

Analysis of factors affecting Dust Explosion

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Abstract

In the US alone, the Chemical Safety Board reported 281 dust explosions that occurred between 1980 and 2005; resulting in 199 fatalities and 718 injuries. The basic factors required for a dust explosion are: a combustible dust, suspension of dust in high concentration, atmospheric oxygen, and an ignition source. Typically it is very difficult to eliminate factors in a factory setting handling dust particles. This study focuses on the electrostatic charge produced when dust particles are transported pneumatically in a pipe. This electrostatic charge can lead to ignition source and hence cause a catastrophe. Humidity is found to be in direct correlation with electrostatic charge. At a higher humidity, conductivity increases and the charge is more likely to dissipate. Besides looking at related works of other researchers (who looked at electrostatic charges and the influence of humidity on them), experiments were also carried out to analyze the influence of charge on different powders when suspended in different environment and the charge decay time at low humidity as well as at high humidity. It was confirmed that humidity mitigates the situation by decreasing the charge decay time (unless the powder is hydrophobic).

Introduction

Combustible dusts are fine particles, such as coal, sawdust, magnesium, grain, flour, sugar, powdered milk, etc., that presents hazards for dust explosions in certain environments and concentrations. Four basic things are necessary for a dust explosion to occur; the ignition source, the dust suspension at the right concentration, the dust confinement, and oxygen. A dust explosion can also occur even in the absence of ignition sources. Spontaneous ignition could occur as a result of the accumulation of heat of reaction, which raises the local temperature and, in turn, causes the rate of reaction to give off more heat. [2] When the ignition temperature is reached, a certain amount of time is required for ignition; this is called induction time.

Every day, thousands of tons of pulverized powders are handled in the United States (US), such as paint, chemical fertilizer, flour, starch, detergent, etc. For transportation within the plant systems, the powders are transported pneumatically (typically by dilute-phase and dense-phase pressure-conveying or vacuum conveying). While being conveyed, the powders get charged (static electrification); the dust clouds produced from these charged powders could be easily ignited, leading to a dust explosion. In the US alone, the Chemical Safety Board reported 281 dust explosions that occurred between 1980 and 2005, resulting in 199 fatalities and 718 injuries.

Related Work by Others

Masaharu Nifuku and Hiromi Katoh [3] investigated the static electrification characteristics such as dust concentration, transportation velocity and their relationship with powder charge. The apparatus

used to investigate these characteristics is shown below in figure 1.

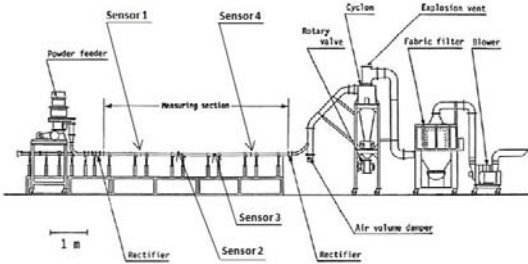


Figure 1: Horizontal static electrification apparatus used by Masaharu Nifuku and Hiromi Katoh. [3]

A powder sample is supplied into a horizontal piping system by the powder feeder (adjusted by the motor revolution and scraper depth). The measuring section measures the electrostatic charges and is composed of five brass pipes and two rectifiers are also installed just prior to the measuring section to ensure improved dispersion of the dust sample. The sample used in their experiment was pulverized coal with an average diameter of 20 μ m (number size basis).

The relationship between dust concentration and electrostatic charge is shown below in figure 2. It shows that the charge per mass of dust increases with the concentration up to a certain level then decreases.

The relationship between dust concentration and electrostatic charge is shown below in figure 3; this shows that with velocity charge increases and then falls to zero and eventually goes negative.

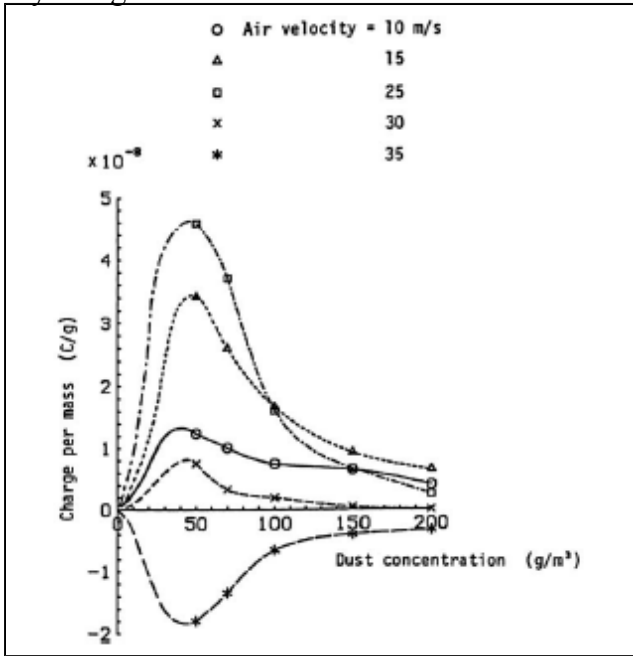


Figure 2: Charge per mass of coal by pneumatic transportation^[3]

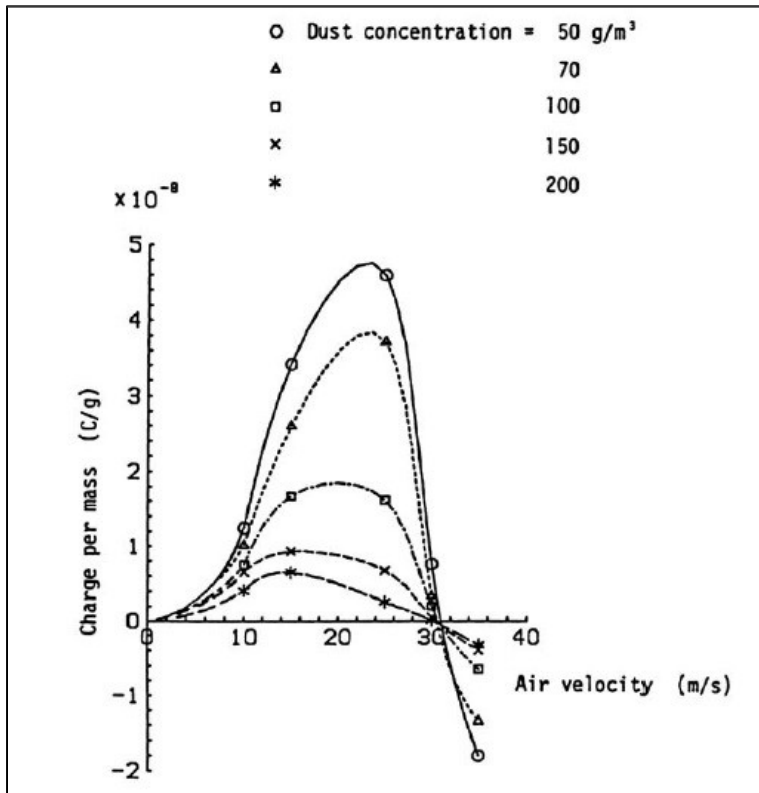


Figure 3: Charge per mass of coal by pneumatic transportation^[3]

