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RELIEF OF EXPLOSIONS IN MOVING PROPANE AIR MIXTURES IN A STRAIGHT DUCT CONTAINING OBSTACLES

by

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SUMMARY

The effect of obstacles on the maximum explosion pressure in a vented duct 30 ft x 1 ft^2 has been investigated with propane air mixtures moving with velocities of 10-40 ft/sec.

Explosions in a duct containing an obstacle gave 6-8 times higher pressures than explosions in a similar duct with no obstacles, the highest pressures were obtained when the gas was ignited near the obstacles.

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INTRODUCTION

Work on the venting of explosions in a moving propane-air mixture in an unobstructed duct has been described(2). It was not possible to predict the effects of obstacles with gas mixtures which are moving, and are therefore already turbulent. This paper describes the results of the measurement of pressure and flame speed with moving propane-air mixtures in a duct containing obstacles.

EXPERIMENTAL

Apparatus.

Figure 1 shows the apparatus diagrammatically. AB represents the test section of the duct which consisted of four lengths of 1 ft square section duct 6 ft long. Air was pulled along this duct in the direction AB by means of a spray S operating in a further length of duct BC, the spray being ejected towards the open end C. Flammable gas or vapour was introduced into the air stream within a section AD. The top surfaces of the four 6 ft lengths of duct which made up section AB were completely open and flanged in such a way that the openings could be closed to any degree thus allowing a controllable amount of explosion relief at the top of the duct; a diagram and further details of this design of duct have been given elsewhere(2). During experiments these relief vents were covered either with loose covers weighing 450g/ft^2 of vent area or with covers clamped by magnets to the duct-weighing 570g/ft^2 of vent area.

In all experiments a propane air mixture containing 4.5 per cent of propane was used as the flammable gas. The propane was stored in a vessel of 50 cu.ft capacity at a pressure up to 60 lb/sq.in and was injected into the air stream when required by the use of a solenoid controlled valve. The flow rate was controlled by the pressure regulating valve and gate valve and measured by a venturi - in this way the flow of velocity up to 40 ft/sec could be obtained within the duct. The air flow was indicated by a pitot tube situated on the axis of the duct: this pitot had been calibrated in preliminary experiments against the total air flow along the duct.

Provision was made at a number of points along the duct for the insertion of pressure gauges and flame detecting devices for the measurement of explosion pressure and flame spread respectively. Obstacles were steel strips 1 ft long of an area 13 and 26 in^2 and they were mounted within the duct in vertical position, their centre coinciding with the axis of the duct.

The explosion was initiated and recorded with the aid of a timeswitch which initiated and terminated operations in predetermined sequence.

Experimental programme

Figure 2 shows the duct arrangements used in this investigation. Arrangments a, b, c and d had four vents each, arrangements e, f, and g had two vents each.

RESULTS

The great majority of tests were carried out at speeds of flammable gas mixtures of 20, 30 and 40 ft/sec. Before evaluating any other factors the effect of relative position of ignition obstacle and the nearest vent was investigated. All these tests were carried out with loose panels resting on the vents.

Figure 3 shows the maximum explosion pressures obtained with arrangements a, b, c and d plotted against the speed of flammable gas using an obstacle of 13 in^2 area. In these series the highest pressures were obtained with arrangment c, arrangement d at low speeds of unburnt gas gave maximum explosion pressures of the same order as arrangement c, however, at higher velocities these pressures were substantially lower. In all tests where the ignition was near the obstacle there was one peak on the pressure record, but when ignition was removed from the obstacle, two peaks occurred in some tests and on a few occasions the second peak showed the maximum pressure, this being slightly higher than the pressure shown by the first peak. Some records of the flame travel indicated that this second peak occurred when the flame had reached a position downstream of the obstacle where presumably the gas was particularly turbulent.

Figure 4 shows the maximum explosion pressures plotted against the speed of flammable gas for duct arrangement e, f and g using loose covers; in these arrangements only two vents were used. The highest pressures were obtained when both ignition source and obstacle were between the two vents. Duct arrangements where both ignition and obstacle were opposite the vent were not used since these were expected to produce pressures of the same order as arrangement c described above. In all tests there was one peak when ignition was near the obstacle and two peaks when ignition was removed from the obstacle.

Some tests were carried out using an obstacle of 26 in^2 area with duct arrangements a and c. Figure 5 shows the maximum explosion pressures plotted against the velocity of the flammable gas. Curves shown in broken lines indicated the corresponding results from Fig.3 for an obstacle of 13 in^2.

