

# **CORONA CHARGING AND ELECTROSTATICS FOR PIPE COATING**

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## Pipe Coating Industry Paper

This paper is intended to provide some theoretical and practical understanding of electrostatics and corona charging in the context of the pipe coating industry. The paper is subdivided into three parts: a treatment of the basic physics of corona charging, a discussion of the spraying process in three zones, and finally, an application section which ties the first two sections to the process of actually coating pipe. Throughout the paper the discussion is in terms of negative polarity, because it is most commonly used. However, positive polarity corona charging is in use and works effectively.

### Section I: Electrostatic Theory

The beginning point for understanding of electrostatics is the concept of charge and electric fields. Everyone is familiar with these parameters through everyday phenomena like static cling, plastic food wrap, and the problems of handling plastic packaging “peanuts.” Without getting too far into the realm of particle physics, the electron is the basic carrier of charge. The electron is defined as possessing negative charge, so if there is a local surplus of electrons, there is a region of negative charge. If there is a local shortage of electrons, there will be a net positive charge in that region.

The clinging together of charged surfaces is caused by the forces which exist between charges. Like charges repel each other, and unlike charges attract each other. So if we have a substantial concentration of charge at a location, we can observe a substantial force. The strength and direction of this force in the space around the charge concentration is referred to as the electric field.

The two are inextricably tied together. Wherever there is charge, there is an electric field. It is also important to remember that when someone talks in terms of “fields,” they are really referring to patterns of forces.

When dealing with fields it is important to have some way of visualizing how the field is arranged in the space

Figure 1

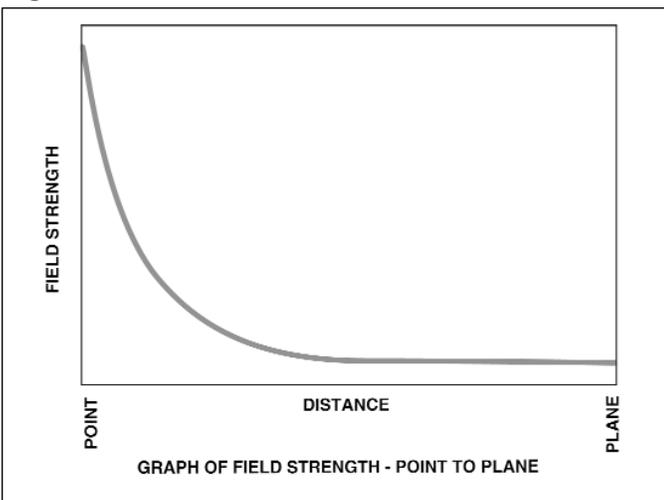
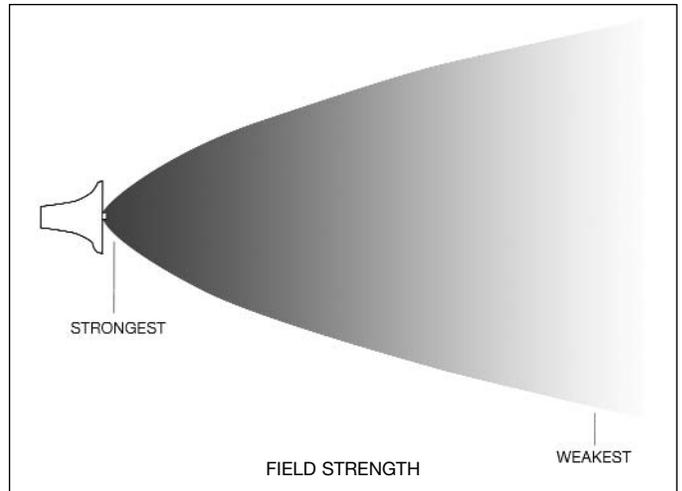


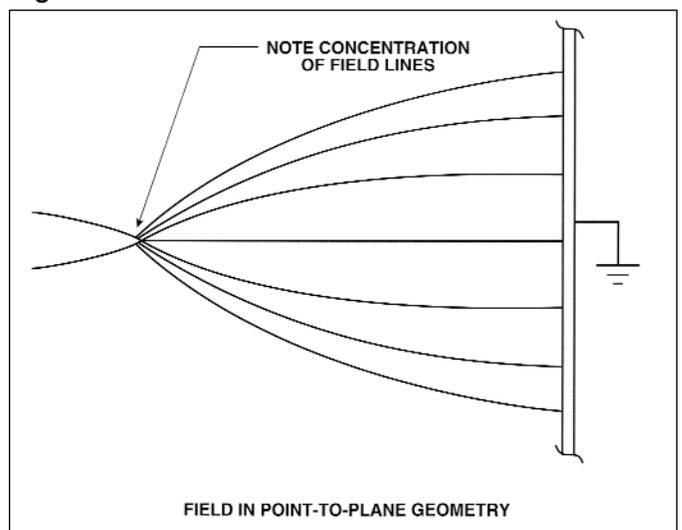
Figure 2



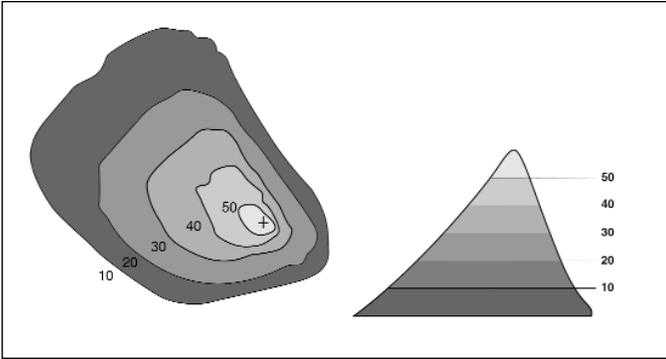
between the gun and target. The accompanying Figures 1, 2 and 3 show three ways of plotting fields. In Figure 1, a simple graph shows the strength of the field as a function of the distance between the spray gun and target. In Figure 2, a shaded figure is used where the darkest shading represents the strongest field and the lightest represents the weakest field. Color may also be used instead of shading. Typically, bright red would be the strongest and blue (at the other end of the spectrum), the weakest.

