KTH ROYAL INSTITUTE
OF TECHNOLOGY

WASTE HEAT RECOVERY IN INTERNAL COMBUSTION ENGINES

Sandhya Thantla

Supervisors: Prof. Anders C Erlandsson, Dr. Jens Fridh

07.09.2017, CCGEx – Research Day

CONTENTS

PROJECT GOAL

Design and develop a Rankine cycle (RC) system to recover unused potential heat from the Automotive ICEs with the most suitable expansion Machines

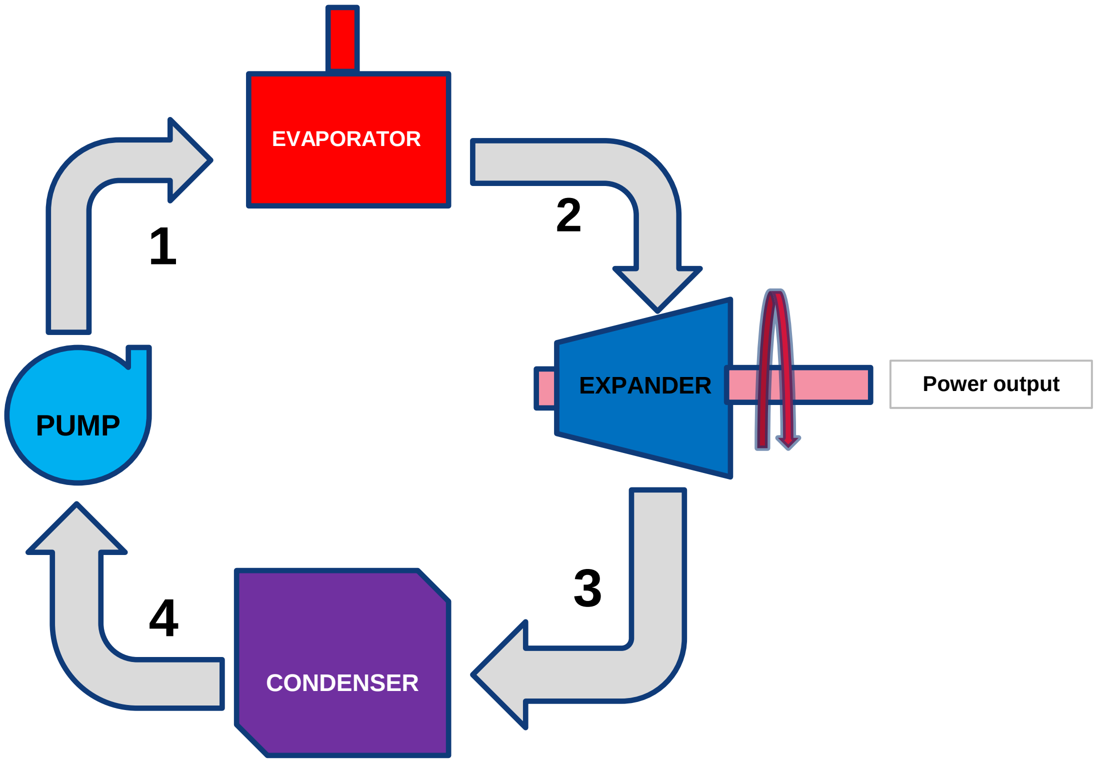
FOCUS

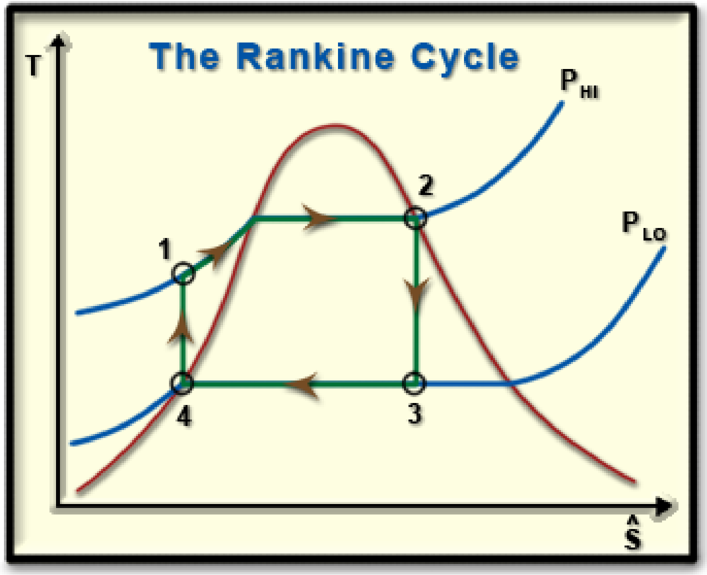
- Heavy duty diesel engine
- Medium and low temperature heat sources
- Expansion machines – modeling, design & development
- System integration

