

INTERACTIONS BETWEEN FREEZE LINING AND SLAG BATH IN ILMENITE SMELTING

by

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To my Father in Heaven, who created it all, made this work possible and gave me the ability and strength to carry it through. I give to Thee all the glory, all the honour, and all the praise.

To Ennes, a wonderful father and friend. I am privileged to have shared but a small part of your life. The example you set changed me, and will keep doing so until we meet again.

ABSTRACT

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Key words:

Ilmenite smelting, mathematical modelling, process modelling, heat transfer, DC furnace, freeze lining, slag bath, titania slag.

This study focused on the dynamic behaviour of the freeze lining and slag bath, and the interactions between these components in an ilmenite-smelting furnace process. The purpose of the work was to gain a better understanding of these issues and to ultimately contribute to an improved understanding of the ilmenite-smelting process in its entirety, and to future improvements in the design, operation and control of these processes.

A mathematical model of the freeze lining and furnace sidewall was developed. This model was used in isolation for focused characterisation of the dynamic behaviour and interactions of the freeze lining and slag bath. The influences of net power input and slag composition were studied and various aspects of the freeze lining and slag bath were considered. These aspects included freeze lining thickness, temperature distribution through the freeze lining and furnace sidewall, composition distribution through the freeze lining, slag bath temperature and slag bath composition. The thermal response of thermocouples installed in the furnace sidewall to changing conditions on the inside of the furnace was also investigated.

A mathematical model of the crust that forms on the slag bath surface was developed. This model was not used in isolation, and was only incorporated into a complete model of the process.

A mathematical model of the entire ilmenite-smelting furnace process was constructed. This model incorporated the two models mentioned above and was able to describe the metal bath, slag bath, furnace atmosphere, freeze lining, furnace sidewall and the crust that is sometimes present on top of the slag bath. The model was used to study the influence of changes in operational parameters on the slag bath and freeze lining. The operational parameters that were studied included electrical power and reductant feed rate, both relative to ilmenite feed rate. The influence of severe operational errors and furnace down time were also investigated. Operational errors included loss of all feed while maintain electrical power input, and loss of reductant feed while maintaining power input and ilmenite feed.

The above-mentioned studies were conducted by executing numerous experiments with two of the mathematical models. The experimental results were processed into sets of graphs displaying variations in the aspects that were considered. Many valuable insights resulted from the interpretation of these results.

One specific aspect that formed part of the scope of this work was the origin of the compositional invariance of the slag close to the stoichiometric M_3O_5 composition. This invariance was studied and a mechanism was proposed that explains the observed behaviour. The proposed mechanism created some questions about other mechanisms in the process. These mechanisms were also considered and elaborated on.

The models and results produced in this study provide valuable insights into the behaviour of the ilmenite-smelting process. It also represents a useful foundation for future modelling work, and finally, it presents numerous opportunities for organisations operating ilmenite-smelting furnaces to improve their understanding and even the performance of their processes.

SAMEVATTING

INTERAKSIES TUSSEN VRIESVOERING EN SLAKBAD IN ILMENIETSMELTING

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Sleutelwoorde:

Ilmenietsmelting, wiskundige modellering, prosesmodellering, hitteoordrag, DC oond, vriesvoering, slakbad, titania slak.

Hierdie studie het gefokus op die dinamiese gedrag van die vriesvoering en slakbad en op die interaksies tussen hierdie komponente van 'n ilmenietsmeltproses. Die oogmerk van die werk was om 'n beter begrip van hierdie sake te verkry en om by te dra tot 'n breër begrip van die ilmenietsmeltproses in sy geheel, en tot toekomstige verbetering in die ontwerp, bedryf en beheer van hierdie prosesse.

'n Wiskundige model van die vriesvoering en die oondmuur is ontwikkel. Hierdie model is in isolasie gebruik om die dinamiese gedrag en interaksies van die vriesvoering en slakbad gefokus te karakteriseer. Die invloede van netto kraginset en slaksamestelling is bestudeer en verskeie aspekte van die vriesvoering en slakbad is beskou. Hierdie aspekte het vriesvoeringdikte, temperatuurverspreiding deur die vriesvoering en oondmuur, samestellingverspreiding deur die vriesvoering, slakbad temperatuur en slakbad samestelling ingesluit. Die termiese reaksie van termokoppels in die oondmuur op veranderende toestande in die oond is ook ondersoek.

'n Wiskundige model van die kors wat op die slakbad oppervlak vorm is ontwikkel. Hierdie model is nie in isolasie gebruik nie. Dit is slegs ingesluit as deel van 'n groter model wat die proses in sy geheel beskryf het.

