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J.P. Mogan, S. Ferguson, N. Sarin, and D.B. Stewart

Canadian Explosive Atmospheres Laboratory
Mining Research Laboratories

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FACTORS AFFECTING EXPLOSION PRESSURES IN FLAMEPROOF DIESEL EXHAUST SYSTEMS

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AUTHORS NAMES: J.P. Mogan* S. Ferguson** N. Sarin***
D.B. Stewart*

RESEARCH INSTITUTE: Canadian Explosive Atmospheres Laboratory
Mining Research Laboratories
Canada Centre for Minerals and Energy Technology
(CANMET)
555 Booth Street,
Ottawa, Ontario, Canada.
K1A 0G1

ABSTRACT

Most flameproof diesel exhaust systems share the same basic components: manifold plus exhaust pipe, exhaust dispersion chamber, baffled water scrubbing chamber (generally single-pass), water de-entrainment chamber, spaced plate flame arrester, and exhaust deflection duct. Reduction of the internal explosion pressures generated in such systems to a minimum, would result in safer and/or more economic exhaust treatment systems.

Tests of actual exhaust systems and an investigation of an adjustable mock-up water scrubbing unit, have thus far shown in general that the highest and most hazardous explosion pressures are those resulting from unfavourable interaction between the collective volumes upstream of the gas dispersion point into the scrubber water, and the volume of the mist de-entrainment chamber immediately prior to the exhaust flame arrester. However, a definitive correlation of maximum explosion pressure data with the volume ratios for the prototype and the mock-up scrubbers was not forthcoming. Therefore, on the basis of tests done thus far, minimum pressure design requires a modest series of prototype explosion tests.

Other parameters, such as slot widths, internal baffling, and suitably selected exhaust flametrap free area, appear to have a minor influence on the generation of high pressures.

Further maximum explosion pressure reduction can result from the prevention of 'pressure piling' effects in both series and parallel scrubber chamber configurations, if small 'ignition transmission' holes are placed such that gas flow is not substantially affected and subsequent or adjacent chambers communicate with the chamber in which primary ignition occurs allowing simultaneous deflagration.

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* Research Scientists, Mining Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Ottawa, Canada.

** Scientific Support Technician

*** Investigation Officer

INTRODUCTION

Diesel powered units approved for operation in potentially gassy environments (such as coal mines) are required to be equipped with elaborate exhaust treatment systems. In addition to removing some of the noxious constituents of the exhaust gas, the system serves two safety functions. It keeps surface and gas outlet temperatures below the ignition temperature of coal dust, and prevents explosions originating within the exhaust system from propagating to an external flammable atmosphere. As the latter function requires that the integrity of the system be maintained during an explosion, most regulatory bodies require that the system be explosion tested and over-pressure proof tested.

Mobile diesel-powered coal mining machines are frequently adaptations of hard rock units, so the flameproof exhaust system must often be fitted into quite restricted available spaces. This space factor, plus efficient water utilization, are currently the two aspects which become the major design constraints.

An additional aspect, which could advantageously be considered at the design stage, is an examination of the factors which influence the generation of maximum explosion pressures in the system. In some cases, a minor change in the configuration can result in a significant reduction in explosion pressure. While including explosion pressure as a design parameter may not always result in a cost reduction, it will generally produce an increased margin of safety, particularly in the later stages of the life cycle of the equipment (after some corrosion and fatigue have occurred).

Comparison of explosion pressures reached during tests of several commercial flameproof exhaust systems has provided some insight into the factors contributing to higher explosion pressures. In addition, tests with a variable experimental "scrubber", which incorporated the means to vary scrubber geometry, permitted a determination of the relative contribution of some of the significant system characterisitics.

The work described in this paper, then, will enable the equipment designer to consider explosion pressure as a third design parameter, even though no definitive correlation of explosion pressure with system geometry proved feasible.

TEST RESULTS

The Effect of Exhaust Pipe Bends

An unexpected and significant reduction of explosion pressure in tests on a commercial water scrubber resulted from the addition of a single 90^0 bend to the exhaust pipe system between the manifold and the scrubber. Similar effects had been communicated in informal exchanges at the XVIIth Conference in Bulgaria in connection with detonation pressures in scrubbers.

