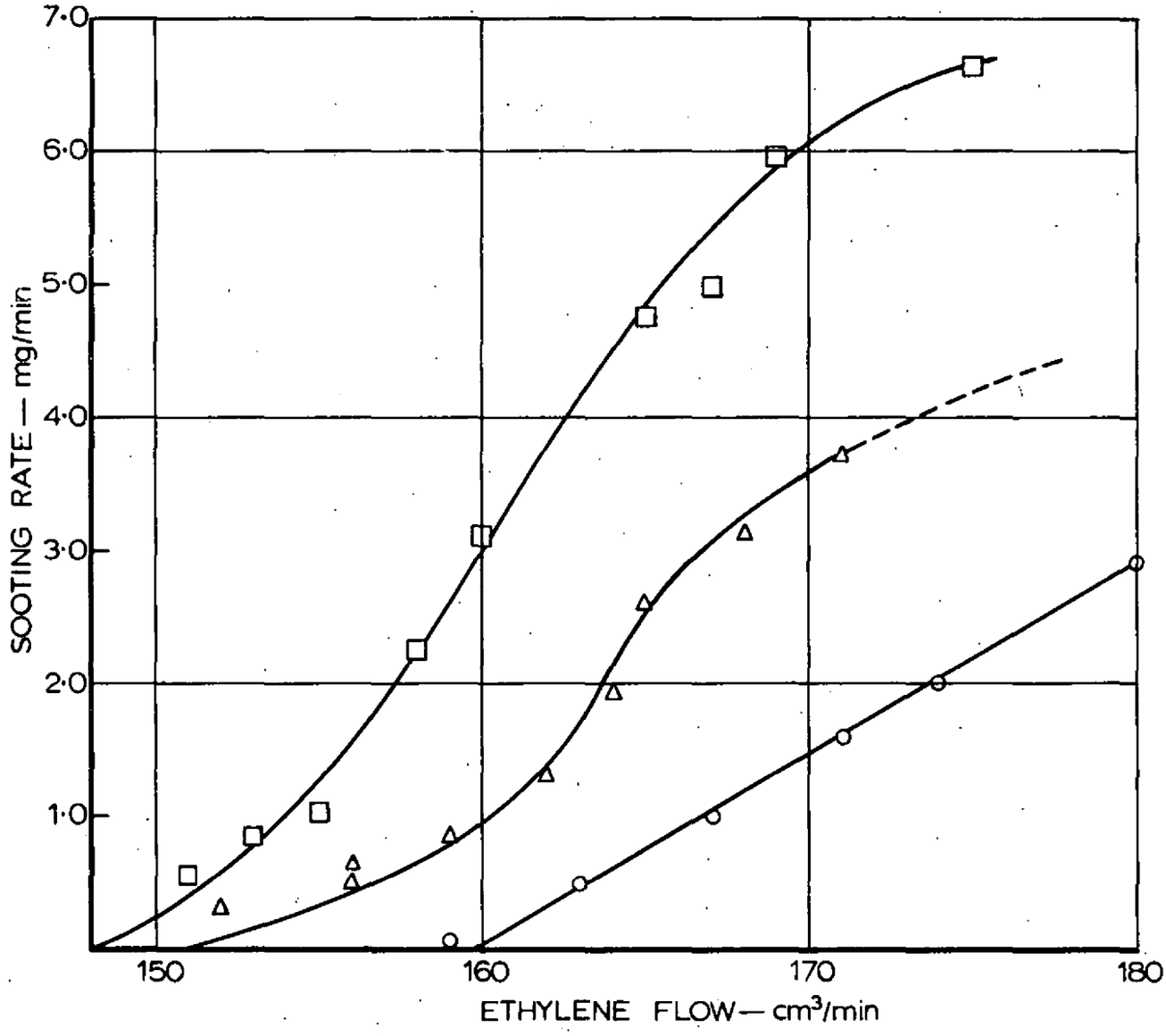
Nitrogen as diluent

Oxygen flow constant at 210 cm^3/min

Nitrogen flow varying

Ethylene flow cm^3/min	Symbol
170	●
165	•
160	□
155	▲
150	○
145	△
140	▽

FIG. 5. SOOTING RATE VERSUS OXYGEN INDEX FOR VARIOUS ETHYLENE FLOWS



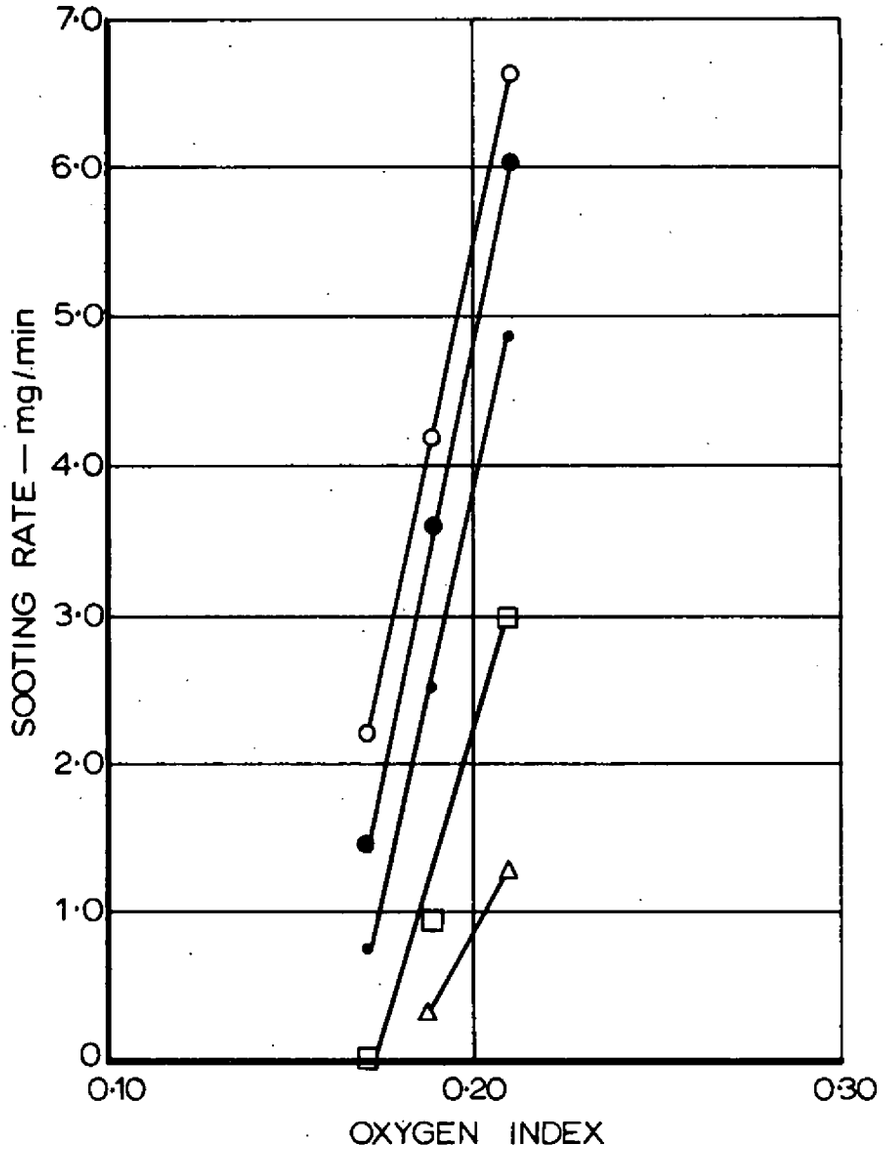
Nitrogen as diluent

Oxygen flow constant at 210 cm^3/min
