# Quenching of Particle-Gas Combustible Mixtures Using Electric Particulate Suspension (EPS) and Dispersion Methods

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## INTRODUCTION

A cooperative study is being carried out between Iowa State University and McGill University. The new study concerns wall and particle quenching effects in particle-gas mixtures. The primary objective is to measure and interpret flame quenching distances, flammability limits, and burning velocities in particulate suspensions. A secondary objective is to measure particle slip velocities and particle velocity distribution as these influence flame propagation. Two suspension techniques will be utilized and compared: electric particle suspension/EPS (ISU) and flow dispersion (McGill). Microgravity tests will permit testing of larger particles and higher and more uniform dust concentrations than is possible in normal gravity.

Cloud Uniformity and Modeling: Flame quenching distance for dusts is an important parameter in laminar flame theory as it closely relates to the characteristic flame thickness and structure. Achieving a uniform dust concentration has been identified as a key problem to be resolved in dust flame studies. This uniformity can be accomplished with ISU's electric particle suspension method (EPS). Results obtained with EPS will be compared with the flow dispersion technique developed at McGill. Reliable measurements of flame quenching distance and flammability limits will serve as a basis for theoretical modeling of the mechanisms for flame propagation in dust suspensions.

## EXPERIMENTAL APPROACH

The EPS method perfected at ISU is fundamentally simple [1]. It utilizes a cylindrical test section enclosure comprised of two parallel plate electrodes (15 to 20 cm diameter) and Pyrex glass tubing for the insulated sides (Teflon and quartz are also used). Quenching distance is adjustable over distances of typically 0 to 6 cm. Both parallel plate and inert particle quenching are possible. During combustion, the test cell pressure is equalized to that of the ambient pressure. A dc supply drives the particle dispersion process. Spark ignition is utilized.

The McGill setup is a flow dispersal system in which a powder flame burns from one end of a tube (80 cm in length by 5 cm diameter) through a series of parallel plates having variable separation distance in which quenching takes place. The powder dispersion system features acoustic flame damping and a unique powder dispersal method developed from McGill's current NASA and Canadian research programs.

## DETAILED OBJECTIVES FOR MICROGRAVITY AND 1-g RESEARCH

Achieving uniform dust concentration has been identified as a key problem to be resolved in dust flame studies. This goal is addressed using a comparison of two distinct methods of powder dispersion, Iowa State's EPS method and McGill's powder dispersal method.

The specific objectives of the proposed microgravity and 1-g research investigation are:

- To compare parallel plate quenching distance and flame velocity measurements for combustible powders (e.g. aluminum, zirconium) using McGill's flow dispersion technique and ISU's EPS method in which the electric field strength is extrapolated to zero value.
- To evaluate the influence of inert particle concentration (glass, copper) on flame quenching/flame velocity of combustible gas mixtures (propane-air) using the EPS method.
- To quantify the effect of electrically controlled particle-gas slip velocity on quenching distance of powder flames using the EPS method (aluminum, zirconium, $10\ \mu m < d < 100\ \mu m$).
- To quantify the effect of electrically controlled particle-gas slip velocity on gas flame quenching (propane-air) by inert particles using the EPS method (glass, copper, $10\ \mu m < d < 100\ \mu m$).
- To characterize the particle velocity and particle velocity spread (velocity distribution) using the EPS method.

## ELECTRIC PARTICULATE SUSPENSION (EPS METHOD)

The Electric Particulate Suspension (EPS) method permits the formation of steady-state uniform suspensions. It is well suited for small-volume testing of powders and consequently can be used to measure quenching distance. It also provides up to four methods for measuring and calibrating particle concentration [2]. Excellent reproducibility of powder concentration is possible by monitoring the attenuated signal from a laser beam passed through the suspension. This is an important testing advantage in the present research. At 1-g, laser attenuation scans of an EPS show that gravitational stratification occurs in particle concentration over the height if the test section (few centimeter plate separation) although the cloud remains visually uniform and steady. In microgravity, gravitational stratification is effectively eliminated, permitting the formation of steady-state particulate clouds of improved uniformity. Microgravity also extends the range of testing to $E = 0$, which is useful to extrapolate the EPS quenching results to the field-free case used by McGill.

## PARTICLE SLIP VELOCITY AND VELOCITY DISTRIBUTION (EPS METHOD)

A slip velocity and velocity distribution between particles and gas is expected in certain conditions of larger particles flowing near walls and in vertical transport (against gravity) such as accelerating flows in burners and pulsating combustors. In a pulverized coal combustor, the minimum scale of microturbulence is 10-100 times the diameter of a pulverized-coal particle, which is also the scale of particle separation so that the gas within this distance from the surface of the particle is non-turbulent relative to the particle. The present study permits a study of particle slip velocity using the applied electric field [3]. In principle, both the Sherwood (mass transfer) and Nusselt numbers (heat transfer) of particles can be increased by increasing the particle-gas relative velocity. Both ground-based and microgravity based studies will be considered as regards effects of slip and particle velocity distribution.

