Dielectrophoresis can be used in a large number of practices. However, most dielectrophoresis applications are in a laboratory and pilot plant stage. The existing industrial applications are only restricted to the filtration of dielectric fluids, such as petroleum and separations of impurities from food substances (Knoll, et.al, 1988). However, dielectrophoresis can be used as an alternative approach in the area of physical processing, biological processing, biophysical processing, or pollution control.

In the separation area, the work conducted by Jordan et.al. (1979) at the Tuscaloosa Research Center had a large influence to the development of a laboratory or pilot scale “continuous dielectric separator”, which was used for mineral beneficiation. Indeed, Hatfield (1924) previously developed his first dielectrophoretic separator using an a.c. non-uniform field and a liquid medium, whose dielectric constant lay between those of two materials to be separated. His second separator, in which a dielectric was coated on the electrodes, was developed later to avoid the liquid medium.

The “continuous dielectric separation” technique is, in fact, not a dry process when concerned technically, and sometimes particle polarizability is less useful than its density, magnetic susceptibility, electrical conductivity or triboelectric effect, etc. However, it is noteworthy to briefly describe the process. The continuous dielectric separator includes a drum with fine wires placed along its surface and parallel to its axis. Beneath the drum, a screen electrode is positioned in an intermediate dielectric liquid. An a.c. potential is used and located across the electrode and drum assembly. In this process, the mixture of solid particles are fed onto the drum. The higher-dielectric-constant particles become polarized and attracted to the region of the high electric field gradient (the wires) on the drum’s surface, while the lower-dielectric-constant ones are repulsed to a region of low field gradient by the intermediate dielectric liquid and then fall through the screen electrode. The outcome of the experiments performed by using this continuous dielectric separator and a variety of intermediate dielectric liquids provided somewhat satisfactory results in several minerals. The recoveries of the high-dielectric minerals were reported in the range of 51-94%. It is conceivable that the cost and
hazard associated with the use of intermediate dielectric liquids are the ascription to the nonsuccess in commercial use.

It is instructive to mention another dielectrophoretic separation that has been developed by Knoll et.al. (1982) at Carpco, Inc. The “multifield electrostatic separator” was devised to dryly separate the polarizable materials based upon their differences in shape, material structure, and dielectric properties. By using a vibratory feeder, the materials to be separated are conveyed through the multifield separation zone. In this zone, air is used as a medium and a selective electrostatic field is produced by a high voltage source. In the active area, particles that are highly polarized are picked up and attached to the surface of the multifield roll. When the roll rotates, it bears the attached particles out of the separation zone over a divider to a discharge zone. As claimed by the developers, the separator has its unique ability to also separate lightweight materials.

Electrophoresis

Electrophoresis is a phenomenon where a charged particle is moved by the response to free charge on the particle in a uniform or non-uniform electric field, which can either be from a high voltage source or from the charged particles themselves (see figure 1.2). The electrophoretic separation involves a charge transfer, which depends on the electrification characteristics of particles and the particle-charging method, as well as the interaction of the charged particles and the electric field. The methods of generating charges on particles vary greatly, as listed by Ralston (1961). However, only three mechanisms are the most widely used particle-charging methods: i) ion bombardment, ii) conductive induction, and iii) tribo- or contact electrification. Further details will be discussed in section 1.2.2.

The electrostatic separation of conductive minerals from non- or less conductive minerals is probably the most important application of the electrophoresis technology. However, the most encouraging application of this technique is the beneficiation of coal, which will be discussed at length in the following section (section 1.2). Other notable applications of this technique are the
dry electrostatic separation of salts (Fricke, 1977) and electro-filtration, or electrically augmented vacuum filtration (Adams, 1983; Freemann, 1979).

**Comparison of Dielectrophoresis and Electrophoresis**

Some of the distinctions between the two phenomena are given in Table 1.3:

<table>
<thead>
<tr>
<th><strong>Dielectrophoresis</strong></th>
<th><strong>Electrophoresis</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Produces motion of bodies suspended in a fluid medium. However, the sign of the field does not matter to the direction of that motion. As a result, either a.c. or d.c. fields can be used.</td>
<td>(1) Produces a motion of the suspended particle in which the direction of the resultant path is dependent upon both the sign of the particle charge and the sign of the field. As a result, reversal of the field can reverse the direction of that motion.</td>
</tr>
<tr>
<td>(2) Gives rise to an effect which is proportional to the particle volume and is, hence, more easily observed on coarse particle. It is noticeable at the molecular level only under special conditions.</td>
<td>(2) Is observable with particles of any size. Atomic ions, molecular ions, charge colloidal particles, or charged macroscopic bodies can be perceptible.</td>
</tr>
<tr>
<td>(3) Generally requires quite divergent fields for strong effects.</td>
<td>(3) Can operate in both uniform and non-uniform or divergent fields.</td>
</tr>
<tr>
<td>(4) Requires relatively high field strengths. The strength of the field depends on dielectric constants of the particles to be separated.</td>
<td>(4) Requires relatively low fields since the particles are previously charged.</td>
</tr>
</tbody>
</table>
1.2 Electrophoresis: Electrostatic Separation for Coal Beneficiation

1.2.1 General

Electrostatic separation technologies are among the dry processes that have been of considerable interest in recent years as the promising methods for coal beneficiation. The dry electrostatic separation processes have been proclaimed to have many advantages over the wet separation processes or other dry processes, such as the mechanical or magnetic separating processes. As pointed out earlier, dewatering, water demand, and water pollution are the major problems present in the use of all wet methods for coal cleaning. However, when the dry mechanical or magnetic separation techniques are used as the alternative to those wet methods, some dilemmas arise due to their inflexibility. Particle size is probably a sensitive criterion for the mechanical separation technologies since the fines below 1 mm are normally beyond the capability of the techniques. Even the magnetic susceptibility of particle may cause a counterproductive situation while the separation is happening. This inferiority of the magnetic technique is ascribed to the fact that the magnetic susceptibility of particle is a bulk property and can not be varied substantially without a chemical change or an attachment of magnetic material. In contrary, electrical properties can be varied more easily, particularly at the surfaces of particles. Therefore, the electrostatic separation process is believed to be a potential dry technique that can be both efficiently and commercially justifiable for coal beneficiation purposes.

In general, all electrostatic separation systems consist of at least four elements: i) a charging-discharging mechanism, ii) an external electric field, iii) a non-electrical particle trajectory regulating device, and iv) feeding and product collection systems. The operating environment also appears to be a crucial character in any electrostatic separation system.

For coal beneficiation, early this century, many attempts had been made in Germany and by the U.S. Bureau of Mines to use a drum-type electrostatic separation for coal cleaning, but the early results were somewhat disappointing. The technique has further been developed, continuously scrutinized, and ultimately become commercially available. It is reported that the
first commercial-scale system of an electrostatic-separation technique for coal beneficiation in U.S. was developed by Advanced Energy Dynamics, Inc. (AED) and installed at the Picway Station power plant (Columbus, Ohio), owned by American Electric Power Service Corp. (Rich, 1984). Numerous tests by AED on pulverized coals have been carried out before by the use of a Carpco laboratory / pilot-size machine that differs only in the length of rotor from the full-size module. It is of interest that the system is to be used at the power plant where the coal will be pulverized, pretreated, electrostatically separated and the concentrate burned as fuel. According to Rich (1984), the AED commercial system claimed to remove more ash and more pyritic sulfur (up to 68%), at lower coal-losses, than the conventional wet methods.

Look concisely over the history of using electrostatic technique for coal cleaning. From the review made by Ralston (1961), coal beneficiation by electrostatic methods was first seriously taken into account in the United States. The first type of coal believed to receive a great deal of attention was anthracite. The very first electrostatic processes for coal cleaning were exceedingly simple but not enough efficient. However, numerous further attempts to have coal become commercially electrostatic beneficiated had been sustained. Until 1914, Withington (1914), with the Huff Electrostatic Separator, Co., proposed a process that claimed to remove slate, bone, sulfides and phosphates effectively from dry anthracite coal. The separation process was based on the differences in the conductivity properties between coal and impurities. It was shown that the cleaned product obtained with the electrostatic separation contained less than 10% ash. However, Kühlwein (1941) reported years later that German anthracite cannot be reasonably cleaned by electrostatic methods, which is contrary to the result shown by Whithington and obtained with the United States anthracite.

Contemporaneously, Schniewind had his two patents issued posthumously in 1915, showing the promising processes by which bituminous coal can be electrostatically beneficiated. Interestingly enough, in his first patent, the dry-fine coal was remoisten in moist air to the level where there was the maximum difference in susceptibility of coal and ash or of the different coal constituents. Schniewind (1915) believed that the necessary moisture content varied with the hygroscopicity of the different constituents. His second patent reported a test on using
electrostatic method for removing ash and sulfide sulfur from a sized coking coal. The overall results showed the rejection of ~ 78-81% ash in the feed and ~ 55-68% of the sulfide sulfur. However, it was not possible at that time, from the economics standpoint, to convince the industry to pay more attention at these processes.