For a given duct arrangement in most experiments the area of the obstacle did not affect the pressure but there was one exception for arrangement c where at a speed of the flammable gas of 30 ft/sec the larger obstacle gave a substantially higher pressure in one test out of two.

Magnetically held closures were tested using duct arrangement c and the 13 in^2 area obstacle. Figure 6 shows the maximum pressures obtained in these tests plotted against the velocity of flammable gas. The pressures obtained using loose covers with this duct arrangment are shown as a broken line and the magnetically held covers gave slightly lower pressures than corresponding tests with loose covers.

DISCUSSION

In order to assess the effect of obstacles on maximum pressure, the pressures obtained with obstacles need to be compared with the pressure obtained in a duct with no obstacles. Figure 7 shows the maximum explosion pressure obtained in a duct with no obstacle but with ignition and vents as arrangement a or c. Values for the maximum pressure shown in this graph are very similar to those obtained with duct arrangement a. In these experiments the peaks were largely determined by the combustion that took place before the flame reached the obstacle. Thus any effect that might have shown in the later stages of the explosion where a turbulent pocket of gas near the obstacle was burning had little influence on the maximum pressure; this peak apparently was not affected by the presence of an obstacle when this was some distance from the flame front. The small difference could be accounted for largely by the use of heavier covers.

With vents spaced every 6 diameters the highest pressures were obtained when the obstacle, the ignition source and the vent were in close proximity e.g. arrangement c. Under these conditions the maximum pressure was about 6-8 times greater than when no obstacle was present. It seems that this may be due to particularly high rates of combustion as a result of the interaction of effects caused by the obstacle and the vent. Thus the presence of the igniting source near the obstacle insures that a high rate of combustion occurs very soon after ignition and before any vents are open; this occurred with both arrangements c and d. However, greater pressures were obtained with arrangement c even though ignition occurred very close to the vent. This increase in explosion pressure appears to have been caused by further disturbance to the flame fronts caused by the opening of this vent; evidence for this explanation was shown by the sudden increase in the rate of pressure rise immediately before the peak pressure occurred. Further evidence is furnished by the lower pressure obtained when magnetically held covers were used; these experiments gave lower peak pressures without a sudden increase in the rate of pressure rise in spite of a possible delay in opening caused by the magnetic forces holding the covers. This suggest that the delayed opening resulted in a smaller disturbance of the flame front.

When the vents were spaced 12 ft apart the highest pressures were obtained with ignition taking place between the two vents. It appears that with large distances between vents the inertia of the gas between ignition and nearest vent had sufficient effect to outweigh any advantage to be gained from not disturbing the flame fronts by opening the vents in close proximity to the flame front.

The present work does not give conclusive information on the effect of increasing the area of the obstacle, but there is evidence that this may cause a substantial increase in pressure at higher speeds of flammable gas.

Data presented in this paper in conjunction with (2) may be applied directly to ducts containing obstacles within the range of velocities tested. Such vent systems could be formulated assuming no greater obstacles are present than the 12 in^2 area strip. It has been shown in (1) that larger obstacles or their equivalent are rarely present in duct systems.

It appears that for commercial ducts an upper limit of 2 lb/in^2 for maximum explosion pressure could not be exceeded without damage(2). In order to ensure that such pressures are not exceeded, a duct similar to that employed in this investigation would require vents having an area equal to the cross-sectional area of duct and spaced every 6 ft. No vents should be placed close to an obstacle. More general application of this data in conjunction with the work described in references (1) and (2) will be discussed elsewhere.

ACKNOWLEDGMENT

Mr. Galvin who assisted in experimental work.

REFERENCES

(1) RASBASH, D. J. and ROGOWSKI, Z. W. Relief of Explosions in Duct Systems. Inst. Chem. Engrs. Symposium on Chemical Process Hazards with Special Reference to Plant Design, March 1960.

(2) ROGOWSKI, Z. W. and RASBASH, D. J. Relief of Explosions in Propane Air Mixtures Moving in a Straight Unobstructed Duct. Inst. Chem. Engrs. Symposium on Chemical Process Hazards with Special Reference to Plant Design, April 1963.