Figure 3 shows the most common representation, the use of field lines. Field lines are used in the same way as contour lines on maps or marine charts to show changes in elevation (Figure 4). Field lines are most commonly used since they can show both field strength and the direction of the forces. It is also convenient to talk about field lines as if they were real entities, and in later parts of this paper field lines are described as if they were real for the sake of convenience. But it is important to remember that they are only a mapping tool and are no more real than the depth contours on

Figure 3



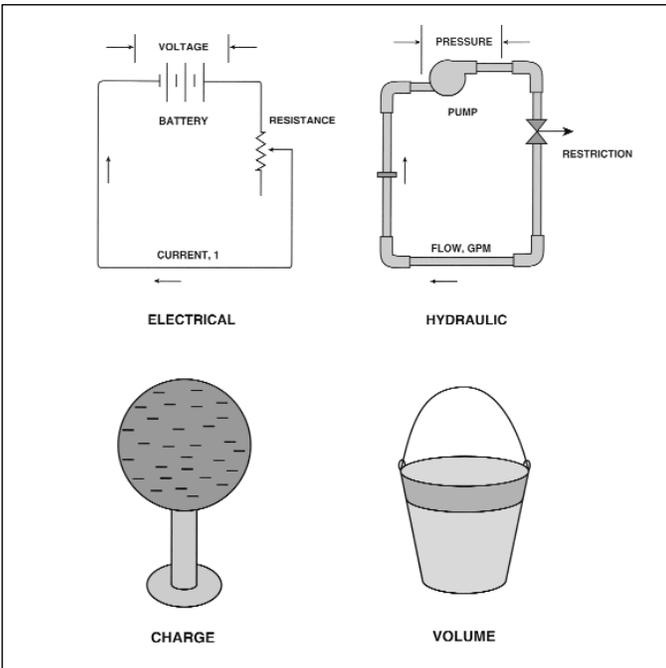
**Figure 4**



a marine chart. Just as one would not expect to find depth contour lines painted on the ocean floor, one should not expect fields to behave as if there were tracks in space for charge to follow.

The concept of voltage is also tangled up in these parameters. But to keep things fairly simple, we'll talk about voltage in terms of an analogy to hydraulic pressure (Figure 5). In these terms, if we have some charge on a wire and we want to add more charge, we use more pressure (voltage) to "push" or "pump" more charge up there. Voltage implies work done against a resisting force.

**Figure 5**

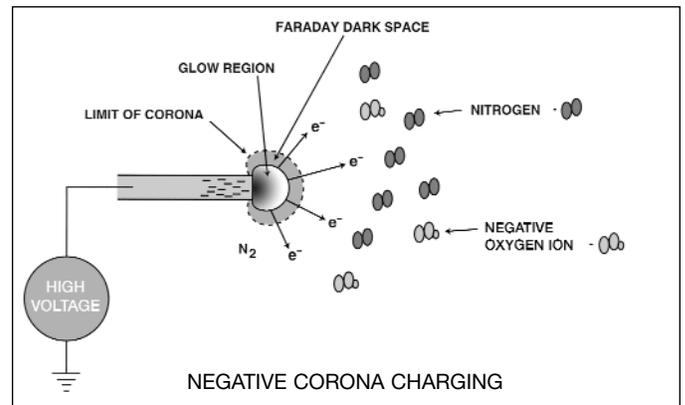


If the voltage is turned up high enough, and there is enough charge concentrated in a small enough space, then the electric field that results can be so strong that individual electrons can be torn off of air molecules. This process is called ionization, and if it is intense enough, results in the formation of a region known as a corona. The field strength required for the formation of a corona is 4,000,000 volts per meter.

A corona discharge or simply "corona" is a cold plasma. Normally plasma is associated with very high temperatures in the range of 10,000° Celsius. In this type of plasma, the gas molecules break down into atoms, which in turn lose their electrons due to the intense thermal agitation. In a corona, the energy to strip off the electrons comes from very strong electric fields, so the temperature is far lower.

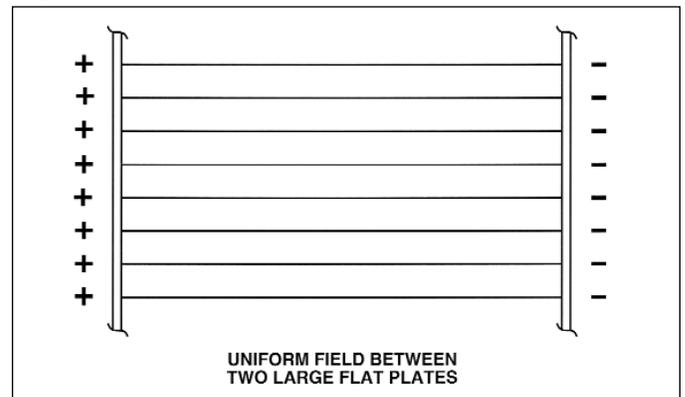
The formation of the corona is critical to the entire process. This is because the corona, although gaseous, is electrically conductive since it contains free electrons. And since it is conductive, it provides a pathway for current to flow from the charging electrode into the surrounding air. In typical electrostatic spray equipment, the corona is about the size of a matchhead, about 2 mm in diameter. The corona is seen as a faint blue-violet glow region, although it emits much more ultraviolet light than visible light (Figure 6).