'n Wiskundige model van die totale ilmenietsmeltproses is ontwikkel. Hierdie model het die twee bogenoemde modelle ingesluit en kon die metaalbad, slakbad, oondatmosfeer, vriesvoering, oondmuur en die kors, wat van tyd tot tyd op die slakbad teenwoordig, is beskryf. Die model is gebruik om die invloed van veranderinge in bedryfsparameters op die slakbad en vriesvoering te ondersoek. Die bedryfsparameters het elektriese kraginset en reduktant voertempo ingesluit, beide relatief tot ilmeniet voertempo. Die invloed van ernstige bedryfsfoute en oond aftyd is ook bestudeer. Bedryfsfoute het ingesluit die verlies van alle materiaalvoer terwyl elektriese kraginset onveranderd bly, en die verlies van reduktantvoer terwyl elektriese kraginset en ilmenietvoer onveranderd bly.

Die bogenoemde studies het die uitvoering van talryke eksperimente met twee van die wiskundige modelle behels. Die eksperimentele resultate is verwerk tot 'n stel grafieke vir elke eksperiment wat variasies in die aspekte wat beskou is aantoon. Die interpretasie van hierdie resultate het gelei tot waardevolle insig.

'n Spesifieke saak wat deel was van die bestek van hierdie werk was die oorsprong van die onveranderlikheid van die slaksamestelling naby die M_3O_5 samestelling. Hierdie onveranderlikheid is ondersoek en 'n meganisme is voorgestel wat die waargenome gedrag verklaar. Die voorgestelde meganisme het vrae laat ontstaan oor ander meganismes in die proses. Hierdie meganismes is ook beskou en bespreek.

Die modelle en resultate wat voortgevloei het uit hierdie studie gee waardevolle nuwe insig in die gedrag van die ilmenietsmeltproses. Dit verskaf ook 'n nuttige platform vir toekomstige modelleringswerk, en skep talryke geleenheid vir organisasies wat ilmenietsmelters bedryf om hul begrip van die prosesse en selfs die prestasie van die hul prosesse te verbeter.

TABLE OF CONTENTS

ABSTRACT.....	III
SAMEVATTING.....	V
TABLE OF CONTENTS.....	VII
LIST OF FIGURES	XV
LIST OF TABLES	XVIII
ACKNOWLEDGMENTS	XIX
CHAPTER 1 INTRODUCTION.....	1
1.1 INDUSTRY BACKGROUND.....	1
1.1.1 Minerals	2
1.1.2 Hard Rock Mineral Processing.....	2
1.1.3 Mineral Sands Processing	3
1.1.4 Ilmenite Smelting.....	3
1.1.5 Synthetic Rutile Production.....	5
1.1.6 Sulphate Process Pigment Production.....	7
1.1.7 Chloride Process Pigment Production	7
1.1.8 Titanium Metal Production	8
1.1.9 Importance of Ilmenite Smelting	9
1.2 OVERVIEW OF CURRENT WORK.....	9
1.2.1 Objectives.....	9
1.2.2 Impetus for Study	10
1.2.3 Approach.....	12
1.3 ORGANISATION OF CURRENT TEXT.....	12
CHAPTER 2 ILMENITE SMELTING PROCESS OVERVIEW.....	13
2.1 OPERATIONAL OVERVIEW.....	13
2.2 FURNACE CONTROL.....	14
2.3 FURNACE VESSEL	15
2.3.1 Hearth	15
2.3.2 Sidewalls.....	16
2.3.3 Roof.....	16
2.3.4 Tap holes	16
2.4 PROCESS INPUTS	16
2.4.1 Ilmenite	16
2.4.2 Reductant	17
2.4.3 Graphite Electrodes.....	17
2.4.4 Refractory Material	17
2.4.5 Water.....	18

