

## TABLE OF CONTENTS

TITLE PAGE .....	i
ABSTRACT.....	ii
ACKNOWLEDGEMENTS .....	iv
TABLE OF CONTENTS .....	v
LIST OF TABLES .....	viii
LIST OF FIGURES.....	ix
CHAPTER 1: INTRODUCTION .....	1
1.1    Coal Beneficiation.....	1
1.1.1    Chemical Coal Beneficiation.....	2
1.1.2    Physical Coal Beneficiation.....	4
1.2    Electrophoresis: Electrostatic Separation for Coal Beneficiation.....	29
1.2.1    General.....	29
1.2.2    Particle Charging Mechanisms.....	35
1.3    Triboelectrostatic Separation.....	45
1.3.1    Triboelectrostatic Separation for Coal Beneficiation.....	47
1.3.2    Contact Electrification or Triboelectrification.....	49
1.4    Triboelectric Charge Measurement and Experimental Method .....	79
1.5    Scope and Objective of the Present Work.....	95
1.6    References .....	97

<b>CHAPTER 2: TRIBOELECTRIC CHARGING OF COAL, QUARTZ AND PYRITE BY IN-LINE STATIC MIXER CHARGER.....</b>	<b>107</b>
2.1 Introduction.....	107
2.2 Apparatus and Experimental Procedure .....	110
2.3 Materials .....	112
2.4 Results and Discussions.....	112
2.5 Conclusions.....	116
2.6 References.....	117
<b>CHAPTER 3: PARAMETRICAL STUDY OF THE OPERATING PARAMETERS ON PARTICLE CHARGING CHARACTERISTICS IN IN-LINE STATIC MIXER CHARGER.....</b>	<b>130</b>
3.1 Introduction.....	130
3.2 Apparatus and Experimental Procedure.....	136
3.3 Materials .....	137
3.4 Results and Discussions .....	139
3.5 Conclusions .....	145
3.6 References .....	146
<b>CHAPTER 4: CONTACT ELECTRIFICATION MECHANISMS OF COAL AND QUARTZ IN IN-LINE STATIC MIXER CHARGER.....</b>	<b>164</b>
4.1 Introduction.....	164
4.2 Theoretical Overview: Tribo- or Contact Electrification.....	167
4.3 Apparatus and Experimental Procedure.....	174
4.4 Materials .....	176
4.5 Results and Discussions .....	177
4.6 Conclusions .....	181
4.7 References .....	182

CHAPTER 5: TRIBOELECTRIC CHARGING OF COAL AND QUARTZ BY TURBOCHARGER.....	193
5.1    Introduction.....	193
5.2    Apparatus and Experimental Procedure.....	201
5.3    Materials .....	203
5.4    Results and Discussions .....	203
5.5    Conclusions .....	211
5.6    References .....	212
CHAPTER 6: SUMMARY AND CONCLUSIONS .....	225
APPENDIX .....	230
VITA .....	234

## **LIST OF TABLES**

Table 1.1	Summary of major chemical coal cleaning process.....	5
Table 1.2	Wet physical coal beneficiation.....	8
Table 1.3	The variances between dielectrophoresis and electrophoresis.....	28
Table 3.1	The operating conditions varied at the three code levels .....	150
Table 3.2	The test matrix of various combinations of parameters at different levels including the charge density data obtained from the tests .....	151
Table 4.1	The work function of metals .....	169
Table 4.2	The work function of various compounds.....	170
Table 4.3	The work function of different materials used to construct tribocharger for the particle-charging mechanism study.....	177

## LIST OF FIGURES

Figure 1.1	Comparison of behaviors of neutral and charged bodies in (a) a uniform electric field; (b) a non-uniform electric field .....	25
Figure 1.2	Triboelectrification mechanisms explained by means of the work function.....	53
Figure 1.3	Two metals, A and B: (a) before contact, (b) after contact.....	57
Figure 1.4	The variation of the energy of an electron inside and outside a metal.....	58
Figure 1.5	Dependence of the potential energy of an ion on its position between two plane parallel insulator surfaces .....	65
Figure 1.6	Metal and Insulator.....	69
Figure 1.7	Evidence that contact charging of insulators by metals is determined by the energy difference between the metal Fermi energy and some energy $E_0$ characteristics of the insulator.....	73
Figure 1.8	Contact between a metal and an insulator or semiconductor containing localized states.....	75
Figure 1.9	The standard methods of measuring the charge on an insulator.....	84
Figure 1.10	Coaxial cylindrical capacitor with grounded outer tube .....	85
Figure 1.11	Schematic diagram of closed tube and the equivalent circuit diagram.....	85

