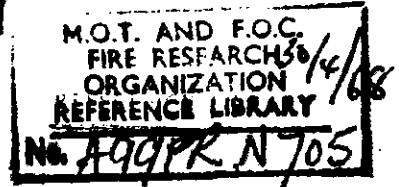# Fire Research Note
No.705

THE CONTRIBUTION OF COOLING TO THE EFFECTIVENESS
OF VAPORIZING EXTINGUISHING AGENTS

by

D. J. RASBASH

April, 1968.

FIRE
RESEARCH
STATION

Fire Research Station,
Borehamwood,
Herts.
Tel. 01·953·6177

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SUMMARY

The contribution which cooling of the fuel might make, to the effectiveness
of vaporizing extinguishing agents has been estimated and compared with the
inerting or inhibiting effect of these agents. For all agents examined the
cooling effect is comparable to the inerting effect. The cooling effect
can only be exercised appreciably with certain types of fire, for example -
spill fires. Solid carbon dioxide has a very large cooling effect and it is
suggested that this agent might be used in the form of low temperature slurries
in a liquid agent.

MINISTRY OF TECHNOLOGY AND FIRE OFFICES' COMMITTEE

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INTRODUCTION

In a previous paper [1], reference was made to the potential usefulness of the
cooling capacity of liquefied gases to help extinguish fires. If when an agent is
applied to a fire, the absorption of heat by vaporization of the agent reduces the
load of fuel vapour being fed into the flames then the amount of agent required to
inert or inhibit the flames is also reduced. The concept applies also to other fire
extinguishing agents which rely for their effectiveness predominantly, on their
activity in the flames. In this note the combined effect of cooling and inerting
of a vaporizing liquid agent is expressed in quantitative terms.

Theoretical

Let the heat of vaporization of unit mass of vaporizing agent be H. Let the
heat required to vaporize unit mass of fuel at a fire be F; the rate of vaporization
may be equated to the rate of burning of the fire. If it is assumed that all the
heat required to vaporize the agent, would have, in the absence of the agent led to
the vaporization of the fuel, then the mass of fuel that may be prevented from
vaporizing by the application of unit mass of agent is given by H/F; let this be
called the coding factor C.

Let the amount of fuel vapour that may be inerted (or inhibited) by unit mass
of agent vapour at all dilutions with air, be called the inerting factor V.

Let B equal the rate of burning of the fire per unit area per unit time,
prior to the application of the agent.

Let M equal the mass rate of application of the agent per unit area per unit
time.

On the assumption that the heat transfer from the flames to the fuel surface
does not change during the application of the agent, then this application would
result in a reduction of the rate of burning to B_s where

$$B_s = B - MC \ldots \ldots (1)$$

The fire will then be extinguished by inerting

$$\text{if } MV \; < \; B_s \text{ i.e.}$$

$$MV \; > \; B - MC \; \ldots\ldots\ldots\ldots \; (2)$$

$$\text{or } M(V + C) \; > \; B$$

The total extinguishing capacity E of the agent may be represented by the sum $V + C$ and may be taken as the maximum burning rate of the fire that might be extinguished by unit mass of the agent.

This concept may be applied to the evaluation of E for certain common vaporizing agents when used against hydrocarbon fires. The value of V may be obtained directly from appropriate flammability limit curves; it is the product of the inverse of the slope of the line through the origin tangential to the curve and the ratio of the molecular weight of the fuel to the agent. There is some doubt about the value of F, the heat required to vaporize the fuel, that is appropriate in the context of estimating the cooling factor C. If the agent can vaporize near the surface of the fuel without depressing its temperature greatly, then F would be approximately equal to the latent heat of vaporization of the fuel at the surface temperature. For petrol and kerosine this is approximately 80 and 60 cal/g. However, it is essential that the vaporization of the agent should reduce the surface temperature since it is intrinsically the reduction of this temperature followed by a reduction of the vapour pressure of the fuel that causes the reduction of the flow of fuel vapour into the flames. If the heat content of the liquid fuel down to the fire point is considered as part of F, then F would be approximately 130 and 150 cal/g for kerosine and petrol respectively. For the purpose of this calculation it is sufficient to take F as 120 cal/g.

On the above basis V, C and E have been calculated for a number of vaporizing liquid agents and are listed in Table 1. For the purpose of comparison a value has also been included for dry powder.