Figure 4 below shows the effect of relative humidity (RH) on static electrification. The charges shown here were measured at the four designated points (numbered 1 to 4) in the measuring section shown above in figure 1.

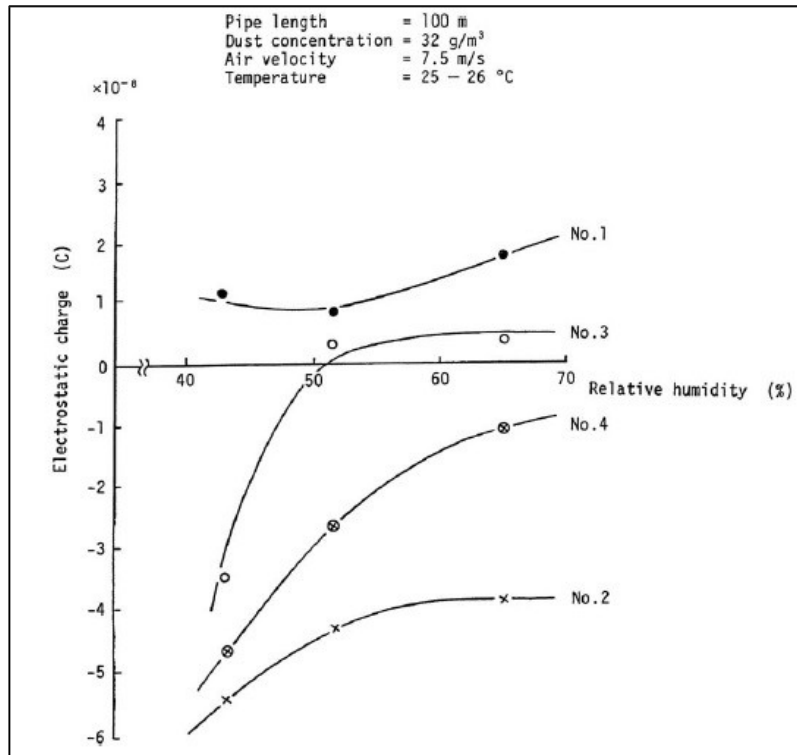


Figure 4: Influence of relative density on electrostatic charge ^[3]

The data indicate that as the relative humidity is increased, electrostatic charge decreases too except for sensor no. 1 which increases at 65% RH ^[3]. Electrostatic charge is generated by the contact of heterogeneous surfaces; in this case, the pipe's inner surface in contact with the dust particles. Humidity increases the conductivity between both the surfaces and hence the charge is reduced accordingly. The charge could be regarded to be small above 65% RH.

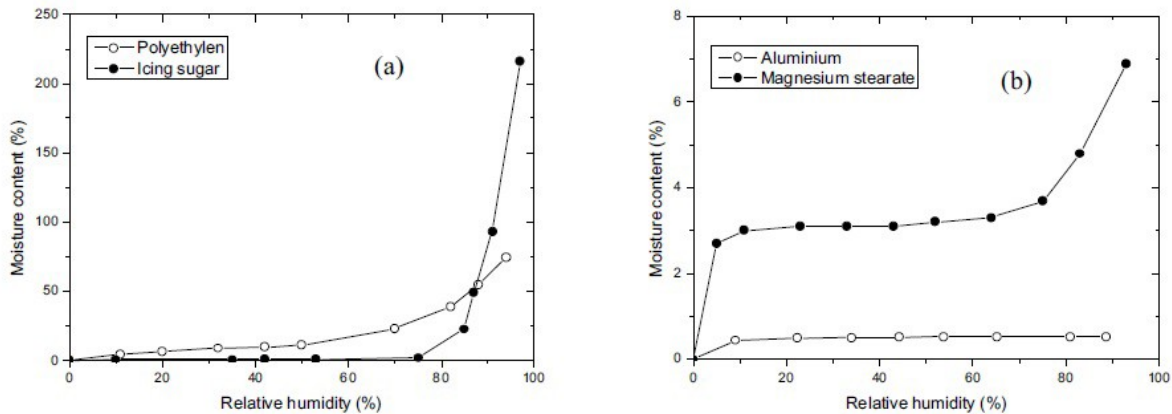
Another related work on the influence of humidity on dust explosions was carried out by M. Traoré et al. The influence of humidity on metallic (aluminum) and organic materials (icing sugar, polyethylene and magnesium stearate) has been studied. There were two types of test carried out: one was where the sample was stored at a certain RH and the other was when the dried sample was dispersed in a humidity controlled atmosphere. ^[4]

Statistics on dust explosions in the US from 1979 to 1986 shows that most of the explosions occurred during the winter months when the humidity is at its lowest. Despite these statistics, the majority of standards and procedures related to dust explosion characterization overlooks the influence of humidity and only requires that humidity is to be noted down. ^[4] The powders used in this experiment by M. Traoré et al were characterized by d_{10} , d_{50} and d_{90} of the volumetric distribution; the d_x is the diameter where 'x' refers to the size at which x% of the particles are smaller. $d_{3,2}$ refers to the Sauter mean diameter. The diameters are shown in table 1 below.

