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NATIONAL BUREAU OF STANDARDS REPORT

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EXTINGUISHMENT EFFICIENCY OF SOME POWDERS
ON GASOLINE FIRES

by

T. G. Lee
and
H. Shoub

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U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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ABSTRACT

Extinguishment efficiency of 12 common powders on gasoline fires were determined by visual observations. Tests consisted of discharging 2 to 2.5 pounds of powder at a rate of 0.4 to 0.5 lb/sec into 4- by 4-ft, free-surface, gasoline fires. Several powders tested were able to extinguish the fire. Free flowing, 325 mesh $NaHCO_3$ and $KHCO_3$ had the highest extinguishment efficiency.

Extinguishment efficiency seemed to depend primarily on particle size and powder dispersibility. The nature of the powder itself showed some influence on its behavior as an extinguishing agent.

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1. INTRODUCTION

The advent of dry-chemical powder fire extinguishers into the market and their outstanding effectiveness on gasoline fires have stimulated discussions as to the mechanism by which they operate. An early and still advanced theory attributed their effectiveness to the process of an inerting-gas effect[(1),(2)]. It held that the CO_2 and H_2O gases released from the decomposition of the powder particles ($NaHCO_3$) as a result of heating in the fire, would inert the atmosphere in and around the fire. The momentarily suspended particles in the fire together with the expanding inert gases released by the particles, would effectively block further diffusion of oxygen to the flammable vapor.

That theory was challenged recently on the ground that the transit time of particles passing through the fire was insufficient to allow them to reach their decomposition temperature of 270°C.[3] The actual percentage of decomposition of $NaHCO_3$ discharged from a dry-chemical extinguisher onto a free-surface gasoline fire, using established fire-fighting methods, was recently measured here. The decomposed powder was found to be less than 15% of the discharged powder. Others have obtained an average of 20% decomposition. Even assuming total decomposition, the inert gases released by $NaHCO_3$ would be only one-tenth as much as that required to extinguish a given fire by use of conventional CO_2 extinguishers. Both the cooling and inerting effect have been considered as the mechanism in the conventional CO_2 extinguisher.[4]

One of the other possible theories which might explain the effectiveness of this extinguishing material is based on the radiant-heat absorption and scattering characteristics of the powder. It emphasized the fact that the surface area of the powder exceeds 1000 ft^2/lb.[5] With continuous powder application to a fire, a point may be reached where all combustible gases are cooled below their ignition temperature. In addition to the cooling effect, the powder would greatly reduce the radiant heat transfer from the burning gas downward to the fuel surface, thus reducing the evaporation rate.

Another possible reason for the effectiveness may result from a negative catalytic effect. Sodium bicarbonate may be considered as a salt of high chain-breaking efficiency. Such a powder is likely to inhibit the chain-branching reaction of hydrocarbon combustion by adsorbing the intermediate products. Experimental data are needed on this point.

In view of the above theories and the lack of published data on the subject, it was felt that preliminary experiments should be performed with various commonly available powders. Undoubtedly, variables such as particle concentration, unit surface area, size-distribution, adsorptivity, thermal properties, etc. would influence the final fire-extinguishing property of a powder. The relative importance of each of these factors could not be studied in detail in the work described. It appeared, however, that qualitative information of value might be obtained by a comparison of the efficiency of some common powders in gasoline-fire extinguishment.

2. APPARATUS AND METHOD

A practical approach to the tests was made by simulating actual fire-fighting conditions. The tests consisted of discharging 2 to 2.5 lb of a given powder at a 4- x 4-ft free-surface gasoline fire. The powder was propelled from a cylinder pressurized with inert gas. The comparative extinguishment efficiency and characteristics of each powder were evaluated during three separate runs.

