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INERT GAS GENERATORS FOR FIGHTING FIRES

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INTRODUCTION

Inert gas, particularly carbon dioxide in first-aid appliances, has been a common extinguishing agent for small liquid fires for many years. The current fire brigade interest in inert gas for filling whole compartments is associated with the recent development of facilities for generating large flow rates of gas using a mobile appliance which can be taken to a fire. This development opens up wide possibilities for the use of inert gas to control or extinguish difficult fires and large fires, particularly in large buildings and in ships.

METHODS OF PRODUCING INERT GAS

The most direct way of producing a large flow of inert gas at a fire, is to convey the gas to the scene of the fire in liquid form, and to apply it either directly in liquid form or after evaporation. This method has been used to a limited extent in the past,(1),(2) but the method may become more general in future because of the growing availability of liquid carbon dioxide and liquid nitrogen and the increasing number of trucks that are employed in the transport of these gases when used in industry.

The more common method of obtaining inert gas in large quantities is to make it as and where required using a combustion apparatus. The raw materials of this process are a fuel (usually diesel oil or kerosine) and atmospheric air, these being burnt in a combustion chamber; the inert gas is made by cooling the products of combustion. For compactness it may be convenient to carry out the combustion process in a gas turbine or a jet engine provided with an after-burner. The compactness arises because the jet engine acts as its own blower, feeding the air to the combustion chamber, the size of which is small. By varying the proportion of the amount of fuel burnt to the amount of air passing through the apparatus, the oxygen concentration of the gas produced can be reduced to any desired value.

In combustion appliances, water is used to cool the combustion products. The size of the cooling plant required, and the type and quantity of the gas produced, depend on the extent to which water is evaporated during the cooling process. If the water is completely evaporated, then only a small quantity of water is required (about 2-2.5 gallons/1 000 ft^3 of gas) and the inert gas is augmented by the steam produced during the evaporation but the temperature of the gas produced is high, i.e. between 80 and 120°C. If water is not evaporated then a much larger flow rate of cooling water is required (100 gallons/1 000 ft^3) and the gas is not augmented by the production of steam, but quite cool gas can be obtained (temperatures less than 30°C). For an appliance of a given weight, it is possible to produce ten times the flow rate of a hot gas of a given oxygen concentration if the appliance is designed on the basis of water being evaporated, than if the appliance were designed to produce cool gas. It is of course possible to compromise between these two extremes to give warm gases at temperatures of between 50° and 70°C at the cost of a reduction in the gas flow or an increase in the oxygen concentration.

An additional method of cooling the combustion products of a combustion gas generator is to mix them with air, for example, by air entrainment. Of course the oxygen concentration of the cooled gas increases directly with the amount of cooling air used, but there is an accompanying increase in gas flow rate. Mixing with air is not of great practical use as a cooling method in itself, since far too much air would be required; it is a useful supplementary form of cooling, however, when the bulk of the cooling has already been done by the evaporation of water spray.

CHARACTERISTICS OF INERT GAS GENERATORS

Table 1 summarizes some of the operational characteristics of a range of inert gas generators which are based on the above principles. The items shown are all either commercially available or are being developed commercially. The generators fall into two groups; Nos. 1-3 which produce cold or cool gas at flow rates less than 2 000 ft^3/min and Nos. 4 and 5 which produce warm or hot gas at flow rates of 10 000 to 70 000 ft^3/min. There are three types of generator producing cold or cool gas:- liquid gas trucks, combustion apparatus of the traditional type and combustion apparatus using a gas turbine.

Both the warm and hot gas generators are based on a gas turbine or a jet engine. The combustion apparatus for all kinds of gases are about the same weight, about 1-2 tons, in addition to 1-2 tons of fuel and foam compound; liquid gas trucks, however, are considerably heavier when fully loaded.

It is not possible in this paper to give precise costs of the equipment described, although some comparative figures are given in Table 2. Both capital and running costs per unit of output are much lower for the high flow rate producers of warm and hot gas than for low flow rate producers of cold and cool gas.

