Aerosol Particle Charging in Explosive Disseminations

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TECHNICAL CHALLENGE

Determine whether aerosol particles can become electrically charged during explosive dissemination.

BACKGROUND

The performance of novel obscurant particles depends greatly on effective dissemination. Dissemination of traditional obscurant materials such as TiO_2 and brass flakes are often disseminated explosively from grenades. Performance (absorption and scattering) of obscurant materials is typically better when pneumatically disseminated via sonic nozzles. Discussions to improve explosive dissemination of obscurants generated questions concerning the basic nature of explosive dissemination. It is likely the pneumatic dissemination imparts large amounts of charge to the particles. Does this charge possibly help disperse the particles? If so, could something be done to pre-charge grenade payload particles or impart charge to the particles in the explosive dissemination. Then the basic question arose: What do we know about charge on particles from an explosive dissemination. Is the resulting aerosol highly charged or does it quickly reach equilibrium? If they are charged, are they uni-charged? Questions were posed to various SMEs and a literature search revealed: "…there does not seem to be an abundance of reports/papers on this topic..."

We hypothesize that charge could be imparted to the individual particles either by tribo-charging due to particle-particle interaction, free radicals present in the explosive reaction or from the intense gas heating and pressure discontinuities of the shock wave, or perhaps resulting from the breaking of the particle's frangible surface boundaries.

RELEVANCE

Explosive dissemination of materials is considered a realistic and potentially effective method to create a threat aerosol in addition to the dissemination of threat defeat scavengers and obscurants. Many dissemination methods will result in the aerosol particles having an electrical charge[1]. The presence of an electrical charge will certainly affect the tendency of aerosol particles to agglomerate or disperse. Therefore propagation of the threat cloud and subsequently the transport of these particles through detection devices, human respiratory tract[2], and the deposition of threat to contaminate surfaces can be tremendously dependent on particle charge. Furthermore, the performance of obscurants greatly depends on effective dispersion which can be influenced by particle charging. Also, if it were possible to produce highly charged particles from an explosive dissemination, there could be potential use in the scavenging of Agent particles or screening smokes.[3]

APPROACH

Several experimental explosive devices were created based on an M106 obscurant grenade configuration. These devices were filled with conductive and non-conductive materials (varying dielectric constant) whose native size is in the sub-micron range. These devices were functioned in an explosive test chamber and the resulting aerosols were characterized to determine particle size, concentration, and particle charge. The Dekati Electrical Low-Pressure Impactor (ELPI™) is especially suited to performing these measurements. The aerosol resulting from the explosive dissemination was compared to various non-explosive disseminations. These other disseminations each present different primary particle charging mechanisms to provide perspective to the characteristics of the electrical charge resulting from the explosive device.

EXPERIMENTAL DEVICES

- Explosive Device: ½ of M106 body, 8-grams C4 central burster. Filled with 124-cc of payload material.
- Pneumatic Device: "SRI" sonic nozzle + 6-ft of PVC pipe outlet
- Pneumatic Device: Powdercoat sprayer with corona charger
- Air Atomizer
- Non-explosive Burst-Disc grenade (219 innovative project product)
- Pyrotechnic Device: 8-gram mix (1.7-g red dye payload) endburner
- Combustion: HUMVEE diesel

Figure 1. The explosive device was ½ of an M106 body with an 8-gram C4 central burster.

Figure 2. Explosive dissemination of TiO2.

TEST CONFIGURATIONS

Test Configurations		
Dissemination Method	**Plausible Charging Mechanism**	**Test Material**
Explosive	Flame, Triboelectric, Shock Wave	Titanium Dioxide, TiO2, (Dk~80)
		Toner Powder, Polyester, (Dk~3)
		Brass Powder (Dk~∞)
Pneumatic	Triboelectric	Titanium Dioxide, TiO2, (Dk~80)
		Toner Powder, Polyester, (Dk~5)
		Brass Powder (Dk~∞)
Pneumatic past Corona Discharge	Triboelectric, Field (>1um), Diffusion(<0.1um)	Titanium Dioxide, TiO2, (Dk~80)
Burst Disk	Shock Wave= Tribocharging (?)	Titanium Dioxide, TiO2, (Dk~80)
Pyrotechnic/Combustion	Flame	DR-9 (red smoke dye), diesel

USING THE DEKATI ELPI FOR CHARGE DISTRIBUTION

Particle charge was measured using the Dekati Electrical Low-Pressure Impactor (ELPI™):

- Aerosol particles enter a low-pressure cascade impactor and are sorted into 14 different stages based on aerodynamic diameter.[4]
- Corona charger puts high charge on particle, which is well-defined for the particle size,. and detectable by electrometers on each stage. The charge per particle is known therefore providing Number Count of particles on each stage.[5]
- If the corona charger is turned off then the charge measured on each stage is due to the net charge of particles on that stage.[5] The electrometers can measure currents as small as 1-2fA)[6]
- By turning the charger on and off in cycles, the Number Count and the overall Charge Distribution are measured.[5]
- These Charge and Number measurements are then used to obtain the Charge per Particle of the aerosol.