Table 1: Particles sizes of the powders. ^[4]

Samples	d ₁₀ (μm)	D ₅₀ (μm)	d ₉₀ (μm)	d _{3,2} (μm)
Aluminum	3	7	13	3
Icing Sugar A	7	22	41	7
Icing Sugar B	17	45	76	12
Magnesium Stearate	3	6	15	3
Polyethylene	34	136	249	58

For the dried sample part of the experiment, the samples were dried at 50°C under vacuum for two hours before handling. ^[4] The dry dust was then dispersed in a controlled humidity atmosphere in an explosion vessel (20L). For the other part of the experiment, samples of dust particles were stored in a glove box at constant humidity for a sufficient period to allow for equilibrium to be reached. The water content in the powder is determined from the adsorption isotherm. The adsorption isotherm of icing sugar, polyethylene, aluminum and magnesium stearate are shown below in figure 5.

**Figure 5:** Adsorption isotherm of icing sugar, polyethylene, aluminum and magnesium stearate at 25°C ^[4]

The plots show that although the moisture content of polyethylene, icing sugar, magnesium stearate increased with increasing RH, the moisture content of aluminum was almost unaffected by humidity. This is expected as aluminum is a metal and is not expected to absorb moisture.

According to the article, volume resistivity and charge decay time of a powder are prominent characteristics and they need to be understood properly to understand the valuable information on its electronic hazards. [4] The volume resistivity was determined by placing the powder sample in a resistivity cell. The charge decay time (τ) is the time it takes for the charge of a powder to decrease to 0.37 of its initial value.

Although it was noticed above that the electrostatic charge decreases significantly above 65% RH, this assertion could be challenged depending on the powder properties. Icing sugar and magnesium stearate behave differently at elevated RH humidity levels and is shown below in figure 6 below.

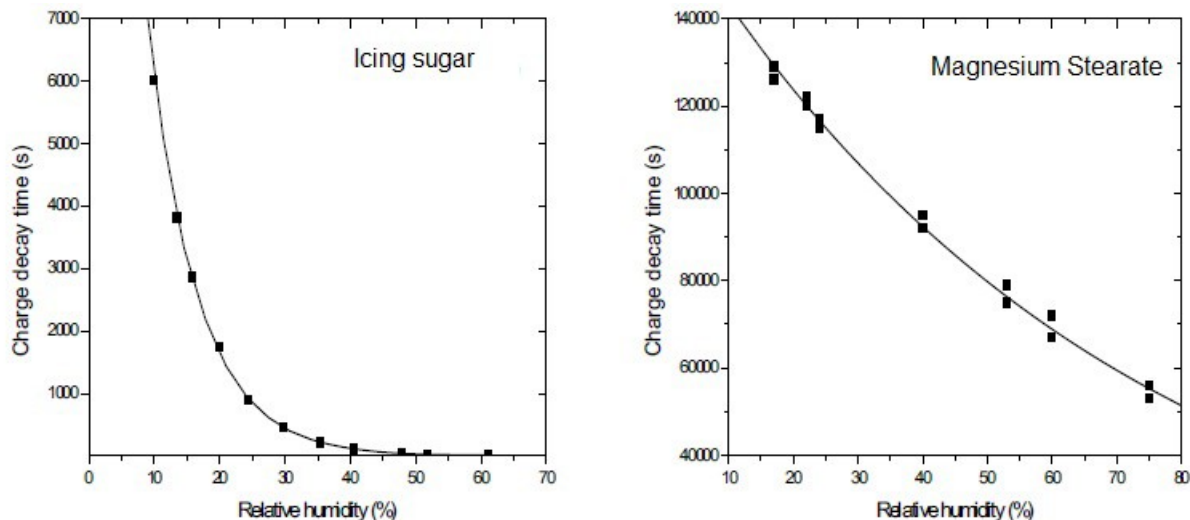


Figure 6: Influence of relative humidity on the charge decay time on icing sugar – 22mm and on magnesium stearate – 6mm (at 25°C) [4]

It was observed that for icing sugar, the charge decay time was significantly reduced at 60% RH and the charge decay time for magnesium stearate was almost reduced to half at 60% RH as compared to 15 % RH. Thus it can be concluded from these experiments whether relative humidity, and thus the moisture content, would inhibit or aid the dusts' ignitability; this depends on the chemical properties of the powder.

The Experiment

In our experiments, we looked at the charge dissipation over time for Micro Crystalline Cellulose (MCC), granulated sugar, sand and corn starch. Charge was generated by mimicking flow through pipe made of different materials (Polyvinyl Chloride, Polyethylene, Glass, and Copper) using a rotary tumbler. The pipes were filled with the powdered material and electrostatic charge was generated by friction (between the powders and the inner surface of the piping material) due to the rotary motion generated by the rotary tumbler for 1 minute.

Extra caution was used when handling the pipe after charge was produced to prevent discharging of the material through grounding. Oven mitts, made of silicon, were used when handling the

pipes. A tin can was used to hold the charged particles and it was then placed in a Faraday's ice pail (Model: Pasco ES9057C) shown in figure 7 below.



Figure 7: Pasco ES9057C; Ice pail

Charge decay time was then measured with the help of a basic electrometer (Model: Pasco ES9078A) shown in figure 8 below, connected to a computer.



Figure 8: Pasco ES-9078A Basic Electrometer

Charge at a given time was tabulated in a spreadsheet with the help of *Data Q* (MS Excel add-in). Higher humidity was obtained by flowing air through water in a glass cylinder and into the tin can.

Results

All the graphs have two axes, one for voltage and the other for RH. It is recommended to view or print in color as it is easier to see the colors (red for RH and blue for electrostatic charge of the powder).

The charge dissipation of MCC particle after being on a rotary tumbler inside a Polyvinyl Chloride (PVC) pipe is shown below. The rate of decay of charge is fairly constant and is very low of about -0.0164 volt/min at $\sim 39\%$ RH. Whereas, when MCC is negatively charged in a PVC pipe, shown in figure 10, the rate of charge decay is much higher (0.1443 volt/min) because of a higher density ($\sim 60\%$ RH).