2.4.6 Air	18
2.4.7 Energy.....	18
2.5 PROCESS OUTPUTS.....	18
2.5.1 Titania Slag.....	18
2.5.2 Pig Iron	19
2.5.3 Off-gas.....	19
2.5.4 Dust and Fumes	19
2.5.5 Energy.....	19
2.6 PROPERTIES OF TITANIA SLAG	19
2.6.1 Thermodynamic Data	19
2.6.2 Liquidus and Solidus Temperatures and Solidification Behaviour.....	22
2.6.3 Heat Capacity	25
2.6.4 Viscosity	26
2.6.5 Thermal Conductivity.....	26
2.6.6 Compositional Invariance	26
CHAPTER 3 A 1D MODEL OF THE FREEZE LINING AND FURNACE WALL.....	27
3.1 IDENTIFICATION.....	27
3.2 PROBLEM DEFINITION	27
3.3 SYSTEM DESCRIPTION.....	27
3.3.1 System geometry.....	28
3.4 KEY PHENOMENA.....	28
3.4.1 Heat Transfer	28
3.4.2 Mass Transfer	31
3.4.3 Momentum Transfer.....	31
3.4.4 Chemical Reaction	32
3.4.5 Mechanical Effects	33
3.4.6 Summary of Key Phenomena	33
3.5 APPROACH AND MODEL COMPLEXITY.....	34
3.5.1 Modelling of Heat Transfer.....	34
3.5.2 Modelling of Chemical Reaction.....	35
3.6 MODEL FORMULATION	35
3.6.1 Assumptions.....	35
3.6.2 Simplifications.....	39
3.6.3 Material Definitions	39
3.6.4 Model Structure.....	42
3.6.5 Heat Transfer	43
3.6.6 Slag Solidification and Melting.....	48
3.7 MODEL SOLUTION.....	48
3.7.1 Flow Sheet.....	48
3.7.2 Initial Conditions.....	50
3.7.3 Solution	51
3.8 MODEL VALIDATION	52
3.8.1 Purpose	52
3.8.2 Objectives	52
3.8.3 Methodology	53
3.8.4 Validation Experiments	54

3.8.5 Validation Results	55
3.9 COMPARISON WITH ACTUAL DATA	62
CHAPTER 4 A 1D MODEL OF SOLIDIFICATION ON THE SLAG BATH SURFACE.....	63
4.1 IDENTIFICATION.....	63
4.2 PROBLEM DEFINITION	63
4.3 SYSTEM DESCRIPTION.....	63
4.3.1 System Geometry	64
4.4 KEY PHENOMENA.....	64
4.4.1 Heat Transfer	65
4.4.2 Mass Transfer	67
4.4.3 Momentum Transfer	67
4.4.4 Chemical Reaction	68
4.4.5 Summary of Key Phenomena	68
4.5 APPROACH AND MODEL COMPLEXITY	69
4.5.1 Modelling of Heat Transfer.....	69
4.5.2 Modelling of Chemical Reaction.....	70
4.6 MODEL FORMULATION	70
4.6.1 Assumptions.....	70
4.6.2 Simplifications.....	71
4.6.3 Material Definitions	71
4.6.4 Model Structure	72
4.6.5 Heat Transfer	73
4.6.6 Slag Solidification and Melting	76
4.7 MODEL SOLUTION	76
4.7.1 Flow Sheet	76
4.7.2 Initial Conditions	78
4.7.3 Solution	78
4.8 MODEL VALIDATION	79
4.8.1 Purpose	79
4.8.2 Objectives	79
4.8.3 Methodology	80
4.8.4 Validation Experiments	82
4.8.5 Validation Results.....	83
4.9 COMPARISON WITH ACTUAL DATA	88
CHAPTER 5 A DYNAMIC MODEL OF THE ENTIRE ILMENITE-SMELTING FURNACE PROCESS	89
5.1 IDENTIFICATION.....	89
5.2 PROBLEM DEFINITION	89
5.3 SYSTEM DESCRIPTION.....	90
5.3.1 Dimensions.....	90

5.4 KEY PHENOMENA	91
5.4.1 Heat Transfer	91
5.4.2 Mass Transfer	94
5.4.3 Momentum Transfer.....	99
5.4.4 Chemical Reaction	103
5.4.5 Mechanical Effects	108
5.4.6 Summary of Key Phenomena	109
5.5 APPROACH AND MODEL COMPLEXITY	110
5.6 MODEL FORMULATION	110
5.6.1 Assumptions.....	110
5.6.2 Simplifications.....	113
5.6.3 Material Definitions	113
5.6.4 Model Structure.....	115
5.6.5 From Model Structure to Process Model.....	119
5.6.6 Sub-models to Calculate Heat Losses.....	121
5.6.7 Sub-models to Calculate Product Flow Rates.....	124
5.6.8 Sub-models to Calculate Mass Transfer Rates to Phase Boundaries	125
5.7 MODEL SOLUTION	133
5.7.1 Initial Conditions	134
5.7.2 Solution	134
5.8 MODEL VALIDATION	134
5.8.1 Purpose	134
5.8.2 Objectives	134
5.8.3 Methodology	135
5.8.4 Validation Experiments	135
5.8.5 Validation Results.....	135
5.9 COMPARISON WITH ACTUAL DATA	136
CHAPTER 6 THE DYNAMIC RESPONSE OF A FREEZE-LINING TO STEP CHANGES IN INPUT HEAT FLOW RATE	137
6.1 EXPERIMENTAL SETUP	137
6.2 EXPERIMENTS	137
6.3 EXPERIMENTAL RESULTS	139
6.3.1 Experiment 6.1	144
6.3.2 Experiment 6.2	145
6.3.3 Experiment 6.3	146
6.3.4 Experiment 6.4	147
6.3.5 Experiment 6.5	148
6.3.6 Experiment 6.6	149
6.3.7 Experiment 6.7	150
6.3.8 Experiment 6.8	151
6.3.9 Experiment 6.9	152
6.3.10 Experiment 6.10	153
6.3.11 Experiment 6.11	154
6.3.12 Experiment 6.12	155
6.3.13 Experiment 6.13	156
6.3.14 Experiment 6.14	157
6.3.15 Experiment 6.15	158
6.3.16 Experiment 6.16	159