2.1 Powders

The choice of powders was dictated by consideration of one or more outstanding physical properties of each powder. As examples, the characteristics of high heat capacity and low decomposition temperature of borax; the dark surface color of cement and fire clay; the hard and smooth surface of SiO_2 as compared to the soft and irregular surfaces of talc particles; the high internal surface area of the activated Na_2CO_3[(8)] against the high external surface area of the $MgCO_3$; the inertness of SiO_2; the fine and free flowing quality of commercial dry chemical, etc., were reasons for their selection.

The 14 powders tested were of sizes ranging from 200 to 400 mesh. It was realized that particle size, hence surface area, was likely to be of particular importance in radiant heat adsorption, but in this preliminary survey, it seemed impractical to standardize all powders to a uniform size. However, some grinding was done to bring all powders within the range of sizes used. The particle sizes mentioned mean that over 85% of the particles passed that particular mesh screen.

The weight of each powder charge varied from 2 to 2.5 lb, depending on the bulk density of the powder. On some low density powders, slight packing was needed to bring the charge up to 2 lb.

2.2 Fire Extinguisher

A commercial stored-pressure, dry-chemical fire extinguisher of nominal 2.5 lb capacity was used for these tests. Through the use of a removable discharge nozzle, the gas inlet could be adapted for either charging or discharging purposes. The effective opening of the discharge nozzle was

0.015 in^2. Dry nitrogen at a pressure of 350 lb/in^2 gage was used to pressurize the cylinder. The average discharge rate for the various powders varied over the range of 0.4 to 0.5 lb/sec.

2.3 Fire

A slightly indented 4- x 4-ft flat, concrete, surface basin held the 5/8 gallon of leaded gasoline which served as the fuel for the test fire. The test powder was applied at the end of a 5-sec pre-burn period. This 5-sec period was designed to standardize the initial warm-up period and permit an approach to the maximum combustion rate prior to extinguishment. The burning rate of free surface gasoline was estimated to be about 0.009 lb/ft^2/sec.[6] An effort was made by the operator to keep the discharging operation uniform for all tests. The method consisted of aiming the discharge nozzle at the base of the fire and advancing slowly while sweeping from one side to the other.

3. TEST OBSERVATIONS

In performing tests with the various powders, three performance characteristics were noted:

1. Was the fire extinguished?
2. Dispersibility of discharged powder.
3. Efficiency of fire extinguishment.

The first of these required only a positive or negative listing. The two other characteristics were evaluated in qualitative manner by visual observation and classification as A, B, or C. The letter "A" was used for high efficiency or dispersion and the letter "C" was used to designate the poorest performance.

Dispersibility of the powder was defined as the percentage of the total number of particles which were suspended as individual particles without adhering to others. Its determination was based on visual observations during use of the extinguisher.

Extinguishment efficiency was based on the time rate of extinguishment or the extent to which flames were suppressed. It was evaluated by two observers.

4. RESULTS AND DISCUSSION

The results of these tests are presented in table 1. In this table the various powders are arranged in order of apparent effectiveness. Factors considered in order of importance were, was fire extinguished, efficiency of extinguishment, and dispersibility of the powder. Three separate tests were performed on each of the powders mentioned. In most cases the powder performed in a very similar manner during each of the tests. In cases where extinguishment was not accomplished, all the available powder had been discharged without extinguishing the fire.

The results seem to demonstrate that both fine particle size and good dispersibility are required for extinguishment of fires. The fact that both borax and silica were effective in extinguishment tends to confirm the belief that release of carbon dioxide from the dry chemical has little effect on performance of the powders. The heat capacity of the powder also seems to be relatively unimportant, as evidenced by the relative performance of borax and dry chemical, although the slightly inferior behavior of the decomposed dry chemical prevents any definite conclusions being drawn on the importance of heat capacity of the powder.

The value of good dispersibility is demonstrated by the commercial grade of $NaHCO_3$ tested both in the dried and undried states. The dried powder was effective in extinguishing the fire while the untreated material was ineffective, being judged as one of the poorest powders tested. The importance of maintaining a particular particle size [7],[8] for optimum dispersion was neglected in this particular study.

