NATIONAL BUREAU OF STANDARDS REPORT

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A TECHNIQUE FOR STUDY
OF
FLAME QUENCHING PROPERTIES OF SALTS

by
T. G. Lee

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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ABSTRACT

A 100 mesh stainless steel screen coated with a thin (3 to 5 microns) deposit of crystalline salt, was held horizontally inside a long 48 mm ID pyrex tube to intercept the propagating flame front of a heptane-air mixture. Under certain conditions this interaction resulted in quenching of the flame by the screen. For flame front velocities in the region of 3,000 cm/sec the quenching efficiency of bare, potassium bicarbonate, potassium oxalate monohydrate, and rubidium iodide coated screens appeared to be the same. Quenching depended on flame front velocity and could be explained by thermal considerations alone.

At a flame front velocity of about 5,000 cm/sec however, potassium oxalate monohydrate quenched readily whereas the others did not. Interpretation of streak photographs seemed to show that quenching was caused by the vapor phase of the salt at distances up to 15 mm above the screen. This indicates that quenching ascribable to chemical influence becomes effective at this velocity.

INTRODUCTION

The use of dry chemical powder, mainly $NaHCO_3$, as a fire extinguishing agent has become increasingly common in the past 5 years. The exact mechanism of extinguishment involved is not completely understood. A study of the mechanism of interaction between powder material and flame would provide valuable aid in the search for better extinguishing agents.

At present the general chain-breaking mechanism, to a limited extent at least, is applicable to both the inert and thermally unstable powders. The theory was developed and shown to be in good agreement with data based on wall quenching and quenching distance studies [1][2][3]. It attributes the loss of energy and/or radicals (energy and/or radical chain need not be specified) of the reacting gases to collisions with the cold surfaces of solids.

Thus flame extinction would result when the rate of chain-breaking (deactivation of chain carrier or energy transfer) processes exceed that of chain-branching. Similarly, the initial cold and large surface area of the powder particles would precipitate chain-breaking in the fire.

However, two questions may be raised immediately [4].

1. (1) To what extent is the chain-breaking efficiency of the surfaces controlled by temperature and/or by the chemical nature of the salt?
2. (2) Is chain-breaking by the powder a surface reaction or a gas phase reaction?

One of the aims of this study is to develop a method in which experimental data may be obtained for solution of the above problems. Any hypothesis that may be formulated on the mechanism of flame extinction by the use of powder, must also be consistent with the following three generalized observations which are based on qualitative and available quantitative data:

1. (1) The minimum concentration required for extinction and suppression of flames is determined by the total surface area of a given salt regardless of particle size, or weight for 5 to 100 micron particles [5][6].
2. (2) Some salts are more effective than others as measured by minimum weight concentration required for extinction [4][7].
3. (3) Generally, salts of alkali metals and especially those that decompose below 200°C are among the most effective salts reported [5][8].

This report will describe a method and give some preliminary results on comparison of the extinction efficiencies of salts and the effect of flame front velocity on the efficiency. This method means close control of variables such as fuel type, fuel-air ratio, pressure, temperature of both the mixture and salts as well as salt concentration. Although the ultimate usefulness of a powdered salt depends primarily on its effectiveness against hydrocarbon diffusion flames, such flames are not particularly suited for the study of extinction mechanisms. A diffusion flame burning on the surface of a liquid fuel for example, lacks homogeneity both in structure and in types of reaction. If powder is applied to such flames,

additional aerodynamic complications, such as varying transit time of powder particle through the flame, etc., are encountered.

To avoid some of these objections, a flame burning premixed gas and air was propagated through a tube. A screen (60 to 100 mesh) or a series of screens coated with a thin and uniform layer (3-5μ thick) of the salt to be studied was held horizontally in the upper part of the tube to intercept the advancing flame front. Thus the mesh and wire diameter of the screen were used to simulate the salt concentration. This type of salt concentration model was readily standardized.

In addition, the temperature of the salt (plus screen) as well as the fuel could be controlled. Streak photography using Tri-X as well as Super Anscochrome color film was used to measure flame front velocity and record the result of interaction near the screen area.