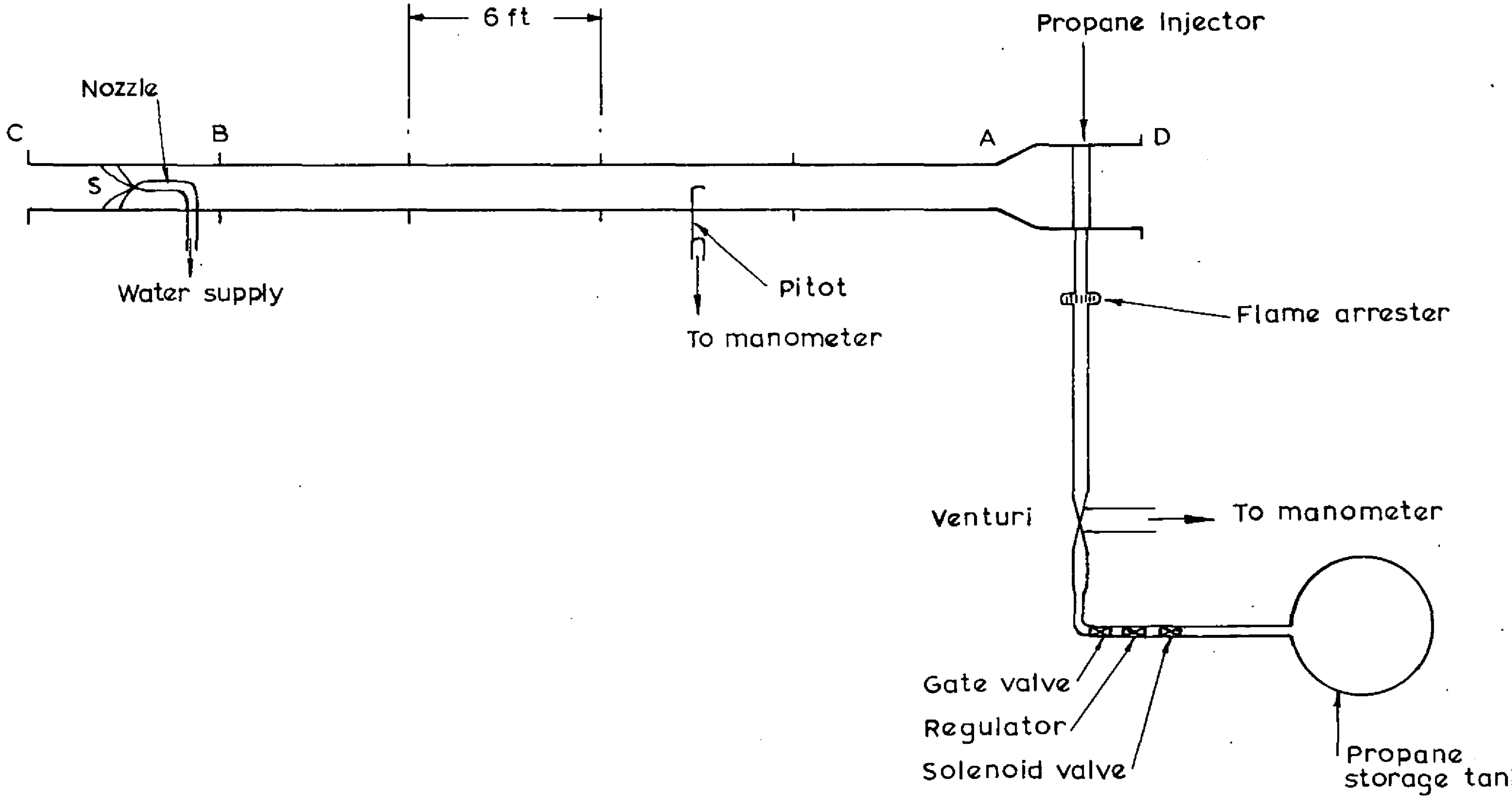

FIG.1. DIAGRAM OF APPARATUS