6.3.17 Experiment 6.17	160
6.3.18 Experiment 6.18	161
6.3.19 Experiment 6.19	162
6.3.20 Experiment 6.20	163
6.3.21 Experiment 6.21	164
6.3.22 Experiment 6.22	165
6.3.23 Experiment 6.23	166
6.3.24 Experiment 6.24	167
6.3.25 Experiment 6.25	168
6.3.26 Experiment 6.26	169
6.4 DISCUSSION	170
6.4.1 Freeze Lining Thickness	170
6.4.2 Thermal Response of Freeze Lining and Furnace Wall	170
6.4.3 Slag Bath Composition	172
6.4.4 Slag Bath Temperature	174
6.4.5 Freeze Lining Composition.....	174
 CHAPTER 7 THE DYNAMIC RESPONSE OF A FREEZE-LINING TO CHANGES IN SLAG BATH COMPOSITION	 176
7.1 EXPERIMENTAL SETUP	176
7.2 EXPERIMENTS.....	178
7.3 EXPERIMENTAL RESULTS.....	179
7.3.1 Experiment 7.1	181
7.3.2 Experiment 7.2	182
7.3.3 Experiment 7.3	183
7.3.4 Experiment 7.4	184
7.3.5 Experiment 7.5	185
7.3.6 Experiment 7.6	186
7.3.7 Experiment 7.7	187
7.3.8 Experiment 7.8	188
7.3.9 Experiment 7.9	189
7.3.10 Experiment 7.10	190
7.3.11 Experiment 7.11	191
7.3.12 Experiment 7.12	192
7.3.13 Experiment 7.13	193
7.3.14 Experiment 7.14	194
7.3.15 Experiment 7.15	195
7.3.16 Experiment 7.16	196
7.3.17 Experiment 7.17	197
7.3.18 Experiment 7.18	198
7.3.19 Experiment 7.19	199
7.3.20 Experiment 7.20	200
7.3.21 Experiment 7.21	201
7.3.22 Experiment 7.22	202
7.3.23 Experiment 7.23	203
7.3.24 Experiment 7.24	204
7.3.25 Experiment 7.25	205
7.3.26 Experiment 7.26	206
7.3.27 Experiment 7.27	207
7.3.28 Experiment 7.28	208
7.3.29 Experiment 7.29	209
7.3.30 Experiment 7.30	210
7.4 DISCUSSION	211

7.4.1 Freeze Lining Thickness	211
7.4.2 Thermal Response of Freeze Lining and Furnace Wall	212
7.4.3 Slag Bath Composition	212
7.4.4 Slag Bath Temperature	213
7.4.5 Freeze Lining Composition.....	213
CHAPTER 8 THE DYNAMIC PROCESS RESPONSE TO STEP CHANGES IN FURNACE OPERATING PARAMETERS.....	214
8.1 EXPERIMENTAL SETUP	214
8.2 EXPERIMENTS.....	215
8.3 EXPERIMENTAL RESULTS	216
8.3.1 Experiment 8.1	219
8.3.2 Experiment 8.2	221
8.3.3 Experiment 8.3	223
8.3.4 Experiment 8.4	225
8.3.5 Experiment 8.5	227
8.3.6 Experiment 8.6	229
8.3.7 Experiment 8.7	231
8.3.8 Experiment 8.8	233
8.3.9 Experiment 8.9	235
8.3.10 Experiment 8.10	237
8.3.11 Experiment 8.11	239
8.3.12 Experiment 8.12	241
8.3.13 Experiment 8.13	243
8.3.14 Experiment 8.14	245
8.3.15 Experiment 8.15	247
8.3.16 Experiment 8.16	249
8.3.17 Experiment 8.17	251
8.3.18 Experiment 8.18	253
8.3.19 Experiment 8.19	255
8.3.20 Experiment 8.20	257
8.4 DISCUSSION	259
8.5 THE IMPACT OF SEVERE OPERATIONAL ERRORS	259
8.5.1 Freeze Lining Thickness.....	259
8.5.2 Freeze Lining Composition.....	260
8.5.3 Thermal Response of Freeze Lining and Furnace Wall	260
8.5.4 Slag Bath Temperature	260
8.5.5 Slag Bath Composition	261
8.5.6 Metal Bath Composition	262
8.5.7 Off-gas Composition	262
8.5.8 Reactor Power	262
8.5.9 Heat Losses	262
8.6 INDEPENDENT ADJUSTMENT OF REDUCTANT AND ENERGY INPUTS	263
8.6.1 Freeze Lining Thickness.....	263
8.6.2 Freeze Lining Composition.....	263
8.6.3 Thermal Response of Freeze Lining and Furnace Wall	264
8.6.4 Crust Thickness.....	264
8.6.5 Crust Composition	264
8.6.6 Slag Bath Temperature	264
8.6.7 Slag Bath Composition	265
8.6.8 Metal Bath Composition	265
8.6.9 Off-gas Composition	266