A commercial system was tested in three configurations which varied only in the number of bends in the scrubber intake pipe. In all cases the ignition source was located in the end of the intake pipe remote from the scrubber, simulating ignition at the engine exhaust valves by backfire. Standard pipe ($3\frac{1}{2}$ inch - 8.9 cm inside diameter) was used exclusively for the exhaust system piping. The scrubber was tested without water and its internal volume was $0.047m^3$.

The first exhaust pipe system, comprising three connected pipes of total length equal to 3m and separated from the water scrubber by one 180^0 bend, resulted in an explosion pressure of 317 kPa, for 9.0% methane/air mixture.

The addition of two 90^0 bends to the first configuration apparently quenched the flamefront before it emerged into the water scrubber resulting in a scrubber explosion pressure of only 28 kPa.

Finally, one of the added 90^0 bends was removed resulting in a scrubber explosion pressure of 331 kPa, confirming the sensitivity of such systems to significant explosion pressure reductions by simple configuration changes.

Basic Single-Pass Scrubber

The first commercial single-pass scrubber which was observed to produce abnormally high explosion pressures was similar to that shown in Figure 1. It featured a relatively short exhaust pipe leading to a transverse dispersion slot. Exhaust gas then passed over a baffle to chamber B, and then across to a weir to a de-entrainment chamber C. The demisted gas then travelled through a spaced plate flame arrester and dispersion duct D. The average pressures reached during repeated 9% methane/air explosion tests were 700 kPa in chamber A, 600 in chamber B, and 425 in chamber C, as recorded on an oscillograph from the output of a dynamically calibrated piezoelectric transducer.

In order to isolate the contributions of the various design features which are typical of exhaust systems arranged as shown in Figure 1, a 0.13m^3 test "scrubber" was equipped with movable baffles, Figure 2. Maximum explosion pressure reached during a number of 9% methane/air explosions were then determined for the following variations in system characteristics:

1) 150, 120, 60 and 0 cm of 7.5 cm diameter inlet pipe
2) Inlet chamber A of 18 and 7.5 litre volume
3) Outlet chamber D of 26, 18, 14, and 7.5 litre volume
4) Inlet and outlet baffle gaps of 1.8, 1.2, and 0.6 cm

In each test, a spaced plate flame arrester with a free area of 70 cm^2 was fitted to the outlet and the system was tested without water in the scrubber.

The results of a number of explosion tests with this apparatus are summarized in Figure 3. Maximum pressures reached in chamber C are plotted versus the outlet chamber volume as a proportion of the total chamber volume, (Vo/V) = (D)/(A+B+C+D). The effects of different combined inlet volumes are shown by the various point designations. Each point plotted is the average of several explosion tests; the actual tests varied 14 kPa on average from the values plotted.

The clusters of like points (circles and diamonds) at Vo/V = 0.057, 0.107, and 0.139 are identical tests with varying slot widths. Apparently the width of the inlet or outlet gap does not have a significant effect on explosion pressures from 1.8 to 0.6 cm gap width.

The range of pressures observed at Vo/V = 0.139 illustrates the dramatic interaction between inlet and outlet volumes. Five other prototype exhaust systems which shared the same basic configuration yielded similar maximum pressures (500 to 700 kPa) but no correlation was found which would permit prediction of the actual explosion pressures. The point designated by a square, Vo/V = 0.139, Vinlet/V = 0.057, P = 330 kPa, however, illustrates that the basic exhaust system can be "tuned" for low explosion pressure, but this would likely require testing with an adjustable prototype.

Scrubbers which "Pressure Pile"

A variation in the basic design is shown in Figure 4. Here, chamber A functions as an inactive water reservoir, communicating above the baffle and through two 10 cm diameter holes. The explosion is transmitted via the dispersion slot to chamber B. Some unburned mixture from B is pumped into A in advance of the flame front so that A "pressure piled" to 750 kPa, while B only developed a pressure of 560 kPa. Connecting the dispersion tube directly with A via three one cm diameter holes (K) eliminated the "pressure piling" by producing simultaneous ignition in A and B, thereby lowering the pressure to 560 kPa in chamber A, without unduly disrupting the normal gas flow.