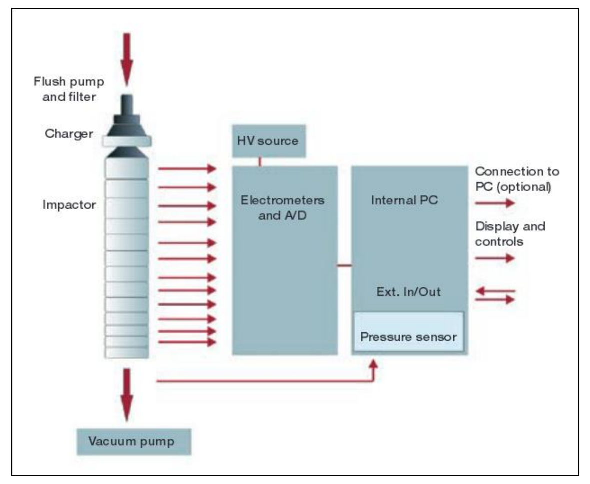
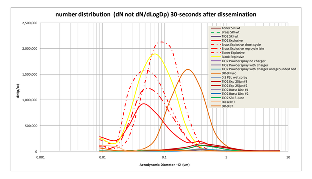


Figure 3. Diagram of the Dekati ELPI™

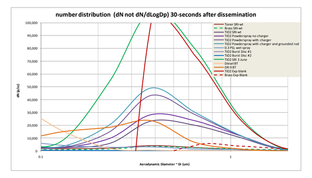
PRELIMINARY RESULTS

- Overall Number Distribution results are used to narrow our charge characterization to data pertaining to the payload particles (primarily 0.1 to 2.0 μm).
- Charge Distribution is determined from the ensemble particle charge per stage ($Q = I\,t$), where $\mathbf{I}$ is the current detected by the electrometer and t is the sampling time for that data set (1-second).
- Number Count per stage is determined from the ELPI calculated number concentration (dN) and the ELPI sampling flow rate and sampling time.
- Charge Per Particle (CPP) is determined from the Charge and the Number Count per stage (particle size bin).

Figure 4. Number Count Distributions

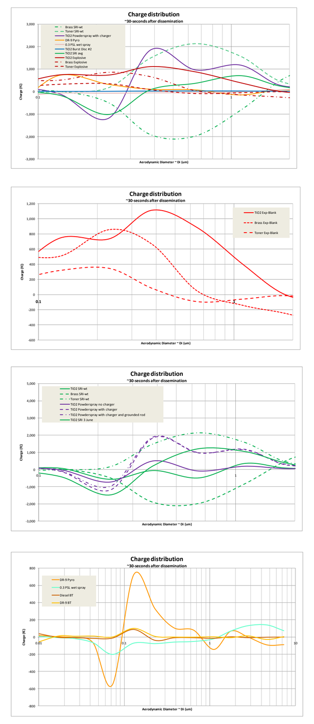


Particle number distribution from all trials. Note the blank explosive trial indicates that the high particle concentration below 0.1 um appears to be from explosive debris, not payload.



Particle number distribution (Blank has been subtracted from the Explosive trials) indicates that charge on particle analysis should focus on the charge data in the 0.1 to 2.0 um range.

Figure 5. Charge Distributions



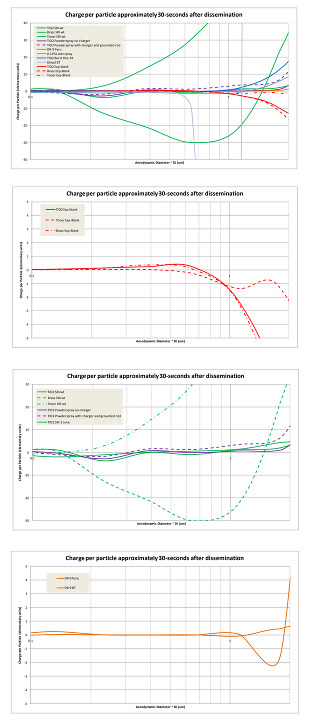
All Dissemination Configurations

Explosive Dissemination Configurations

Pneumatic Dissemination Configurations

Pyrotechnic Dissemination Configurations

Figure 6. Charge Per Particle (CPP)



