THE USE OF RETICULATED METAL FOAM AS FLASH-BACK ARRESTOR ELEMENTS

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A reticulated metal foam has been evaluated as a medium for quenching detonations in high pressure acetylene and low pressure oxy-acetylene lines. The material has successfully quenched detonations in static acetylene at initial pressures up to 2.6 MN/m^2a and static oxy-acetylene at initial pressures up to 450 KN/m^2a in 12.7 mm bore pipe. It appears that with the grade of material used, the ability to successfully quench detonation is a function of the flow resistance and thickness of the material.

INTRODUCTION

A variety of means have been proposed to arrest detonation in the gas carrying passages of equipment employing explosive gases. Arrestors may be required to prevent the spread of decomposition in the gas phase under a variety of conditions which can give rise to anything from slow deflagrations to detonations. Most arrestors consist of a porous solid mass having apertures to allow passage of gas but which are sufficiently narrow to quench flame if an explosion should occur. Arrestors utilising such materials as perforated metal sheeting, wire gauze, and crimped metal ribbon, may have a low flow resistance whereas those utilising such materials as sintered metals, compressed wire, and inert powder, may have a high impedance to flow. In order to quench detonations in gaseous mixtures an arrestor is required which has mechanical strength, resistance to heat, and very small gas passages. Such arrestors normally have a high resistance to flow which is a great technical and economic disadvantage under normal circumstances. Thus, there is an industrial requirement for an arrestor element with as varied an application and with as low a flow resistance as possible.

Recently a new material in the form of a metallic foam has been developed by Dunlop Co Ltd. It has a uniform, three dimensional, open duodecahedral cellular structure which gives it rigidity and strength. When uncompressed this material has a porosity of approximately 95%. It has been manufactured from various metals and alloys and the pore size has been varied whilst the overall density has been kept constant. The material has a relatively low resistance to fluid flow and can be compressed to 20% of its initial volume whilst retaining its open structure. These properties suggested that the material would give a very good performance as a flame arrestor.

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Although flame arrestors based on the material[1,2] have proved satisfactory for flame velocities up to 200 m/s the designs have not been suitable for incorporation in high pressure gas lines for the purpose of arresting detonations. As a large part of the work of this laboratory concerns the safe storage, transport and use of acetylene, this new material has been assessed as an arrestor element capable of quenching detonations in high pressure acetylene and oxy-acetylene. Oxy-acetylene has the very small quenching diameter of 0.12 mm[3] and hence very small gas passages are required. Terminal pressures developed when oxy-acetylene mixtures detonate have been reported[4] as fifty times the initial pressure and thus high mechanical strength is required. In addition the ignition temperature of 297°C [5] is low and hence it is necessary to prevent hot combustion products coming into contact with unreacted gas. Therefore, it was necessary not only to determine the thickness of material required to quench detonation but also the additional thickness required to cool the combustion products below this ignition temperature.

EXPERIMENTAL

Materials

A 70/30 nickel-chromium metal foam, supplied by the Dunlop Co in the form of 11 and 16 mm thick sheets having 80 pores per linear inch, was cut into discs 31 mm in diameter. Sufficient of these were pressed hydraulically into lengths of 31.0 mm i.d. and 38.0 mm o.d. steel pipe to completely fill them at a pressure of 78 MN/m^2g. The foam density was increased from 0.52 kg/l to 2.6 kg/l. Flow resistance was shown to be related to the thickness of material (see Fig 1).

Arrestor (Fig 2)

The arrestor was designed for use with 12.7 mm i.d. and 22.2 mm o.d. cold drawn seamless steel pipe to simulate the conditions used in acetylene compressing stations. Each pipe containing metal foam was designed to fit inside a 38.1 mm i.d. cylindrical housing supported by perforated plates either side. The 38.0 mm diameter support plates were made from 6.4 mm thick steel and were perforated with eight 6.35 mm diameter holes equispaced around a 11.1 mm radius circle. Plates with an additional 3.2 mm diameter centrally positioned hole were also used. Gas seals were affected by fibre washers and the core and support plates were held in position by end plugs terminating in 12.7 mm i.d. and 22.2 mm o.d. pipes. Cubbage[6] has shown that when detonation waves pass into a wider pipe there is an initial reduction of flame speed, hence a conical expansion section was incorporated into each end plug.

