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Experimental Investigation of a 1-kW ORC System

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Aim

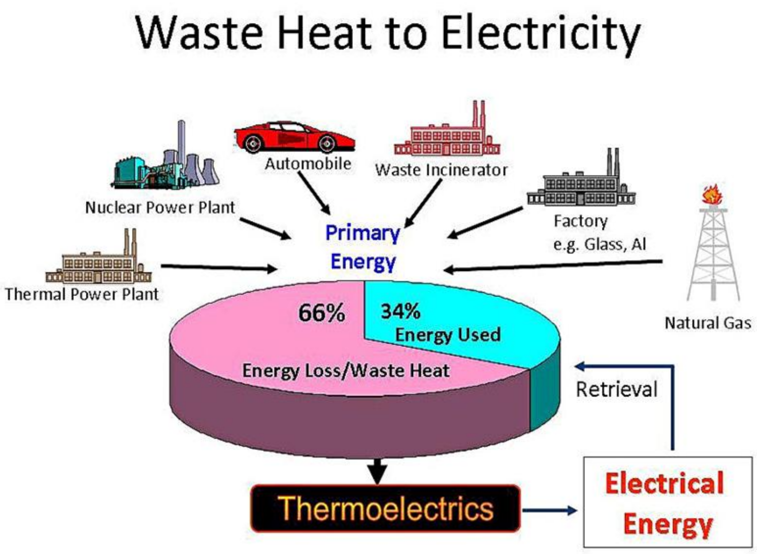
- To investigate the effects of changing external boundary conditions and operating conditions (evaporating temperature, pump speed and expander load) on
  - ORC thermal efficiency
  - Expander isentropic efficiency
- Complement modelling efforts by providing expander operation maps
- Model validation purposes

Outline

- Motivation
- The ORC set-up
- Experimental results
- Conclusions and discussions

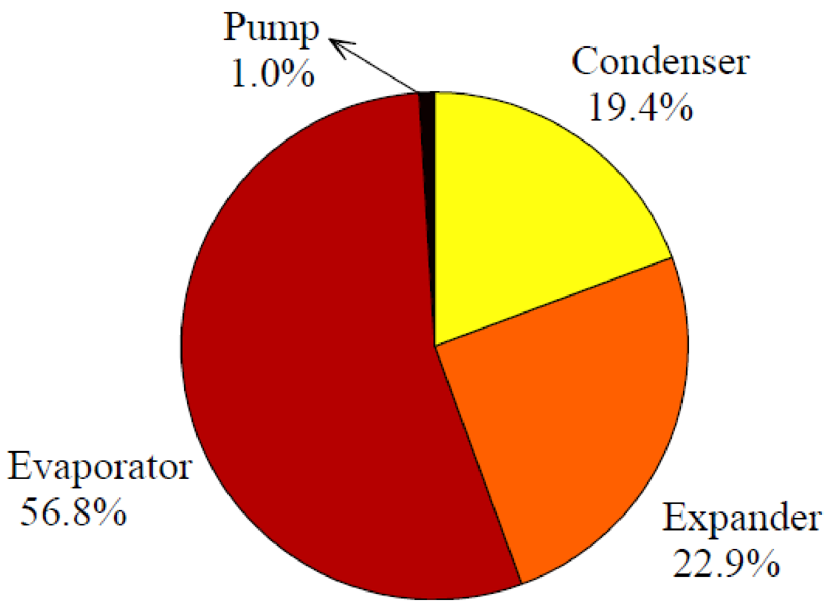
Motivation

- Low-grade heat to power
- Wide range of working fluids



More energy is available from waste heat than all renewable sources combined (US Department of Energy Annual Energy Survey, 2006)

Lost work in an ORC System



The expander accounts for the second highest exergy loss

Mago P.J., Srinivasan K.K., Chamra L.M., and Somayaji C., An examination of exergy destruction in organic Rankine cycles, International Journal of Energy Research, Vol. 32, 2008, 926-938