TODAY'S PRESENTATION

Sensitivity of the Power output towards some thermodynamic parameters

THE RANKINE CYCLE (RC) SYSTEM





Source: http://www.learnthermo.com

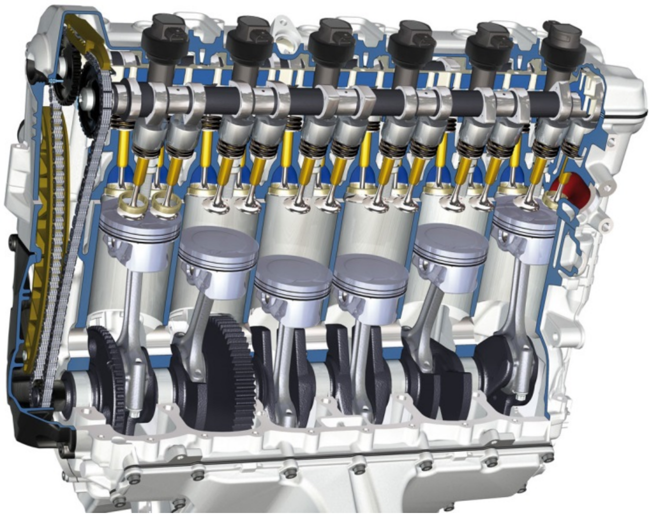
ENGINE'S ENERGY DISTRIBUTION

Scania DL6 EU5 12,7l Heavy duty diesel engine

1100 rpm, Full load

Fuel energy: 100%

Brake power: 44%



(Picture for representation only) Source: Microsoft Powerpoint

Friction & other losses: 1,42%

Coolant loss: 12%

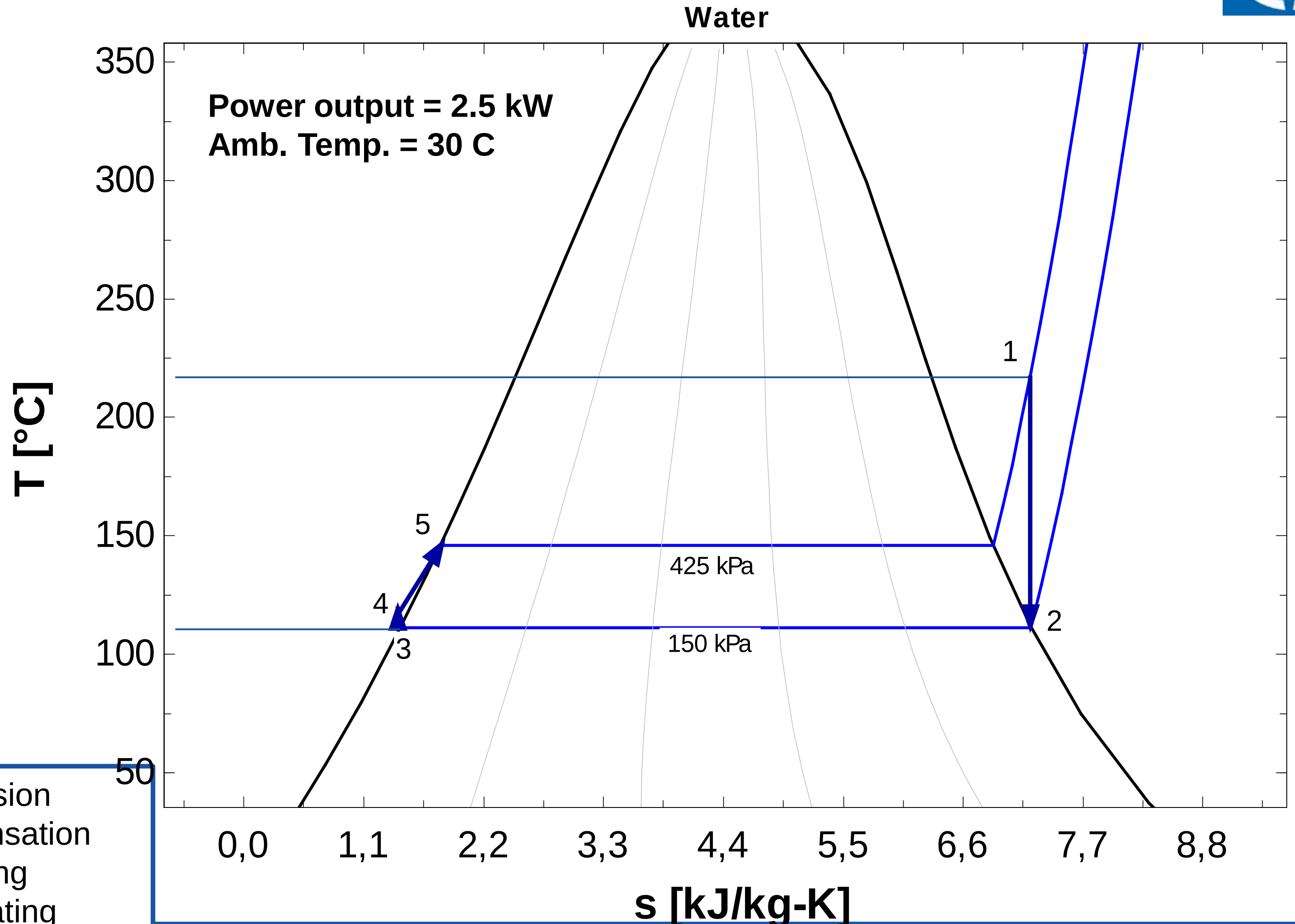
In-cylinder loss: 15%

Exhaust energy: 40%

THERMODYNAMIC PROPERTIES OF HEAT SOURCES

Heat Source	Speed	Load	Avg. T_in	Avg. T_out	Del_T	Avg. mass flow rate	Avg. Pressure	Cp,avg	Available heat
	RPM	%	C	C	C	g/s	bar	kJ/kg.K	kW
Exhaust	1100	35	330,53	30	301	144	1,02	1,091	47,21
EGR	1100	35	343	102	341	45	1,58	1,102	11,95
CAC	1100	35	76	25,57	50,42	139	1,57	1,007	7

PRELIMINARY RC OPERATING CONDITONS (EXHAUST)



1-2	Expansion
2-3	Condensation
3- 4	Pumping
4-5	Preheating
5-1	Vaporisation

PRELIMINARY RC OPERATING CONDITONS (EXHAUST)

PARAMETER	UNIT	VALUE
Q_absorbed	kW	46,18
Pressure ratio		2.8
Expander isentropic & mech. efficiency		0,8 (assumed)
Pump isentropic efficiency		0,8 (assumed)
Mass flow rate_ of_working fluid	g/s	18,99 (actual)
Expander inlet volume flow rate	m^3/h	35,85
Specific volume at turbine inlet	m^3/kg	0,52
Expansion ratio		2,2
Thermal efficiency of the cycle	%	5,39

PRELIMINARY SENSITIVITY ANALYSIS @ FIXED AVAILABLE HEAT (WATER)