8.6.10 Reactor Power	267
8.6.11 Heat Losses	268
8.7 APPROPRIATELY COMBINED ADJUSTMENT OF REDUCTANT AND ENERGY INPUTS	268
8.7.1 Freeze Lining Thickness	268
8.7.2 Freeze Lining Composition.....	269
8.7.3 Thermal Response of Freeze Lining and Furnace Wall	269
8.7.4 Slag Bath Temperature	269
8.7.5 Slag Bath Composition	270
8.7.6 Metal Bath Composition	270
8.7.7 Off-Gas Composition.....	271
8.7.8 Reactor Power	271
8.7.9 Heat Losses.....	272
CHAPTER 9 THE DYNAMIC PROCESS RESPONSE TO SOLIDIFICATION AND MELTING OF THE FREEZE LINING AND CRUST	273
9.1 EXPERIMENTAL SETUP	273
9.2 EXPERIMENTS.....	273
9.3 EXPERIMENTAL RESULTS	274
9.3.1 Experiment 9.1	275
9.3.2 Experiment 9.2	277
9.3.3 Experiment 9.3	279
9.3.4 Experiment 9.4	281
9.4 DISCUSSION	283
9.4.1 Freeze Lining Thickness	283
9.4.2 Freeze Lining Composition.....	283
9.4.3 Thermal Response of Freeze Lining and Furnace Wall	283
9.4.4 Crust Thickness.....	284
9.4.5 Crust Composition	284
9.4.6 Slag Bath Temperature	285
9.4.7 Slag Bath Composition	285
CHAPTER 10 COMPOSITIONAL INVARIANCE OF HIGH-TITANIA SLAG.....	286
10.1 THE RELATIONSHIP BETWEEN FeO AND Ti₂O₃.....	286
10.2 REACTION EQUILIBRIUM AS A POSSIBLE MECHANISM.....	288
10.2.1 Arguments For.....	288
10.2.2 Arguments Against	288
10.3 KINETIC EFFECTS AS A POSSIBLE MECHANISM.....	288
10.3.1 Arguments For.....	288
10.3.2 Arguments Against	289
10.4 EUTECTIC GROOVE PHASE EQUILIBRIUM AS A POSSIBLE MECHANISM.....	289
10.4.1 Arguments For.....	289
10.4.2 Arguments Against	289
10.5 A NEW MECHANISM PROPOSED.....	290
10.5.1 Requirements	290
10.5.2 Background Information	290
10.5.3 A Step-by-Step Batch Experiment	293

10.5.4 Description.....	294
10.6 A REFLECTION ON REDUCTION MECHANISMS	297
10.6.1 Reactions in the Bulk Slag and on the Slag Bath Surface	297
10.6.2 Reactions at the Interface between the Slag and Metal Baths	297
10.6.3 Reactions in the Turbulent Zone underneath the Electrode	297
CHAPTER 11 CONCLUSION	299
11.1 OBJECTIVES AND APPROACH	299
11.2 CONTRIBUTION OF THIS WORK.....	299
11.2.1 Process Models	299
11.2.2 Interactions between Freeze Lining and Slag Bath.....	300
11.2.3 Process Mechanisms	300
11.2.4 The Nature of Thermocouple Signals.....	301
11.3 OPPORTUNITIES FOR FUTURE WORK	301
11.3.1 Model Improvements	301
11.3.2 Model Applications	302
BIBLIOGRAPHY.....	304
APPENDIX A – MATERIAL PROPERTIES	307
APPENDIX B – MODEL ELEMENT DESCRIPTIONS.....	308