Later in 1951, Johnson (1951), also with the Huff Electrostatic Separator Co., took in a study of electrostatic separation for coal beneficiation and his work became patented. He used his standard carrier roll with smaller active roll electrode to investigate a variety of bituminous coals and anthracite. Moreover, his well-known conception of reversible negative, reversible positive and non-reversible materials was a real breakthrough at that time. He found bituminous coal was reversible positive, being actively repelled when the carrier was grounded positive, but being depressed when the carrier was negative. Anthracite, on the other hand, was repelled from the carrier electrode, no matter what the polarity. For the usual ash constituents, he found them reversible negative. His electrostatic separators, undoubtedly, took advantage of reversibility of the coal and ash to produce reasonable separation.

In Germany, Kühlwein (1941) and Niggemann (1941), as individuals, published their reports and discussion of the development work in this area. These included the work done in 1930 on brown coal and the intensified program performed in 1939 on a series of coals, coal fines, and other materials from coal fields. A simple free falling stream separator in both laboratory and industrial sizes was used for some tests on coals in 1941 by Niggemann (1941). Some effects were observed and reported, particularly the effect of grain size, the effect of sign of charge on plate electrode next to which coal was dropped, the effect of coal size, and the effect of moisture content of coal. For the last one, Niggemann found that the dryer the coal the better the separation, which is not consistent with the recommendation of Schniewind (1915).

It is recorded that a large number of researches and development in coal beneficiation using this technique were solidly pushed during 1942-1953, and mostly done in Germany. A full-scale plant unit was eventually constructed at Essen in the Ruhr area, Germany, during the war, but was never operated because of the bomb damage. The installation included a fine sizer and
shaking screen to obtain good results and good capacities; all sizes down to 0.2 mm. were recommended, below which capacity was low. However, the pilot plant tests were, thereafter, continued at the Osterfeld colliery, primarily on a carrier roll separator of conventional design (Graham and Schmidt, 1949).

In addition, the electrostatic separation was also conducted on lignite, or brown coal, by Von Szantho (1939, 1949, and 1953). He reported a reasonably good separation, in which the lignite dust was separated from the rock dust by using a contact potential technique. The lignite dust was introduced into a blowing flask through where dried air was blown and the dust cloud departing from the exit channel passed between two electrodes charged with opposite polarity direct current from a voltage supply. This technique is similar to that of Frass and Ralston (1942 and 1961). The exception was that the more reliable vacuum tube rectifier on a high-tension transformer, as an activator of the separating electrodes, was used and combined with the use of the self-electrification originated by rubbing and impact of two different minerals against each other while in dust form (Frass and Ralston, 1942). Evidently, the particle charging methods applied to these studies are known as “contact electrification.”

The pre-conditioning of coal has been postulated to alter the surface conductivity of pyrite and ash particles present in coal, so the electrostatic separation for coal beneficiation can become more effective. This technique has indeed called for application since early century: for example, by Schniewind (1915). Unfortunately, it has not received much attention. A proposed process of conditioning patented by Heinrich (Heinrich, 1942a) described a preparation treatment of drying the mixture well and cooling then to the freezing temperature of water. The mixture was subsequently made into contact with moist air at a higher temperature. Particles of the greatest heat conductance or of hydrophilic properties became more efficiently filmed with water and then became separable (at the moment) if put through the electrostatic separator. The other proposal patented in the same year (Heinrich, 1942b) recommended that the coal, while drying, should also be sufficiently heated to reduce the natural substances (such as bitumen, paraffin, etc.,) that making the particles less susceptible to the electrostatic field. Remarkably, many studies of the coal pre-conditioning concluded that proper moisture content of coal or of
atmosphere may enhance the separation efficiency (Heinrich, 1954; Schnitzler, 1951 and 1953; Wiemer, 1953). Also, a definite temperature differential should be established between the materials and the ambient by heating or cooling one of them. A study carried out later by Duba (1977) showed that coal macerals were ordinarily insulators when dry but revealed a much higher conductivity than expected when saturated with water. Clearly, it is in general agreement that the moisture content of coal when treated is important and each coal requires separate study as to what condition is best for separation.