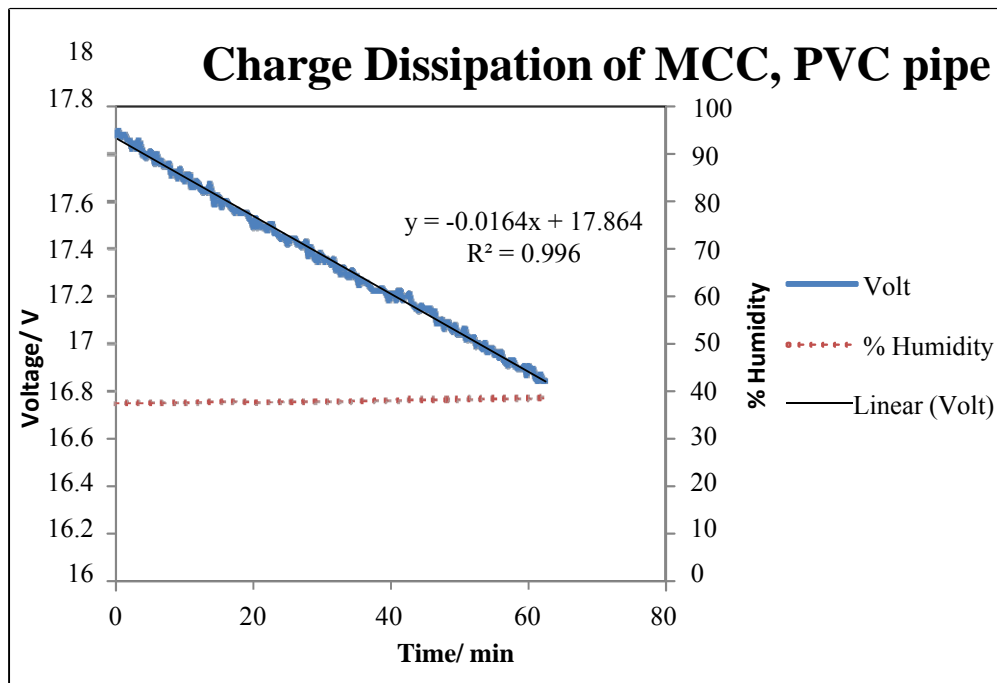


Figure 9: Charge dissipation of Micro Crystalline Cellulose after it was tumbled in a PVC pipe.

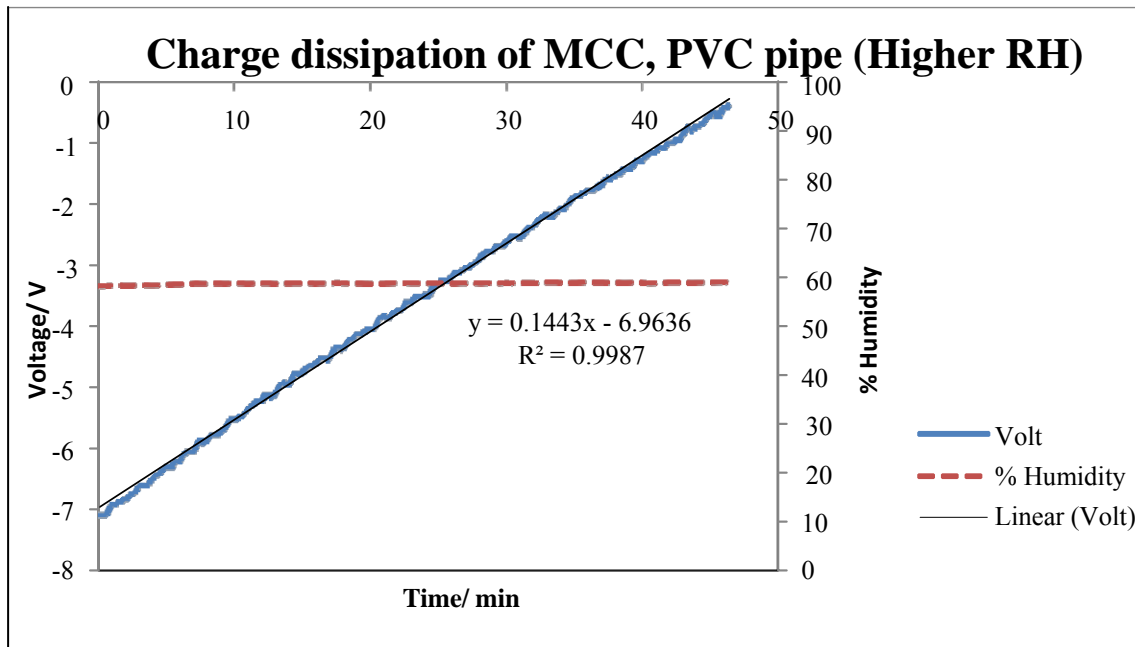


Figure 10: Charge dissipation at a higher humidity of Micro Crystalline Cellulose after tumbled in a PVC pipe.

For MCC in a polyethylene (PE) pipe, at about 40% RH, the charge stays almost unaffected (figure 11) but the charge changes significantly for 70% RH (figure 12).

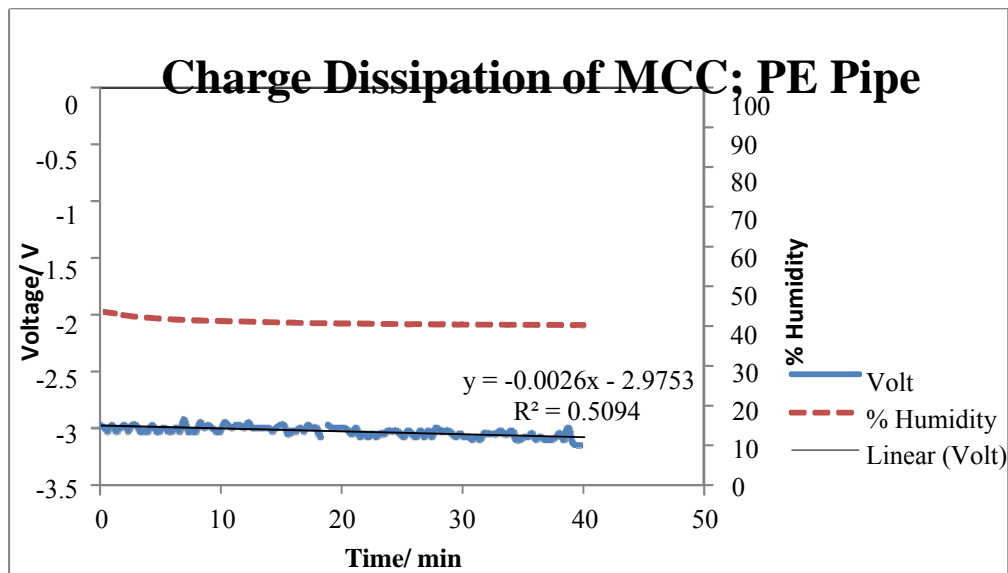


Figure 11: Charge dissipation of Micro Crystalline Cellulose after it was tumbled in a PE pipe.

