Contents

Contents **xiii**

Nomenclature **xvi**

1 Introduction **1**
1.1 State of the art 3
1.1.1 Falling particle receiver 3
1.1.2 Rotary kiln 6
1.2 The Centrifugal Particle Receiver 8
1.2.1 Concept 9
1.2.2 Receiver dimensioning 10
1.3 Objective 13

2 Convection in Rotating Cavities **15**
2.1 State of the art 16
2.1.1 Convection losses in solar cavity receivers . 16
2.1.2 Rotating convection 18
2.2 Theory 19
2.2.1 Convective heat loss mechanisms in cavity receivers 20
2.2.2 Characteristic dimensionless parameters . . 21
2.3 Experimental set-up and procedure 22
2.3.1 Test receiver 23

2.3.2 Instrumentation 24
2.3.3 Experimental procedure 26
2.3.4 Measuring conduction losses 27
2.3.5 Calculating radiation losses 28
2.3.6 Uncertainty analysis 30
2.4 Results and discussion 32
2.4.1 Heat transfer 32
2.4.2 Temperature distribution 37
2.4.3 Comparison to literature 39

3 Receiver Prototype 43
3.1 Experimental set-up 43
3.1.1 Receiver 46
3.1.2 Particle feeding 47
3.1.3 Insulation 48
3.2 Instrumentation 49
3.2.1 Temperature measurement 49
3.2.2 Mass flow rate measurement 53
3.2.3 Input power measurement 55
3.2.4 Rotation rate measurement 55
3.3 Error analysis 56
3.3.1 Temperature uncertainty 57
3.3.2 Mass flow rate uncertainty 59
3.3.3 Uncertainty of the input power 60
3.3.4 Overall uncertainty 60

4 Numerical Receiver Model 63
4.1 Model simplifications 63
4.2 Governing equations 66
4.2.1 Conduction and convection 66
4.2.2 Radiation 67
4.3 Numerical method 68
4.3.1 Boundary conditions 68
4.3.2 Material properties 70

4.3.3 Finite element approximations 71
4.4 Discretization 73
4.4.1 Particle trajectory 73
4.4.2 Cavity 74
4.5 Incoming heat flux 78
4.6 Grid study and validation 79

5 Experiments **87**
5.1 Feasibility study 87
5.1.1 Dense particle film 89
5.1.2 Particle movement 92
5.1.3 Critical rotation speed and retention time . 94
5.1.4 Discussion 98
5.2 High flux tests 100
5.2.1 Receiver inclination 45° 100
5.2.2 Receiver inclination 90° 113
5.2.3 Discussion 117

6 Simulation **119**
6.1 Temperature profiles 119
6.2 Receiver efficiency 127
6.3 Sensitivity analysis 130
6.3.1 Material properties 131
6.3.2 Heat flux distribution 134
6.3.3 Conduction effects 137
6.3.4 Convection effects 142
6.4 Discussion 144

7 Conclusions **147**

References **153**

Appdx A **165**

Appdx B **169**

List of Figures **171**

List of Tables **177**

Publications **179**