

# Contents

|          |                                                                                                |           |
|----------|------------------------------------------------------------------------------------------------|-----------|
| <b>1</b> | <b>Introduction</b>                                                                            | <b>1</b>  |
| 1.1      | Importance of Coal Washing.                                                                    | 1         |
| 1.2      | Ultrasound-Assisted Process Intensification.                                                   | 3         |
| 1.2.1    | Basic Mechanism of Ultrasound                                                                  | 3         |
| 1.3      | Outline of Thesis.                                                                             | 6         |
|          | References                                                                                     | 6         |
| <b>2</b> | <b>Literature Review</b>                                                                       | <b>7</b>  |
| 2.1      | General                                                                                        | 7         |
| 2.2      | Effect of Burning High-Ash and High-Sulfur Coal                                                | 7         |
| 2.2.1    | Boiler Equipment                                                                               | 7         |
| 2.2.2    | Environmental and Health Hazards of Coal Burning<br>Power Plants                               | 11        |
| 2.3      | Conventional Methods for De-Ashing and De-Sulfurization                                        | 12        |
| 2.4      | Ultrasound-Assisted Coal Particle Breakage and Application<br>of Ultrasound in Various Fields. | 16        |
| 2.4.1    | Ultrasound-Assisted Coal Particle Breakage                                                     | 16        |
| 2.4.2    | Application of Ultrasonic Process                                                              | 18        |
| 2.4.3    | Patented Ultrasonic Coal-Wash Process<br>for De-Ashing.                                        | 19        |
| 2.4.4    | Ultrasound in Aqueous Medium                                                                   | 20        |
| 2.5      | Ultrasonic Process for De-Ashing and De-Sulfurization                                          | 22        |
| 2.6      | Scope and Objectives for the Present Work                                                      | 24        |
|          | References                                                                                     | 25        |
| <b>3</b> | <b>Assessment of Fly-Ash Erosion Potential of Indian Coals.</b>                                | <b>29</b> |
| 3.1      | Introduction                                                                                   | 29        |
| 3.2      | Experimental Details                                                                           | 30        |
| 3.2.1    | Materials Used and Their Properties                                                            | 30        |
| 3.2.2    | Test Equipment and Procedure                                                                   | 32        |

|          |                                                                                                                      |           |
|----------|----------------------------------------------------------------------------------------------------------------------|-----------|
| 3.3      | Results and Discussion . . . . .                                                                                     | 34        |
| 3.3.1    | Effect of Process Parameters on Erosion Mass Loss . . . .                                                            | 34        |
| 3.3.2    | Effect of Surface Roughness on Erosion Mass Loss . . . .                                                             | 34        |
| 3.3.3    | Effect of Ash and Substrate Alloy Properties<br>on Erosion Mass Loss . . . . .                                       | 37        |
| 3.3.4    | Predictive Model for Ash-Impact Erosion . . . . .                                                                    | 37        |
| 3.4      | Summary . . . . .                                                                                                    | 40        |
|          | References . . . . .                                                                                                 | 40        |
| <b>4</b> | <b>Experimental Studies on Ultrasonic Coal Beneficiation . . . . .</b>                                               | <b>41</b> |
| 4.1      | Overview . . . . .                                                                                                   | 41        |
| 4.2      | Materials, Methods and Equipment Used . . . . .                                                                      | 41        |
| 4.2.1    | Materials . . . . .                                                                                                  | 41        |
| 4.2.2    | Methods . . . . .                                                                                                    | 42        |
| 4.2.3    | Equipment Used . . . . .                                                                                             | 44        |
| 4.3      | Experimental Procedure . . . . .                                                                                     | 47        |
| 4.3.1    | Aqueous-Based De-Ashing Experiments . . . . .                                                                        | 47        |
| 4.3.2    | Aqueous-Based De-Sulfurization Experiments . . . . .                                                                 | 47        |
| 4.3.3    | Solvent-Based De-Ashing Experiments . . . . .                                                                        | 48        |
| 4.3.4    | Reagent-Based De-Sulfurization Experiments . . . . .                                                                 | 49        |
| 4.4      | Results for Aqueous-Based Coal Beneficiation . . . . .                                                               | 51        |
| 4.4.1    | Motivation . . . . .                                                                                                 | 51        |
| 4.4.2    | De-Ashing . . . . .                                                                                                  | 51        |
| 4.4.3    | De-Sulfurization . . . . .                                                                                           | 59        |
| 4.5      | Results for Solvent-Based Coal Beneficiation . . . . .                                                               | 62        |
| 4.5.1    | Introduction . . . . .                                                                                               | 62        |
| 4.5.2    | De-Ashing . . . . .                                                                                                  | 62        |
| 4.5.3    | De-Sulfurization Studies . . . . .                                                                                   | 68        |
|          | References . . . . .                                                                                                 | 71        |
| <b>5</b> | <b>Experimental Studies and Mechanistic Modeling<br/>of Reagent-Based Ultrasonic Coal De-Sulfurization . . . . .</b> | <b>73</b> |
| 5.1      | Motivation . . . . .                                                                                                 | 73        |
| 5.2      | Experimental . . . . .                                                                                               | 73        |
| 5.2.1    | Materials . . . . .                                                                                                  | 73        |
| 5.2.2    | Experimental Design . . . . .                                                                                        | 74        |
| 5.2.3    | Experimental Procedure . . . . .                                                                                     | 74        |
| 5.2.4    | Reaction Mechanism . . . . .                                                                                         | 74        |
| 5.3      | Results and Discussion . . . . .                                                                                     | 76        |
| 5.3.1    | Effect of Ultrasonic Frequency on Total<br>Sulfur Removal . . . . .                                                  | 76        |
| 5.3.2    | Effect of Reagent Concentration on Total<br>Sulfur Removal . . . . .                                                 | 77        |
| 5.3.3    | Effect of Sonication Time on Total Sulfur Removal . . . .                                                            | 78        |