Number	Page
Figure 1 – Process routes in the Ti/TiO ₂ industry. (Kahn, 1984; Stanaway 1994)	1
Figure 2 – Main process steps in a mineral sands operation. (Kahn, 1984)	3
Figure 3 – Main process steps in ilmenite smelting operations.	4
Figure 4 – The Kerr–McGee synthetic rutile process (Kahn, 1984).	6
Figure 5 – The Becher synthetic rutile process (Kahn, 1984).	7
Figure 6 – Main steps in the chloride process for pigment production (Kahn, 1984).	8
Figure 7 – Simplified process flow of closed-loop titanium sponge production (Kahn, 1984).	9
Figure 8 – Schematic representation of an ilmenite–smelting furnace (Pistorius, 1999).	13
Figure 9 – Constant–FeO binary sections through the TiO ₂ –FeO–Ti ₂ O ₃ ternary phase diagram.	21
Figure 10 – Liquidus diagram for the TiO ₂ –FeTiO ₃ –Ti ₂ O ₃ system including Magnéli phases.	23
Figure 11 – Liquidus diagram for the TiO ₂ –FeTiO ₃ –Ti ₂ O ₃ system excluding Magnéli phases	23
Figure 12 – Solidus diagram for the TiO ₂ –FeTiO ₃ –Ti ₂ O ₃ system including Magnéli phases.	24
Figure 13 – Solidus diagram for the TiO ₂ –FeTiO ₃ –Ti ₂ O ₃ system excluding Magnéli phases	24
Figure 14 – Liquid slag composition trajectories during solidification.	25
Figure 15 – Temperature vs. enthalpy curves for three different slag compositions.	26
Figure 16 – Schematic representation of the freeze lining and wall region of the furnace.	28
Figure 17 – One-dimensional representation of the region being modelled.	42
Figure 18 – Flow sheet of a simple process model incorporating the FLC model.	49
Figure 19 – Schematic representation of steps in the FLC model solution procedure.	52
Figure 20 – Analytically calculated steady state freeze lining thickness vs. heat flow rate.	53
Figure 21 – Analytically calculated steady state temperature profiles.	53
Figure 22 – Validation experiment 3.1 results for a heat flow rate of 300 kW (the 300kW Base Condition).	56
Figure 23 – Validation experiment 3.1 results for a heat flow rate of 250 kW.	56
Figure 24 – Validation experiment 3.1 results for a heat flow rate of 350 kW.	56
Figure 25 – Validation experiment 3.2 results for a heat flow rate of 300 kW (the 300kW Base Condition).	57
Figure 26 – Validation experiment 3.2 results for a heat flow rate of 250 kW.	57
Figure 27 – Validation experiment 3.2 results for a heat flow rate of 350 kW.	57
Figure 28 – Validation experiment 3.3 results for a heat flow rate of 300 kW (the 300kW Base Condition).	58
Figure 29 – Validation experiment 3.3 results for a heat flow rate of 250 kW.	58
Figure 30 – Validation experiment 3.3 results for a heat flow rate of 350 kW.	58
Figure 31 – Validation experiment 3.4 results for a heat flow rate of 300 kW (the 300kW Base Condition).	59
Figure 32 – Validation experiment 3.4 results for a heat flow rate of 250 kW.	59
Figure 33 – Validation experiment 3.4 results for a heat flow rate of 350 kW.	59
Figure 34 – Validation experiment 3.5 results for a heat flow rate of 300 kW.	60
Figure 35 – Validation experiment 3.6 results for a heat flow rate of 300 kW (the 300kW Base Condition).	61
Figure 36 – Validation experiment 3.6 results for a heat flow rate of 250 kW.	61
Figure 37 – Validation experiment 3.6 results for a heat flow rate of 350 kW.	61
Figure 38 – Schematic representation of the slag bath and crust region of the furnace.	64
Figure 39 – Representation of the finite-difference model used to describe the crust.	72
Figure 40 – Flow sheet of a simple process model incorporating the SBCC model.	76
Figure 41 – Schematic representation of steps in the SBCC model solution procedure.	79
Figure 42 – Analytically calculated steady state crust thickness vs. heat loss rate from slag surface.	80
Figure 43 – Analytically calculated steady state temperature profiles in the crust layer.	81
Figure 44 – Validation experiment 4.1 results for a heat input of 1000 kW.	84
Figure 45 – Validation experiment 4.1 results for a heat input of 2000 kW.	84
Figure 46 – Validation experiment 4.2 results for a heat input of 1000 kW.	85
Figure 47 – Validation experiment 4.2 results for a heat input of 2000 kW.	85
Figure 48 – Validation experiment 4.3 results for a heat input of 500 kW.	86
Figure 49 – Validation experiment 4.3 results for a heat input of 1000 kW.	86
Figure 50 – Validation experiment 4.4 results for a heat input of 500 kW.	87
Figure 51 – Validation experiment 4.4 results for a heat input of 1000 kW.	87
Figure 52 – Schematic of the furnace and process as described by the ISFP model.	90
Figure 53 – Dimensions in meters of the furnace configuration used in CHAPTER 5.	91
Figure 54 – Heat transfer phenomena in an ilmenite–smelting furnace.	91
Figure 55 – Bulk mass flow phenomena in an ilmenite–smelting furnace.	95
Figure 56 – Solubility limits of carbon in liquid iron as functions of temperature. (FactSage 5.2)	98