FIRE-FIGHTING PROPERTIES OF INERT GAS

Inert gas extinguishes a fire by diluting or replacing the air in which the fire burns. This reduces the oxygen concentration from the atmospheric value of 21 per cent to a value at which burning does not take place. For flames from ordinary combustible materials it is necessary to reduce the concentration of the oxygen to below between 12 and 15 per cent depending on the nature of the gas used. Volume for volume nitrogen is less efficient for this purpose than carbon dioxide or water vapour. Extinction of the flame follows almost immediately when the oxygen concentration is reduced to the required value and there is no significant difference between cool, warm or hot gas as defined in Table 1. The flow rate required to extinguish a large flaming fire inside a compartment will depend on the size of the ventilation openings that feed air to the fire. It has been found that a flow rate of 3 300 ft^3/min of a gas containing 10 per cent oxygen is required to extinguish the flames of a fully-developed fire in a room with an open window space measuring 4 ft x 3 ft 6 in[3].

To extinguish smouldering combustion, the oxygen concentration must be reduced to much lower values. It is also difficult to be specific. Superficial smouldering may be extinguished with oxygen concentration as high as 8-10 per cent, but generally values less than 5 per cent are required. Moreover, extinction of deep-seated smouldering usually takes a long time (hours or days). A cool gas is more efficient than a hot gas for this purpose, since unless packed combustible materials have been well-cooled, reignition can take place after the application has stopped. This is illustrated by the difficulty in bringing about the complete extinction of a smouldering fire with steam[4][5], whereas in general no such difficulty has been encountered with a cool gas. Hanel[5] reports that smouldering in a deep layer of brown coal cannot be extinguished with steam because reignition takes place if the temperature exceeds 57°C (135°F).

An inert gas that is transparent and not too humid may also be used to replace smoke. If there is no fire in the smoke-filled compartment, or if the fire is small, then it is not necessary to use a gas which can extinguish fire before the smoke can be cleared and the smoke can be removed with a gas containing more than 15 per cent oxygen. It would be an advantage to use such a gas since under emergency conditions it would be respirable for short periods, as long as the gas did not carry more than about 1-2 per cent of carbon dioxide or 0.1 per cent of carbon monoxide. It should be noted, however, that gas containing less than 21 per cent oxygen will give a lower rate of burning at fires than air(6) and that the presence of water vapour in quantities greater than 5 per cent might also bring about a significant reduction in the rate at which smoke is formed by a fire(7).

If there is a substantial fire in the compartment before smoke can be cleared then it would be necessary to extinguish the flames with an appropriate gas unless either

(i) The gas can be introduced in such a way as to allow a stratified clear layer to form near the ground(8)

(ii) A gas speed can be established sufficient to prevent smoke spreading upstream of the fire. This has been estimated as being about 5 ft/s for a compartment 10 ft high and for a gas containing 17 per cent oxygen. The method is therefore practicable only for corridors even with an appliance which produces a very high flow rate of gas.

HIGH EXPANSION FOAM

With any of the generators examined in Table 1 it is feasible to provide ancillary apparatus to convert the gas generated to high expansion foam, and generators Nos. 5 and 6 are being designed to incorporate this facility. To do this the gas speed must be reduced to about 5 ft/s and passed through a fine mesh net which is sprayed with detergent solution. High expansion foam has a greater cooling capacity than inert gas and has very good extinguishing properties even when the gas in the bubbles is air and the foam is produced using a simple fan. Tests have shown that high expansion foam can extinguish superficial smouldering; it is unlikely that high expansion foam in which the gas phase contains more than a few per cent oxygen, will extinguish deep-seated smouldering for example in packed fibrous materials or in stored coal. Reduction of the oxygen concentration in the gas bubbles from 21 to 17 per cent substantially improves the ability of the foam to extinguish liquid fires, particularly fires in alcohol(9).

PRACTICAL USE OF INERT GAS GENERATORS

For ordinary combustible materials, the best extinguishing agent is water, it is important, however, that the water should reach the burning surfaces quickly and remain there for a sufficiently long time for its cooling capacity to be efficiently utilised. It is under conditions when water cannot be used efficiently that an inert gas producer may find useful application. There are at least three types of fire where the above limitation in using water for fires is met.-

(1) The fire is deep set and inaccessible, because of the presence of packed or stacked goods. This situation is common for fires in holds of ships.