All Dissemination Configurations

Explosive Dissemination Configurations

Pneumatic Dissemination Configurations

Pyrotechnic Dissemination Configurations

*Burst Disc distributions were heavily influenced by the low particle concentration and not shown here

ANALYSIS & DISCUSSION

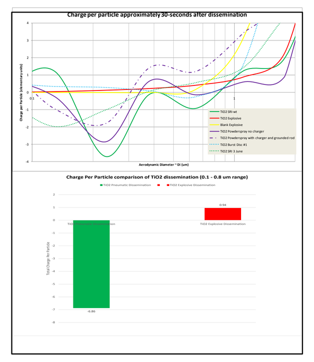


Figure 7. The Charge Per Particle (CPP) comparison of the Explosive Dissemination to the Pneumatic Dissemination, which should produce a significantly charged aerosol, indicates that the Explosive Dissemination does not produce a significant CPP level.

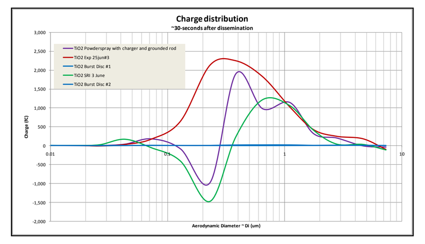


Figure 8. The Charge Distribution comparison of the Explosive Dissemination to the Pneumatic Dissemination and Pneumatic with Corona charging, and Burst Disc (shock wave). This indicates that the Explosive Dissemination produces a positive charged payload aerosol, whereas the Pneumatic disseminations start with a negative charge that becomes positive as the particle size increases. The Burst Disc Dissemination does not impart a significant charge to the payload

Indications that there is a material effect (dielectric constant-Dk) in the charge per particle characteristics when particles are disseminated via a method that imparts tribo-charge:

- Low Dk (~3) produces a relatively high CPP that increases in positive charge as size increases.
- Medium Dk (~80) produces a relatively low CPP that starts negatively charged and goes to positive charge as size increases. (correlates to Davison 1985[7])
- High (∞) produces a relatively high CPP that increases in negative charge as size increases (This correlates to previous study of charge on conducting particles used as smoke scavengers[3]).

Challenges:

Electrically-charged aerosol particles will dissipate the charge due to collisions with oppositely-charged ions in the air. Typical charge relaxation times (where the charge dissipates by 37%[8]) can range from 2 seconds to over 100 minutes depending on ion concentration[1], but is commonly reported to be on the order of 30 seconds for many processes. The time for the aerosol to move from the center of the test chambers, through the sampling lines and into the ELPI for measurements is on the order of 30 seconds. So it is possible that a short-lived aerosol charge is not detected. Also, humidity plays a large part in whether charging will happen in certain processes and how quickly the charge will dissipate. We could not control humidity in our explosive chamber, but measured it to be between 45-60% RH for all trials.

Data Validation:

There is very little from the literature search to guide expectations on particle charging due to explosive dissemination. However there is some literature on Charge Distribution and Charge Per Particle from the Pharmaceutical industry[9].Their experiment was on Metered Dose Inhalers (MDIs) which can impart tribocharging. Their Charge distributions were similar to ours for tribocharging disseminations, showing a switch from negative to positive charging as particle size increased Charges from Corona Discharge should be high. We see a definite increase in charge when a corona discharge is imparted on pneumatic disseminations.

PRELIMINARY CONCLUSIONS

- Explosive dissemination of submicron payload particles do not produce particle charge levels (charge per particle) that are significantly higher than other dissemination processes.
- However, the charge distribution of explosively-disseminated submicron particles show that they are mainly positively-charged whereas other disseminations show charge distributions that can be negatively-charged or contain bipolar charges that are dependent on particle size.
- There is very little, if any, literature to compare to our explosive dissemination results. However, charge distribution characterizations from our disseminations where tribocharging should dominate compare to those found in literature that used the ELPI instrument.

LESSONS LEARNED and RECOMMENDATIONS

- As a response to interest in particle charge measurement studies, Dekati has incorporated a "Charge Measuring" feature into the latest ELPI™ control software[5]. However, we have found that electrometer instability from cycling the ELPI charger at high particle concentrations renders this feature unreliable. Data reduction and analysis is best done by manual inspection of the raw current history and selecting small blocks of sampling times from the charger off cycle where raw current is consistent and pairing it with number concentration measurements from the end of the previous charger on cycle.
- Charge of particles from the explosive dissemination is hard to discern from charge on particles produced as by-product of the explosion (i.e. debris and reaction compounds).
- This effort focused on sub-micron particle fraction of the payload. However there is a significant payload mass fraction around 10-um, which is not sensed by the ELPI+. This larger size fraction could be important, especially in scavenging applications and might be explored further with other instrumentation.

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