# Table of Contents

Abstract ......................................................................................................................... I

Kurzfassung ................................................................................................................... IV

Table of Contents ......................................................................................................... VII

Nomenclature .............................................................................................................. X

1 Introduction ............................................................................................................... 1

1.1 Coal combustion in power generation in response to environmental issues .......... 1

1.2 Flameless oxidation, development and potential in pulverised coal combustion ...... 3

1.3 Tasks and objectives of the present work ......................................................... 7

1.4 Approach and outline of the present work ....................................................... 9

2 State of the art ......................................................................................................... 11

2.1 Flame dilution technology in pulverised coal combustion .............................. 11

2.1.1 Flameless oxidation of pulverised coal under pressurised conditions .......... 12

2.1.2 History of study on the HiTAC of pulverised coal ........................................... 13

2.2 Nitrogen oxides in pulverised coal combustion .............................................. 15

2.2.1 Major NO formation processes in pulverised coal combustion .................. 16

2.2.2 NO reduction processes in pulverised coal combustion .............................. 18

2.2.3 NOx emissions control technologies in pulverised coal-fired utility boilers 20

3 Experimental setup ............................................................................................... 23

3.1 Bench-scale combustion test facility ................................................................. 23

3.2 Pilot-scale combustion test facility ................................................................... 24

3.3 Measurement equipment, calibration and error discussion ......................... 26

3.3.1 Standard flue gas analysis ........................................................................... 26

3.3.2 Volatile nitrogenous components analysis ................................................. 27

3.3.3 Coal and ash sample analyses ................................................................ 30

3.4 Fuels ..................................................................................................................... 30
### 4 Study on pulverised coal flameless oxidation

#### 4.1 Burnout
- 4.1.1 Carbon burnout
- 4.1.2 Coal burnout

#### 4.2 NO formation
- 4.2.1 Thermal and fuel NO in air-staged conditions
  - 4.2.1.1 Total volatile fuel-N
  - 4.2.1.2 Influence of the air ratio at the burner on fuel NO
- 4.2.2 Thermal and fuel NO in unstaged conditions
  - 4.2.2.1 Influence of the furnace wall temperature on fuel NO

#### 4.3 NO\textsubscript{x} emissions
- 4.3.1 Influence of the burner air ratio
- 4.3.2 Influence of the secondary air velocity

### 5 Optimisation of the near burner aerodynamics

#### 5.1 Burner-port (quarl)

#### 5.2 Burner air injection scheme
- 5.2.1 Secondary air nozzles pitch circle diameter
- 5.2.2 Number of secondary air nozzles

#### 5.3 Trade-off between NO\textsubscript{x} and unburned carbon

### 6 Scale-up of the PC-FLOXTM burner

#### 6.1 Scale-up methodology

#### 6.2 Numerical investigations
- 6.2.1 Modelling of the pilot-scale PC-FLOXTM burner

#### 6.3 Pilot-scale PC-FLOXTM burner design

### 7 Demonstration of the pilot-scale PC-FLOXTM burner

#### 7.1 Experimental trials with the Lausitz lignite
- 7.1.1 Continuous measurements
- 7.1.2 Detailed in-flame measurements along the furnace axis

#### 7.2 Experimental trials with the El Cerrejón bituminous coal
- 7.2.1 Continuous measurements
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.2.2 Detailed in-flame measurements along the furnace axis</td>
<td>98</td>
</tr>
<tr>
<td>7.2.3 Detailed in-flame measurements along the furnace plane</td>
<td>103</td>
</tr>
<tr>
<td>7.2.4 Effect of air staging on PC-FLOX™ combustion</td>
<td>110</td>
</tr>
<tr>
<td><strong>8 Conclusion and outlook</strong></td>
<td>112</td>
</tr>
<tr>
<td>8.1 Conclusion</td>
<td></td>
</tr>
<tr>
<td>8.2 Outlook</td>
<td>116</td>
</tr>
<tr>
<td><strong>9 References</strong></td>
<td>118</td>
</tr>
</tbody>
</table>