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BEHAVIOR OF BICARBONATE POWDERS IN COUNTERFLOW DIFFUSION FLAMES

Mark D. Reed*, Bradley A. Williams, Ronald S. Sheinson, and James W. Fleming
Combustion Dynamics Section, Code 6185
Navy Technology Center for Safety and Survivability
Naval Research Laboratory
Washington, D.C. 20375-5342
fleming@code6185.nrl.navy.mil
202-767-2065 fax 202-767-1716

We are examining halon replacement agents and alternative fire suppression technologies including the use of aerosols and powders [1]. We report here propane/air counterflow diffusion flame extinction experiments as a function of strain and added powder concentration, size, and composition for various samples of potassium and sodium bicarbonate. Experiments were performed in propane/air counterflow diffusion flames in a counterflow burner [2] which consisted of two 10 mm ID opposed burner tubes. Powder was delivered to the flame in the air flow through the top tube. The powder delivery system consisted of a variable orifice for gross adjustment of the delivery rate and a variable frequency vibration unit to accomplish fine adjustment and to maintain powder flow. Light scattering (90°), using a chopped HeNe laser beam and a lock-in amplifier, was used to monitor the amount of powder exiting the air tube and entering the flame. Calibration of the relationship between the scattering signal and the quantity of the powder being delivered to the flame was determined by collecting and weighing the powder as it exited the air tube in the absence of the flame. A Phase Doppler Anemometry (PDA) System (Dantec Measurement Technology) was used to measure the powder particle velocity, size, and concentration.

Powders examined include Purple-K (commercial product which is essentially potassium bicarbonate, $KHCO_3$), sodium bicarbonate ($NaHCO_3$), and potassium bicarbonate ($KHCO_3$). $KHCO_3$ and $NaHCO_3$ powders were separated into various size groupings (< 38 μm, 38-45 μm, 45-53 μm, 53-63 μm, and 63-75 μm). Upon addition of any of these powders, the flame exhibited a very bright emission which grew brighter with further powder addition. The emission is attributed to increased C_2 emission [5]. Because this emission greatly dominated the flame appearance, filters were used to attenuate this emission in order to better view the flame using a video camera. In order to determine the extinction concentration, the powder concentration was increased until the flame extinguished. For these flames, extinction was typically only achieved along the centerline, leaving an annular flame. The flame emission was used to determine the extinction point. This emission was monitored using an optical fiber to record the flame image on the video monitor. Extinction concentration were determined as a function of the strain of the uninhibited flame. Global strain rates of the uninhibited flames are reported, determined as the ratio of the oxidizer stream exit velocity to the estimated distance to the stagnation plane based on the relative momenta of the fuel and air flows. In order to determine the powder concentration at the point of extinction, both the powder scattering intensity and the flame emission intensity were recorded.

Extinction mass concentration measurements for $KHCO_3$ and $NaHCO_3$ powders in the air flow of a propane-air flame versus global strain rate for various particle size bins is given in Figure 1 and tabulated in Table 1. As seen in the figure, the potassium powders were more effective (~ 2.5 times by weight) than the sodium powders for all particle size grouping and at all strains except for the 38-45 μm

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group at highest strain. This greater suppression effectiveness of the potassium compound is consistent with the lower decomposition temperature of this compound and has been observed by others [3,4]. Within the experimental uncertainty, there was a monotonic increase in extinction efficiency based on weight with decreasing particle size for both compounds. The extinction concentration for the low strain was not linear in particle surface area (nominal based on average diameter for the size bin), surface/volume ratio, or particle volume although the mid strain results were equally linear with both nominal volume and surface area. The size histogram, particle sample volume, and surface area will be determined in future experiments to investigate if such a relationship on particle properties can be determined.

The size histogram of unsieved Purple-K was determined and is shown in Figure 2. This figure shows the size histogram at three positions in a low strain (~ 115 s^{-1}) propane/air flame. Figure 2a shows the size histogram for the powder as it exited the air tube. The powder had a fairly broad size distribution with a mean diameter of 25 μm; more than 50% of the particles had diameters less than 12 μm. Figure 2b shows the histogram at a position in the flame. Figure 2c shows the size histogram after the flame. The average particle diameter decreased after passing through the flame to approximately 1/3 of its preflame value. Only particles <~ 30 μm are observed in any appreciable amounts in or beneath the flame zone. The concentration (as counts/cc) at the various positions reflect the consumption of the powder particles (primarily by decomposition) as it passes through the flame and the number density increase after the flame due to the drop in gas temperature.