There is evidence (Knoll, et.al., 1988) that the use of gaseous ammonia to modify the particle conductivity of electrostatic precipitator feed has been successfully adapted to fine coal. In 1974, Kali und Salz Aktiengesellschaft (1974) had its patent based on conditioning of coals with fatty acid glycerides to enhance the electrostatic separation of pyrite from coal. It is shown that a continuous electrostatic separation of a coal pretreated with olive oil under a certain field density can yield 54% of a 94% pure coal.

Fundamentally, the electrostatic separation for coal beneficiation is based on the premise that the finely pulverized coal and the mineral matter particles have different electrical charging characteristics. Once the particles become selectively charged, a separation can be accomplished by passing them through an electric field (Inculet, 1984). In any such processes, the selective charging of the particles to be separated generally demands most of the developmental effort prior to the fabricating of an industrial installation, while the external electric field can be readily created and controlled (Inculet: in Liu, 1982).

Coal is ordinarily less conducting than mineral matters. However, there is compelling evidence showing that brown coal may be more conducting by reason of its high water and ion contents (Lockhart, 1984). It is also of interest that coal may become a semiconductor with increasing rank (Hower and Parekh, 1991). Nevertheless, among the mineral matters commonly present in coal, pyrite is the most conducting mineral.
Looking back again in 1939, Johnson (1939) came to conclusion that bituminous coal can acquire a positive charge in a high-tension static-field-electrode system and is therefore electrostatically separable from ash minerals. Years later, in the study of the other particle charging mechanisms, these positive charges on coal were confirmed by Thomas (1953). He, furthermore, measured the charges magnitude after passing coals through a rotating electrifier separator and reported the effective concentration of the coal macerals.

When the coal constituents (lithotypes) are taken into consideration, vitrain has been found to be less conducting than durain and fusain (Pope et.al., 1961). Indeed, Schniewind (1915) was the first to call attention to the possibility that the ordinary petrographic constituents of coal: such as clarain, durain, vitrain and fusain, might be electrostatically separated from each other (Ralston, 1961). Nevertheless, no report shows that he actually did such separations. Clarain and vitrain are the two most desirable constituents of coal substance for coking, while fusain (mineral charcoal) is usable as a steam coal. The most recent studies show that the three major maceral groups occurring in coals, namely: vitrinite, liptinite and inertinite, have been found to have differences in the conducting properties. Inertinite shows the expected preference to be the best electrical conductor among the macerals, due to its electron delocalized pi bonding (Tennal, 1997).

Basically, electrostatic beneficiation of coal depends on a number of factors: for example, particle size and density, the conductivity of the surface and the surface condition. These properties in turn depend on temperature, relative humidity, moisture content, chemical conditioning, etc. Separation performance can be affected by these factors, both directly because of the effect on particle charging and discharging processes and indirectly from the associated physical occurrences, which include the associated forces of gravity, viscous drag, centrifugal force, or molecular adhesion. In any electrostatic separation processes, the separation efficiency depends critically on the charging processes that can establish differential charge between components to be separated. A variety of particle charging processes have been studied, tested and reported extensively in the literature, but only three major processes described in the next section find an application in the electrostatic beneficiation facility.
1.2.2 Particle Charging Mechanisms

According to Ralston (1961), electrostatic separating processes depend primarily on the methods of charging particles. The design of a separating machine usually relies on the type of charging mechanisms used for the separation. Although there are many ways to cause the particles the electric charge, only three charging mechanisms are used in commercial electrostatic separation, namely: i) charging by ion or electron bombardment, ii) charging by conductive induction, and iii) charging by contact or friction (triboelectrification).

It would be unnecessary to provide complete information in this dissertation for the first two charging methods mentioned above, since many reference relevant to the charging by corona and conductive-induction can be accessed readily elsewhere. Provided here is, therefore, a brief summary. Only the charging by contact or triboelectrification will have an extensive discussion in a separate section (see section 1.3).

i) Charging by Ion Bombardment or Corona (Kelly and Spottiswood, 1982; Lawver and Hopstock, 1985; Knoll, et.al., 1988)