**Figure 6**



Because the charging electrode and the corona are biased strongly negative, there is a strong repulsion of negative charge. Thus, at the fringes of the corona, any electrons will be accelerated outward into the surrounding air. These free electrons will not travel more than a few millimeters before they are captured by an oxygen molecule to form a negative oxygen ion. In a positive corona, a nitrogen molecule which has

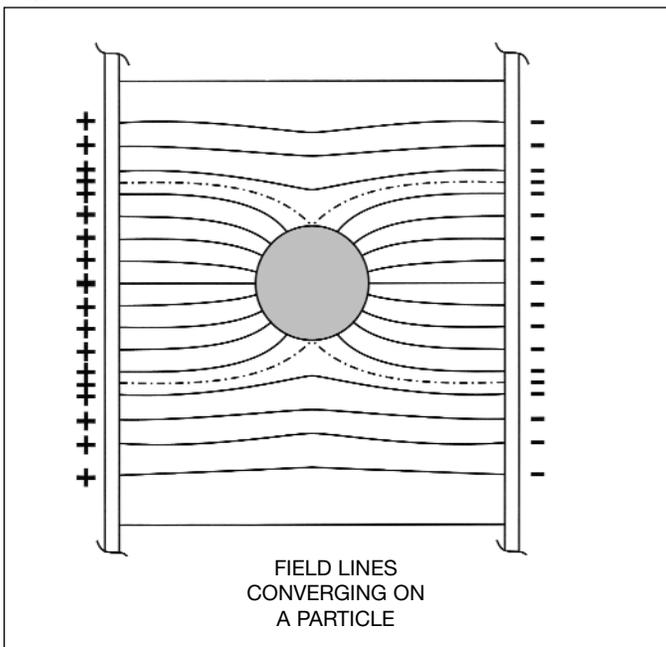
**Figure 7**



given up an electron will become a positive nitrogen ion. It is these ions which do the actual charging of powder through the process of “ion bombardment,” or field charging.” Although these terms are considered interchangeable, ion bombardment will be used in this paper as being more descriptive.

The electric field between the target (the object to be painted) and the gun is not uniform as shown in Figure 7, but is distorted by the presence of powder particles, as shown in Figure 8. Since the particles have a higher dielectric constant than the air around them, the field will be concentrated near the particles. And the larger the particle, the greater the concentration. It is also important to remember that this is a three-dimensional process and that the field distortion is related to the volume of the particle. Thus, an 80-micron diameter particle will distort the field eight times as much as a 40-micron particle.

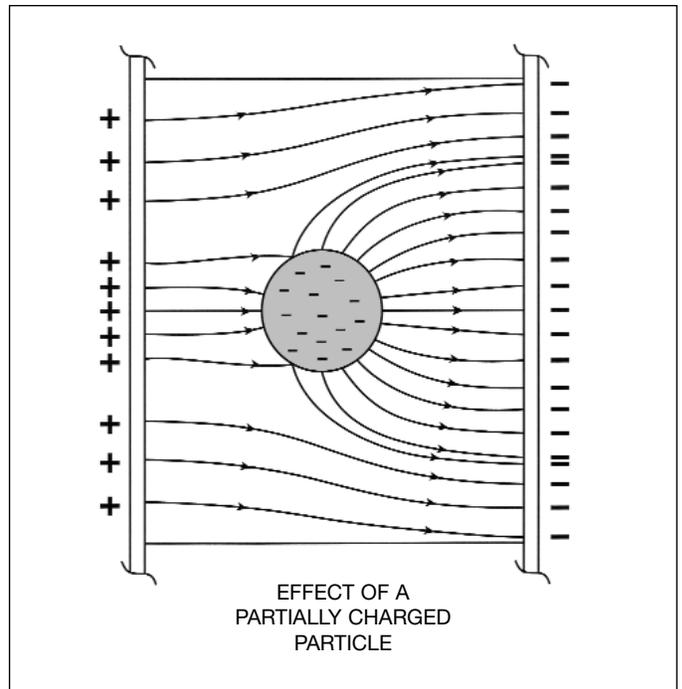
**Figure 8**



Since the ions have a net charge, the electric field will affect them, pushing them away from the electrode and toward the target. But since the field is concentrated around the particles, the ions will be urged toward the particles. We talk of this as “following the field lines,” much as if there were tracks to follow. Yet however we describe the process, the effect is the same; the ions are influenced to impact the powder particles in the vicinity and in doing so they transfer charge to the particle.