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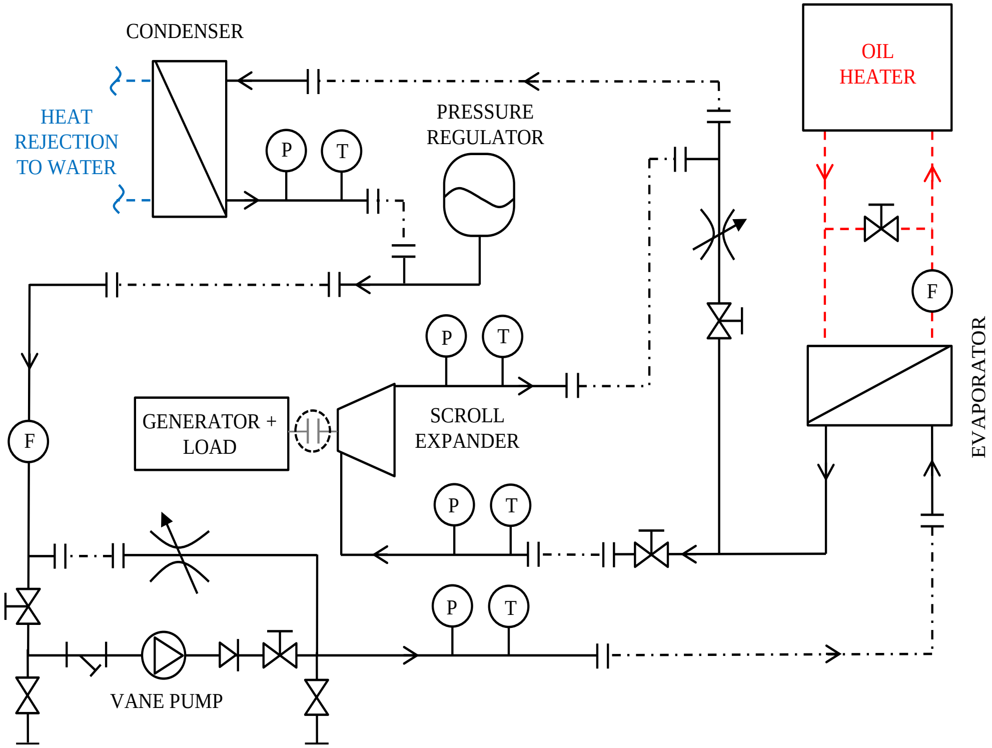
The ORC set-up

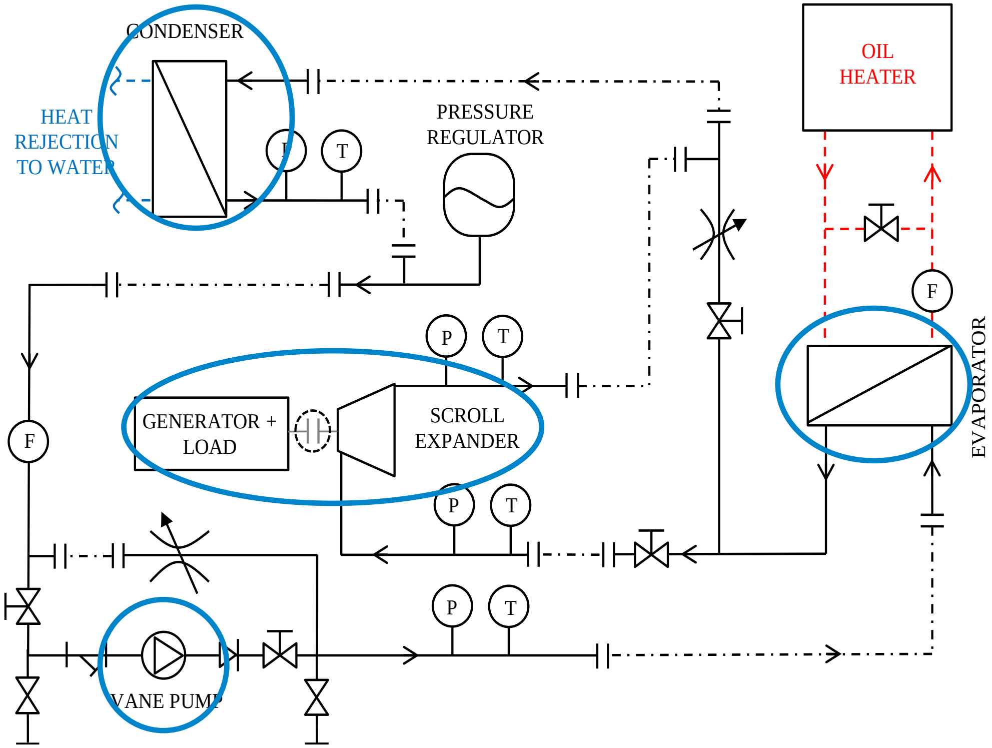
The ORC System



External Conditions

- 20 kWth oil thermal heater
- T_{hot} = 120 ^{0}C to 140 ^{0}C
- Flowrate 1.4 l/s
- Mains water, T_{cold} = 19 ^{0}C
- Maximum Carnot efficiency 29.3%