Velocity Measurements

A Venner TSA 249 twenty channel timer with micro-second resolution and nine decades per channel was used for velocity measurements. This is designed such that all twenty channels can be started by a single pulse and that each channel can be stopped subsequently by a negative-going pulse of amplitude 2 to 50V. The flame detectors consisted of threaded plugs carrying an 8 mm length of 0.13 mm diameter pure tin wire supported between insulated steel electrodes and the timer trigger pulses were derived from the melting or breaking of these tin bridge wires by the decomposition flame.

Procedure For Explosion Tests

A schematic diagram of the apparatus used for acetylene explosion tests is given in Fig.3. The arrestor was coupled to 4.25 m of 12.7 mm i.d. and

22.2 mm o.d. cold drawn steel pipe upstream of the arrestor and to 2.4 m of similar pipe downstream. Eight bridge wire flame detectors were fitted upstream of the arrestor and three downstream. The pipe was closed downstream by bursting discs and upstream by a firing plug. Pre-calibrated aluminium bursting discs enabled an estimate to be made of the maximum pressure generated in the firing tube downstream of the arrestor.

The apparatus was evacuated, filled and flushed with low pressure acetone-free acetylene, and then filled with high pressure acetylene generated from a liquid acetylene reservoir. After venting to the required pressure the firing pipe was isolated and decomposition of acetylene initiated by the discharge from a 100 mFd condenser, charged to 2000V (200J), through a tungsten wire helix.

The assembly used for tests with oxy-acetylene was similar to that used for acetylene and is represented schematically in Fig.4. The required mixtures were obtained by the simultaneous release of oxygen and acetylene at the same pressure, from variable capacity reservoirs through a mixing chamber into the firing pipe. The composition used was 48% acetylene with 52% oxygen (g.c. analysis, 3% squalane on alumina at -20°C, gave 48.1% acetylene and 51.9% oxygen) which is reported[4] to have the highest detonation velocity.

RESULTS AND DISCUSSION

Acetylene

From the velocity measurements, the amount of heating and the distribution of soot, it was evident that detonative decomposition of acetylene was established in the firing pipe upstream of the arrestor in every experiment. The criteria used for successful quenching of detonation were:-

1. No evidence of heating or sooting downstream of the arrestor.
2. Bursting discs intact.
3. No broken probe wires downstream of the arrestor.

The experimental conditions are summarised in Table 1 and the physical effects of detonation are summarised in Table 2.

TABLE 1 - Conditions for high pressure acetylene experiments

Core Thickness (±0.5mm)	Firing Pressure (±35kN/m²a)	Average flame velocity between probes 3-8 (±90m/s)	9-10 (±1m/s)	10-11 (±1m/s)	Observations of flame downstream of arrestor
13	2350	1740	110	178	Deflagration going to detonation[1]
16	2350	1710	0	0	No flame
19	2620	1840	89	184	Deflagration going to detonation
30	2620	1810	51	0	Deflagration dying out
30	2620	1750	0	0	No flame
16 + 10	2620	1800	51	0	Deflagration dying out
19 + 10	2620	1810	0	0	No flame
40[2]	2620	1800	0	0	No flame
40[2]	2620	1810	0	0	No flame
40[2,3]	2770	1800	0	0	No flame

1. Coupling adjacent to bursting disc holder shattered and firing pipe belled.
2. No central perforation in support plate.
3. Filled with 50% pre-compressed material.

TABLE 2 - Physical effects of detonation of high pressure acetylene

Core Thickness (±0.5mm)	Flow resistance[1] before (±2kN/m²g)	Flow resistance[1] after (±5kN/m²g)	Set-back of material 2mm from edge (±0.5mm)	Set-back of material centre (±0.5mm)	Pressure on relief disc (±0.1MN/m²g)
13	12	-	Disintegrated		>11.0
16	15	660	6.0	9.0	5.9
19	16	50	7.0	10.0	>11.0
30	26	72	7.5	10.0	7.0
30	30	590	9.5	13.5	2.6
16)	12	27	6.0	8.5	10.3
10)	6	30	0.0	4.0	
19)	16	174	7.0	10.0	6.9
10)	10	1140	0.0	0.0	
40[2]	32	150	10.3	10.3	2.6
40[2]	32	125	10.5	10.5	2.6
40[2]	35	170	10.8	10.8	2.8