TABLE 1

Inerting, cooling and extinguishing capacity of vaporizing extinguishing agents (for petrol and kerosine fires)

Agent	Boiling or sublimation point $°C$	Inerting factor (V) (reference given)	Cooling factor (C)	Extinguishing capacity (E)
Solid carbon dioxide	$-78°C$	0.15 [2]	1.14	1.29
Chlorobromomethane	67 *	0.24 [3]	0.47	0.71
Methyl iodide	42.5*	0.26 [3]	0.38	0.64
Bromochlorodifluoromethane	-4	0.32 [4]	0.27	0.59
Carbon tetrachloride	77 *	0.16 [3]	0.39	0.55
Liquid nitrogen	-196	0.12 [2]	0.40	0.52
Bromotrifluoromethane	- 59	0.28 [5]	0.23	0.51
Dichlorodifluoromethane	- 29	0.15 [3]	0.33	0.48
Sodium bicarbonate (dry powder)	Not volatile	0.3	Nil	0.3

*Cooling capacity of these liquids not likely to be effective against petrol fires because of high boiling point.

DISCUSSION

Table 1 shows that the cooling factor C can play a major role in the extinction of fires by volatile agents, even though these agents are thought of primarily as flame extinguishing agents. Indeed for all agents listed (except dry powder), the cooling factor C is comparable to the inerting or inhibiting factor. To manifest this effect the agent must vaporize in such a way that the heat absorbing capacity of the vaporizing process is used to reduce the vaporization of the fuel. For this to happen the agent must firstly be able to reach the fuel surface, and secondly be capable of vaporization near the surface at a rate comparable to the rate at which it is applied. In general as far as volatile flammable liquid fires are concerned these conditions are likely to occur only when the fuel layer is thin. If the agent is too finely divided, it would be vaporized by the flames before reaching the fuel surface and if the agent is applied in large drops, it would quickly sink. If the fuel layer is thick the vaporization of the agent would reduce the sensible heat of the fuel remote from the surface, and would not quickly reduce the flow of fuel into the flames.

However, there are a number of important types of liquid fire in which the layer of fuel is thin. For example, the large spill fire is the predominant type of fire for aircraft crashes. Fires in foam rubber or plastics also come into this category since the material melts before it burns and flows as a thin layer over the surface of the unaffected solid or on the ground. The cooling action of the agents listed in Table 1 would also be effective in dealing with ordinary wood fires, but for this type of fire, none of the agents can compare with water as a cooling agent.

Inspection of Table 1 shows that it is dominated by the cooling factor for solid carbon dioxide which is about three times as great as the inerting factor of any agent. The use of solid carbon dioxide in finely divided form either by itself as a slurry with any of the other agents should result in a marked improvement over agents in current use in circumstances where the cooling effect can be exercised. For example according to Table 2 a 50 per cent weight/weight slurry of solid carbon dioxide in difluorobromochloromethane should have a value of 0.94 and therefore be almost twice as effective as the liquid agent itself. Of course, such slurries would need to be maintained at a temperature below $-78^\circ C$.

It should be noted that liquefied carbon dioxide has been used for many years against large spill fires. It has not been found particularly effective, even though almost half the agent changes to a solid when it emerges into the atmosphere. The probable reason for this is that the other half of the agent, which emerges as a high velocity gas, gives rise to the entrainment of a great deal of air. As well as feeding air to the fire, this probably vaporizes much of the solid carbon dioxide before it can reach the burning fuel. Moreover, the very fine condensed particles of solid carbon dioxide would tend to follow the motion of the gas stream rather than impinge on the fuel surface. For this reason, only a small proportion of the initial agent might reach the surface of the fuel in the solid state. If the agent is available as a cold slurry, it can be ejected as a coherent jet or a coarse spray to reach through the flames to the surface of the liquid, in the same way that water or foam may be thrown.

In Table 1, dry powder has been shown to have a nil cooling effect, since such powder as falls into the fuel would not produce much cooling and in general would not either vaporize or decompose. On the other hand the introduction of a cloud of dry powder in the flame might reduce the heat transferred by the flame to the fuel surface. This would have a similar result to the direct cooling of the fuel surface since it would reduce the amount of fuel vapour fed into the flames. For this reason the extinguishing capacity of dry powder may well be greater than the value given in Table 1.

CONCLUSIONS

1. The capacity of vaporizing liquids to cool fuel surfaces and reduce the amount of fuel fed into the flames, might, in certain circumstances make a large contribution to the total extinguishing power of the agents.

2. Solid carbon dioxide has a large capacity for cooling the fuel in volatile, flammable liquid fires. The use of this agent by itself or as a finely divided slurry with liquid vaporizing agents might improve the current effectiveness of vaporizing agents used to fight spill fires by a factor of two to three.

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