A second typical design which is subject to "pressure piling" is shown in Figure 5. Here, the baffles are arranged to effectively produce four consecutive linked chambers, A, B, C, and D. Excess unburned mixture is pumped to each in turn as the explosion propagates from the dispersion slot to the flame arrester. The maximum explosion pressure reached rises from 620 kPa in A to 760 kPa in D. All these tests were conducted without water in the scrubber.

With this type of construction, there would seem to be little remedy for the high explosion pressures. Increasing the volume upstream of the dispersion slot by only 10 percent increased the chamber D pressure to 850 kPa, while eliminating the upstream contribution by igniting the gas mixture in the chamber A at location II only reduced the pressure in D to 620 kPa. (This may be contrasted with the result for the point Vo/V = 0.139, Vinlet/V = 0, Figure 3, which attained a pressure of only 238 kPa).

CONCLUSIONS

Most flameproof diesel exhaust systems share the same basic components; manifold plus exhaust pipe, dispersion chamber, baffled scrubbing chamber (generally single-pass), de-entrainment chamber, spaced plate flame arrester, and deflection duct. The system tested should duplicate the actual system as closely as possible because it is apparent that relatively minor changes can greatly affect the explosion pressures generated. Explosion testing of the complete system ensures that the design is adequate to contain the pressure developed, so than an internal explosion cannot readily propagate to an external flammable atmosphere. It would be worthwhile particularly when large batch-type scrubbers are used, to design the overall system to minimize the internal explosion pressure.

Minor changes in the inlet configuration, in some cases the addition of a single 90^0 bend, can prevent the explosion from propagating into the main body of the scrubber. It is unlikely that this effect should be exploited to lower the explosion pressures however, Rather, it suggests that explosion test results involving such features be interpreted with caution.

Numerous tests of actual exhaust systems, plus an investigation with an adjustable mock-up unit have shown that the pressures reached are mainly the result of an interaction between the inlet pipe volume upstream of the scrubber inlet dispersion point (slot or sparger) and the volume of the water de-entrainment chamber prior to the arrester. Other parameters, such as slot widths and internal baffling in the scrubber chamber (unless the arrangement produces pressure piling) apparently have only a minor influence. Similarly, because the design size of the flame arrester is increased in proportion to the scrubber volume to accommodate larger engines, the impact of flame arrester free area is also normally minor.

Nevertheless, although the explosion pressure was shown to be mainly due to the interaction of only two chambers, it was not possible to combine the results of the mock-up and the prototype tests to produce a workable pressure prediction correlation. The results did show that the explosion pressure for a particular design can likely be reduced by a relatively modest series of prototype tests, but it is doubtful that this would be justified unless a large number of machines are to be built.

The investigation has also demonstrated how "pressure piling" can affect the maximum explosion pressure. Baffles which form linked chambers as in Figure 5 should be avoided. If space criteria require this design, small "ignition holes" connecting subsequent chambers with the primary chamber (i.e., between A and C and D) will significantly reduce the explosion pressure without greatly disturbing the exhaust gas flow. Similarily, "pressure piling" into an inactive chamber (A in Figure 4) can be reduced by the judicious addition of "ignition holes". In contrast to the inlet chamber/de-entrainment chamber interaction, these "pressure piling" effects are relatively predictable and should therefore be taken into account during the initial design stage of all flameproof exhaust systems.

DESIGN GUIDELINES

Although no exact criteria for the design of flameproof exhaust systems for diesel engines has resulted from this work, the investigation did produce the following design principles.

1) Minimization of the volume upstream from the inlet dispersion slot. This effect is demonstrated by the low pressures reached at Vinlet/V = 0.0 or 0.021, Figure 3. If the lay-out of the machine makes this impossible, prototype explosion tests may be necessary to locate the region of minimum interaction (eg. Vo/V = 0.139, Vinlet/V = 0.052 or 0.057, Figure 3), if the design cannot accommodate higher explosion pressures.

2) Avoidance of "dead ended" inactive chambers (reservoirs). If this is impossible, these should be vented via "ignition holes" to the dispersion chamber, Figure 4.