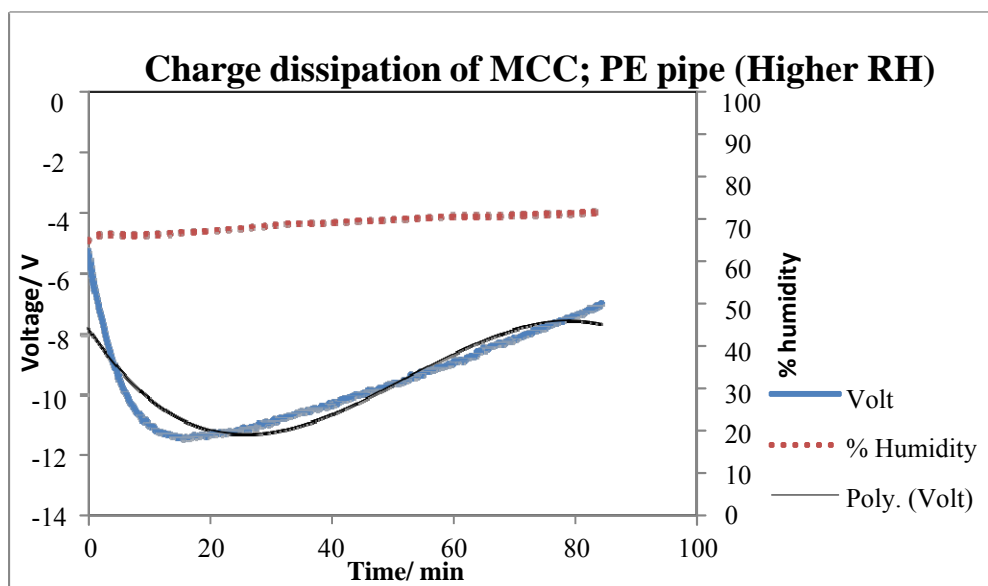


Figure 12: Charge dissipation at a higher humidity of Micro Crystalline Cellulose when it was tumbled in a PE pipe.

The charge dissipation of sugar for PVC pipe at ~50% RH seems to behave differently from that for ~78% RH. It is interesting that the sugar reverses its charge. The charge dissipation looks like an exponential decay and not a linear one. The charge dissipation at ~50%RH is probably the tail end of an exponential decay.

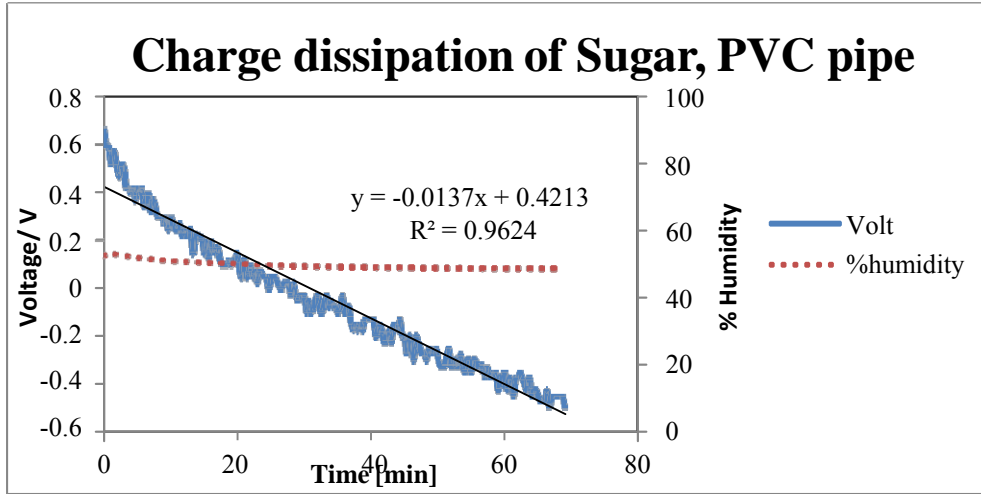


Figure 13: Charge dissipation of granulated sugar when it is tumbled in a PVC pipe.

Charge Dissipation of Sugar; PVC pipe(higher RH)

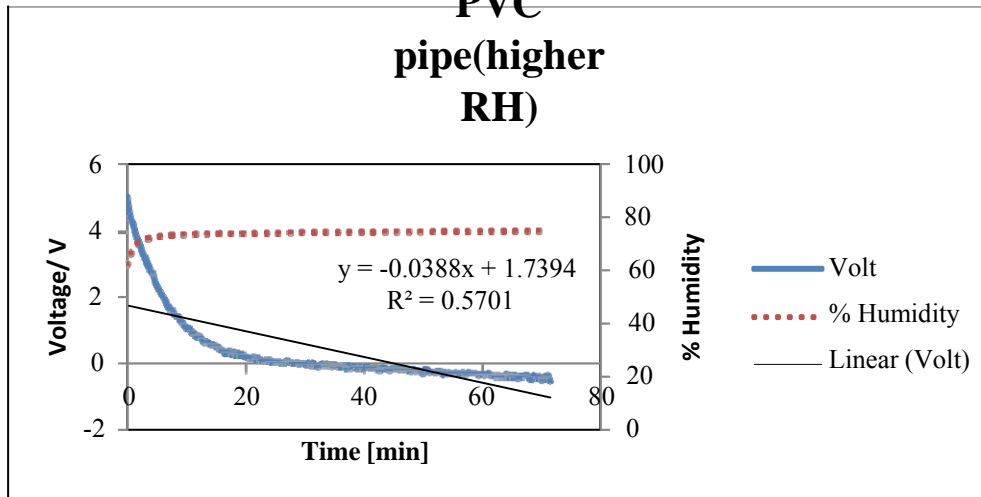


Figure 14: Charge dissipation at a higher humidity of granulated sugar when it is tumbled in a PVC pipe.