Figure 57 – Flow patterns in a 30 kA, 270 V arc. (Stenkvist and Bowman, 1987)	103
Figure 58 – Flow sheet of ISFP model.	116
Figure 59 – Compositional invariance of ilmenite smelter slags close to M_3O_5 composition.	126
Figure 60 – Experiment 6.1 results.	144
Figure 61 – Experiment 6.2 results.	145
Figure 62 – Experiment 6.3 results.	146
Figure 63 – Experiment 6.4 results.	147
Figure 64 – Experiment 6.5 results.	148
Figure 65 – Experiment 6.6 results.	149
Figure 66 – Experiment 6.7 results.	150
Figure 67 – Experiment 6.8 results.	151
Figure 68 – Experiment 6.9 results.	152
Figure 69 – Experiment 6.10 results.	153
Figure 70 – Experiment 6.11 results.	154
Figure 71 – Experiment 6.12 results.	155
Figure 72 – Experiment 6.13 results.	156
Figure 73 – Experiment 6.14 results.	157
Figure 74 – Experiment 6.15 results.	158
Figure 75 – Experiment 6.16 results.	159
Figure 76 – Experiment 6.17 results.	160
Figure 77 – Experiment 6.18 results.	161
Figure 78 – Experiment 6.19 results.	162
Figure 79 – Experiment 6.20 results.	163
Figure 80 – Experiment 6.21 results.	164
Figure 81 – Experiment 6.22 results.	165
Figure 82 – Experiment 6.23 results.	166
Figure 83 – Experiment 6.24 results.	167
Figure 84 – Experiment 6.25 results.	168
Figure 85 – Experiment 6.26 results.	169
Figure 86 – Change in freeze lining thickness as a function of net input heat flow rate.	170
Figure 87 – Influence of net input heat flow rate on time lag in thermal response inside the brick wall.	171
Figure 88 – Temperature profile in the freeze lining after 1 hour.	172
Figure 89 – Flow sheet of the model used for CHAPTER 7 experiments.	176
Figure 90 – New slag compositions used in CHAPTER 7 experiments.	179
Figure 91 – Experiment 7.1 results.	181
Figure 92 – Experiment 7.2 results.	182
Figure 93 – Experiment 7.3 results.	183
Figure 94 – Experiment 7.4 results.	184
Figure 95 – Experiment 7.5 results.	185
Figure 96 – Experiment 7.6 results.	186
Figure 97 – Experiment 7.7 results.	187
Figure 98 – Experiment 7.8 results.	188
Figure 99 – Experiment 7.9 results.	189
Figure 100 – Experiment 7.10 results.	190
Figure 101 – Experiment 7.11 results.	191
Figure 102 – Experiment 7.12 results.	192
Figure 103 – Experiment 7.13 results.	193
Figure 104 – Experiment 7.14 results.	194
Figure 105 – Experiment 7.15 results.	195
Figure 106 – Experiment 7.16 results.	196
Figure 107 – Experiment 7.17 results.	197
Figure 108 – Experiment 7.18 results.	198
Figure 109 – Experiment 7.19 results.	199
Figure 110 – Experiment 7.20 results.	200
Figure 111 – Experiment 7.21 results.	201
Figure 112 – Experiment 7.22 results.	202
Figure 113 – Experiment 7.23 results.	203
Figure 114 – Experiment 7.24 results.	204
Figure 115 – Experiment 7.25 results.	205

