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THE USE OF DIFFERENT AGENTS FOR INERTING CONFINED SPACES

by

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Fire Research Station,
Boreham Wood,
Herts.

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Introduction

Although foam is the main extinguishing agent used in fighting aircraft crash fires, subsidiary agents are often carried to extinguish fires in enclosed or obstructed spaces, such as engine nacelles, where foam cannot readily be applied. In addition, such agents are often required for rendering inert the atmosphere within wing spaces, where the rupture of fuel tanks or fuel lines would otherwise give a risk of explosion or fire.

Carbon dioxide is the most widely-used subsidiary agent, but dry powders and chlorobromomethane have been suggested as alternatives. In this note, an estimate is made of the relative values of the three agents for inerting confined spaces, based upon available information of their properties.

Estimation of minimum weights of inerting agents

Assuming that the agents can be uniformly distributed throughout the volume, the minimum weights of inerting agents are calculated as follows:

Assume the wing volume to be inerted as V cu ft = area ($A^1 ft^2$) x height (h ft).

Carbon dioxide

The peak value for inerting n-hexane/air mixtures = 28 per cent CO_2 by vol.

$$\text{Weight of } CO_2 \text{ required} = \frac{0.28\ V \times 44}{22.4 \times 16} = \frac{3.08\ V}{89.6} = 0.0344\ V \text{ lb.}$$

Minimum weight of CO_2 required for inerting = $0.0344\ V$ lb.

Dry powder

The majority of dry powders consist mainly of sodium bicarbonate and although there is no information available for n-hexane/air mixtures Dolan and Dempster (1) give a figure of 2.6 cm^2/cc as the peak value for sodium bicarbonate for inerting methane/air mixtures.

$$\text{Minimum weight required} = \frac{V \times 2.83 \times 10^4 \times 2.6}{S \times 454} = 1.62 \times 10^2 \frac{V}{S} \text{ lb}$$

where S is the specific surface of the powder (cm^2/gm).

S varies for commercial powders between 1100 cm^2/gm and 3500 cm^2/gm giving a variation in the weight required from $0.148\ V$ lb - $0.046\ V$ lb.

This weight of powder must be kept dispersed in the volume and since the powder settles out it must be continuously replenished to maintain this concentration. If it is assumed that the powder is always uniformly dispersed in the volume, then by considering the settling velocity of the powder an approximation to the rate of replenishment required can be made. The powder will however be injected at velocities well above the settling velocity and this can only be an approximation.

Table 1 shows the particle size distribution of a dry powder of specific surface 1100 cm^2/gm, and the settling velocities of the different fractions.

Table 1

Particle size μ	Percent by weight	Percent by area	Terminal velocity cm/sec
0-10	3	16·2	0·157 (5μ)
10-20	14	25·2	1·4 (15μ)
20-40	38	34·3	5·6 (30μ)
> 40	45	24·3	15·5 (50μ)

If the concentration is maintained at 2·6 cm^2/sec, then the amount settling per unit time is

$$A \times 0{\cdot}157 \times 2{\cdot}6 \times 0{\cdot}162 + A \times 1{\cdot}4 \times 2{\cdot}6 \times 0{\cdot}252 + A \times 5{\cdot}6 \times 2{\cdot}6 \times 0{\cdot}343 + A \times 15{\cdot}5 \times 2{\cdot}6 \times 0{\cdot}243 \text{ cm}^2/\text{sec}$$

$$= 2{\cdot}6\,A\,(0{\cdot}025 + 0{\cdot}353 + 1{\cdot}92 + 3{\cdot}77)$$

$$= 2{\cdot}6\,A \times 6{\cdot}068$$

$$= 15{\cdot}7\,A \text{ cm}^2/\text{sec} \qquad (A - \text{area cm}^2).$$

If the Sauter mean particle diameter (d_s) is used in calculating the rate of settling, then for $d_s = 26\,\mu$ (corresponding to above powder) the terminal velocity is 4·25 cm/sec and the amount settling per unit time is

$$A \times 4{\cdot}25 \times 2{\cdot}6 \text{ cm}^2/\text{sec} \approx 11\,A \text{ cm}^2/\text{sec}.$$

The rate of settling will decrease in time as the particle size distribution of the suspended particles changes due to the rapid settling of the heavier fractions. The rate of replenishment required will therefore be calculated using the Sauter mean particle diameter.

The rate of replenishment required to maintain a concentration of 2·6 cm^2/sec in the wing is

Powder A.S. $= 1100 \text{ cm}^2/\text{gm} - \dfrac{11.A.}{1100} \text{ gm/sec} = \dfrac{11 \times 930\,A'}{1100 \times 454} = 0{\cdot}02\,A'\text{lb/sec}$

where A' - area in square feet.