3) Avoidance of sequential "linked" chambers. If linked chambers must be used, they should be vented to the primary chamber via "ignition holes", Figure 5.

Enclosure Data:

inlet pipe (dia. x length)	- 10 x 120	cm
total scrubber volume	- 0.50	m^3
volumes: chamber A	- 0.22	m^3
B	- 0.22	m^3
C	- 0.017	m^3
D	- 0.04	m^3

gaps:	inlet	2 x 50	cm
	A to B	10 x 60	cm
	B to C	2 x 60	cm
	D to exit	10 x 35	cm
flame arrester			
	free area	280	cm^2

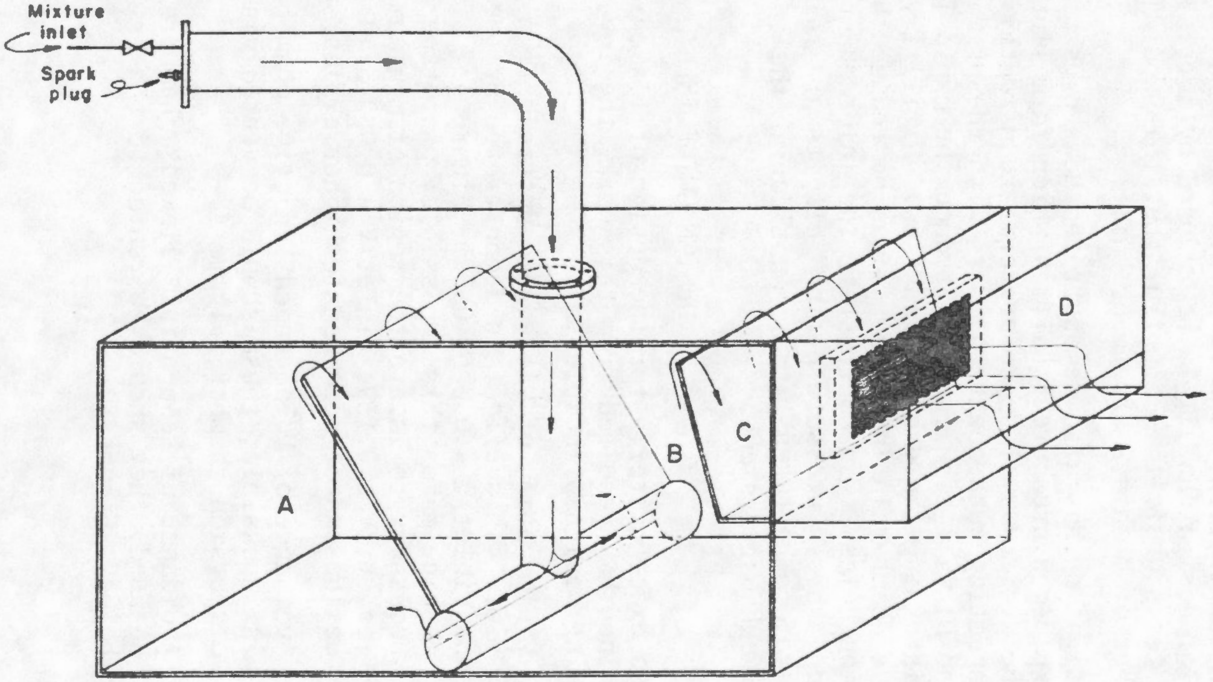

Fig. 1 Flameproof Exhaust System with Single-Pass Scrubber

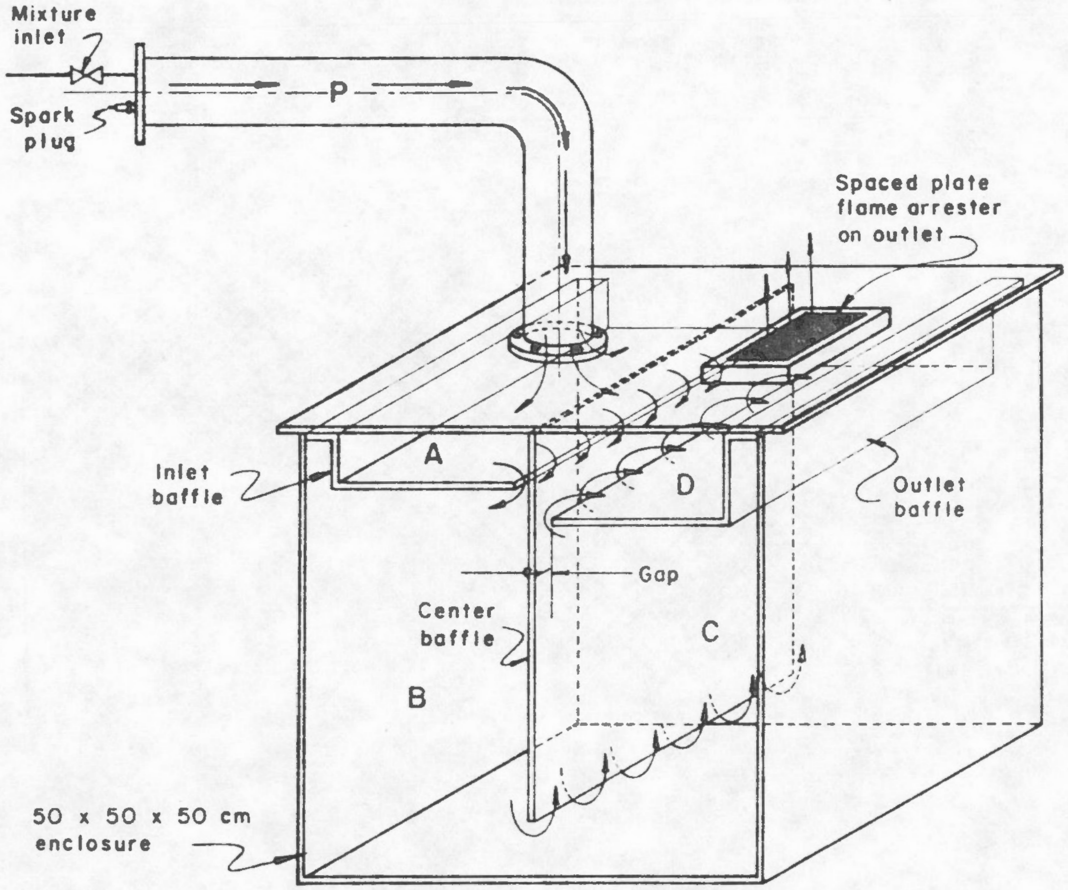

Fig. 2 Research Enclosure for Determining the Effect of Dispersion and De-Entrainment Chamber Volume on Maximum Explosion Pressure

