

Contents

Vorwort des Herausgebers	iii
Vorwort des Autors	v
Contents	vii
Nomenclature	ix
1 Introduction	1
1.1 Background	1
1.2 Motivation	2
1.3 Objective & Structure	3
2 Principles	5
2.1 Thermodynamic Principles	5
2.1.1 State Quantities	5
2.1.2 Internal Energy, Enthalpy and Entropy	6
2.1.3 Thermal Transfer and Heat Flow	7
2.1.4 Efficiency	8
2.1.5 Thermodynamic Cycles	10
2.1.6 Clausius Rankine Cycle	10
2.2 State of the Art in Mobile Applications	14
2.2.1 Waste Heat Recovery Technologies	14
2.2.2 Limitations of the Real Clausius Rankine Cycle	16
2.2.3 Boundary Conditions	18
2.2.4 Utilization of Feedback Power	24
3 Test Setup	27
3.1 Test Bench	27
3.1.1 Engine	28
3.1.2 Waste Heat Recovery System	29
3.1.3 Measuring Devices	30
3.2 Control Systems	30
3.3 Simulation	33
4 Results for Steady-State Operation	35
4.1 Influence of System Operating Parameters	35
4.1.1 Working Fluid Mass Flow / Steam Quality	36
4.1.2 Low-Temperature Level	37
4.1.3 Low-Pressure Level	40
4.1.4 Conclusion	44
4.2 Influence of Additional Heat Sources	44
4.2.1 Partial Flow Recuperator	44

4.2.2	Preheater	47
4.2.3	Full Flow Recuperator	52
4.2.4	Turbocharger	55
4.2.5	Conclusion	58
4.3	Influence of Engine Operating Parameters	61
4.3.1	Coolant Temperature	61
4.3.2	Charge Air Temperature	63
4.3.3	Injection Pressure	65
4.3.4	Air-Fuel Equivalence Ratio	66
4.3.5	Injection timing	68
4.3.6	Wastegate Position	70
4.3.7	Ignition Timing	71
4.3.8	Conclusion	75
5	Results for Cold Start Operation	76
5.1	System Behavior during Cold Start	76
5.1.1	General Behavior	76
5.1.2	Influence of Start Temperature	79
5.1.3	Influence of Steam Quality	81
5.1.4	Influence of Low-Temperature Level	83
5.1.5	Influence of Low-Pressure	84
5.1.6	Influence of Power Feedback	86
5.1.7	Influence of Additional Heat Sources	87
5.1.8	Conclusion	91
5.2	Synergies in the use of Condenser Heat	91
5.2.1	Influence of Condenser Coolant Flow	92
5.2.2	Influence of Coolant Circuit Connection	94
5.2.3	Conclusion	98
6	Summary and Conclusion	99
6.1	Summary	99
6.2	Evaluation	101
A	Appendix	103
A.1	Working principle of a scroll expander	103
A.2	Depictions of relevant Thermodynamic Cycles	104
A.3	Schematic of a preheater supplied with engine coolant	104
A.4	Simulation Models	105
A.5	Influence of steam quality for different working fluids	106
A.6	Possible Coolant System Connections	107
A.7	Diesel Combustion	111
A.8	Measurement uncertainty	112
	Bibliography	121