Figure 1.12	Schematic diagram of the system for measuring the charging tendency of particle.....	87
Figure 1.13	Experimental set-up for fine particles .....	87
Figure 1.14	Experimental set-up of ultra-fine particles.....	88
Figure 1.15	Electrostatic Ball Probe.....	90
Figure 1.16	The developed “Phase Doppler Particle Analyzer (PDPA)” and triboelectrostatic separation system.....	94
Figure 2.1	Schematic representation of the principle of particle charge measurement using a Faraday cage .....	122
Figure 2.2	The on-line charge measurement device developed for the experiments .....	122
Figure 2.3	Schematic representation of the on-line tribocharge analyzer and the experimental set-up .....	123
Figure 2.4	A printout from the data acquisition system used in conjunction with the on-line charge- measurement device.....	124
Figure 2.5	The effect of air velocity on charge densities of Pittsburgh No.8 clean coal (6.27% ash), quartz, and pyrite samples.....	125
Figure 2.6	The effect of particle feed rate on charge densities of Pittsburgh No.8 clean coal (6.27% ash), quartz, and pyrite samples.....	126
Figure 2.7	The effect of particle size on charge density of a Pittsburgh No.8 coal sample assaying 19-22% ash.....	127

Figure 2.8	Effect of ash content on the charge density of Pittsburgh No.8 coal Samples .....	128
Figure 2.9	Effect of temperature on charge densities of Pittsburgh No.8 clean coal (6.27% ash), quartz, and pyrite samples.....	129
Figure 3.1	The schematic view of the tribocharger and charge measuring device developed for the experiments .....	153
Figure 3.2	The schematic representation of the on-line tribocharger analyzer and the experimental set-up .....	154
Figure 3.3	The k = 3 Box-Behnken Design with a center point.....	155
Figure 3.4	The effect of air velocity on the charge density of different coal samples, including quartz and pyrite samples.....	156
Figure 3.5	The effects of operating parameters on particle charging characteristics .....	157
Figure 3.6	The effects of operating parameters on particle charging characteristics .....	158
Figure 3.7	The results of charge measurement presented in unit of coulomb per unit Particle.....	159
Figure 3.8	The results of charge measurement presented in unit of coulomb per unit area from the same experiments as present in Figure 3.7 .....	160
Figure 3.9	Printouts of analog signals recorded during the the period of particle charging characteristics study by the tribocharger analyzer developed in the present work .....	161

Figure 3.10(a) The correlation between sample ash content and net charge .....	162
Figure 3.10(b) The correlation between sample ash content and net charge .....	163
Figure 4.1 The schematic view of the tribocharger and charge measuring device developed for the experiments .....	187
Figure 4.2 The schematic representation of the on-line tribocharger analyzer and the experimental set-up .....	188
Figure 4.3 Results of charge measurement conducted for the quartz sample on a variety of different charging materials.....	189
Figure 4.4 The correlation between the charge density of the coal samples; (a) Pittsburgh No.8 clean coal (~ 5.3% ash) and (b) pre-cleaned utility mill reject (~ 6.1% ash), and the work function of metal employed to construct the tribocharger.....	190
Figure 4.5 Results of particle triboelectrification mechanism study: the correlation between the charge density of the quartz sample and the work function of the material used to fabricate the tribocharger.....	191
Figure 4.6 Schematic view of electron transfer mechanism explained by Thermodynamic Equilibrium Hypothesis for the samples involving in triboelectrostatic process.....	192
Figure 5.1 The schematic view of the new turbocharger and the charge-measuring device developed for the experiments.....	218
Figure 5.2 The schematic representation of the experimental set-up incorporating with the new designed turbocharger.....	219

Figure 5.3	The effect of the rotor-blade rotation speed on the charge density of the coal and quartz samples at different particle sizes .....	220
Figure 5.4	The effect of the rotor-blade rotation speed of the Plexiglas turbocharger on the charge density of the coal and quartz samples at different particle size .....	221
Figure 5.5	The effect of particle feed rate on the charge density of the clean Pittsburgh No.8 coal sample (5.2% ash) at particle size -42+65-mesh fraction.....	222
Figure 5.6	The effect of particle feed rate on the charge density of the quartz sample at the particle size -42+65-mesh fraction.....	223
Figure 5.7	The charge density of the coal and quartz samples as a function of particle feed rate. The results show the influence of two different materials (Cu-Ni alloy and Plexiglas) used to construct the new turbocharger.....	224