Powder B

$S = 3{,}500 \text{ cm}^2/\text{gm}$ ($d_s = 8$) - settling velocity 0·4 cm/sec

$$- \frac{A' \times 0{\cdot}4 \times 2{\cdot}6 \times 930}{3500 \times 454} \text{ lb/sec} \approx 5{\cdot}15 \times 10^{-4}\,A' \text{ lb/sec.}$$

Chlorobromomethane

The peak value for inerting n-hexane/air mixtures = 6·4 per cent CB. by volume. Weight of CB. vapour required

$$= \frac{0{\cdot}064\,V \times 130}{22{\cdot}4 \times 16} \text{ lb} = 0{\cdot}0231\,V \text{ lb.}$$

Assuming that the CB. will be applied in the form of a spray vaporization can take place either from the wetted surface of the wing or from the spray.

Vaporization from wetted surface

Wade (2) gives for the rate of evaporation E gm/sec from a surface 8·9 cm square

$$E = 10^{-7}\, M^{0{\cdot}71} \Big[9{\cdot}810^{-0{\cdot}011v} (pe - pa)^{1{\cdot}25} + 1{\cdot}57v^{0{\cdot}85} (pe - pa) \Big]$$

M - molecular weight - 130 for CB.
v - tangential velocity of air stream (cm/sec). Although the entrained air velocity in the spray will be of the order 10 ft/sec the tangential velocity over the fairly large area of wing surface which is likely to be wetted will be appreciably less than this and v is assumed to be 100 cm/sec.
pe - vapour pressure of the liquid (mm of mercury) 1·13 mm at 60°F.
pa - partial vaporization pressure of liquid in incident air stream - assumed = 0.

It has been suggested that the rate of evaporation depends on $L^{1{\cdot}5}$.

If an area L ft square of the wing is wetted

$$E = \left(\frac{L \times 30{\cdot}5}{8{\cdot}9}\right)^{1{\cdot}5} \Big[\ldots$$

$$= L^{3/2} \times 0{\cdot}187 \text{ gm/sec.}$$

A reasonable wetted area is 15 ft square and this would give a value of E = 10·4 gm/sec.

Considering a wing volume of 750 cu ft - 17·3 lb of CB. must be vaporized and this would take a minimum of 13 minutes - since pa was assumed = 0.

Vaporization from spray

Mass transfer rates from a spray of CB. can be predicted from the heat transfer data (3).

$$\frac{\dot{m}}{D^{2/3} \log(1 + B)} = \frac{h}{C_p \alpha^{2/3}}$$

$\dot{m}$ - mass of component transferred/unit area/unit time.
h - heat transfer coefficient.
C_p - specific heat of gas at constant pressure.
α - thermal diffusivity.
D - molecular diffusion coefficient.
B - mass transfer number.

Where $B = \frac{mg - ms}{ms - 1}$ and m is the fractional mass concentration, the suffices g and s referring to the gas and the surface.

Let us assume that CB is sprayed into the wing of an aircraft of volume 750 cu ft at a rate of 4 gallons/min and nozzle pressure of 100 p.s.i. and that the spray travels 3 ft before impinging on the inner surface of the wing. The velocity at the nozzle will be approximately 120 ft/sec and after travelling 3 ft, approximately 50 ft/sec. A mean velocity of 85 ft/sec will be assumed.

The vapour pressure of CB. at 16°C = 2·2 p.s.i.

The concentration of CB. required in the volume is 6·4 per cent and mg will be assumed at 3 per cent in calculating the mass transfer number. Assuming the temperature of the surface is equal to the ambient temperature

then $m_s = 0{\cdot}475 \qquad m_g = 0{\cdot}137$

$$B = \frac{0{\cdot}338}{0{\cdot}525} = 0{\cdot}64$$

$C_p = 0{\cdot}24$
$\alpha = 0{\cdot}225$
D = assumed equal to 0·1 no data available for CB
$$R_e = \frac{85 \times 30 \times 2\times10^{-2} \times {\cdot}0011}{1{\cdot}8 \times 10^{-4}} \approx 310.$$

From the correlations given this is equivalent to $Nu = 11$.

Thus $\frac{hd}{K} \doteq 11$

$$h = \frac{11 \times 6 \times 10^{-5}}{2 \times 10^{-2}} = 0{\cdot}033 \text{ cal/cm}^2\text{/sec/}^\circ\text{C}$$

$$\dot{m} = \frac{0{\cdot}033\ (0{\cdot}1)^{2/3}\ \log(1{\cdot}64)}{0{\cdot}24\ (0{\cdot}225)^{2/3}}$$

$$= \frac{0{\cdot}033 \times 0{\cdot}2156 \times 0{\cdot}4950}{0{\cdot}2417 \times 0{\cdot}3709}$$

$\underline{\dot{m} = 0{\cdot}039 \text{ gm/cm}^2\text{/sec}}$

Specific surface of spray ($200\mu = d_s$) = 158 cm^2/gm.