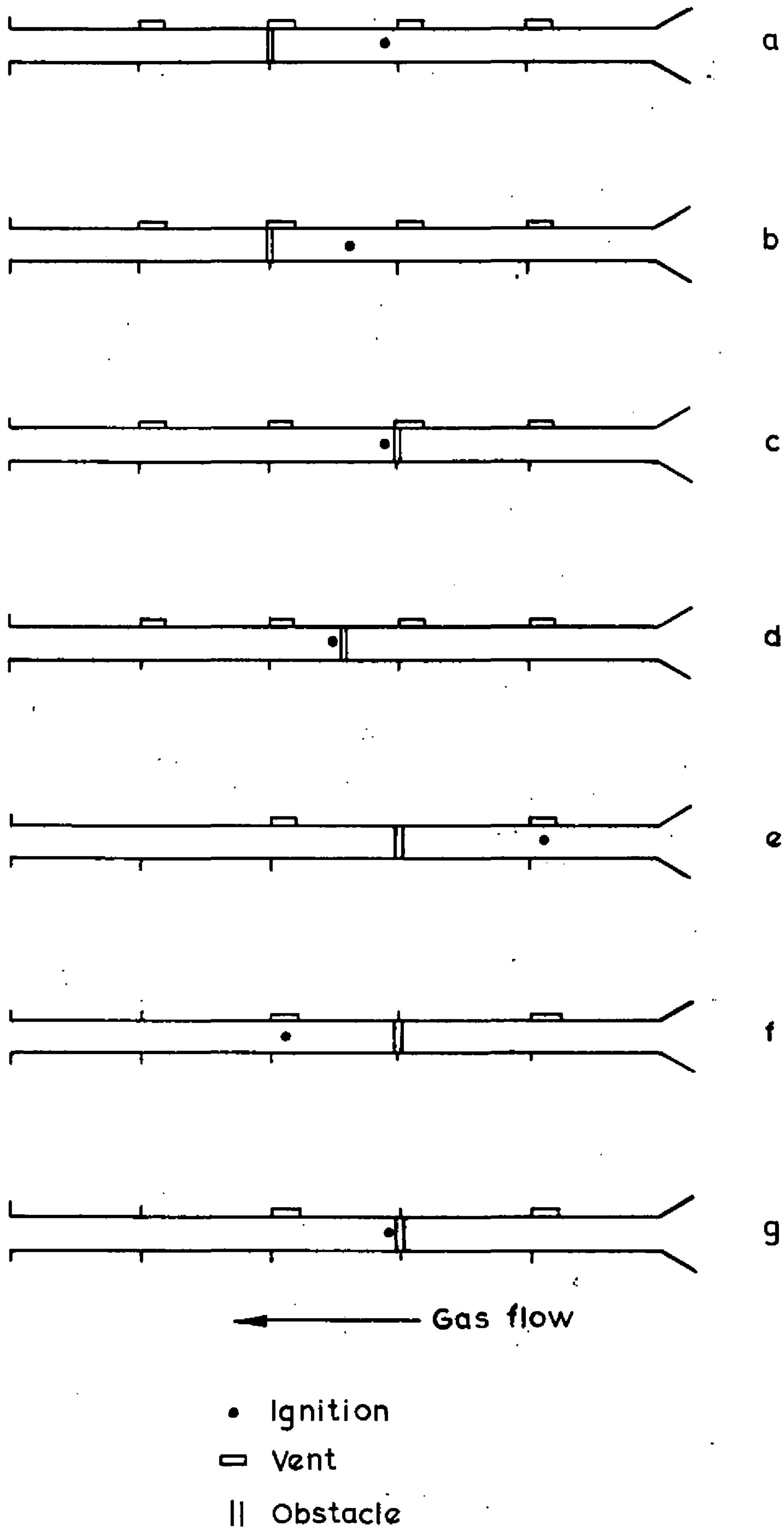

FIG.2. DUCT ARRANGEMENTS USED