Studies by Hamins *et al* [6] on three particle size ranges of $NaHCO_3$ including 0-10 μm, 10-20 μm, and 20-30 μm were conducted in a counterflow air/heptane liquid pool flame. $NaHCO_3$ was added to the air stream to determine the extinguishing effect of the powder. They observed a minimum extinction concentration for the 0 - 10 μm powder, followed by the 20-30 μm, and the least effective being the 10-20 μm. Data for potassium bicarbonate were not reported. Our smallest size for $NaHCO_3$ (< 38 μm) encompasses their entire range. We found that the effectiveness of $NaHCO_3$ or $KHCO_3$ powders decreases with increasing particle diameter for particles above 40 μm. Our size measurements near and in the flame show that sieved powders delivered to the flame always exhibit a fair number of particles larger than the sieve limit, due presumably to clumping. This is particularly true for the smaller sizes. Data on the actual particle sizes delivered to the flame are needed for powder samples characterized as less than 30 μm to determine the optimum size for maximum suppression effectiveness.

Acknowledgments

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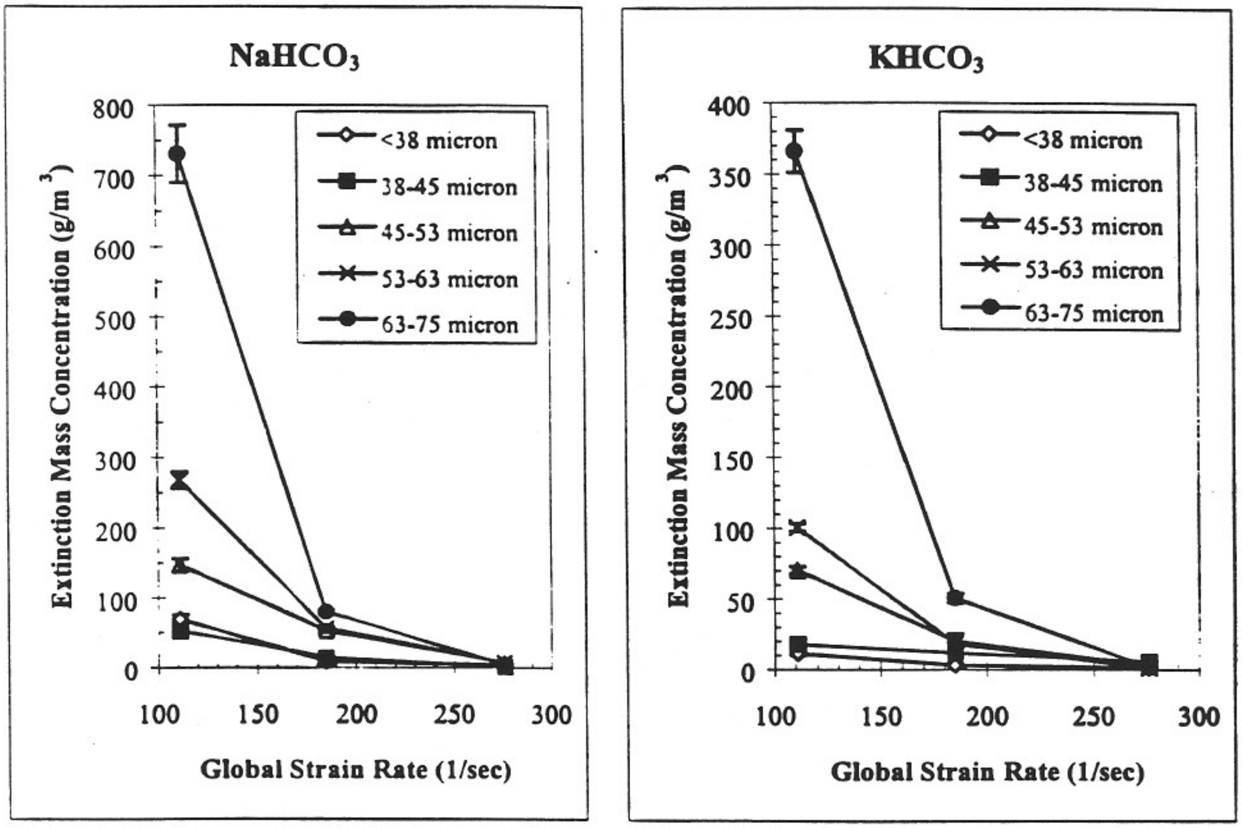

Figure. 1: Extinction mass concentration vs. global strain rate as a function of particle diameter for $NaHCO_3$ and $KHCO_3$.