The particle charging by a corona or an ion bombardment is the most common charging process in the area of electrostatic beneficiation. For many years, it has been employed mostly for mineral processing, in which the mixture of good- and poor- electrical-conductor minerals can be separated by using a high-tension process. The basic principle of charging by corona or ion bombardment involves the bombardment of ions or electrons through air, which is, in other words, the conduction of electricity through air. Such mechanism may be visualized by considering the theory of electrical conduction. It is previously known that gases conduct electricity in the different manner from liquids and solids. Yet the way metals and insulators, both solids and liquids, conduct electricity is also dissimilar. The charge is carried by ions in the case of insulators, but the movement of electrons within metals is the explanation why metals conduct electricity. Gases have neither an ion nor an electron under normal conditions. Moreover, the gas molecules are far apart that gases are considered as good insulators. However,
in case that the potential between two electrodes is raised high enough, there will be an electric breakdown of the gas and the gas will discharge. With this information, a corona discharge can accordingly be obtained by the appropriate shaping of the electrodes and the sufficient potential between two electrodes. (More details regarding the theory of electrical conduction can be found elsewhere in the literature.)

In the corona or ion-bombardment charging process, a granular mixture of conducting and insulating particles is fed through the corona discharge from a “corona-producing electrode” (usually a fine wire or a series of needle points) located parallel to a grounded rotor of a separating machine. The corona discharge is produced whenever the wire or needle points are elevated to an electrical potential that the electric field in the immediate vicinity exceeds the electrical breakdown strength of the ambient atmosphere (generally air). As the electric field varies inversely with the radius of a conductor, the fine-diameter wires or needle points and adequate potentials are practically needed. A fine corona wire electrode is usually made of tungsten. In general, the equipment to generate an ion or corona discharge normally includes a specially fabricated electrode to produce corona and a high-voltage d.c. power supply. To prevent “sparkover” when treating combustible materials (such as coal), the separating system needs to have its special electrodes.

The polarity of the ionizing electrode indicates the type of corona that is produced. If the ionizing electrode is positive, negative ions are expedited toward the electrode. The breakdown of air molecule then occurs with the result that positive ions are rejected outward from the electrode in the form of a “corona glow.” On the other hand, if the polarity of the ionizing electrode is negative, positive ions are accelerated toward the electrode, causing the repellent of negative-charged oxygen ions from the electrode and sequentially a “corona discharge.”

When the feed particles are carried by the grounded rotor into an intense field of the charge-ionizing electrode, they receive their charges by ion bombardment. All particles obtain the same sign of charge and the key to the separation is the different rates of losing this charge. While both conductors and non-conductors become charged, only the conductors are able to lose
their charge rapidly. The non-conductors or dielectrics lose their charge slowly to the grounded rotor and are, hence, held to the rotor surface by the “image force” associated with their surface charge. Conversely, the conductors rapidly share or lose their charge to the grounded rotor and are thrown from the rotor surface in a projectile motion determined by a combination of centrifugal force, gravity, and air resistance. This phenomenon serves as a basis in “electrodynamic” electrostatic separation or “high-tension separation.”

As a matter of fact, the conductive particles also have their own “image force,” but they discharge instantly to the grounded surface upon touching. The “image force” represents the attraction between the charged particle and the grounded surface, which is equivalent to a similar charge of opposite sign in the mirror-image position. One can obtain an amplification regarding the theory of image force in the literature (Sommerfeld, 1952).

Note that the rate of discharging a corona-charged particle in contact with the ground rotor can determine the value of surface charge at any given time in the separating zone. The charge decay on a particle is found to be exponential with time. However, the generation of controlled corona discharge is a rather complex technology and should not be discussed here.

**ii) Charging by Conductive Induction** (Kelly and Spottiswood, 1982; Lawver and Hopstock, 1985; Knoll, et.al., 1988)

When a particle is allowed to make contact with a conducting electrode in the presence of an electric field, the particle will rapidly develop a surface charge by conductive induction. However, the particle charge generated by using this method is practically weaker than that of ion bombardment.

In conductive induction charging, a granular mixture of conductors and non-conductors (or dielectrics) is fed onto a plate or grounded rotor under an active non-discharging electrode or a high voltage static electrode. In an electric field, both conductive and non-conductive particles become polarized, but the conductive particles in contact with the grounded rotor will become
charged to the polarity of the grounded surface and also have the same potential as the grounded rotor. Thus, the inductively charged conductor particles will be lifted away from the surface by attraction to the non-discharging electrode of opposite polarity, while the inductively charged dielectric particles will continue to attach to the rotor surface until gravity causes them to fall.

Still, the overall charging mechanism of this charging method can sometimes be complicated when both types of particle may, in addition, become charged by contact electrification with each other and with the electrode. In this case, the dual charging mechanisms have to be considered and this would lead to the difficulty in predicting electrostatic separations.

