A Century of Development in Applied Electrostatics; Nothing Static Here!

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Topics

• Background
• What is Electrostatics?
• Particle Charging
• Three Important Developments 20\textsuperscript{th} Century:
  1) Electrostatic Precipitation (ESP); 1907
  2) Electrostatic Painting ;1930’s
  3) Electrophotography (Xerography) ; 1950-59
• The 21\textsuperscript{st} Century
In the beginning; there was LIGHTNING

Atmospheric

Volcanic
Thales of Greece 624-536 BC

- Philosopher and “Father of Science”
- Showed magnetic force (lodestone)
- Showed electrostatic force (amber/fur)
- Amber in Greek aka “elektron”
Last 2400 + years
Regarded as a scientific curiosity
Or a force of “tingling” attraction
Or a Shocking Experience
Fast Forward

• Majority of us repeated Thales experiment in grade and/or high school (with varying degrees of success)
• Regarded as a quaint scientific curiosity
• Science of electrostatics generally ignored in university
Electrostatic processes are basis of many important applications

Diverse fields;
air pollution control, printing and copying, painting, materials separation, sand paper manufacture etc.

All came to fruition in the 20th century

Common feature; involve controlled movement of small particles (mm to nm)
Why?

1) Compared to gravity, electrostatic Coulomb force dominant for small particles

Charge to mass ratio (Q/M)

\[
Q \propto \text{surface area} \propto r^2
\]

\[
M \propto \text{volume} \propto r^3
\]

\[
Q/M \propto 1/r
\]

2) Energy efficient

3) **Direction** and **strength** of force controllable by E
What is Electrostatics?
Is it really “static”? 

• Cannot be; otherwise no work is possible
• Unfortunately IEEE definition is misleading;

“the branch of science that treats of the electric phenomena associated with electric charges at rest in the frame of reference”
Formation of “Electrostatics Society of America” in 1970

• ESA definition;

“the class of phenomena recognized by the presence of electrical charges, either stationary or moving, and the interaction of these charges, this interaction being solely by reason of the charges and their positions and not by reason of their motion”
• In practical application means electric field effects *predominate* over magnetic field effects

• In electric circuit terms, ratio of voltage to current is very high i.e. **high impedance**
Also should refute common misconception; need high voltage

- $F = QE$ but $E$ is the gradient of voltage and so depends upon geometry
- Consider a common reference field, the **breakdown strength of air**
  
  $3 \text{ MV/m} = 30 \text{ kV/cm} = 3 \text{ V/µm}$
Key to practical applications in the 20th century?

Reliable **charging** and **power supplies**

- **Ionic charging**; corona discharge
  useful for any material

- **Induction (conduction) charging**; field induced
  only works for conductive materials

- **Contact (triboelectric) charging**; dissimilar materials
  occurs in all materials but only practical for
  cases where at least one is an insulator
Three Important Developments;

1) Electrostatic Precipitation (ESP)

- **Charge** particles in air stream using corona discharge
- **Collect** on grounded plate through Coulombic attraction
  - Very **simple** in concept
  - **Difficult** to translate into practice
  - **Interdisciplinary** problem; complex interaction among electrical, mechanical and chemical properties
Evolution

- Hohlfeld (Germany) 1824
  - used corona to clear fog in a bell jar
O.J. Lodge (U.K.) 1885
- patented process, demonstrated successfully in lab
- installed at a smelter in North Wales
- failed to work!

