

## **Contents**

Acknowledgment .....	v
Abstract.....	vii
Resumen.....	ix
Resum .....	xi
Contents .....	xiii
List of figures.....	xix
List of tables.....	xxv
Chapter 1.....	27
1.    Introduction .....	29
1.1    Motivation.....	29
1.2    Research context and background .....	34
1.2.1    Quasi-two-stage compression system .....	37
1.2.2    Two-stage compression system.....	40
1.2.3    Refrigerant injection technique .....	43
1.2.3.1    Liquid injection.....	44
1.2.3.2    Two-phase injection.....	45
1.2.3.3    Vapor injection .....	46
1.3    Identified gaps and research questions .....	46
1.4    Objectives of the thesis.....	49
1.5    Structure of the thesis .....	49
Chapter 2.....	55
2.    Performance of a scroll compressor with vapor-injection and two-stage reciprocating compressor operating under extreme conditions .....	57
2.1    Introduction.....	58
2.2    Experimental setup and test procedure .....	62
2.3    Methodology .....	64
2.3.1    Comparative study between the performance of the SCVI and the TSRC	64
2.3.1.1    Parameter estimation of the SCVI .....	64
2.3.1.2    Parameter estimation of the TSRC .....	67

---

## Contents

---

2.3.2	Comparative study of the seasonal performance in heating mode	69
2.3.3	Comparative study of the seasonal performance in cooling mode	71
2.4	Results and discussion .....	72
2.4.1	Performance comparison of the SCVI and TSRC.....	72
2.4.1.1	Comparison of compressor efficiency .....	72
2.4.1.2	Comparison of volumetric efficiency .....	74
2.4.1.3	Comparison of cooling COP.....	75
2.4.1.4	Comparison of cooling capacity .....	76
2.4.2	Comparison of cooling SCOP.....	80
2.4.3	Comparison of heating SCOP .....	81
2.5	Conclusions.....	83
Chapter 3.....		87
3.	A comprehensive study of two-stage vapor compression cycles with vapor-injection for heating applications, taking into account heat sink of finite capacity.....	89
3.1	Introduction.....	90
3.2	Methodology .....	96
3.3	Results and discussion .....	100
3.3.1	Optimization of the two-stage cycle with vapor-injection....	100
3.3.2	Optimum intermediate pressure in two-stage cycles with vapor-injection	104
3.3.3	Influence of the system components on the COP .....	112
3.3.3.1	Displacement ratio of the compressors .....	113
3.3.3.2	Economizer size .....	115
3.4	Conclusions.....	121
Chapter 4.....		123
4.	New characterization methodology for vapor-injection scroll compressors .....	125
4.1	Introduction.....	126
4.2	Experimental setup .....	130
4.3	Compressor characterization procedure.....	132
4.4	Results and discussion .....	134

---

---

## Contents

4.4.1	Analysis of the influence of the intermediate pressure .....	137
4.4.2	Determination of the intermediate conditions correlation for vapor-injection scroll compressors .....	140
4.4.3	General model of a vapor-injection cycle .....	142
4.4.4	Validation of the characterization methodology .....	144
4.4.4.1	Description of the experimental heat pump prototype.	144
4.4.4.2	Experimental results and validation of the predicted data	
	145	
4.5	Conclusions.....	148
Chapter 5.....		151
5.	Semi-empirical model of scroll compressors and its extension to describe vapor-injection compressors. Model description and experimental validation .....	153
5.1	Introduction.....	154
5.2	Model description .....	159
5.2.1	Model assumptions .....	159
5.2.2	Leakage .....	163
5.2.3	Compressor efficiencies .....	164
5.2.4	Compressor losses.....	165
5.2.4.1	Vapor heating due to mechanical loss dissipation and motor cooling.....	165
5.2.4.2	Vapor heating due to heat transferred from the hot side of the compressor (discharge plenum) to the inlet flow .....	165
5.2.4.3	Isenthalpic pressure losses in the suction port .....	166
5.2.4.4	Isenthalpic pressure losses at the discharge port.....	167
5.2.4.5	Mechanical losses .....	167
5.2.4.6	Internal work of compression .....	167
5.2.4.7	Heat transfer to ambient.....	168
5.2.5	Determination of the model's parameters .....	168
5.2.6	Vapor-injection modeling methodology .....	169
5.3	Experimental setup and test procedure .....	172
5.4	Results and discussion .....	176
5.4.1	Non-injected scroll compressors .....	176
5.4.1.1	Model validation .....	178

---

---

## Contents

---

5.4.1.2 Compressor losses.....	182
5.4.1.3 Sensitivity analysis .....	186
5.4.2 Vapor injected scroll compressor.....	188
5.4.2.1 Model validation.....	189
5.4.2.2 Model response to the intermediate pressure variation	192
5.4.2.3 Model response to the injection superheat variation....	194
5.5 Conclusions.....	196
Chapter 6.....	199
6. Comparison of the performance of a vapor-injection scroll compressor with a two-stage scroll compressor working with high pressure ratios .....	201
6.1 Introduction.....	202
6.2 Experimental setup .....	205
6.3 Methodology.....	208
6.3.1 Model development.....	208
6.3.2 Optimization of the displacement ratio of the two-stage compressors	215
6.3.3 Comparison of the compressors' performance .....	216
6.3.4 Optimization of the intermediate pressure for a water heating application	217
6.4 Results and discussion .....	218
6.4.1 Optimization of the displacement ratio of the two-stage compressors	219
6.4.2 Comparison of the compressors' performance in a wide range of operating conditions.....	223
6.4.2.1 Comparison of the compressor efficiencies .....	223
6.4.2.2 Comparison of the heating capacity.....	225
6.4.2.3 Comparison of the heating COP .....	227
6.4.2.4 Comparison of the discharge temperature .....	229
6.4.3 Comparison of the optimal intermediate pressure for a water heating application .....	232
6.4.4 Performance comparison of the SCVI and the TSSC working with the same intermediate pressure .....	234
6.5 Conclusions.....	236
Chapter 7.....	239

---

---

Contents

7.	Conclusions and future work .....	241
7.1	Answers to research questions .....	241
7.2	Main contributions .....	244
7.3	Future work.....	248
	Chapter 8.....	251
8.	Appendices .....	253
8.1	Appendix A: List of publications.....	253
8.1.1	Journals .....	253
8.1.2	International Conferences .....	254
8.1.3	National conferences.....	255
8.2	Appendix B: Nomenclature .....	257
8.2.1	Nomenclature of chapter 2 .....	257
8.2.2	Nomenclature of chapter 3 .....	258
8.2.3	Nomenclature of chapter 4 .....	259
8.2.4	Nomenclature of chapter 5 .....	260
8.2.5	Nomenclature of chapter 6.....	261
8.3	Appendix C: References .....	262
8.3.1	References of chapter 1 .....	262
8.3.2	References of chapter 2 .....	269
8.3.3	References of chapter 3.....	270
8.3.4	References of chapter 4.....	273
8.3.5	References of chapter 5.....	276
8.3.6	References of chapter 6.....	278