(2) Smoke hides the position of fire or makes access difficult. This condition is also met in fires on ships and sometimes also in large fires in buildings, particularly in basements; it is particularly difficult if the abundant use of water is also dangerous, as in jute warehouses or on ships.

(3) There is a large amount of flaming which prevents the efficient application of water from points sufficiently close to the burning surfaces. This is a common feature in large fires in buildings.

Inert gas generators had been used at fires of type (1) for some time. It is generally required that the gas should be capable of extinguishing the smouldering fire completely, so that reignition does not take place at least during the time required to unload the hold or dig the fire out. For this reason a cool or cold gas of low oxygen concentration is best. In type (1) fires, it is usually possible to restrict leaks and openings through which an applied gas may leak out, and a flow rate of gas of 500-1 000 ft^3/min is usually adequate. Appliances (1) to (4) in Table 1 are suitable for dealing with this type of fire, although the application time must generally be prolonged to about a day or so. It should be remembered if carbon dioxide is used, that this is a comparatively toxic gas and special care will need to be taken to ensure that the gas is adequately dispersed after leaving the compartment concerned. The gases from the appliance other than the carbon dioxide truck are not particularly toxic except to the extent that they contain carbon dioxide.

Fires of type (2) usually occur in large or complicated compartments. In order to clear smoke quickly, flow rates of tens or even hundreds of thousands of cubic feet per minute are required. These conditions can be met by using the cooler gas produced by appliances (5) or (6). Many deep-set smouldering fires that occur in ships' holds, basements and warehouses are difficult to fight because smoke prevents the fire being located, rather than because the acts of digging the fire out and extinguishing it are themselves difficult. The use of a high flow rate of a smoke clearing gas may be the best way of tackling such fires. If a high flow rate of gas is required to extinguish flame and clear smoke at the same time, then this can ideally be obtained with the combined use of a liquid gas truck and the cooler gas of appliance (5). For many situations however it is likely that one of the warm gases produced by appliance (5) would be adequate.

Fires of type (3) are far more numerous than fires of types (1) and (2) combined. In the past, inert gas has not been used at all by fire brigades for this type of fire, or perhaps even been regarded as a practical possibility. However, it is probably in this field that the greatest scope for the use of inert gas generators lies. For inert gas generators to make a useful contribution to fires of type (3) it will be necessary that

(i) They extinguish most of the flaming combustion in a significantly smaller time than is at present required to control such fires;

(ii) The conditions which should be established after extinguishing the flames should be such as to allow firemen to apply water efficiently to surfaces which are smouldering or which otherwise need cooling.

An examination of the records of large fires, e.g. five-pump fires, has shown that most of these fires occur in buildings between 50 000 and 1 million cubic feet in size and are brought under control in a time between 45 min and 3 h. Moreover, the fire brigade often arrives when the fire is in a fairly advanced state, e.g. flames have extended throughout a floor or broken through several windows or the roof. In order to make an impression on fires of this kind a very high flow rate of a flame extinguishing gas is necessary and a significant contribution to the control of the fire must be obtained within about 15 min after putting the appliance into use. A single generator of type (5), or a group of three to five generators of type (6), should give a sufficiently high flow rate of gas to bring about this control in many fires of this kind, provided they can be put into action soon enough. Moreover, if warm gases are used instead of hot gases then in most cases criterion (ii) above should also be capable of fulfilment.

In the applications of inert gas generators described above, it has been assumed that the gas is conducted from the appliance to the compartments involved through collapsible ducts fitted together by the firemen. Where very high flow rates of gas are used to fight fires in multi-compartment buildings, then corridors and staircases might be used to channel the gas, the appropriate doors being opened or closed. It would certainly widen the scope of inert gas generators if permanent duct systems were installed which would allow firemen to connect an appliance and to direct the delivery of the gas to the right compartment. A permanent delivery duct system is of course a feature in contemporary inert gas protective installations, but its application is quite feasible for much higher flow rates of gas than are at present employed. This is particularly so, if a gas turbine or jet engine is used, as these appliances can generate very high flow rates of gas at a pressure of several pounds per square inch. A single appliance may serve to protect compartments within a radius of 1 000 ft. It is not possible to force high expansion foam at high velocities through ducts and if an installation is designed for high expansion foam it will be necessary to deliver both gas and foaming agent separately to a foam-making net in or near the compartment itself.