In practice, the charge density acquired by means of conductive induction is a function of particle shape, contact time, and electrical conductivity. The equations corresponding to the charge density acquired by this charging method, including some further details, can be found in the literature. This charging process has an application in some industries. These include “xerography” (electrophotography), fluidized bed coating, surface coating with fibers, sand paper and grit cloth manufacturing (Inculet, 1977/1978).

iii) Charging by Contact Electrification or Triboelectrification

Among the known methods of particle charging, triboelectrification has current received a great deal of attention due to its effectiveness and less energy requirement. Indeed, tribo- or contact electrification is one of the oldest methods used in electrostatic separation. It is also noted as the most frequently used charging mechanism to charge two species of dielectric materials selectively before performing an electrostatic separation.

Contact electrification is a phenomenon by which the surface charges are generated when two dissimilar materials are brought into contact and then rapidly separated; one generally becomes positive and the other negative. The surface charge generated by this method is usually weak. However, if the materials are repeatedly contacted, the surface charges can be built up and become high enough for serving as the basis for electrostatic separation. It, nevertheless, remains
unclear about the mechanism by which the charge is transferring. Many published papers have suggested that the charge transfer is attributed to electrons transfer, although there is evidence in some systems that charge transfer involves ions or mass transfer.

Cohen’s rule is one of the often-used principles to predict the sign of the surface charge acquired by contact electrification, especially at the time when the work function of material was not clearly determined. It states that the dielectric material with higher dielectric constant will become positively charged when two dielectric materials are contacted and then separated. However, the most widely used principle to predict the surface charge at present is based on the work function of materials that are brought into contact. The work function is defined as the difference between the energy of an electron at the Fermi level inside the surface of a solid and an electron at rest in vacuum outside the solid (Inculet, et.al., 1982). When the two materials are brought into contact with each other and then separated, the material with lower work function will become positively charged.

Further details involved in the triboelectric charging mechanisms and the theories of the contact electrification will be extensively discussed in section 1.3.2.

1.2.3 Types of Electrostatic Separators

According to Kelly and Spottiswood (1982), there are typically two basic types of electrostatic separators employed in industry: i) “electro-dynamic or corona” electrostatic separator, and ii) “electro-static” electrostatic separator; although various names are used by the manufacturers. The earliest electrostatic separators were of the electro-static type (with no great success), while most of the separators in commercial use nowadays are of electro-dynamic type.

1.2.3.1 “Electro-Dynamic” Electrostatic Separators
“Electro-dynamic” separators are customarily called “high tension” separators. It is probable that all of the electrodynamic separators in use today are primarily based on the original Carpenter design (Carpenter, 1951). Among the separators of this type, “corona rotating drum separators” have, so far, been the most widely used in the industry. The early work on this type of electrostatic separators has been sufficiently reviewed by Ralston (1961) and Frass (1962). It is also adequately included in the review already made in the previous section (section 1.2.1); considering these separators have taken over the major part in the history of electrostatic separation for coal beneficiation. One exception is the studies by Gray and Whelan (1956). They investigated a variety of coals varying in rank, particle size, and moisture content of particle, using the corona drum separator with different electrodes, different drum materials, different drum speeds, and various voltages applied. Their investigation has been a contribution to many works carried out on corona beneficiation of coal. More recent work on this area has been given in the reviews made by Abel (1972).

The principle of the separation is uncomplicated. Theoretically, the separation is based on the conductivity differences in particles comprising a mixture. As described in previous section, particle charging by corona or ion bombardment is accomplished by passing the particles over a grounded rotor through an intense corona discharge obtained from a fine wire or needle points. The particles then are charged to a potential exceeding the electrical breakdown strength of air. The conducting particles rapidly lose their charge to the grounded rotor and are thrown from the rotor by centrifugal force, gravity, and air resistance: they then come under the influence of the electrostatic field of the non-ionizing electrode and are further drawn from the rotor surface. The dielectric or non-conductor particles, on the other hand, can not dissipate their charge promptly to the rotor and are thus held to the rotor surface by their own image forces coupled with their surface charge. These non-conducting particles must be abraded from the backside of the rotor by a fiber brush after they gradually lose their charge while carried by the rotor. In some commercial high tension separators, the non-conductor particles are often partly discharged by the assistant of high voltage “wiping,” a corona discharge electrode installed on the back side of the rotor, to reduce the wear or workload on the brushing system.