During the performance of these preliminary tests, it has become evident that further work of this nature will be greatly aided by development of a more easily controlled standard fire and a regulated method of powder application. Measurements of efficiency and dispersion must also be placed on a quantitative basis to permit more accurate evaluation of relative behavior of the different powders.

Table 1. Extinguishment Efficiency

No.	Powder[1]	Treatment	Special Characteristics
1	$KHCO_3$	2% zinc stear. ground in	Decomposes at 160C fine particles
2	Dry Chem.[4]		Free-flowing decomposes at 270C
3	Borax	2% zinc stearate	High heat capacity $-8H_2O$ at 60C
4	Na_2CO_3*		Activated; high int. surface area
5	70% Na_2CO_3 30% Mg_2CO_3		Mixture had better flow than Mg_2CO_3
6	50% Na_2CO_3 50% Cement	Dried at 120C	
7	60% SiO_2 40% Na_2CO_3	Dry Chem. and SiO_2; 280C 3hr	Mixture had better flow than SiO_2
8	30% SiO_2 70% Na_2CO_3		Same as No. 7
9	Na_2CO_3**		Same as No. 4
10	$NaHCO_3$	Same as No.6	~~Untreated~~; poor dispersibility
11	Silica	2% zinc stearate	Inert, hard and irregular surface
12	Borax($Na_2B_4O_7 \cdot 10H_2O$)	Same as No.11	Particle sizes are larger than No.3
13	Plaster($CaSO_4 \cdot \frac{1}{2}H_2O$)		$-\frac{1}{2}H_2O$ at 163C
14	Portland Cement	Same as No.6	Dark gray color
15	Talc		Soft surface
16	Fire Clay		Low heat conduct. light gray color
17	Silica	Dried at 150C	
18	$NaHCO_3$		Same as No.10
19	Silica		

1) Powders were either technical or commercial grade.
2) Approximate heat required to raise the temperature of the powder from 18C to 300C including heat of decomposition where appropriate. Numbers in parentheses do not include heat of decomposition.
3) In this table both efficiency and dispersibility increase in order from C to A.

of Powders Tested

No.	Density Bulk (gm/cc)	Density Real (gm/cc)	Heat Absorp.[2] ΔH 18C-300C cal/gm	Size Mesh	Dispers.	Efficiency[3]	Fire Out?
1	1.3	2.2	238(59)	<325	A	A+	Yes
2	1.2	2.2	250(68)	325	A	A	Yes
3	0.62	1.7	462(108)	<325	A	A	Yes
4	.58	2.5	79	<325	A	B	Yes
5	.51		72	325	A	B	Yes
6	.85		68	325	B	B	Yes
7	.71		67	>325	B	B	Yes
8	.65		74	325	B	B	Yes
9	.49	2.5	79	<200	B	B	Yes
10	.84		250(68)	200	B	C	Yes
11	.91	2.6	60	400est	B	C	Yes
12	.55	1.7	462(108)	<200	A	B	No
13	.83	2.3	61(58)	400est	B	B	No
14	1.0	3.1	58	>325	C	B	No
15	.56	2.8	66	Impalp.	C	B	No
16	1.3	3.0	63	200	A	C	No
17	.91	2.6	60	400est	B	C	No
18	.84	2.2	250(68)	200	C	C	No
19	.91	2.6	60	400est	C	C	No

4) Dry chemical refers to a commercial extinguisher powder containing 95+% $NaHCO_3$.

* All Na_2CO_3 used was derived from decomposed dry chemical except No. 9. Dry chemical was kept at 270-275C for 3 hrs.

** Derived from untreated $NaHCO_3$.

5. CONCLUSIONS

The following conclusions seem justified from the results of the preliminary work described:

1. Powders other than sodium bicarbonate are very effective as dry chemical fire-extinguishing material.

2. Powders that do not release carbon dioxide on exposure to heat are effective fire-extinguishing materials.

3. Preliminary evidence indicates that the heat capacity of the powder is not of controlling importance in determining its value as a fire extinguisher.

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