As each successive charge is planted on the particle, the charge on the particle gets larger and larger and, at some point, the field from this charge will be large enough to have some significance. At this point there is a substantial repelling force generated by the charged particle which repels the incoming ions (Figure 9), so that each successive charge makes it a bit harder for the next one to get to the particle. What this means is

**Figure 9**

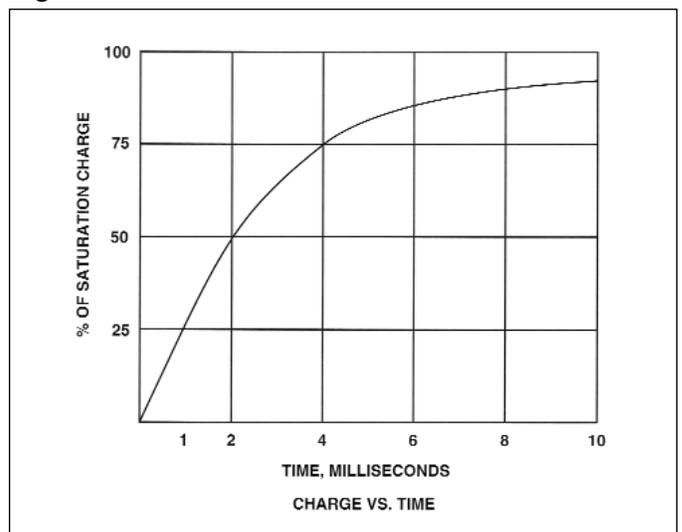


that charging will occur very rapidly at first, and then proceed more and more slowly (Figure 10). The limit for the charge that can be put on a particle of powder is determined by an equation developed by the physicist Pauthenier.

$$Q_{\text{maximum}} = Ae_0 2(1 + 2[e_r - 1/e_r + 2]) E$$

- where: Q = charge  
 A = surface area of the particle  
 $e_0$  = permittivity of a vacuum  
 $e_r$  = ratio of permittivities of powder to that of space (dielectric constant)  
 E = strength of the electric field where charging occurs

**Figure 10**



According to Pauthenier's Theorem, the charge on a particle will increase until the field from that charge equals the external field in which the particle is situated. At this point the forces pushing the ion toward the particle are balanced by the particle's own repulsion force. The field strength,  $E$ , at the particle, all other things being held constant, is a direct function of the voltage at the gun. It is for this reason that designers try to maximize the voltage of powder spray equipment.

Before moving on there are three assumptions made in Pauthenier's equation:

1. That the particle is spherical
2. That the particle is conductive
3. That there is infinite time.

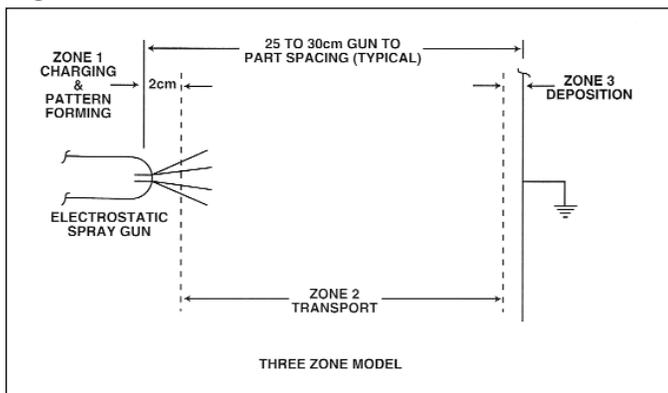
While none of these is true for organic powders, the form of the equation is correct and it provides an insight into the design and set up requirements for powder coating systems.

## Section II: The Three-Zone Model

In the general metal finishing industry, the Three-Zone Model has been useful in providing insight into how the physics of corona charging and spraying apply to the painting process. While there are a number of differing factors in pipe coating, it is believed the model can be modified to provide the same kinds of insight.

The three zones illustrated in Figure 11 are: Charging and Pattern Formation, Transport, and Deposition.

**Figure 11**



### Zone 1, Charging and Pattern Forming

Zone 1 is the region immediately around the exit end of the spray gun and has an extent of about two centimeters. Most of the electrostatic phenomena discussed in the previous theoretical section occur in this region. To briefly recap those phenomena.

1. The high-voltage power supply charges the electrode.
2. The concentrated charge creates a very strong electric field.
3. The strong field breaks down the air and causes a corona to form.
4. The corona emits electrons.

5. The electrons are captured by oxygen molecules to form negative ions.
6. The ions are urged to follow the field lines.
7. The powder particles distort the field around themselves.
8. The distorted field directs the ions to the powder particles.
9. The powder particles are bombarded by the ions and the particles become charged.

All nine of these steps occur within one to two centimeters of the end of the gun where the field is strongest. Referring back to Figure 1, the field strength falls off very rapidly as one moves away from the corona, so that  $E$ , and therefore, the maximum charge, also drops off rapidly. In a practical sense, if the powder has not charged well by the time it has moved more than two centimeters away from the gun, it will receive little or no further charge, because the field strength is too low.

Zone 1 is also the area where pattern formation takes place through means of nozzles, deflectors or air jets. It is also a region of high velocity, so the powder moves through Zone 1 quite rapidly. Typical dwell times in Zone 1 are between four and six milliseconds. If we refer back to Figure 10 again one can see that dwell time in the charging zone is important to achieving a high-charge level. For this reason it is important to keep the powder flow velocity as soft as possible to allow more dwell time.

It is also important to have a well-dispersed powder cloud so that the ions have access to the individual powder particles, and to design the guns to have the right physical relationship of the electrode and the powder. Considerable time and effort are spent to optimize this relationship.

Since charging and air flows are linked together very closely, the role of electrostatics and air flows are about equally important in Zone 1. This viewpoint differs significantly from most classic articles on the subject which stress electrostatics almost to the point of ignoring the role of air flow in this region.