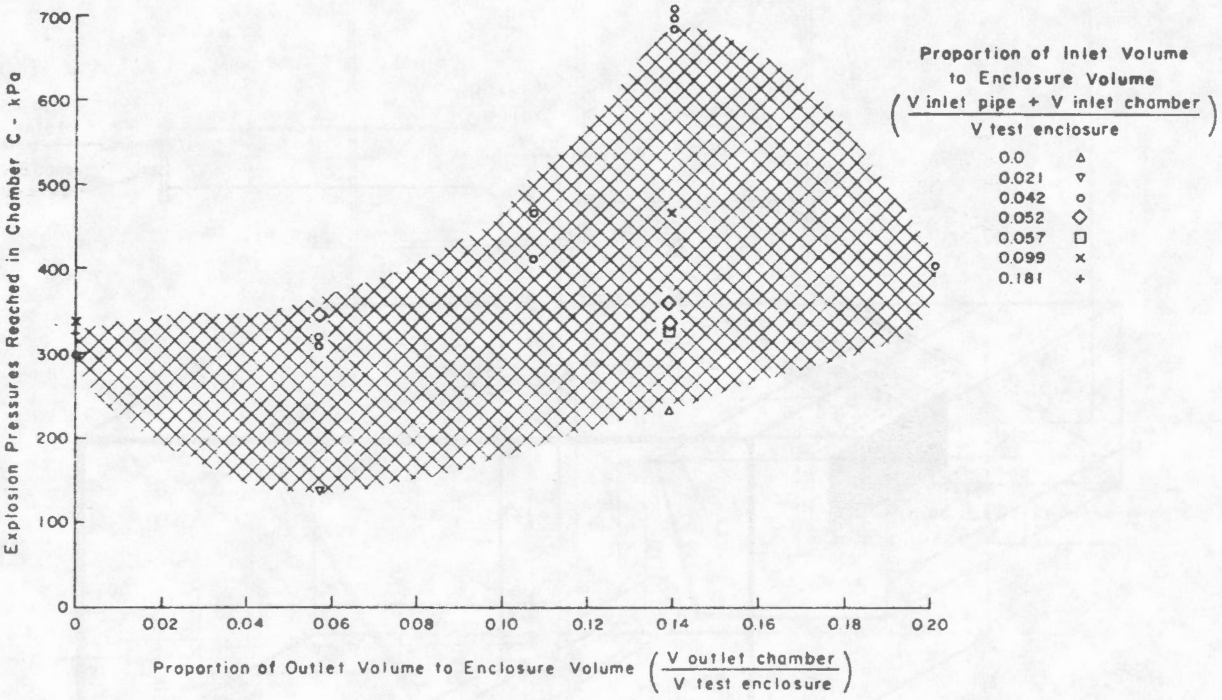

Fig. 3 Maximum Explosion Pressures Reached in the Test Enclosure for a Variety of Dispersion and De-Entrainment Chamber Volumes

Enclosure Data:

inlet pipe (dia. x length) - 10 x 120 cm
total scrubber volume - 0.35 m^3
volumes: chamber A - 0.15 m^3
B - 0.15 m^3
C - 0.05 m^3

gaps: inlet 2 x 30 cm
A to B 2 to 10 x 50 cm plus 2 at 10 cm diameter
B to C 4 x 50 cm
flame arrester free area 140 cm^2