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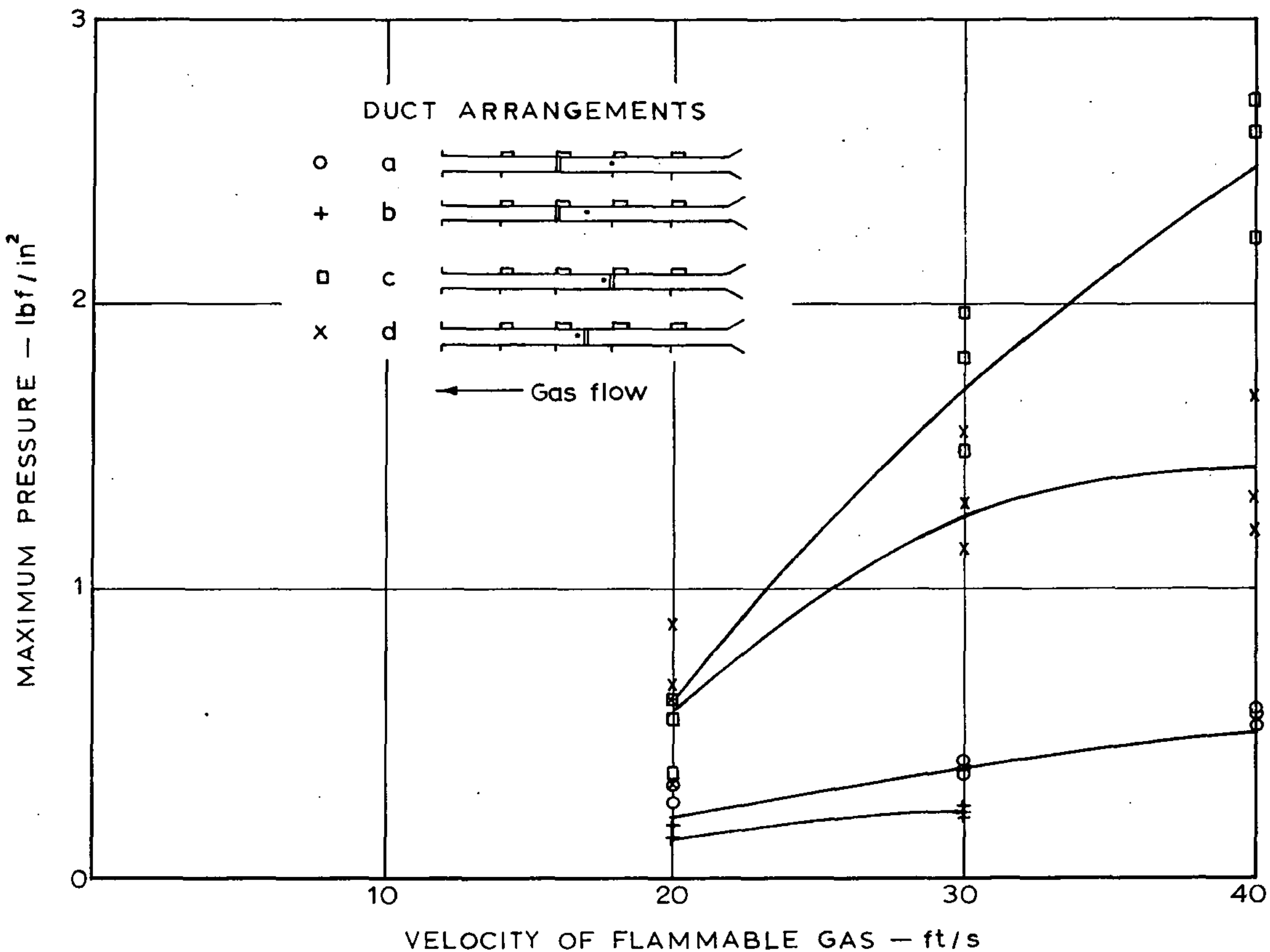