1. Flow rate of 5000 1/h of free air at 15°C.
2. No central perforation in support plates.

In all but one case (13 mm) the metal foam surface incident to the flame front was sintered and set-back 6 to 10 mm. Where support plates with a central perforation were used there was an additional central hemispherical crater (8 mm in diameter and 3 mm in depth) in line with the central hole in the support plate and in some cases this resulted in complete penetration of the material. From this observation it was concluded that the surface of the arrestor element should not be exposed to the flame front along the central axis of the pipe. Radiographs taken at right angles to the axial plane showed an increased compression of the metal foam and a slight outward bulge of the core away from the direction of the flame. The flow resistance of each arrestor was 2 to 4 times greater after the explosion except for the arrestors that completely quenched detonation where the flow resistance was more than twenty times greater. This was probably due to sintering and to the core being sufficiently thick for no holes to be blown through it.

A 13 mm core, subjected to detonation at an initial line pressure of 2350 kN/m²a, disintegrated and a deflagration, running into detonation, was initiated downstream of the arrestor. At a similar line pressure a 16 mm thick core completely quenched detonation but the condition of the bursting discs indicated a terminal pressure of 5.9 MN/m²a. Cores of 19 mm or greater thickness were tested at an initial line pressure of 2620 kN/m²a. The 19 mm core quenched detonation but a rapidly accelerating deflagration was initiated downstream of the arrestor and the bursting discs failed. One 30 mm core completely quenched detonation and another quenched detonation but allowed a rapidly decaying deflagration to be initiated downstream of the arrestor. An arrestor fitted with a 19 mm core and a 10 mm core successfully quenched detonation although the bursting discs were subjected to a pressure of 6.9 kN/m²g. A 16 mm core with a 10 mm core downstream also quenched detonation but deflagration was initiated downstream of the arrestor and the bursting discs were subjected to a pressure of 10 MN/m²g.

Two 40 mm elements were tested using support plates with no central hole and they both successfully quenched detonation. A further 40 mm pipe was filled with sufficient 50% pre-compressed metal foam to give the same final packing density as the other 40 mm cores. This also completely quenched detonation. These results suggest that an element 40 mm thick will completely quench detonation of acetylene at pressures up to 2600 kN/m^{2}a. Such an element would have a flow resistance of 32 kN/m^2 at an air flow of 5000 1/h whereas the lowest measured flow resistance in the best commercial arrestors of comparable performance tested by the Home Office is 60 kN/m^2 at a similar flow rate.

Oxy-acetylene

The criteria for the successful quenching of detonations in oxy-acetylene mixtures were slightly different from those used for pure acetylene. One of the Home Office requirements of an arrestor designed for use with oxy-acetylene mixtures is that it must quench at least six successive detonations. Consequently in this work each arrestor was not considered successful until it had quenched six successive detonations and had sustained no mechanical damage. The results using a 48% acetylene-52% oxygen mixture are summarised in Table 3.

TABLE 3 - Conditions for static oxy-acetylene experiments

Core Thickness (±0.5mm)	Firing Pressure (±4kN/m^{2}a)	Flow Resistance[1] (±2kN/m^2)	Average flame velocity between probes 2-8 (±100m/s)	9-10 (±250m/s)	10-11 (±100m/s)	Observations
13	200	10	2720	0	0	Detonation quenched
13	260	11	2700	2650	2840	Detonation not quenched
30	260	26	2760	0	0	Detonation quenched
30	327	24	2780	2700	2800	Detonation not quenched
40	327	34	2780	0	0	Detonation quenched
40	392	32	2800	2640	2750	Detonation not quenched
50	392	38	2810	0	0	Detonation quenched
50	392	40	2850	0	0	Detonation quenched

1. Flow rate of 5000 1/h of free air at 15°C.

No sooting or mechanical damage was observed after any experiment and the flow resistance was unaltered. A 13 mm thick core quenched detonation at an initial pressure of 200 kN/m^{2}a but a 40 mm element was required to quench detonation at a pressure of 327 kN/m^{2}a. Each of two 50 mm cores successfully quenched detonation at an initial pressure of 392 kN/m^{2}a. It was found that the initial line pressure at which a 50 mm element will quench detonation could be related to the flow resistance at a flow rate of 10000 1/h of air at 15°C (see Fig.5).