Figure 116 – Experiment 7.26 results.	206
Figure 117 – Experiment 7.27 results.	207
Figure 118 – Experiment 7.28 results.	208
Figure 119 – Experiment 7.29 results.	209
Figure 120 – Experiment 7.30 results.	210
Figure 121 – Experiment 8.1 results.	220
Figure 122 – Experiment 8.2 results.	222
Figure 123 – Experiment 8.3 results.	224
Figure 124 – Experiment 8.4 results.	226
Figure 125 – Experiment 8.5 results.	228
Figure 126 – Experiment 8.6 results.	230
Figure 127 – Experiment 8.7 results.	232
Figure 128 – Experiment 8.8 results.	234
Figure 129 – Experiment 8.9 results.	236
Figure 130 – Experiment 8.10 results.	238
Figure 131 – Experiment 8.11 results.	240
Figure 132 – Experiment 8.12 results.	242
Figure 133 – Experiment 8.13 results.	244
Figure 134 – Experiment 8.14 results.	246
Figure 135 – Experiment 8.15 results.	248
Figure 136 – Experiment 8.16 results.	250
Figure 137 – Experiment 8.17 results.	252
Figure 138 – Experiment 8.18 results.	254
Figure 139 – Experiment 8.19 results.	256
Figure 140 – Experiment 8.20 results.	258
Figure 141 – Graph (h) of experiments 8.1 (a) and 8.2 (b) superimposed on the liquidus diagram.	261
Figure 142 – Chapter 8 subset 2 change in freeze lining thickness.	263
Figure 143 – Slag bath composition change relative to initial composition.	265
Figure 144 – Metal bath composition change relative to initial composition.	266
Figure 145 – Changes in reactor power values relative to initial steady state.	267
Figure 146 – Chapter 8 subsets 3 and 4 change in freeze lining thickness.	269
Figure 147 – Chapter 8 subsets 3 and 4 change in slag bath temperature relative to initial steady state.	269
Figure 148 – Chapter 8 subsets 3 and 4 change in slag bath composition relative to initial steady state.	270
Figure 149 – Chapter 8 subset 3 and 4 change in metal bath composition relative to initial steady state.	271
Figure 150 – Chapter 8 subsets 3 and 4 changes in reactor power values relative to initial steady state.	272
Figure 151 – Experiment 9.1 results.	276
Figure 152 – Experiment 9.2 results.	278
Figure 153 – Experiment 9.3 results.	280
Figure 154 – Experiment 9.4 results.	282
Figure 155 – Influence of downtime duration and electrical power on freeze lining thickness.	283
Figure 156 – Chapter 9 summary of crust thickness variation.	284
Figure 157 – Chapter 9 summary of variation in slag bath temperature.	285
Figure 158 – Compositional relationships in industrial high-titania slags.	286
Figure 159 – The relationship between FeO and Ti ₂ O ₃ in industrial high-titania slags.	287
Figure 160 – Slag composition according to reduction reactions at equilibrium.	291
Figure 161 – The influence of solidification on slag composition.	291
Figure 162 – Ternary view on compositions of industrial slags.	293
Figure 163 – Composition points resulting from the hypothetical step-by-step batch experiment.	293
Figure 164 – Illustration of mechanism proposed to cause the observed compositional invariance.	295

LIST OF TABLES

Number	Page
Table 1 – TiO ₂ feedstock composition. (Stanaway, 1994)	1
Table 2 – Summary of key phenomena for the FLC model.	34
Table 3 – List of symbols used in CHAPTER 3 heat transfer formulation.	45
Table 4 – Summary of key phenomena for the SBCC model.	69
Table 5 – List of symbols used in CHAPTER 4 heat transfer formulation.	74
Table 6 – Summary of key phenomena for the ISFP model.	110
Table 7 – Description of energy modules used in the ISFP model.	116
Table 8 – Description of energy flow streams used in the ISFP model.	117
Table 9 – Description of material modules used in the ISFP model.	118
Table 10 – Description of material flow streams used in the ISFP model.	119
Table 11 – Variables and parameters of the HeatLoss1Rate sub-model of the ISFP model.	122
Table 12 – Variables and parameters of the HeatLoss2Rate sub-model of the ISFP model.	123
Table 13 – Variables and parameters of the SlagTapFlow sub-model of the ISFP model.	124
Table 14 – Variables and parameters of the MetalTapFlow sub-model of the ISFP model.	125
Table 15 – Variables and parameters of the Reactor2Flow sub-model of the ISFP model.	128
Table 16 – Variables and parameters of the Reactor3Flow sub-model of the ISFP model.	130
Table 17 – Variables and parameters of the Reactor4Flow sub-model of the ISFP model.	131
Table 18 – Variables and parameters of the FreezeLiningFlow sub-model of the ISFP model.	132
Table 19 – Variables and parameters of the CrustFlow sub-model of the ISFP model.	133
Table 20 – Values of parameters of sub-models of the ISFP model.	136
Table 21 – List of experiments conducted for CHAPTER 6.	139
Table 22 – List of experiments conducted for CHAPTER 7.	178
Table 23 – List of experiments conducted for CHAPTER 8.	215
Table 24 – List of experiments conducted for CHAPTER 9.	273
Table 25 – Physical properties of molten iron and molten high-titania slag.	296

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