FIG. 3. EFFECT OF THE POSITION OF IGNITION AND OBSTACLE IN RELATION TO VENT ON THE MAXIMUM PRESSURE

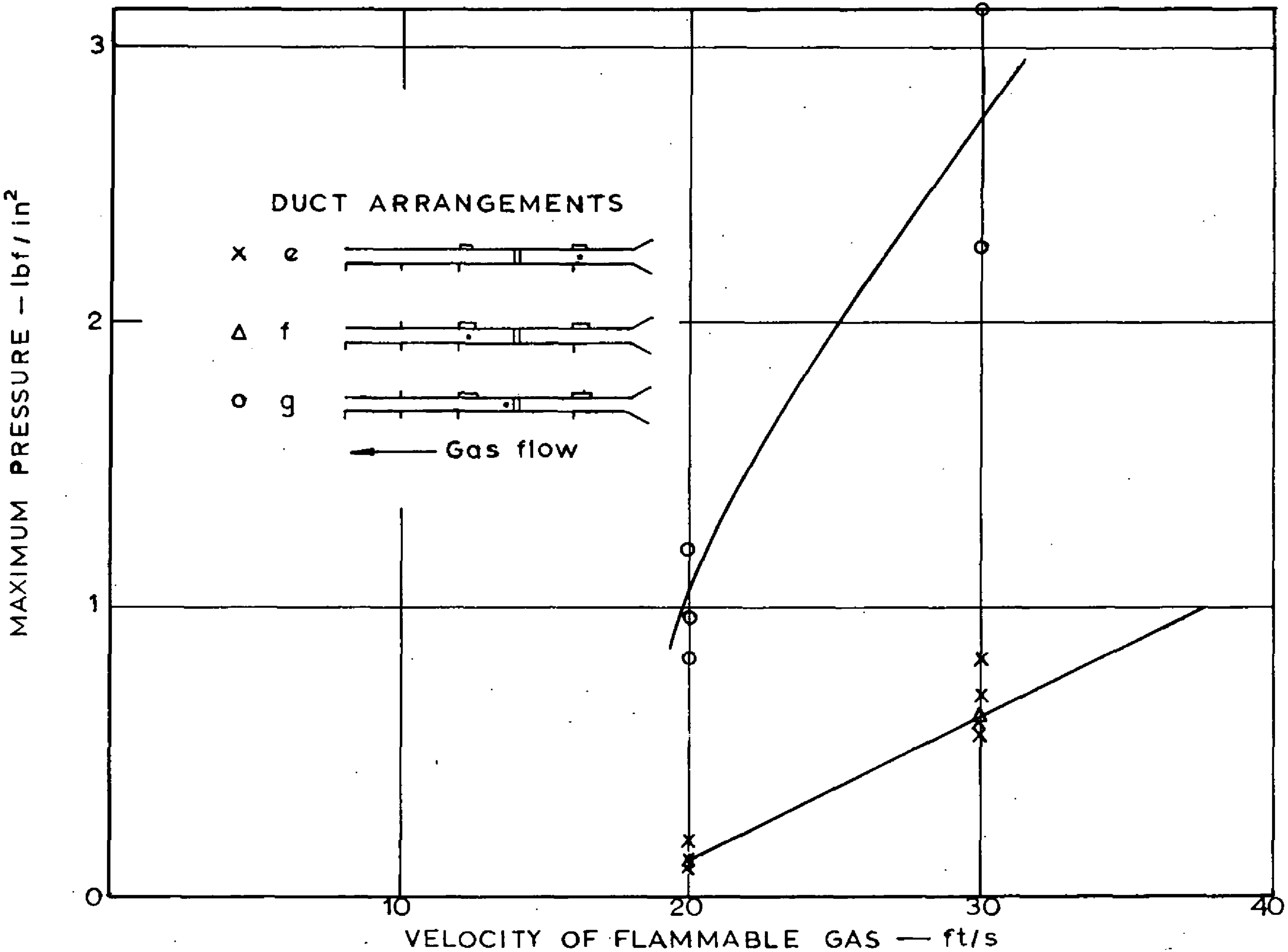

FIG. 4. EFFECT OF THE POSITION OF