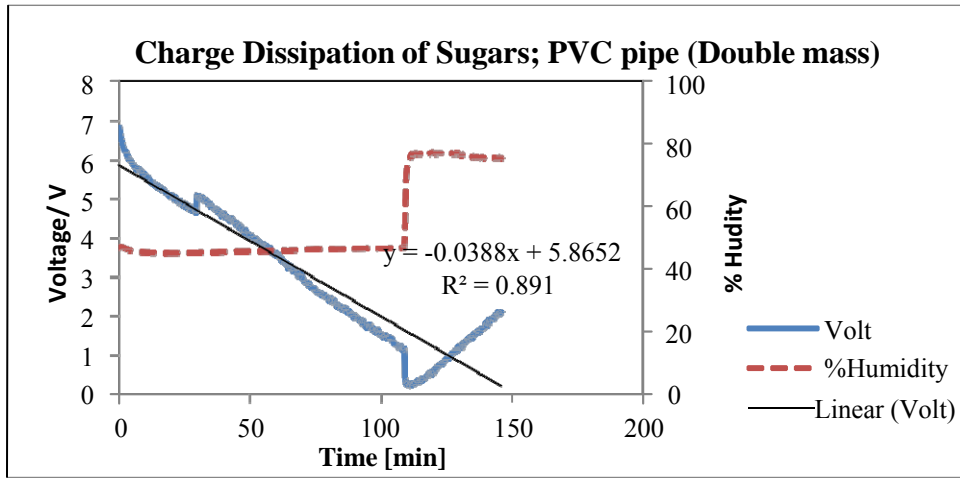


Figure 15: Charge dissipation of granulated sugar (twice the mass in the previous two figures) when it is tumbled in a PVC pipe

The charge dissipation of sugar for glass piping is very interesting. At 50% RH, the charge is not actually decaying – it is increasing in the negative direction and is very slow and fairly linear (figure 16). In figure 17, the charge dissipates slowly for a constant RH of ~42%, but suddenly changes and starts to become positive when RH is increased to ~80%. Thus it shows that charge decay is related to RH.

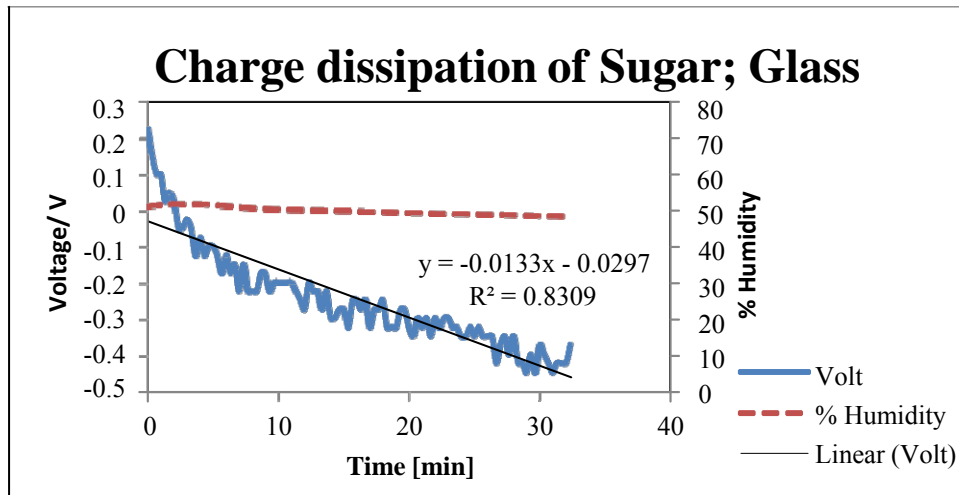


Figure 16: Charge dissipation of granulated sugars when it is rubbed along a glass surface.

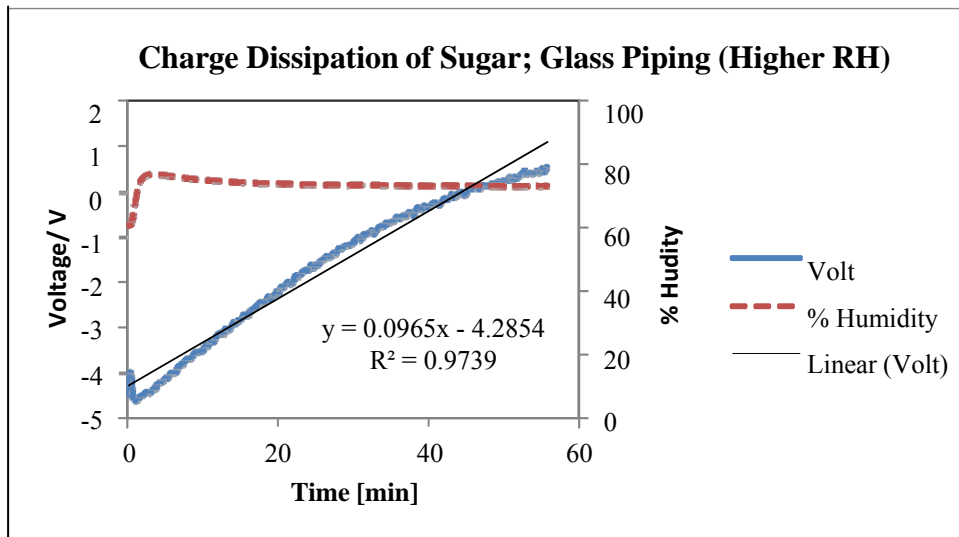


Figure 17: Charge dissipation at a higher RH of granulated sugars when it is rubbed along a glass surface.

The charge dissipation of sand for copper pipe at ~42% RH (figure 18) is slower compared to that at higher RH of ~70% (figure 19). The charge decay rate almost doubled when RH was increased from 42 to 70%. When mass is doubled, at a relatively same RH, charge decay rate seems to drop from 0.05 to 0.03 (figure 20).