### Zone 2, Transport

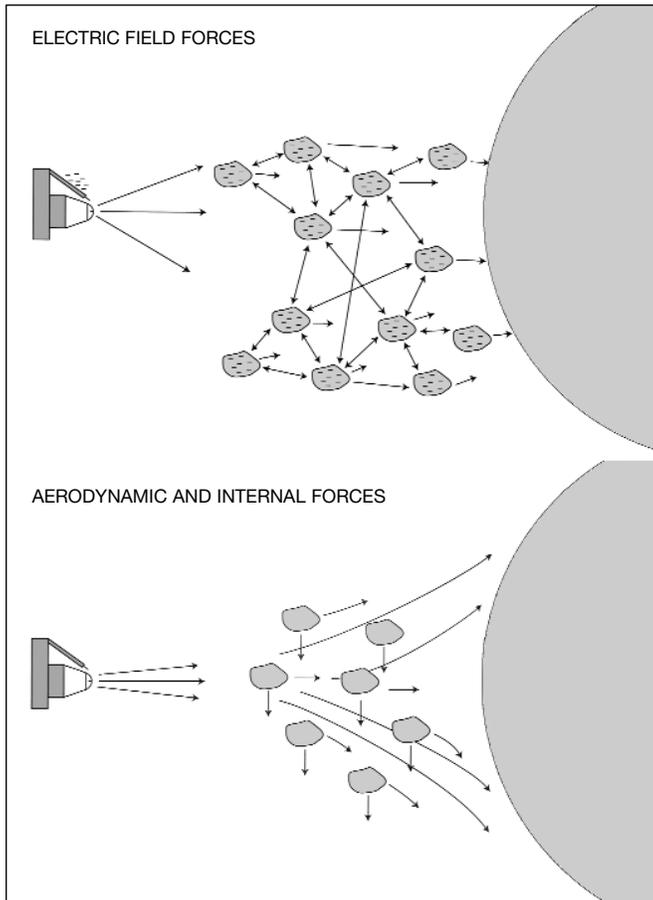
Once the powder is distributed into the desired pattern and a charge put on it, it must be moved to the target. In typical setups about 85 to 90 percent of the powder's journey to the target is in Zone 2. While there are electric field forces at work here, their role is relatively small compared to aerodynamics.

In Zone 2 the powder is influenced not only by the air flows from the gun, but also the booth ventilation flows, which in pipe coating are generally of higher velocity than in general finishing. It is estimated that in general finishing in Zone 2, air flows dominate over electrostatics in a 90/10 percent ratio. In pipe coating it must be closer to 95/5 percent. For this reason alone, a good understanding of air flows is critical in pipe coating.

### Zone 3, Deposition

This is the thinnest region, being only about one centimeter thick. This is the approximate maximum distance over which the electrostatic attraction of the particle to the part is effective. Powder particles farther than one centimeter from the surface and traveling roughly parallel to it have little chance of being captured.

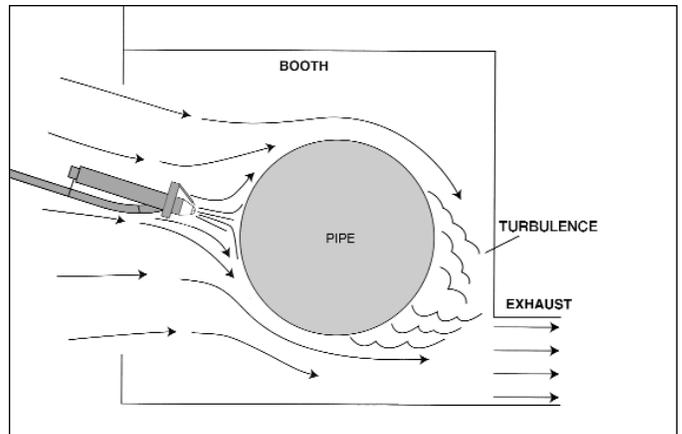
Figure 12



If one looks at this region in detail, there are a number of forces acting on a particle within it (Figure 12). First, there is the field from the gun which is pushing the particle to the part. Second, there are the effects of both the gun's air flow and the booth's air flow on the particle. Third, there is the field from the charged particle attracting it to the target. Fourth, there are interactions between the fields from the individual particles as they repel each other, since all have the same polarity of charge. Fifth, there are inertial forces due to the particle's mass and momentum, and due to gravity. And sixth, there are the aerodynamic effects from the pipe itself; due both to it being hot and also to its movement (Figure 13).

Particles in Zone 2 are approaching the target at approximately a right angle, and many will just keep right on going and collide with the hot surface. Others, particularly near the outer surface of the pattern will be deflected through a right angle and end up moving

Figure 13



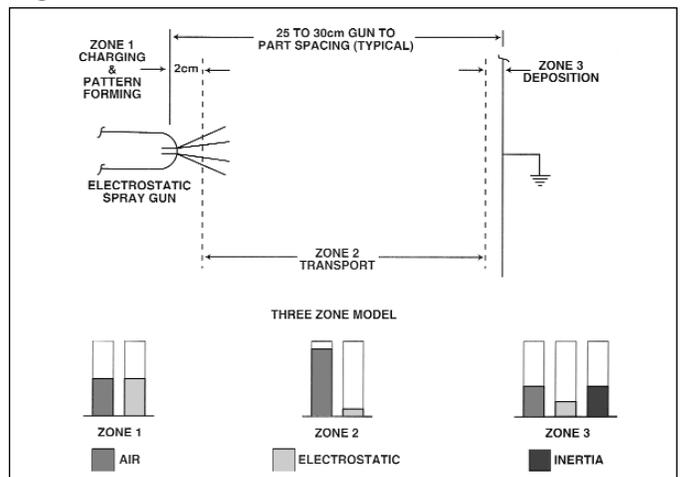
roughly parallel to the surface. It is these particles in particular that need to be within the one centimeter range of Zone 3 if they are to be captured by electrostatic forces.