<u>Rate of vaporization = 6·15 gm/gm/sec</u>

The latent heat of vaporization of CB. at 16°C is approximately 53 cal/gm.

then heat transfer rate = $0{\cdot}039 \times 53$ cal/cm^2/sec
= $h \times \theta$ – (θ is temperature difference between surface and air)

$$\therefore\ \theta = \frac{0{\cdot}039 \times 53}{0{\cdot}033} \approx 55^\circ\text{C}$$

It cannot therefore be assumed that the surface temperature is the same as the ambient temperature.

A reasonable value of $\dot{m}$ can be found by successive approximations such that $\dot{m}_\theta \times 53 = h \times \theta$.

This equation can be satisfied by a value of

$\dot{m} = 0{\cdot}012$ gm/cm^2/sec
and $\theta = 19^\circ$C (i.e. the surface of the drops are assumed at -3°C).

Taking this value of $\dot{m}$ gives a vaporization rate of 1·9 gm/gm/sec for drops of 200 μ diameter.

If CB. is aprayed at 4 gal/min into the wing the mass of CB. present at any time is $\frac{4 \times 19 \times 454}{60} \times \frac{3}{85}$ grams $\approx$ 20 grams.

Giving a rate of vaporization of approximately 38 grams/sec. This together with vaporization from the wetted surface of the wing of 10 grams/sec gives a total vaporization rate of $8\frac{1}{2}$ per cent.

At this rate it would take approximately $2\frac{1}{2}$ minutes to vaporize the 17·3 lb of CB. required to give a concentration of 6·4 per cent in a volume of 750 ft^3.

Comparison of requirements of different agents

Consider the total volume of a wing as 1500 cu ft (50 ft x 15 ft x 2 ft) half of which is taken up by obstructions, such as petrol tanks, leaving a volume to be inerted of 750 cu ft (50 ft x $7\frac{1}{2}$ ft x 2 ft). If it is assumed that there are no losses of agent through ventilation spaces and that the agents are uniformly distributed throughout the volume, the amounts required can be calculated. In Table 2 the following requirements are assumed -

(1) Carbon dioxide - Minimum weight required = $0{\cdot}0344\,V$ lb.

(2) Dry powder - Minimum weight required = $\frac{1{\cdot}62 \times 10^2 V}{S}$ lb

Rate of replinishment ($S = 1100\ cm^2/gm$) = $0{\cdot}02\,A'$ lb/sec

($S = 3500\ cm^2/gm$) = $5{\cdot}15 \times 10^{-4}\,A'$ lb/sec

(3) Chlorobromomethane - Minimum weight required = $0{\cdot}0231\,V$ lb

8 per cent is vaporized.

Table 2

AGENT	Weight to be dispersed in volume of 750 cu ft (lb)	Total weight used in inerting wing for 5 minutes (lb)	Total weight required in inerting wing for 10 minutes
CO_2	25	25	25
DRY POWDER Specific surface 1,100 cm^2/gm	111	4,600	-
DRY POWDER Specific surface 3,500 cm^2/gm	35	151	267
CB.	17	210	210

The agents will presumably be applied at one point in the wing and they must diffuse past obstructions to inert the whole wing volume. The mechanism will be that of eddy diffusion rather than molecular diffusion and CB. and carbon dioxide can therefore be considered to spread similarly throughout the volume. A cloud of dry powder will not diffuse as readily as some powder will settle on the obstructions. This makes dry powder an even less attractive agent for this purpose.

Ambient temperatures of 16°C were assumed in the calculations on the rate of vaporization of CB. The vapour pressure of CB. at this temperature is 2.2 p.s.i. At lower temperatures the vapour pressure is lower and the rate of vaporization will consequently be lower.

Conclusions

The relative efficiencies of three inerting agents have been considered. In terms of the weight of agent required to ensure that an aircraft wing space is kept inerted for a considerable time, carbon dioxide appears to be much more efficient than dry powder and chlorobromomethane. The weight of equipment necessary for the three inerting agents will vary considerably being greatest for carbon dioxide. This as well as the toxicity of the agents has not been considered but would have some bearing on the choice of agent. A number of assumptions have been made in the calculations and some experimental verification would be desirable.

(1) Dolan, J. E. and Dempster, P. G. The suppression of methane-air ignition by fine powders. J. App. Chem. 1955, 5 510-17.

(2) S. H. Wade. Evaporation of liquids in currents of air. Trans. Inst. of Chem. Eng. Vol. 20. 1942.

(3) D. B. Spalding. Some fundamentals of combustion. Butterworths Scientific Publications. London, 1955.

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