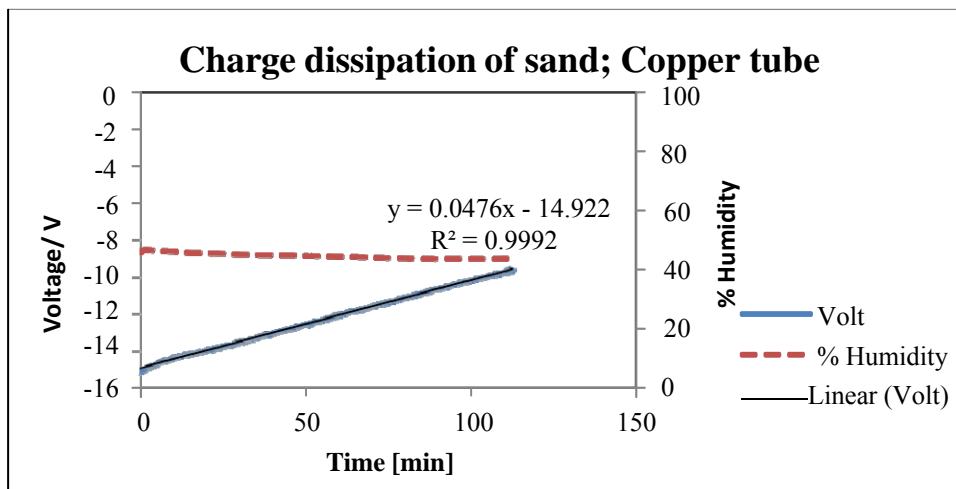


Figure 18: Charge dissipation of sand when it is tumbled in a copper tube

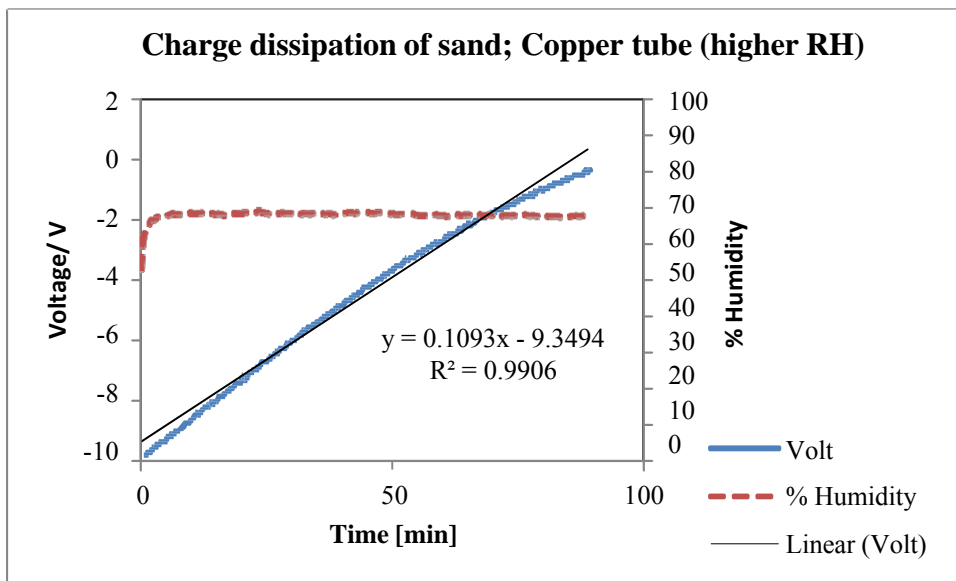


Figure 19: Charge dissipation at a higher RH of sand when it is tumbled in a copper tube.

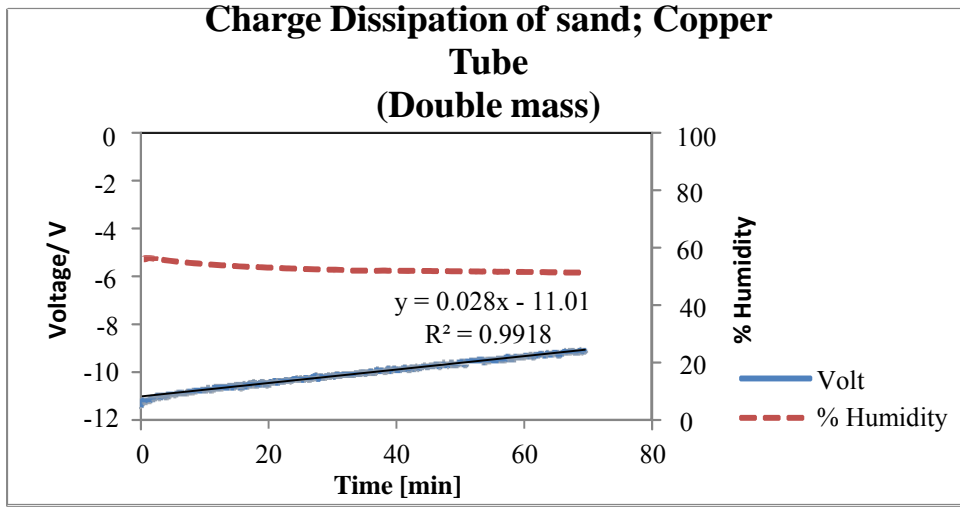


Figure 20: Charge dissipation of sand (twice the mass as in fig 17 and 18) when it is tumbled in a copper tube.

The charge decay rate of sand for PVC pipe at ~38% RH (figure 21) is -0.261 volt/min. In figure 22, when RH is suddenly increased at around 70minute, we can see a sudden drop in the electrostatic charge of sand. The charge decay rate increases to -0.343 volt/min as shown in figure 23.

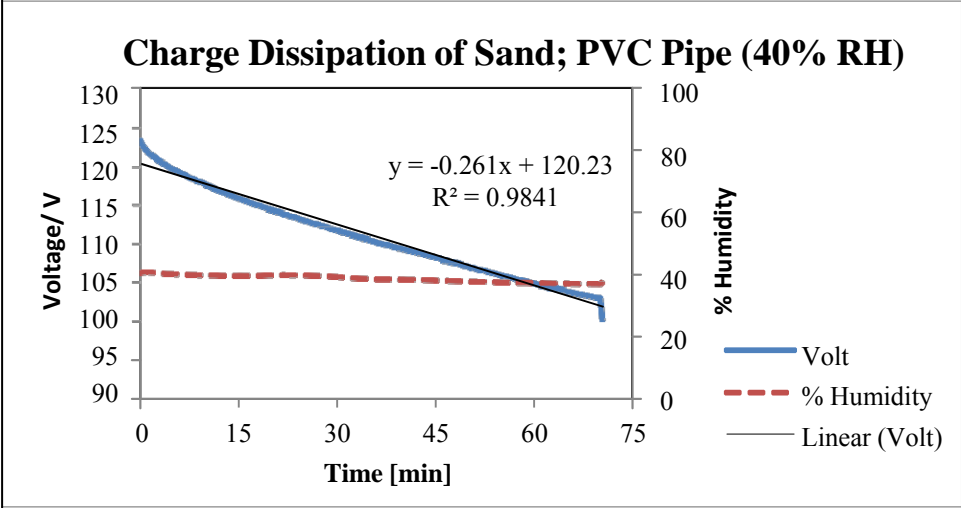


Figure 21: Zoomed in version of Figure 14 for the lower RH region.