Complex as the situation is, it is actually a bit simpler in the pipe industry with hot pipe, than in general finishing with room-temperature parts. There, the powder which is deposited on the part retains its charge, and there can be significant repulsion forces on incoming particles due to this charged layer. But in pipe coating with the heated pipe and melting powder, the charge bleeds off the powder as soon as melting starts. Further, since much of the powder is impacting a molten surface, there is less opportunity for rebounding to occur.

Experimental data indicate that transfer efficiency begins to suffer when air velocities near the surface exceed 30-feet per minute, a very low figure.

Given the lack of a charged layer on the pipe, the high powder flow rates, relatively coarse grinds, and the generally high ventilation velocities used in the pipe coating industry, the role of electrostatics in Zone 3 would be estimated to be no more than 25 percent, inertial effects at 35 to 40 percent, and aerodynamics at 35 to 40 percent (Figure 14).

Figure 14



### Section III: Practical Implications

Now that a base of theoretical considerations has been established, we can begin to apply it to actual pipe coating applications. But first, we need to briefly discuss the conditions in typical applications to provide a background for these discussions.

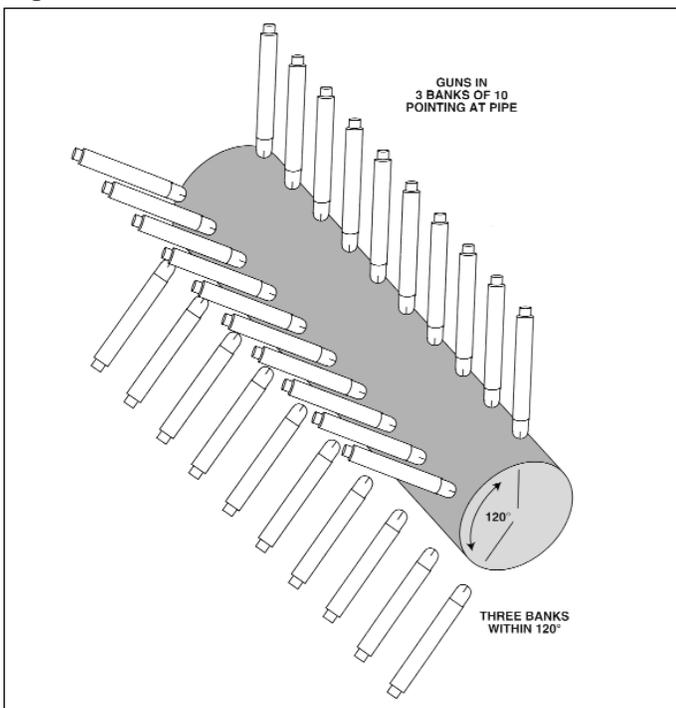
The pipe itself is metallic, 3 to 48 inches in diameter, heated to 400 to 475° Fahrenheit, and moving through the spray area at 20 to 60 feet per minute, while rotating on its axis.

The powder is a special fusion-bond epoxy with a mean size of about 40 microns, as measured with a Malvern laser diffraction instrument. Particle size distribution is fairly broad with 5 to 10 percent less than 10 microns, and 15 to 20 percent greater than 80 microns. These figures are for virgin materials. For reclaimed and recycled powders, the size range is shifted downward, with one sample showing a mean of 19 microns, 25 percent less than 10 microns, and only 2 percent larger than 80 microns. Although this was an extreme case, and one that was measured because of problems in the system, it does illustrate that the coarser particles are preferentially deposited, with the fine particles carried off.

The booths are generally short with one open side for both ventilation and gun placement. Since the overspray collector is separate, safety considerations require high volumes of air per pound of powder sprayed. Coupled with the compact booth size, this leads to high local velocities in the 200 to 500 foot-per-minute range.

Guns are typically arranged in rows which are radial to the pipe (Figure 15). Two or three rows of guns are

Figure 15



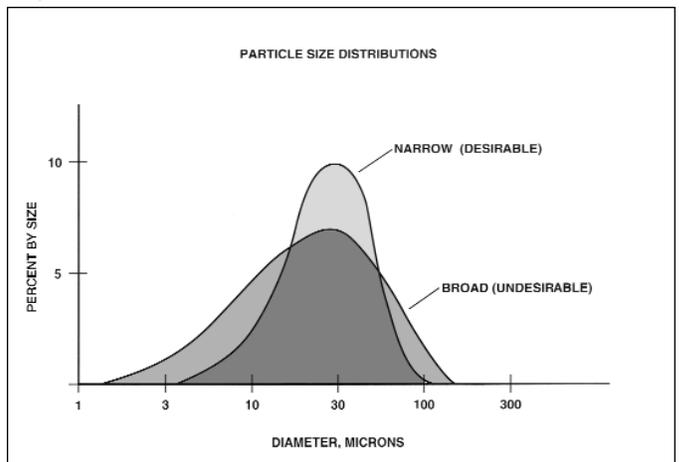
common, with as many as 20 guns per row. Viewed from the end of the booth, rows of guns are arranged on one side of the pipe, where the booth opening is, and the axis of the guns are arrayed over about 1/3 or less of the circumference. Typically, from vertical at top center to 30 degrees below horizontal. Powder flow rates per gun are high and depending on gun model range from 40 to 180 pounds per hour per gun. In contrast, the typical gun in general finishing runs at 25 to 35 pounds per hour.

Coating thickness is usually in the range from 15 to 20 mils (0.015 to 0.020 inches). This is approximately ten times the coating thickness on home appliances.

Given this background, the picture that emerges is primarily one of high-velocity air flows dominating the physics, with electrostatics playing only a supporting role.