CONCLUSIONS

Earlier work has shown[6] that since the housing dimensions affect the speed of the flame incident on the arrestor, the housing and arrestor must be treated as a single unit. Furthermore, it is essential that particular attention is paid to the sealing of the arrestor in the housing. The central hemispherical crater in the surface incident to the flame front behind the central hole in the support plate indicates that the surface of the arrestor should not be

exposed along the axis of the bore of the inlet pipe. Provided that these factors are taken into account a 40 mm long element will completely quench detonation of acetylene at an initial pressure of 2650 kN/m^{2}a and of a 48% acetylene-52% oxygen mixture at an initial pressure of 327 kN/m^{2}a contained in 12.7 mm i.d. pipe.

This work was carried out under static conditions but it is considered that these results may be applied under dynamic conditions and it is intended to confirm this experimentally. Already preliminary work has indicated that an arrestor core 40 mm thick will quench detonation and prevent re-ignition of a 45% acetylene-55% oxygen mixture at an initial pressure of 220 kN/m^{2}a and at a flow rate of 2000 l/h.

Although results are confined to detonations in acetylene and oxy-acetylene mixtures the main conclusion is that the material provides the basis for the design of flash-back arrestors against detonation in most gaseous systems over a very wide range of pressures. In particular its use is foreseen as a disposable flash-back arrestor element for use with portable oxy-acetylene equipment and for use in high pressure acetylene plant.

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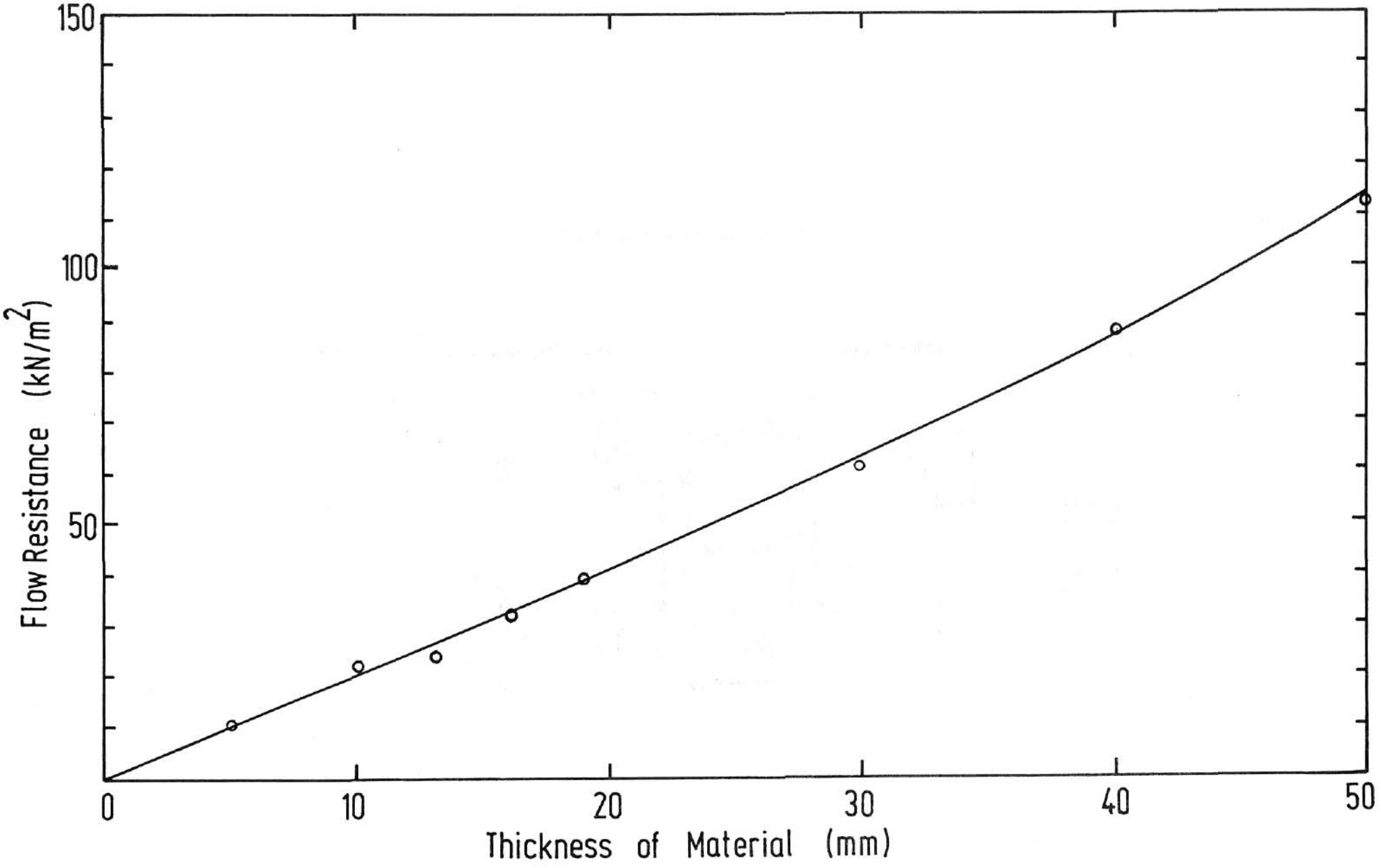