TWO Reasons;

a) inadequate power supply
b) lead oxide fume
F.G. Cottrell

• 1\textsuperscript{st} successful installation at sulphuric acid plant south of S.F. in 1907

• Breakthrough due to four factors
  - mechanical rectifier
  - "pubescent "corona electrode
  - negative corona
  - heated HV bushing

Also lucky; sulphuric acid mist

Patent 1908
Preferred method for cleaning large scale industrial particulate emissions

• By 1960’s $\eta > 99\% \text{ (wt)}$
• Currently $\eta > 99.9\% \text{ (wt)}$ and limits on escaping particles $< 10 \mu m$
• Improvements; gas conditioning, corona wire geometry, power supplies, pre-charging, rapping optimization, intermittent and pulse energization

Figure 9. Conventional Electrostatic Precipitator
Current Challenges

• Improve collection for sub-micron particles
• Remove gaseous pollutants along with particles
  - non-thermal discharge plasmas
  - electron beam reactors
  - advanced oxidation techniques
• Issue of effectiveness and energy efficiency
Three Important Developments;

2) Electrostatic Painting and Coating

- In 1930’s liquid, mechanical atomized *spray painting* developed
- Ease of application but $\eta = 30\%$ common
- Recognition that principle of ESP could improve $\eta$
- By 1940’s automated painting lines regularly achieved $\eta > 70\%$
Liquid Electrostatic Paint Spraying

• Improved *uniformity* of coating (space charge) and “wrap around” (Coulomb attraction)

• Led to *improvements* in atomizers; blade, rotating bell or disc and hydraulic or air; robotic control etc
Led to Powder Coating

• 1960’s, recognized that solvent not necessary
• Spray paint in form of finely dispersed, electrically insulating, thermoplastic powder
• Charge (corona or triboelectric)
• Paint attracted to target, adheres (image force)
  fused in oven
Key advantage; no (VOC) Volatile Organic Compounds

- Widely adopted starting in 1970’s
- Led to major improvements in
  a) equipment
  b) powder formulations (electrical and chemical properties)
Features of Powder Coating

• Note electrostatic force is essential to operation
• Currently $\eta > 80\%$ and overall $\eta > 95\%$ by recycling overspray
• Surface quality and uniformity still needs work
Three Important Developments;

3) Electrophotography (Xerography)

- ESP and liquid painting **significant** improvements in technology
- Powder coating (and elimination of solvent) a **major** improvement in technology
- Demonstration of first electrophotographic image by Chester Carlson in 1938, truly a **revolutionary** development
Chester Carlson

• Initially worked from his “kitchen” laboratory
• First to make true dry copies of documents

Bob Gundlach (1926-2010)
Six Step Process

Most complex combination of electrostatic processes;
- photoconductivity
- corona charging
- triboelectric charging
- coulombic attraction
- image force adhesion
- ionic neutralization
Early Machines

Model A (1949)  XEROX 914 (1959)

3 minute/copy  26 sec/copy
1959; Xerox 914 first black and white plain paper copier
1973; first printer with flash lamp exposure
1975; first laser printer (IBM)
With competition, developments “exploded” in 1980’s and 90’s;
-full colour copiers/printers;
-many billions of dollars of commerce
-revolutionized business/home offices
-desktop publishing
Lesson in all this?

• Don’t forget “old” science
• Reliability of good image production is dependent upon consistent **tribocharging**
• Thank you Thales!
NEW APPLICATIONS?
21\textsuperscript{st} Century

Look to three main characteristics

1) useful for particles from \textit{submicron to millimetre size}

2) force \textit{increases} as distances get \textit{smaller}

3) energy \textit{efficient}
MEMS
(Micro-Electrical Mechanical Systems)

• Revolutionary devices; comparable to effect microprocessors had on computers
• Mass produce integrated sensors, actuators etc
• Interface between computational and physical world
• Fabrication and operation dependent upon electrostatic forces
Biotechnology

• Many biological processes governed by electrostatic factors
• Wide application for electrophoretic and dielectrophoretic forces
Ultrafine Particles and Nanotechnology

- Nanometer sized particles finding increasing application in industry
- Characterized by high surface energy which greatly affect properties of ceramics, metals, optical structures and semiconductors
- Fabrications being pushed to atomic dimensions
Absence of gravity and presence of vacuum allows upper and lower size range of particles to be extended.

“Deep Space I” spacecraft
Thank you very much
Important Characteristic

- In ESP electrostatic force; **basis of process**
- In liquid painting electrostatic force **improves** the process and enhances $\eta$ and uniformity
- If voltage fails, process still works