Nitrogen flow varying

2·8% water vapour present in the nitrogen oxygen mixture

Oxygen index	Symbol
0·210	□
0·189	△
0·171	○

FIG. 6. SOOTING RATE VERSUS FUEL FLOW



Nitrogen as diluent

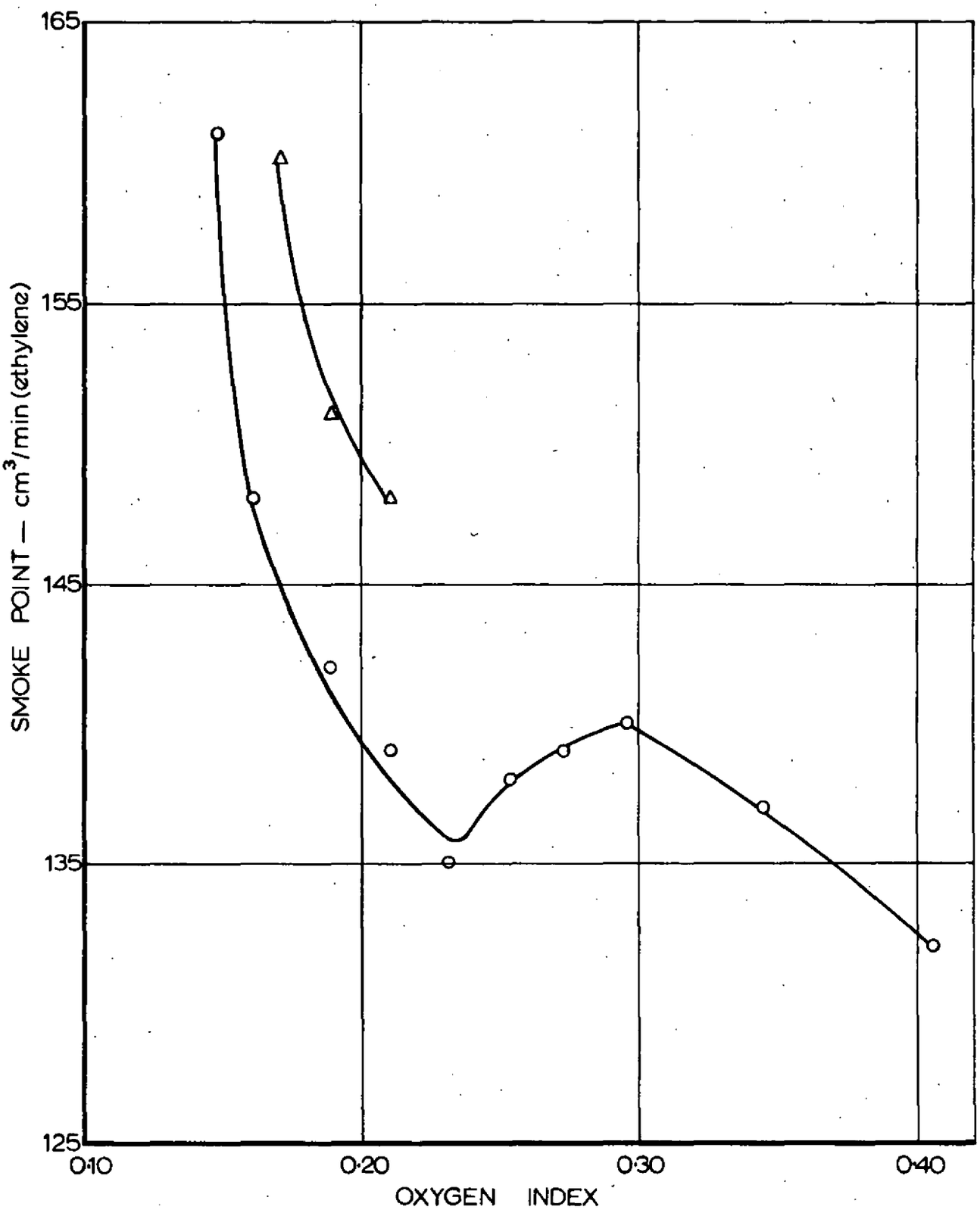
Oxygen flow constant at 210 cm^3/min

Nitrogen flow varying

2·8% water vapour present in the nitrogen oxygen mixture

Ethylene flow cm^3/min	Symbol
175	○
170	●
165	•
160	□
155	△

FIG. 7. SOOTING RATE VERSUS OXYGEN INDEX FOR VARIOUS ETHYLENE FLOWS



Nitrogen as diluent
Oxygen flow constant at 210 cm^3/min
Nitrogen flow varying

Δ — 2·8% water vapour present in the nitrogen oxygen mixture
o — Addition of pure nitrogen

FIG. 8. SMOKE POINT VALUES FROM EXTRAPOLATED SOOTING RATE VERSUS FUEL FLOW PLOTS