Fig. 1. RELATION BETWEEN FLOW RESISTANCE AT A FLOW RATE OF 10000 L/H AND THICKNESS OF MATERIALS

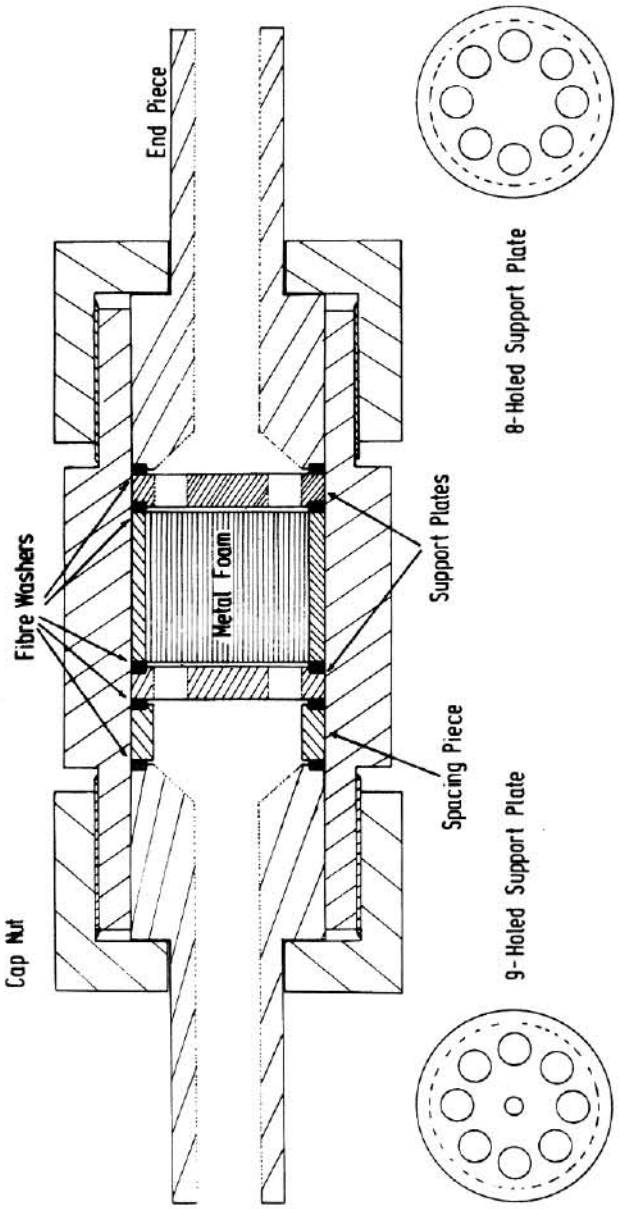

Fig.2 - FLASH-BACK ARRESTOR ASSEMBLY