IGNITION AND OBSTACLE IN RELATION TO VENT ON THE MAXIMUM PRESSURE

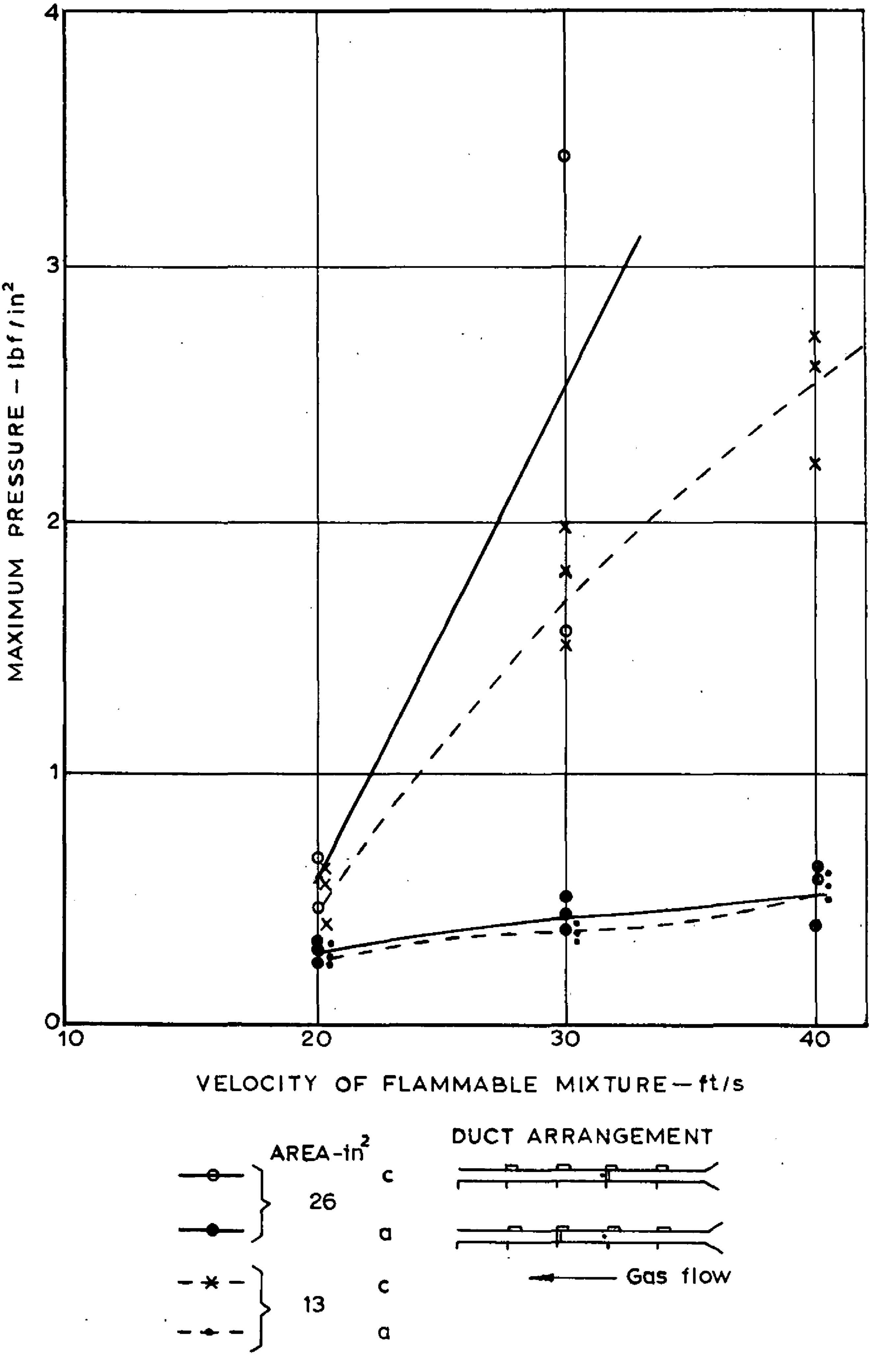

FIG.5. EFFECT OF THE AREA OF THE OBSTACLE ON THE MAXIMUM PRESSURE