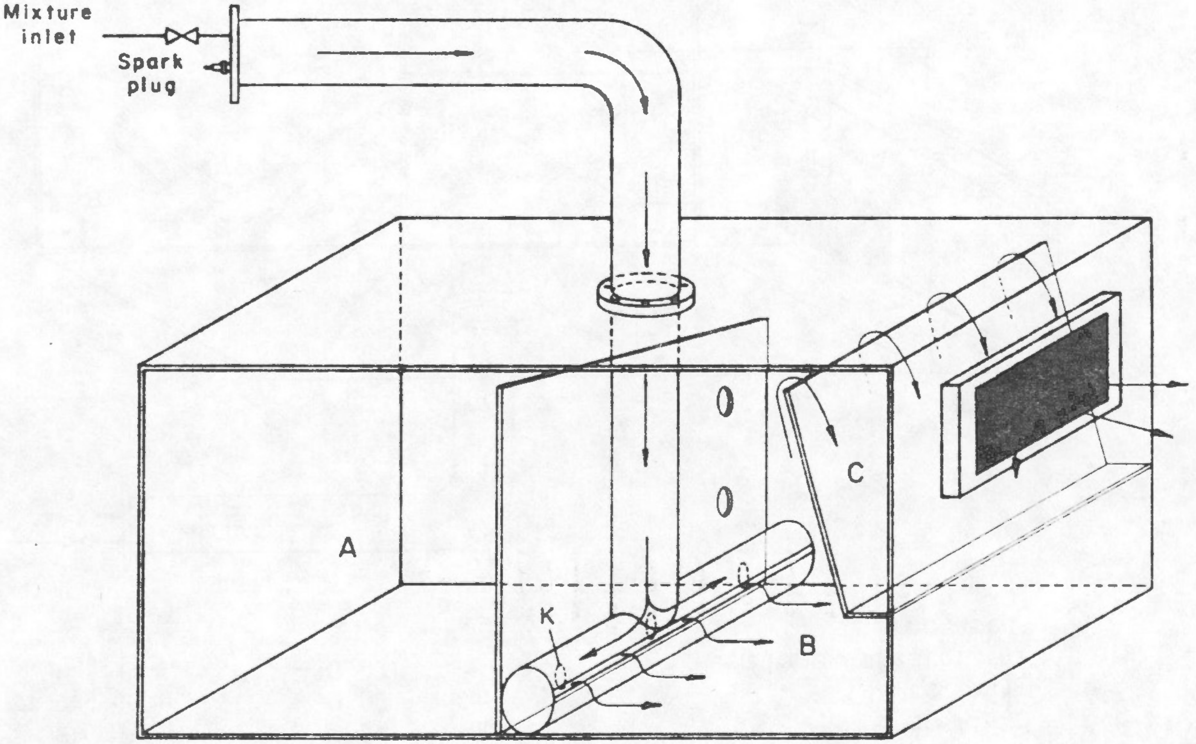

Fig. 4 Flameproof Exhaust System with an Inactive Reservoir "A"

Enclosure Data:

inlet pipe (dia. x length)	- 7.5 x 50	cm
total scrubber volume	- 0.29	m^3
volume: chamber A	- 0.11	m^3
B	- 0.04	m^3
C	- 0.01	m^3
D	- 0.04	m^3
E	- 0.07	m^3
F	- 0.02	m^3

gaps:	inlet	2 x 23	cm
	A to B	14 x 28	cm
	B to C	3.6 x 28	cm
	C to D	1.2 x 28	cm
	D to E	2.5 dia.	cm
	E to A	6.3 x 28	cm
	F to exit	6.5 x 14	cm
flame arrester			
	free area	70	cm^2

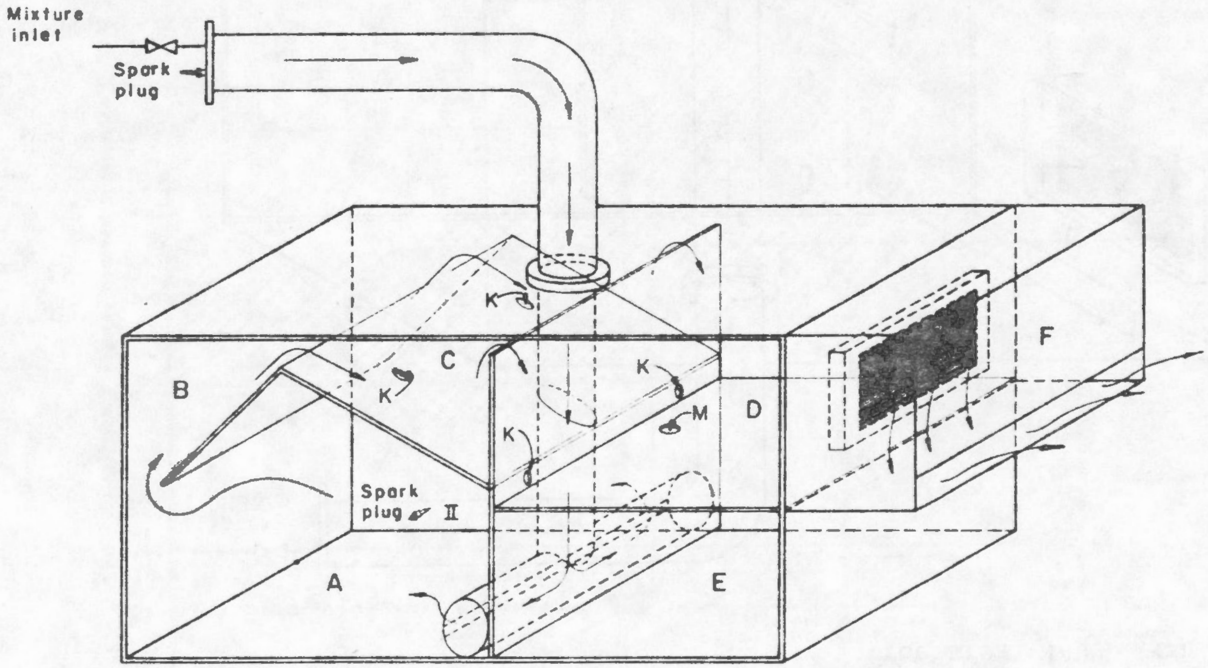

Fig. 5 Flameproof Exhaust System with Sequentially-Linked Chambers