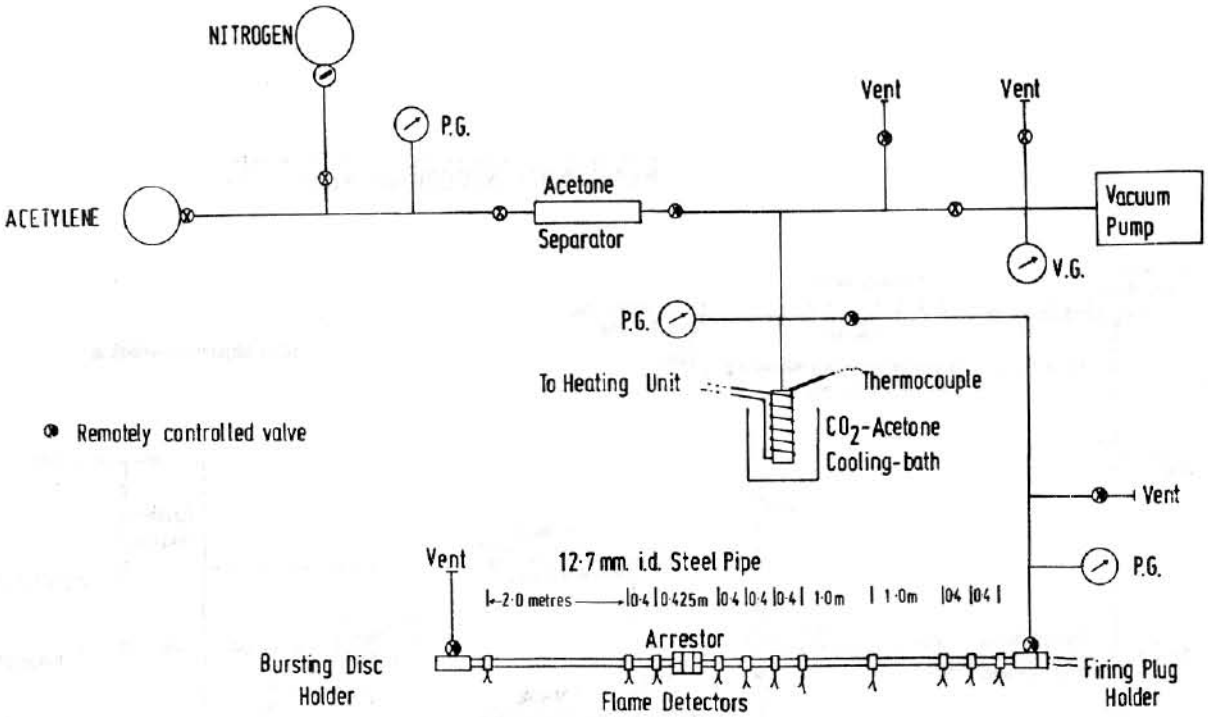

Fig.3.- STATIC HIGH PRESSURE ACETYLENE FIRING SYSTEM

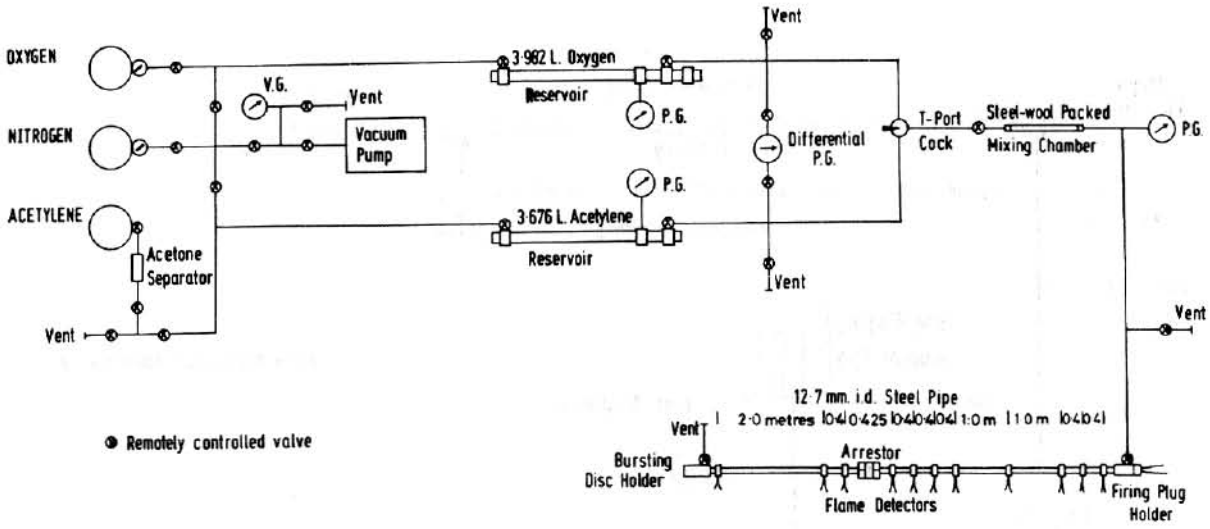