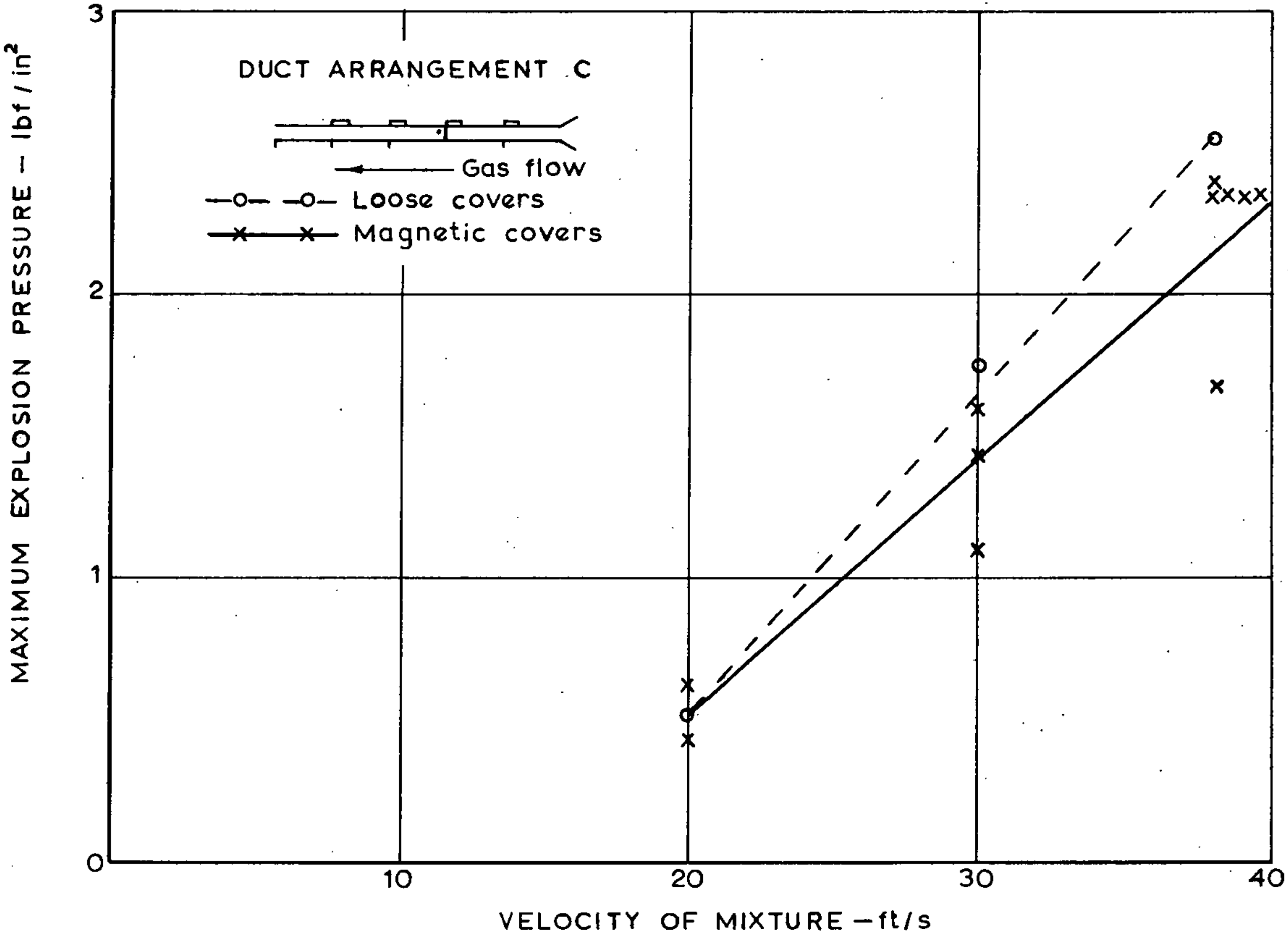

FIG.6. EFFECT OF MAGNETIC COVERS ON THE MAXIMUM PRESSURE

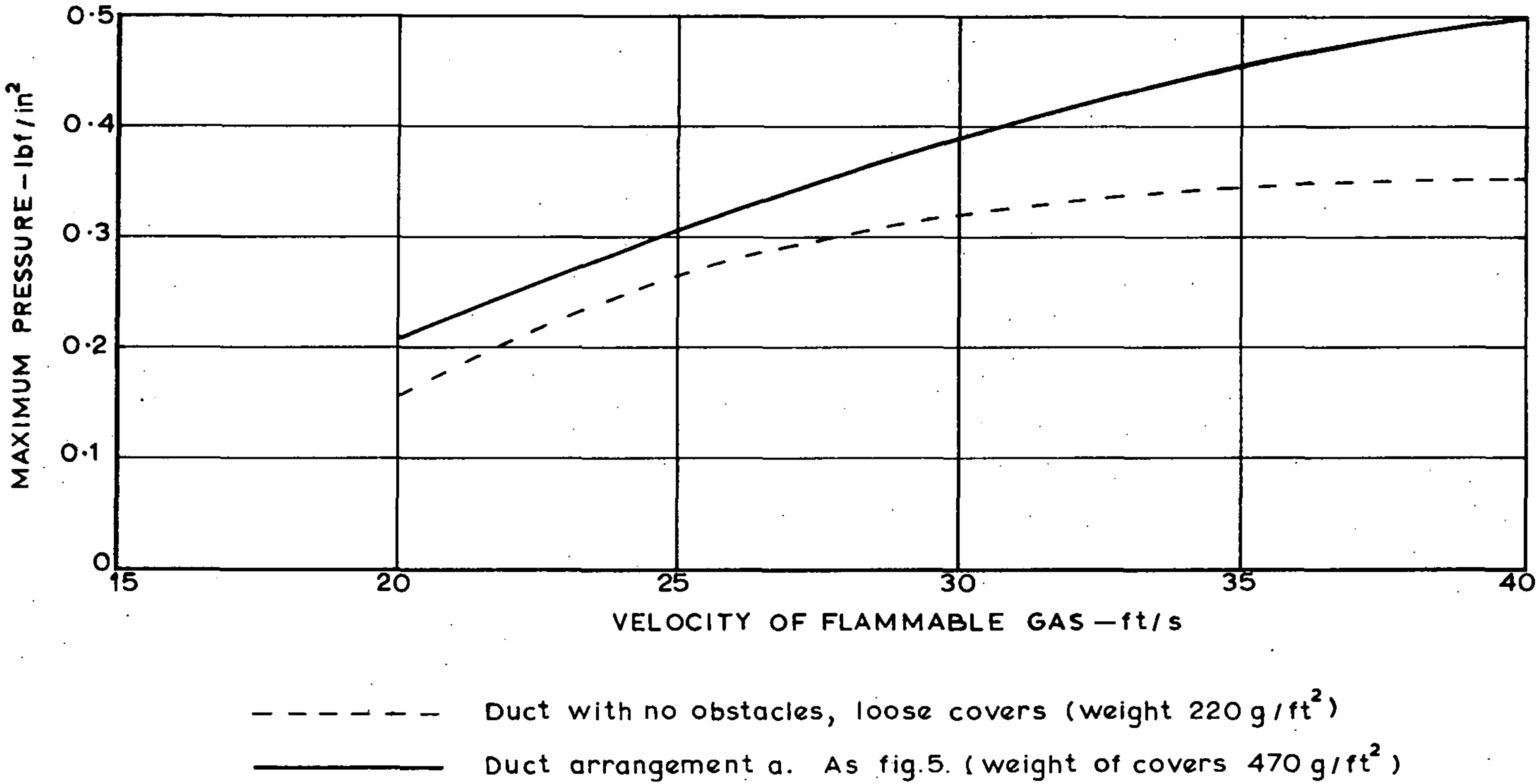

FIG.7. EFFECT OF OBSTACLES ON EXPLOSION PRESSURES