Chapter 6: Summary and Conclusions

The separation efficiency of a triboelectrostatic separation (TES) for fine coal cleaning depends profoundly on the surface charges of the particles involved. In general, the larger the difference between the charges of the particles to be separated, the higher the separation efficiency. To design a highly efficient charger for the triboelectrostatic separator, an evaluation of particle charging properties and charging process parameters that affect the particle charge is of significance. It is, therefore, the objective of this work to study, both experimentally and theoretically, the particle charging mechanisms of coal and mineral matters (represented by quartz and pyrite) in a laboratory-scale charging system. The information obtained with the study will be useful for improving the triboelectrification process and subsequently the design of a TES unit. The major findings of this work may be summarized as follows:

1. A new practical charge-measuring device called “on-line tribocharge analyzer” has been developed incorporating the Faraday cage mechanism and the in-line static mixer tribocharger. This device is equipped with a data acquisition system to achieve a high degree of accuracy. The advantage of using an on-line tribocharge analyzer is that in-situ charge measurement can be performed and a wide range of particle sizes can be studied. With the application of this device, the information on the tribocharging mechanisms of coal, quartz, and pyrite samples has been obtained in an efficient way.

2. By using a Cu-Ni alloy in-line mixer charger, the results of the charge measurements showed that most of the coal samples studied became positively charged during triboelectrification, while the quartz and pyrite samples (representing mineral matters) became negatively charged. This charge difference provides the basis of the TES process. However, during the study some coal samples unexpectedly revealed negative charges. This altered charge polarity may possibly be attributed to i) the unusual chemical composition of the coal sample, ii) the inadvertent surface oxidation of the coal samples and/or the charging material, and iii) the ash content.

3. Six major operating parameters that may affect the particle charging mechanisms of the coal, quartz, and pyrite samples in the Cu-Ni alloy in-line mixer charging system were evaluated, both individually and statistically. These included: i) air or gas velocity, ii) particle feed rate, iii) particle size, iv) temperature, v) feed composition or ash content, and vi) type of charging material. The results can be summarized as follows:
    - The magnitude of the charge density (given in coulomb per unit mass) increases with increasing air velocity at all particle sizes studied.
    - For a given air velocity, the magnitude of the charge density decreases with increasing particle size.
    - The magnitude of the charge density decreases with increasing particle feed rate.
    - An increase in temperature (from 20 to 60^{o} C) has an effect on the charge density of the coal and quartz samples in such a way that the surface moisture be dried away.
    - The pyrite sample becomes more conducting with increasing temperature, resulting in a decrease in the charge density.
    - The magnitude of the charge density decreases with increasing ash content in feed regardless of particle feed rate.
    - Among the parameters studied, air velocity and particle feed rate produce the largest impact on the charge density.
    - Of the various parameters tested, particle size and air velocity are interacting with each other most significantly. The finer the particle size is, the more significantly the air velocity affects the particle charge.
    - Both the polarity and the magnitude of the particle charge can be altered by selecting construction materials with different work functions. It is based on an assumption that the triboelectrification mechanisms of coal and mineral matters are due to the transfer of electrons and can be explained by means of the work function: i.e., when two materials with different work functions are brought in to contact, the one with the higher work function will become negatively charged while the one with the lower work function will lose electrons and become positively charged.