CONCLUSION

The use of high flow rates of gas to fight large fires in buildings and large compartments is a new approach to fire-fighting. For holds of ships which can be made reasonably leak tight the method has been used successfully already using flow rates of about 1 000 ft^3/min and may be recommended. Many more full-scale tests and much properly appraised fire experience with equipment giving much higher flow rates is required before the method can be put into general use for large fires in buildings. Nevertheless these fires are undoubtedly responsible for a disproportionately high fraction of the fire loss; indeed they probably cause the major part of it. If the use of inert gas generators can succeed in reducing the time required to extinguish these fires and the water damage that accompanies extinction, then the method could result in a substantial reduction in fire damage.

References

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TABLE 1

TYPES OF [illegible] GENERATORS

Number	Type of appliance	Development status	Nature of output	Flow of output ft^3/min	Time available before refuelling or reloading min	Reloading or refuelling	Weight and size of laden appliance	Delivery system	Comments
1	Liquid nitrogen 5-ton truck	Commercially available as standard trucks; would need minor adaptation to convert to fire-fighting vehicles	Pure cold nitrogen	2 000	75	At bulk storage depot	10 ton including vehicle	Insulated hose line about 3 inches in diameter	
2	Liquid carbon dioxide 5-ton truck		Pure cold carbon dioxide	2 000	50		14 ton including vehicle		Higher output can be made available over a shorter time. Larger capacity trucks also available.
3	Generator using small gas turbine	Commercially available*	Cool gas (90°F) containing less than 2 per cent (O_2)	2 000	45	Refill fuel tank	4 ton including trailer 13 ft x 4 ft 9 in x 10 ft	12 in diameter collapsible ducts	
4	Generators using traditional combustion apparatus	Commercially available but would need mounting on appropriate vehicle	Cool gas (70°F) containing less than 1 per cent O_2	500 -1 000	Several hours	"	16 ft x 10 ft x 7 ft approx.	6 in diameter ducts	Have been developed generally for static protective installations
5	Generator using jet engine (small aircraft)	Tests on experimental generator carried out at Fire Research Station. Fire-fighting prototype being manufactured commercially.	(i) Hot gas (220°F) 7 per cent - O_2	50 000	30	"	4 ton plus vehicle	30-in diameter supported strong collapsible ducts	(i) is high pressure output delivery system must withstand 3 lb/in^2, (ii) (iii) and (iv) are low pressure output. Appliance will also produce 30 000 ft^3/min of high expansion foam.
			(ii) Warm gas (170°F) 12 per cent - O_2		30	"	30 ft x 7 ft 6 in x 9 ft	54-in diameter light cloth ducting	
			(iii) Warm gas (150°F) 9 per cent - O_2 (probably misty)		30	"	"		
			(iv) Warm gas (120°F) 17 per cent - O_2		30	"	"		
6	Generator using small gas turbine	Small output version of J.F.R.O. experimental prototype being developed commercially	Hot gas (220°F) 2 per cent O_2	12 000	60		About 2-3 ton	Supported collapsible ducts	Could be modified to produce gases of higher oxygen concentration and high expansion foam.

*Recently withdrawn

TABLE 2

COSTS OF INERT GAS GENERATORS

Type of generator	Capital cost £ sterling/1000 ft^3/min output	Running costs pence/1000 ft^3	Comments
Liquid gas trucks (producing cold pure inert gas)	2 000 - 3 500	350 - 400	It is feasible to come to an arrangement with liquid gas producers to hire appliances when necessary thus to avoid capital costs
Combustion apparatus producing cool gas less than 2 per cent oxygen	Not available	20	
Combustion apparatus producing warm or hot gas. Oxygen concentration 2 per cent upward.	450 - 1 000	0.1 - 6	Capital cost/unit output decreases as output increases. Running costs increase as oxygen concentration and temperature decrease