		Extinction Mass Concentration for Specified Size Bin (g/m^3)				
Powder	Global Strain	<38 µm	38-45 µm	45-53 µm	53-63 µm	63-75 µm
$NaHCO_3$	115 sec^{-1}	70	52	147	268	731
	190 sec^{-1}	8	15	53	56	80
	295 sec^{-1}	4	1	7	7	4
$KHCO_3$	115 sec^{-1}	12	18	70	101	366
	190 sec^{-1}	3	12	20	18	51
	295 sec^{-1}	1	6	3	1	2

Table 1: Propane-air flame extinction concentrations for the indicated powders.

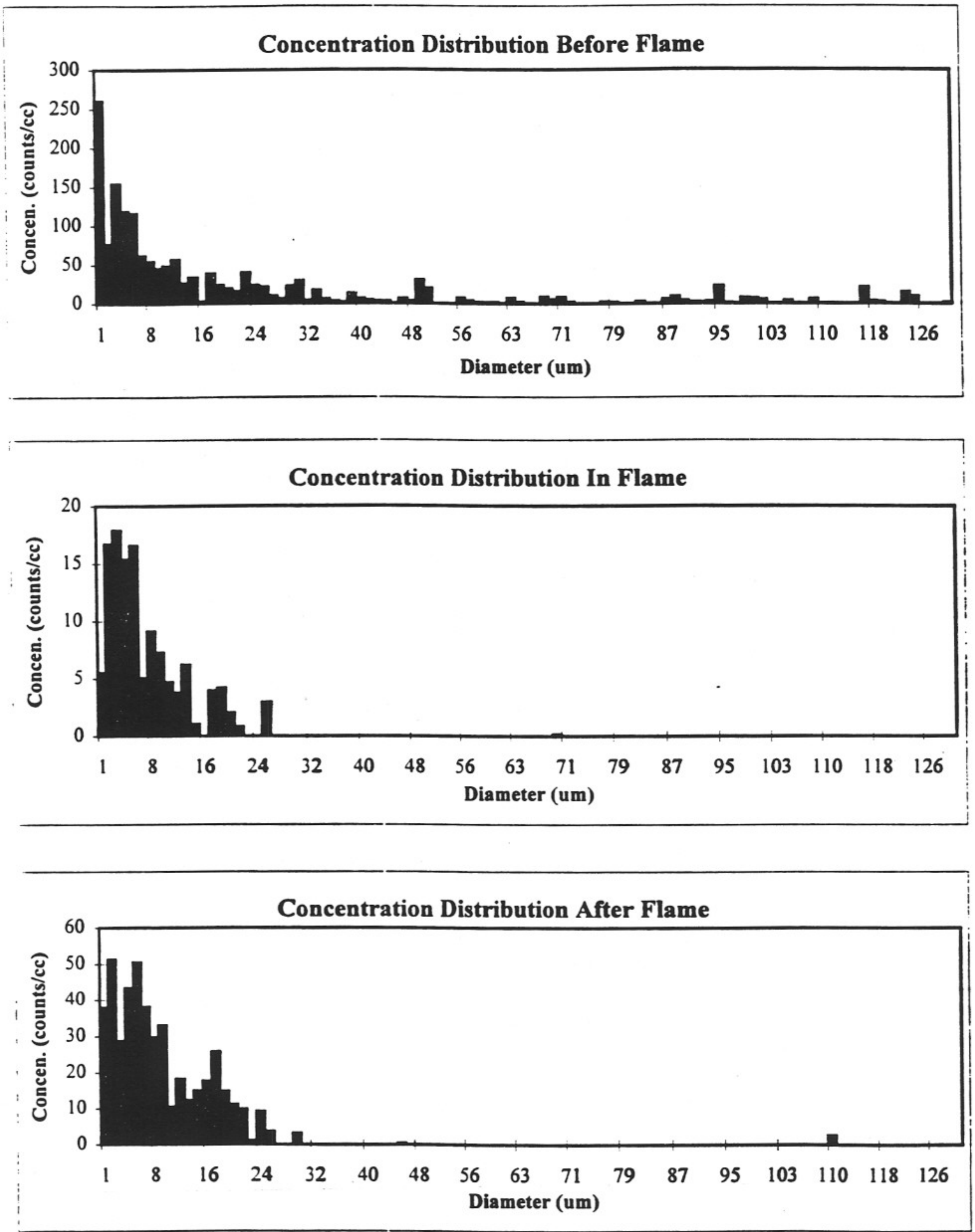

Figure 2: Behavior of Purple-K Commercial Powder at Three Different Axial Positions with Respect to the Flame.