## ISU'S KC-135 AND GROUND-BASED (1-g) APPARATUS

Studies to date at 1-g include the measurement of quenching and ignition energy curves for aluminum powder in various admixtures of oxygen, nitrogen, and carbon dioxide at ambient conditions of temperature and pressure. Aluminum powder 25-30 μm in concentrations of 150-3300 g/m$^3$ was tested with admixtures of oxygen, nitrogen, and carbon dioxide (mole ratio 0.21) [1]. Flammability curves were developed for lean to stoichiometric powder mixtures as shown in Fig. 1. Our quenching tests in 1-g using 17.5 μm spherical aluminum particles and 16.7 μm Illinois No. 6 coal used a system similar to that shown in the Fig. 2. The results indicated that both the quenching distance and lean flammability limit increase with particle size while the quenching distance of coal was observed to decrease with increasing volatile content.

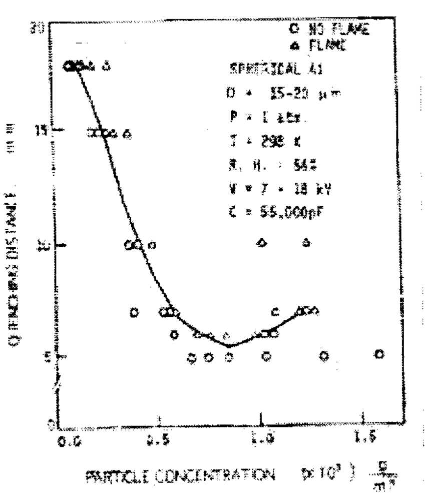


Fig. 1 Quenching distance using EPS 17.5 μm spherical aluminum particles.

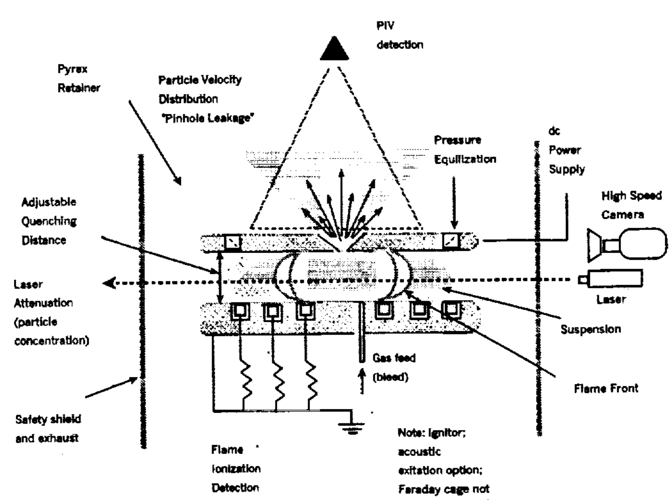


Fig. 2. EPS test facility (proposed)

## MCGILL'S KC-135 AND GROUND-BASED (1-g) APPARATUS

A newly developed dispersion system at McGill has been used to measure quenching distances in uniform dust clouds at constant pressure Figs. 3 and 4. In microgravity, it is possible to extend the ground-based experiments to larger particle sizes and higher dust concentrations. Initial studies of microgravity dust combustion were based on constant volume combustion in a closed spherical bomb. A number of KC-135 campaigns have been flown since 1991 [4]. The main findings indicated that combustion of a quiescent dust cloud in microgravity was reproducible with peak combustion pressure and the rate of the pressure rise. However, the peak pressure obtained indicated that only a fraction of the dust used was being suspended. Microgravity experiments on the KC-135 have demonstrated that a uniform suspension of relatively large particles (18 μm) at dust concentrations as high as 1200 g/m$^3$ can be obtained with the present method. In normal gravity, small particles (≤5μm) and lower concentrations (<600 g/m$^3$) can be suspended uniformly to permit ground-based experiments to be conducted. A Beta-radiation probe in combination with laser light attenuation probe will be used for monitoring dust concentration in our experiments.

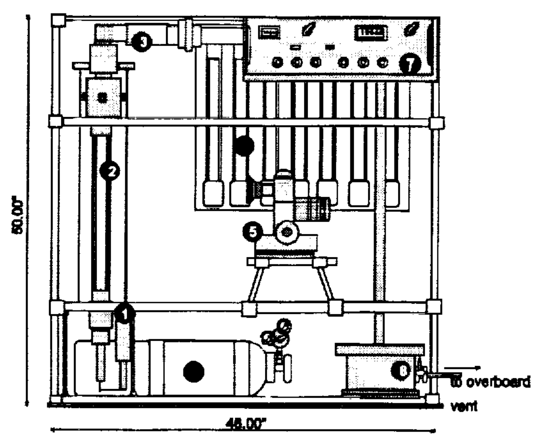


Fig. 3 McGill's Microgravity experimental package.

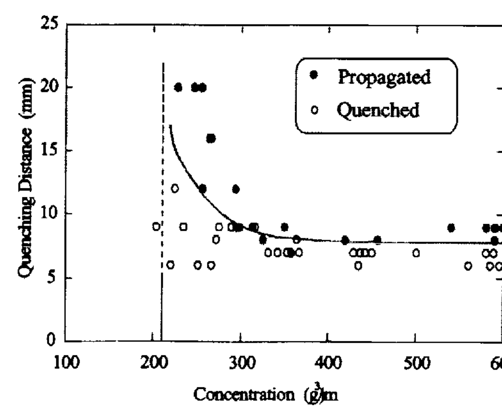


Fig. 4 Quenching distance in aluminum-oxygen-helium dust suspensions.

## ACKNOWLEDGMENT

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## PUBLICATIONS

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