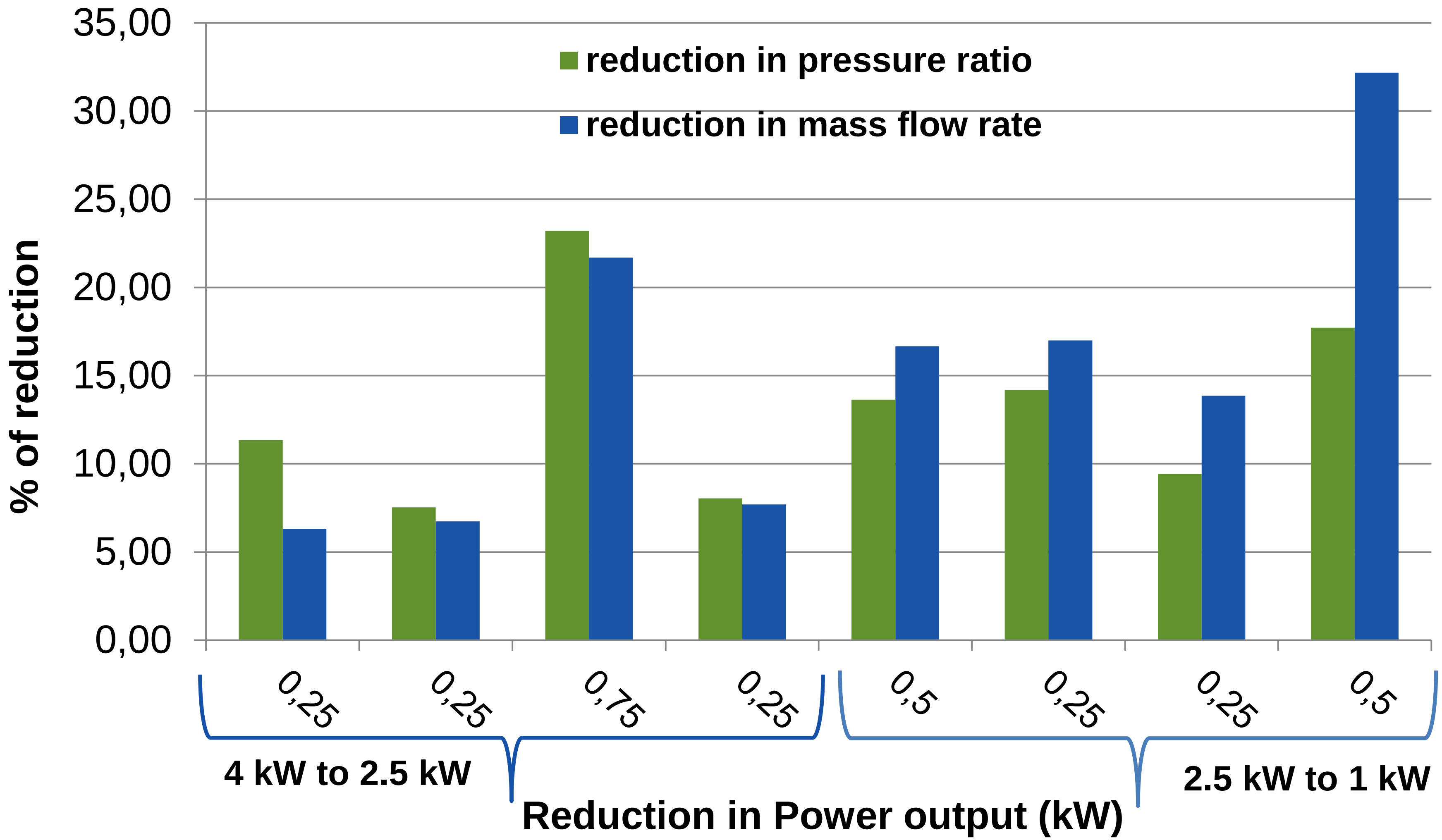
Mass flow rate (CONSTANT)	Pressure ratio (PR)	Reduction in PR	Enthalpy drop ↓	Reduction in enthalpy drop	Thermal efficiency ↓	Power output ↓
g/s	↓	%	kJ/kg	%	%	kW
19,5	4,94		329,34		8,13	4
19,5	4.38	11,34	300,35	8,80	7,5	3,75
19,5	4,05	7,53	281,35	14,57	7,08	3,5
19,5	3,7	8,64	260,49	20,91	6,6	3,25
19,5	3,11	15,95	220,96	32,91	5,69	2,75
19,5	2,86	8,04	202,77	38,43	5,26	2,5
19,5	2,47	13,64	170,99	48,08	4,49	2
19,5	2,12	14,17	139,83	57,54	3,71	1,75
19,5	1,92	9,43	120,23	63,49	3,22	1,5
19,5	1,58	17,71	81,9	75,13	2,22	1

PRELIMINARY SENSITIVITY ANALYSIS

@ FIXED AVAILABLE HEAT (WATER)

Mass flow rate m_wf ⬇	Reduction in m_wf	Pressure ratio (PR) (CONSTANT)	Enthalpy drop (CONSTANT)	Thermal efficiency (CONSTANT)	Heat absorbed, Q_in ⬇	Reduction in Q_in	Power output ⬇
g/s	%		kJ/kg	%	kW	%	kW
19		4,94	329,34	8,13	49,1		4
17,8	6,32	4,94	329,34	8,13	46	11,03	3,75
16,6	6,74	4,94	329,34	8,13	42,9	17,02	3,5
15,25	8,13	4,94	329,34	8,13	36,8	28,82	3,25
13	14,75	4,94	329,34	8,13	33,6	35,01	2,75
12	7,69	4,94	329,34	8,13	31	40,04	2,5