Since the guns are generally spraying at high flow rates, the velocity through the charging region will be high and the time for charging short. This implies poorer charging, particularly for the fines which have to compete with the larger particles for ions. Since the distortion of the field by the presence of the particle depends on the volume of the particle, and the charge depends on the surface area, it can be shown that the larger particles will charge more easily. The implication of this is to keep the particle size distribution narrow and with a high mean size (Figure 16).

Figure 16



Since the coating thickness is very high, and it is not primarily a cosmetic surface, a coarser grind has little implication in the end product. But because the charging situation is difficult at best, the coarser grind will result in better charge, and significantly better inertial effects. For example, a 100-micron particle has eight times the mass (and inertia) of a 50-micron particle, and 64 times that of a 25-micron particle. This gives the larger particles much better ability to retain their forward velocity and drive on to the surface of the pipe. Given that the guns have a coherent flat fan spray pattern and a relatively high initial velocity, the larger particles take better advantage of the dynamics of the situation.

Conversely, the reclaimed overspray will be stripped of the coarse particles and consist mainly of fine particles. Powder of this range is not well suited to the process conditions and will result in poor deposition efficiency. Remedies for this situation are to start with a coarse grind with few fines, to maximize the deposition efficiency on the first pass; or to use cyclonic collectors or classifiers to skim the fines and scrap them. Obviously, all of these remedies can be applied in combination.

The high-ventilation velocity in the booth is one of the most difficult parameters with which to deal, but designers of the equipment have little latitude within which to work. Given that production rates are high, the powder flow rate must be high, and therefore, the codes require high air volumes. Further, since support of the pipe and protection of the applied coating are key, the booth must be worked into a relatively small space. This, of course, has the effect of concentrating the guns and air flows into a small area. The net result is tightly spaced guns and high air velocities (Figures 13 and 15).

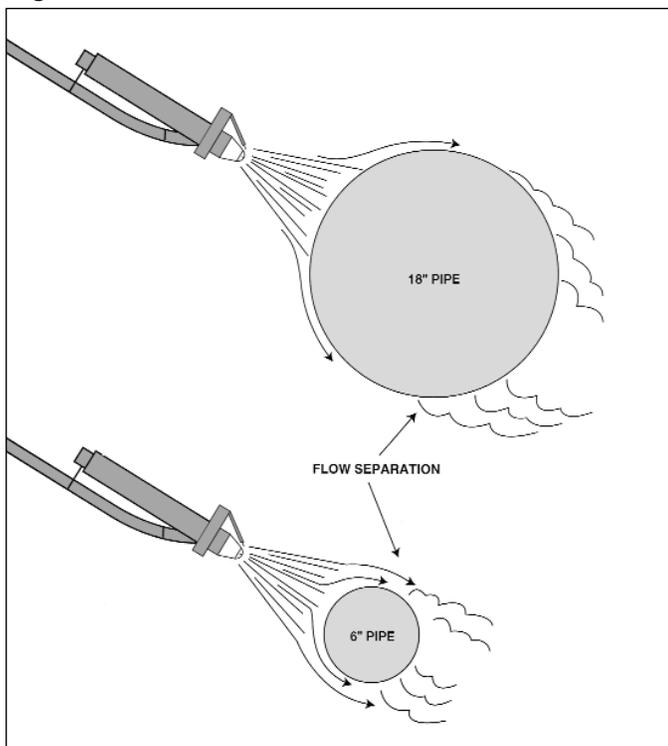
The guns themselves further worsen air flow velocities, since high exit velocities from the guns and flat spray patterns are quite effective at inducing air flows. To illustrate, in conventional booths with gun slots and vertically arrayed guns, we have measured air velocities in the slot of 100 feet per minute with the guns off, and over 200 feet per minute with the guns spraying. The difference is solely the effect of the guns as flow inducers. When the guns are massed, as is the practice in pipe coating, they are even more effective in inducing flow. All of this air flow has to go someplace, and the result is

high velocity around the pipe. The air will tend to flow around the pipe parallel to the surface for some distance, before the flow detaches and forms a turbulent wake. Generally, this will be more than 90 degrees away from the "leading edge." Once the flow detaches, most of the powder in the air stream will be carried away. Although turbulence of the wake will bring some powder into contact with the surface, this is not considered an important effect, and can probably be disregarded.

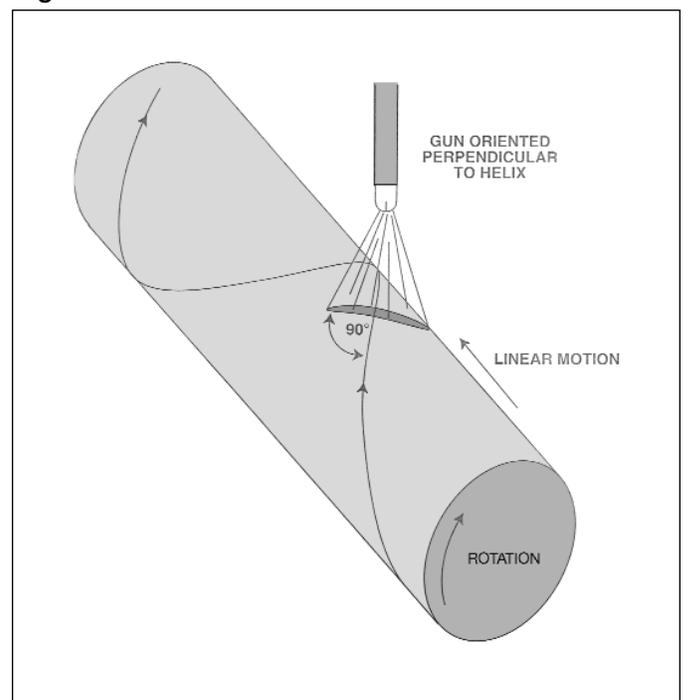
With large pipe, the situation is not too bad since the guns see a large target, which helps to shield the guns from the high booth exit velocities on the other side of the pipe. And with the large circumference, the powder flows in a thin layer around the pipe for quite some distance. This gives the electrostatic attraction between the powder and pipe a reasonable chance to deposit the powder (Figure 17).