EXPERIMENTAL APPARATUS

Fig. 1 is a schematic drawing of the apparatus. The pyrex tube was 4.8 cm ID and 56 cm long. It could be easily removed from the straight joint at the bottom for cleaning. Near the top of the tube were three protrusions which acted as a twist lock to hold a flat aluminum ring. Three stainless steel rods connecting rigidly to this ring extended 15 cm below to support a screen holder. The screen holder consisted of two sections of very thin wall tubing that were machined to give a tight fit. The screen, usually 100 mesh, was held firmly by these two sections when pressed together. The top of the tube was ground flat in order that a plastic plate, coated with vacuum grease, might be used as an air-tight seal during evacuation of the system.

Two tungsten electrodes, separated by a 5 mm gap were located at the bottom of the tube. The outside leads of the electrodes were connected to a 10 KV ignition transformer. A 35 mm, 10 in. long film strip, revolving drum camera, with a f/2 lens was focused near the central axis of the flame tube. The field of view covered 5 cm above and below the screen. The film was used to record flame front velocity following a standard technique [9]. It also revealed ionization, flame front oscillation, and extinction phenomenon. The speed of the built-in motor in the drum camera was varied to suit flame velocity conditions for each run.

A separate electronic circuit was arranged to provide for a timing marker light operating at 1000 cps. It also controlled synchronization of ignition and camera shutter release. An ionization probe, placed near the top of the tube, was used to detect flame passage when the camera was not being used.

The central section of the apparatus consisted of a manifold connected to condenser traps, vacuum pump, manometer, fuel bulb, drying tube and storage plenum. A mixing fan inside the plenum was used for agitating the gas to insure proper mixing. It was driven by a magnetic stirrer at the bottom.

EXPERIMENTAL PROCEDURES

The data and procedures reported in this paper are confined to the quenching of premixed n-heptane-air flames of 1.9 to 2.2 vol. percent heptane (both sides of the flammability peak) at atmospheric pressure and room temperature. The quenching tests were made by intercepting the flame front with the salt coated, 100 mesh screen. The wire diameter of the screen was .114 mm and the width of opening 0.14 mm, which gives an open area of about 30 percent. The fuel-air ratio was determined by the partial pressure method. Vaporized heptane was first slowly metered into the evacuated plenum to a predetermined pressure. Air, which was introduced later, was supplied from a compressed air cylinder in order to assure a consistant and known moisture concentration. The mixture in the plenum was charged to slightly higher than atmospheric pressure in order to fill the evacuated flame tube to exactly atmospheric pressure. The tube was closed by a thin polyethylene film backed up by a 1/8 in. plastic cover. After evacuation and subsequent charging, the plastic cover was removed leaving the film. The film was easily blown away by a slight pressure rise in the tube. Thus the tube may be considered an open tube.

The techniques of depositing a thin and uniform layer of salt on the 100 mesh stainless steel screen were developed gradually. To obtain a coating, the screen was first cleaned in distilled water and then rinsed in the (water) solution of the salt of proper concentration. After draining off the excess solution, it was held horizontally and exposed to a low velocity stream of dry air from the bottom. The adhesion between the crystalline deposit and the metal surface was good. Salt lost was negligible after the explosion for all the salts tested. The quantity of salt applied to the screen was about

5×10^{-4} gm/cm^2. Quantities of salt in this range were not visible to the unaided eye. Microscopic examination showed that the coating was between 3-5μ thick. Since the deposit was small, the difference of pressure drop across a coated and uncoated screen was expected to be very low. Fig. 2 is a photomicrograph of 100 mesh screen coated with potassium oxalate monohydrate crystals.

RESULTS

Table 1 presents a summary of results on the flame quenching properties of various salts at a flame front velocity of about 3,000 cm/sec. It shows the number of runs at which flame velocity measurements were made. Based on these runs, it gave the maximum velocity at which the flame was quenched and the minimum velocity with which it penetrated the screen. The flame velocities ranged from 2600 to 3500 cm/sec for all runs. The results for each salt were about evenly divided between flames which were quenched and those which penetrated the screen. There were no overlapping results for any one salt.