|          |                                                                                                       |            |
|----------|-------------------------------------------------------------------------------------------------------|------------|
| 5.3.4    | Effect of Coal Particle Size on Total Sulfur Removal . . .                                            | 79         |
| 5.3.5    | Effect of Reagent Volume on Total Sulfur Removal . . .                                                | 79         |
| 5.3.6    | Statistical Validation of Results . . . . .                                                           | 80         |
| 5.4      | Optimum Conditions and Validation . . . . .                                                           | 81         |
| 5.5      | Mechanistic Modeling of Ultrasound Assisted<br>Reagent-Based Coal De-Sulfurization . . . . .          | 82         |
| 5.6      | Scale-Up of Ultrasonic Reagent-Based Coal De-Sulfurization . .                                        | 86         |
| 5.7      | Summary . . . . .                                                                                     | 87         |
|          | References . . . . .                                                                                  | 88         |
| <b>6</b> | <b>Assessment of Benefits from Ultrasonic Coal-Wash (USCW) . . . .</b>                                | <b>89</b>  |
| 6.1      | Introduction . . . . .                                                                                | 89         |
| 6.2      | Proposed Flow Chart for USCW on Industrial Scale . . . . .                                            | 89         |
| 6.3      | Effect of USCW on Metal Erosion and Corrosion Due<br>to Burning of High-Ash and Sulfur Coal . . . . . | 91         |
| 6.4      | Particulate and SO <sub>x</sub> Emission . . . . .                                                    | 92         |
|          | Reference . . . . .                                                                                   | 93         |
| <b>7</b> | <b>Summary, Conclusions and Recommendations . . . . .</b>                                             | <b>95</b>  |
| 7.1      | Recommendations for Future Work . . . . .                                                             | 95         |
|          | <b>Appendix I . . . . .</b>                                                                           | <b>97</b>  |
|          | <b>Appendix II . . . . .</b>                                                                          | <b>99</b>  |
|          | <b>Appendix III . . . . .</b>                                                                         | <b>101</b> |
|          | <b>Appendix IV . . . . .</b>                                                                          | <b>105</b> |
|          | <b>Appendix V . . . . .</b>                                                                           | <b>109</b> |
|          | <b>Appendix VI . . . . .</b>                                                                          | <b>113</b> |
|          | <b>Appendix VII . . . . .</b>                                                                         | <b>117</b> |
|          | <b>Appendix VIII . . . . .</b>                                                                        | <b>121</b> |
|          | <b>Curriculum Vitae . . . . .</b>                                                                     | <b>125</b> |

Ultrasonic Coal-Wash for De-Ashing and De-Sulfurization  
Experimental Investigation and Mechanistic Modeling

Ambedkar, B.

2012, XVIII, 126 p., Hardcover

ISBN: 978-3-642-25016-3