But with smaller diameters, the pipe wall curves sharply away from the powder flow, and the pipe does little to shroud the guns. Further, the separation will occur closer to the guns, so less time will be available for deposition. Also, the pattern from the guns is much larger in proportion to the pipe. Purely on theoretical grounds I would expect the efficiency of deposition to drop sharply when the diameter gets smaller than 8 to 10 inches or so. Using more guns with smaller patterns (narrower fan widths); as opposed to using the same set-up as large pipe, but with fewer guns triggered, may help. Smaller patterns will keep more of the fan more nearly perpendicular to the surface. However, the biggest improvement for smaller pipe would be to have the booth air flow cut back proportional to the powder

**Figure 17**



**Figure 18**

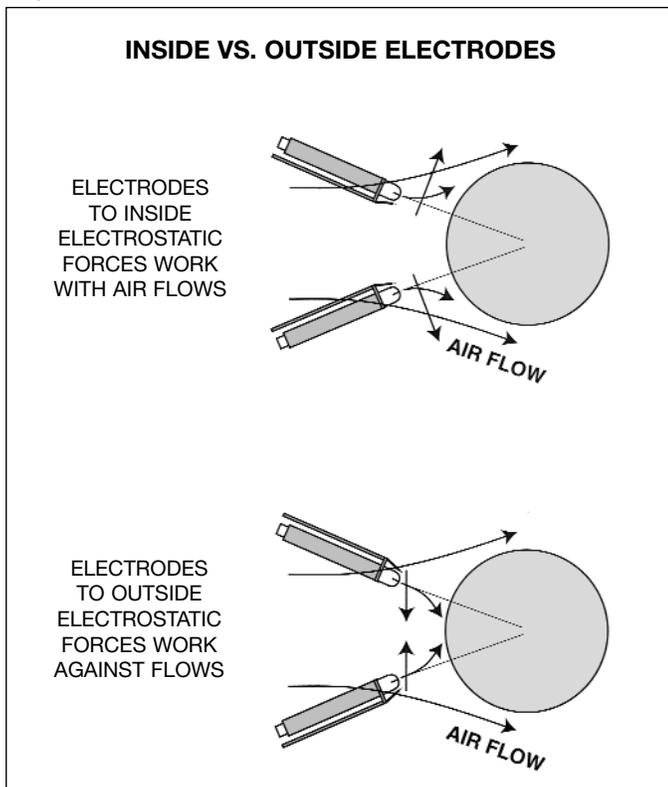


flow to reduce the ventilation velocity. This in turn, would allow the guns to run at lower velocity since there is less powder needed and less tendency for the ventilation flow velocity to affect the patterns. However, this control system would need effective and redundant interlocks to avoid a dangerous situation or violation of the applicable codes (NFPA 33).

If one pictures the path of a point on the pipe as it moves past the guns, that point has a helical path (Figure 18). Normally, for best coverage, the flat fan pattern from the guns should be at a right angle to that helix. This technique will lay down the widest stripe of powder on the pipe. While this works well, where the pipe diameter is large compared to the width of the fan pattern, it is probably not the best solution for smaller pipe. For cases where the pipe diameter is equal to the fan width, or less; there will be less overspray if the fan is more nearly parallel to the centerline of the pipe. Since there will be more gun-to-gun interaction with this arrangement, the guns need to be spaced further apart, probably in several rows.

In the larger diameters, and particularly at the higher linear speeds, getting enough guns in the available space is becoming a problem, even with guns that can manage flows of 180 pounds per hour. Of necessity this results in dense gun placements and very high-air velocities. Under these severe conditions one needs all the help one can get. We are indebted to Marvin Williams of Lilly Powder for pointing out a non-traditional use of electrostatics to help overcome the aerodynamic problems. Normally, for best charging of powder, in cases where there are parallel rows of guns, the electrodes on the two rows would be placed nearest each other, so that the fields from the two rows of guns would repel each other, and drive the ions through the powder cloud for better charging (Figure 19). Instead, Mr. Williams positions the electrodes on the outside of the rows, so that the electric field forces bend the powder clouds toward each other; keeping them better aimed at the pipe. In the traditional arrangement, charging is probably better, but the field bends the powder fans away from each other and away from the pipe, and poorer deposition results.

**Figure 19**



Earlier we had mentioned that electrostatics played a supporting role in pipe coating. The application note in the previous paragraph is a good illustration of this point. There, the electrostatic effects were used not so much to charge the powder for the purpose of deposition, but more as a means of pattern control. It is also apparent that electrostatics are useful in improving the pattern in another way, which is to maintain uniformity.

Since each charged particle is repelling every other nearby charged particle, the result among a large number of particles is for each particle to try and be an equal distance from its neighbors. Even with the strong aerodynamic and inertial forces in pipe coating, the powder cloud is visually more transparent and uniform appearing when the high voltage is turned on. In turn, this results in a more uniform coating thickness. This is particularly important in fusion bond work since the self-limiting effects which play a key role in general finishing are absent. For without self limiting, the only tools available to maintain uniformity are flow rate adjustments and gun positioning, and a reliance on pattern uniformity.



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