4. The mechanisms of triboelectrification of coal and mineral matter were studied using in-line mixer tribochargers constructed from materials having different work functions. The charge densities of the clean coal and relatively pure quartz (representing mineral matter) samples were found to correlate with the work functions of the materials used for fabricating the in-line mixer tribocharger. The relationships were found to fall in a linear fashion for all samples studied. These findings have substantiated the assumption for the charge transfer mechanisms occurred in the studied system, in which the electron transfer has been presumed to be the dominant mechanism. The observation that the charges on the samples after contact depend on the work functions of the contacting metals indicates that the particle charging by triboelectrification in this particular case is conclusively due to the transfer of electrons, rather than the transfer of surface ions or mass. Thermodynamic equilibrium hypothesis appears to be the theory that can satisfactorily explain the particle charging mechanisms of the coal and quartz samples in this charging system. In this theory, each insulator is assumed to have its 'Fermi level' (E_0), which, after contact, becomes coincident with the Fermi level of the metal (E_F). As the experimental results showed that the samples could be charged negatively or positively depending whether the work function of the contacting metal is small or large, the insulators (i.e., the coal and quartz samples), therefore, must contain empty states that can accept electrons from the metal, as well as full ones that can donate electrons. The energy of both kinds of electron state must be close to the Fermi energy of the metals. The linear relationships between the charge densities of the samples studied and the work functions of contacting metals also suggest that the electron states in these samples may be distributed over a wide range of energy, states below a certain energy, E_0*, being full and those above empty. Although this result suggests that the contact charge may be determined by the difference in energy between the metal Fermi level (E_F) and some energy level (E_0) characteristic of the insulator, it should be pointed out that a dependence of the insulator charge on the metal work function does not necessarily mean that the charge density is decided by the relative position of these energy levels. In addition, the charging mechanism for the case of insulator-insulator triboelectrification can also be explained by the same basic mechanism as for metal-insulator triboelectrification.

5. The 'effective' work functions of the pre-cleaned mill-reject coal sample (6.1% ash) from a local utility site and relatively pure quartz sample were estimated from the experimental data. The intercept on the horizontal axis of a plot between the charge density of the insulator and the work function of the contacting metal gives a value of the insulator 'effective' work function (E_0*). By this estimation procedure, the experimental work functions of the pre-cleaned utility coal and quartz sample were found to be approximately 3.5-3.6 eV and 4.95 eV, respectively. Both values are in reasonable agreement with those reported in the literature. These findings confirm the possibility that the charge density of the sample may be predicted from the plot if the work function of the contacting material is known. By the same token, the work function of the contacting material may be approximately estimated from the plot if the charge density of the sample is obtained with contacting such material.

6. With the use of the results obtained from both in-line mixer tribocharger and separator tests, a new feeder/charger has been devised by means of a specially designed impeller, which is driven by air motor. An important characteristic of this new design is that the particles in the feed stream are subjected a strong agitation by impeller, creating turbulent condition and signifying the interparticle charging mechanisms in the charging system. This new charger is, therefore, referred to as turbocharger. Five important parameters that affect the charging mechanisms of the clean coal and quartz samples in turbocharger were investigated by using a developed charge-measuring system. These included: i) rotor-blade rotation speed, ii) particle feed rate, iii) particle size, iv) type of charging material, and v) ash content. The results may be summarized as follows:
    - For a given particle feed rate, the magnitude of the charge density increases with increasing rpm of the rotor blade at all particle sizes studied.
    - An increase in particle size increases the magnitude of the charge density at a given rotor-blade rotation speed.
    - The magnitude of the charge density decreases with increasing particle feed rate at a given rpm of the rotor blade and at all particle sizes studied, although the throughput capacity of the TES unit equipped with this new turbocharger is improved, due to a non-occurrence of the problems associated with the use of the

in-line mixer charger at high particle feed rate (i.e., clogging and/or insufficient charging).

- For a given sample, the magnitude of the charge density obtained with the use of the new turbocharger was lower than that obtained with the in-line mixer charger at low particle feed rate. This finding suggests that the wall-particle charging mechanism plays more important role in triboelectrification at low feed rate, whereas the interparticle charging mechanism is of significance at high feed rate.
- Of the two different materials tested, Plexiglas seems a rather appropriate material to construct the turbocharger than Cu-Ni alloy, due to a higher charging efficiency of the former.
- For the coal samples, the finding that the magnitude of the charge density increases with increasing ash content may suggest that in this new turbocharger the interparticle charging mechanism plays more important role than the wall particle charging mechanism.