10	16,67	4,94	329,34	8,13	25,9	49,90	2
8,3	17	4,94	329,34	8,13	21,5	58,41	1,75
7,15	13,86	4,94	329,34	8,13	18,5	64,22	1,5
4,85	32,17	4,94	329,34	8,13	12,5	75,82	1

PARAMETRIC EFFECTS ON THE POWER OUTPUT



PARAMETER EFFECTS – SUMMARY

- Work outputs higher than 2 & 2,5 kW
  - *Mass flow rate & Enthalpy drop dominate (resp.)*
- Lower work outputs
  - *Pressure ratio dominates*

↑ High mass flow rate ↑ Higher heat input ↑ More heat recovery

At constant pressure ratio,

↑ High mass flow rate

↑ higher heat input

↑ higher work output

↔ same efficiency

CONCLUSION

- Parametric/Sensitivity analysis may help in the choice of expanders
- Drawbacks to be addressed in the sensitivity analysis e.g. pinch-point
- Detailed analysis of the parametric effects on ’*Expansion*’ required
- Comparison of performance of other fluids with water

Competence Center for Gas Exchange

CCGEx KTH VETENSKAP OCH KONST

”Charging for the future”

Energimyndigheten SCANIA VOLVO VOLVO BorgWarner

CCGEx at the Royal Institute of Technology (KTH) • www.ccgex.kth.se