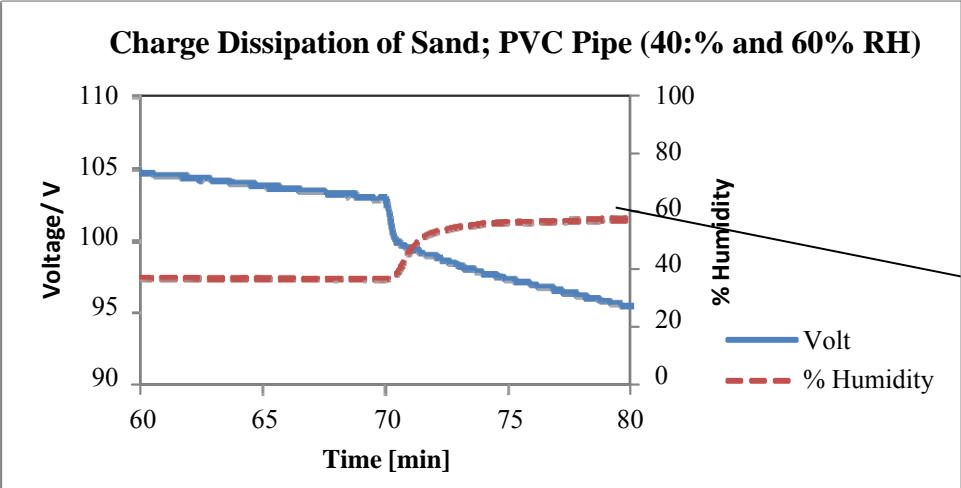


Figure 22: Charge dissipation of sand when it is tumbled in a PVC pipe.

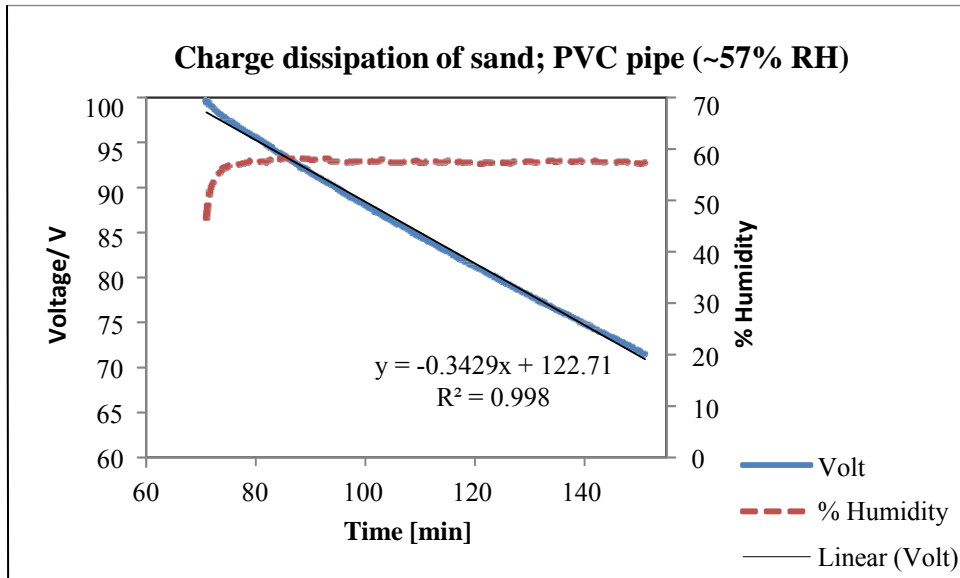


Figure 23: Zoomed in version of Figure 21 for the higher RH region.

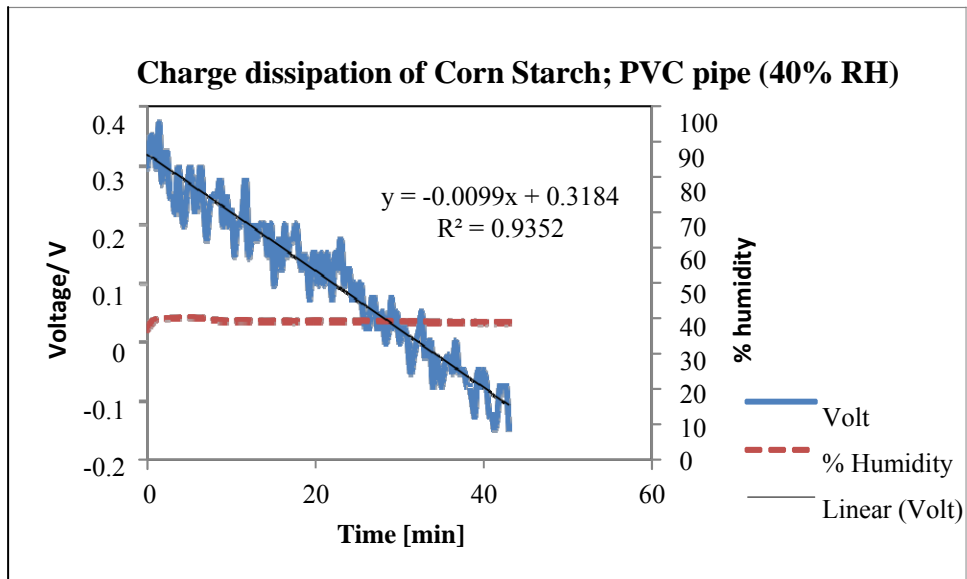


Figure 25: Charge dissipation of Corn Starch when tumbled in a PVC pipe.

Conclusion

After analyzing other related works and conducting our own experiments, it was evident humidity effects charge decay. It has to be noted that different powder dust reacts differently with humidity. Almost all the sample powders used in our experiment showed increased conductivity (and hence greater charge decay rate) at an elevated humidity.

However, hydrophobic substances like magnesium stearate are unaltered by the relative humidity. Although, different piping materials charge up powders differently, there was no effect found in the charge decay rate when different piping material was used.

It highly recommended for a manufacturing plant that is producing or handling pulverized particles such as sugar, flour, sand, etc. to test that particular powder on different sets of piping material at different humidity levels. It will enable the company to choose the safer method of handling the pulverized particles.

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