Error in measurement on the film record was estimated at ±50 cm/sec. The flame front velocity, which resulted from movement of the burned and expanding gas column in the tube, as well as the flame speed, was controlled by the fuel-air ratio, the total pressure of the charge, and other factors. Reproducibility of the velocity was in the order of ±6 percent.

Figures 3 and 4 show streak photographs of the flame front quenched by the screen and those which penetrate the screen respectively. The time marker spacing represents an elapsed time of one millisecond. When the velocity was slightly below critical, stabilization of the flame front below the screen resulted, probably caused by the fuel diffusing down from above (Fig. 5). On the other hand, when the velocity was quite low (at 2800 cm/sec) quenching was immediate.

The vibrations of the flame front above and below the screen were caused by coupling between the sound and combustion waves accentuated by the screen. Its characteristic did not change much within the flame velocity limits reported above. However, change of screen position relative to the tube affected the vibration.

It appears from table 1 that there is very little, if any, significant difference in quenching performance between coated and non-coated screen or among the coated

screens themselves. This is contrary to the results observed when the salts were compared by dispensing them in powdered form into a diffusion flame. The difference in performance might be as large as a factor of five [10]. Apparently, the chemical activity of the salts were non-operative under the conditions of the current experiments. Indeed, the evidence indicates only thermal quenching, since all flames having velocities below 2800 cm/sec were stopped. The critical flame front velocity and mesh width of the screen used fell very close to the curve worked out by Palmer on the basis of thermal considerations [11] for a bare screen.

HIGHER FLAME FRONT VELOCITY

When the flame front velocity was increased to about 5,000 cm/sec, the quenching characteristic of one of the salts appears to change. To obtain these changes, a 40 mm ID pyrex tube 45 cm long was used. Preliminary results shows that at flame velocities of 4550, 5100, and 5300 cm/sec, a screen coated with potassium oxalate monohydrate at a concentration used previously was able to quench the flame. However, the mode of quenching was different from that observed at 3200 cm/sec. Examination of the film records appeared to indicate that decomposition and ionization occurred above the screen. The flame was quenched at some distance above the screen probably by the salt in the vapor phase.

Fig. 6 is a streak photograph of the quenched flame above the screen coated with potassium oxalate monohydrate at a flame front speed of 4,550 cm/sec. Note the high density region above the screen which may indicate ionization.

With other salts, such as titanium potassium oxalate, $KHCO_3$ and $NaHCO_3$, the screens were not effective in quenching velocities in the region of 5,000 cm/sec. However this conclusion is based on limited data only. Further work, such as directly controlling the temperature of the salt might provide additional information on the effect of such salts in quenching flames.

CONCLUSIONS

1. The results obtained by this method indicate its limited usefulness in the study of variables that effect the chemical quenching efficiency of salts.

2. The negligible difference in performance between uncoated and coated screens at the 3,000 cm/sec region show that with the fuels and quenching materials studied the thermal quenching efficiency of all relatively cold surfaces are about equal.

3. The ability of potassium oxalate monohydrate to quench flames at velocities in the region of 5,000 cm/sec, indicate that the chemical quenching factor becomes operative. Decomposition and ionization of the salt as interpreted from the film records, appears to be necessary for chemical quenching which appeared to occur in the vapor phase.

4. Additional work is necessary to determine the conditions under which chemical quenching will appear in other salts.

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Table 1

Quenching Characteristic of Coated and Non-coated Screen

Velocity cm/sec	No Coating	$K_2C_2O_4 \cdot H_2O$	RbI	$KHCO_3$	$NaHCO_3$
Maximum, Quenched	2800	3250	3250	3050	2950
Minimum, Penetrated	3150	3300	3300	3150	3000
Number of Runs	9	11	3	5	5