Fig. 4. - STATIC OXY-ACETYLENE FIRING SYSTEM

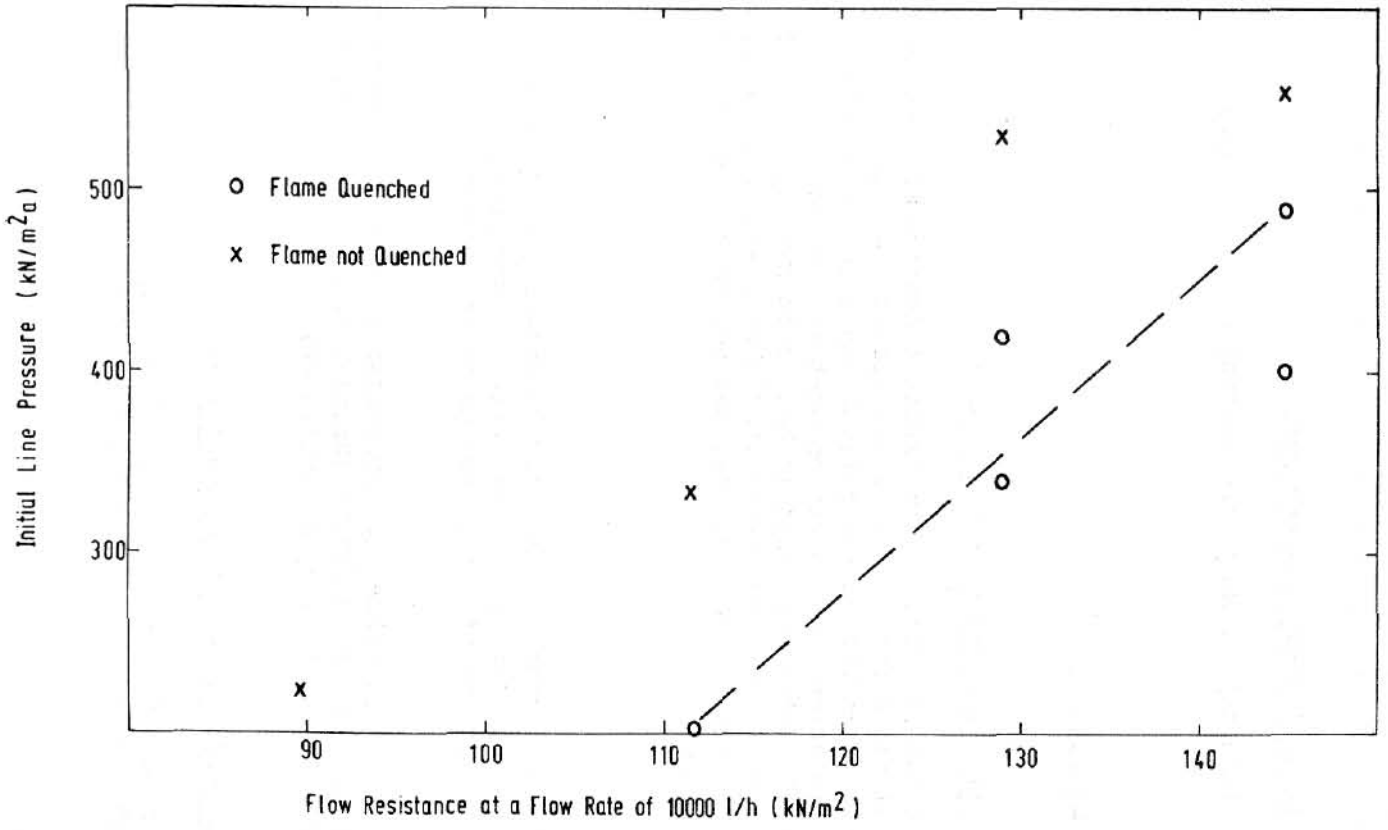

Fig.5.-RELATION BETWEEN QUENCHING EFFICIENCY AND FLOW RESISTANCE FOR A 50mm CORE