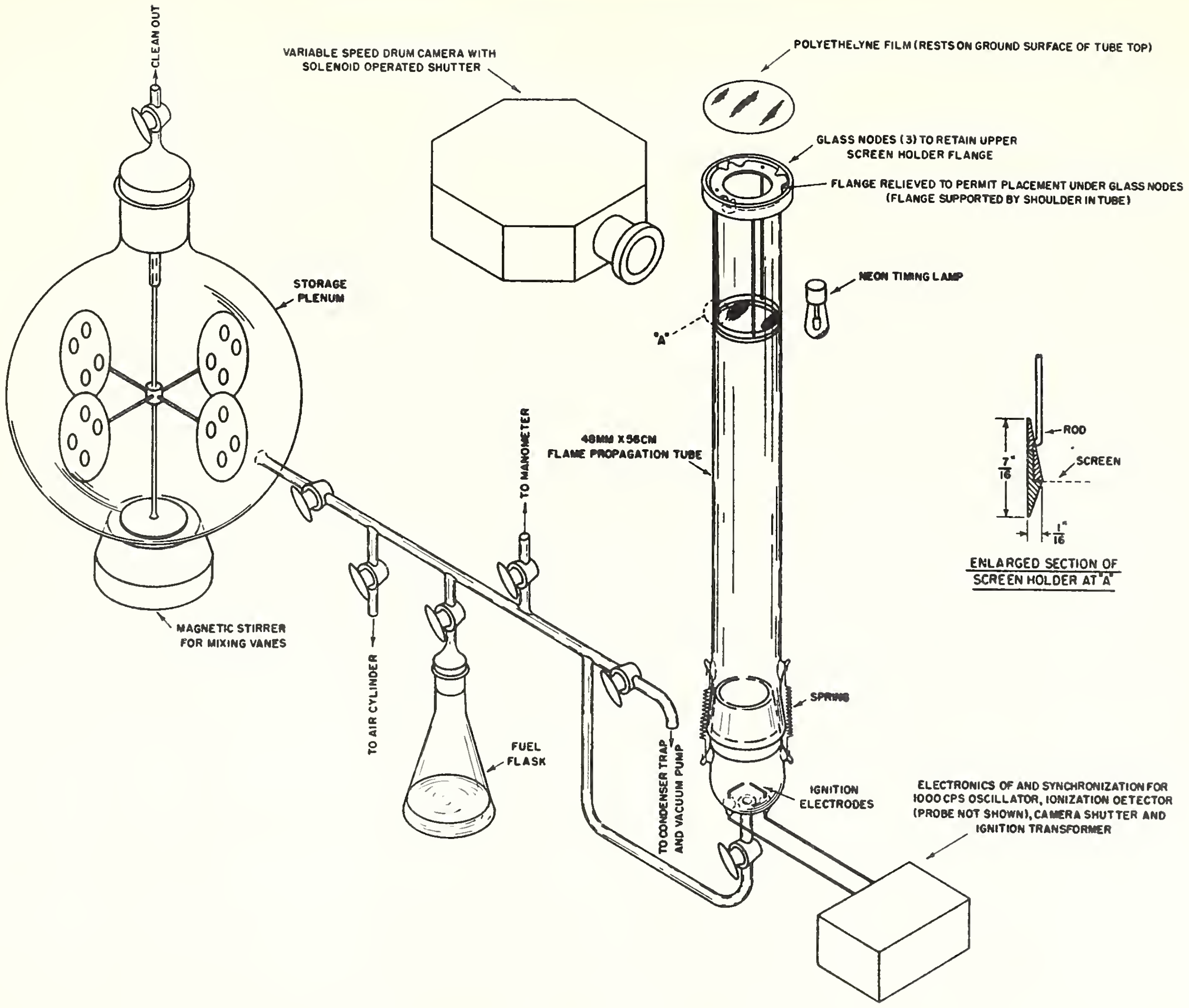

FIG. I - SCHEMATIC DIAGRAM OF APPARATUS

Fig. 2 Photomicrograph of a 100 mesh screen with thin crystalline coating. Light is reflected from coatings on the wires.

Fig. 3 Streak photograph of flame front quenched by a coated screen. Some ionized salt particles are deflected by the screen.

Fig. 4 Flame front penetrating a coated screen.

Fig. 5 Flame stabilized below the screen. Note overlapping of events on film.

Fig. 6 Flame being quenched above the screen, probably by salt in the vapor phase.

U. S. DEPARTMENT OF COMMERCE
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