The ORC System



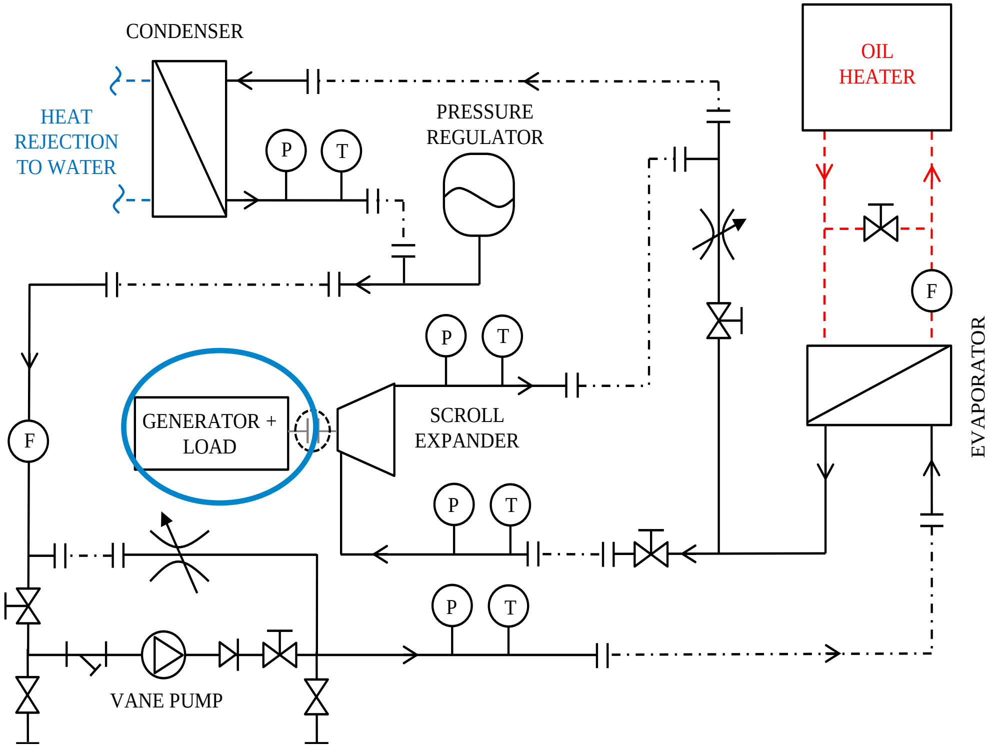
System parts

- Rotary-vane pump (1100 RPM – 3600 RPM)
- 1 kWel scroll expander with VR = 3.5
- AC generator (via magnetic coupling)

- Brazed-plate evaporator
- Brazed-plate condenser

- R245fa

The ORC System



External Load

- Full load – 4X 150 W heat dissipating resistors
- Partial load – 2X 75 W heat dissipating resistors

Measurement: T-type thermocouples (1 ^{0}C), analogue pressure transducers (0.25%), ultrasonic flow meter

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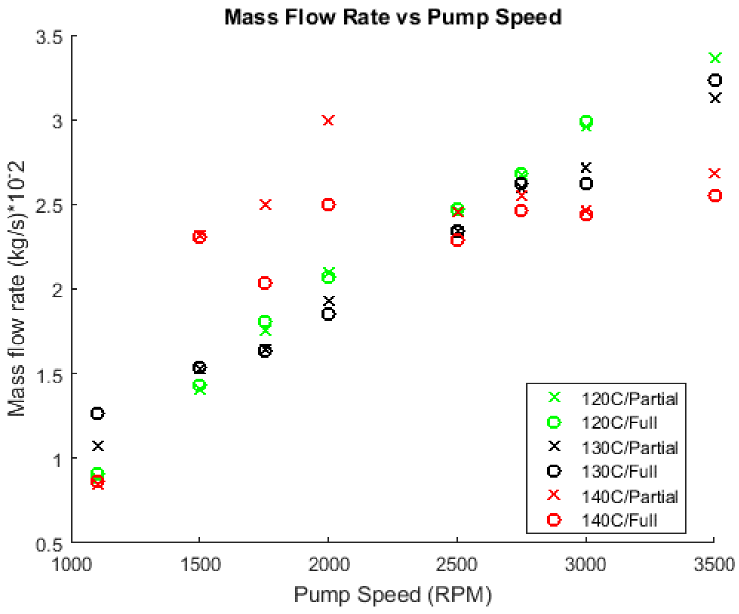
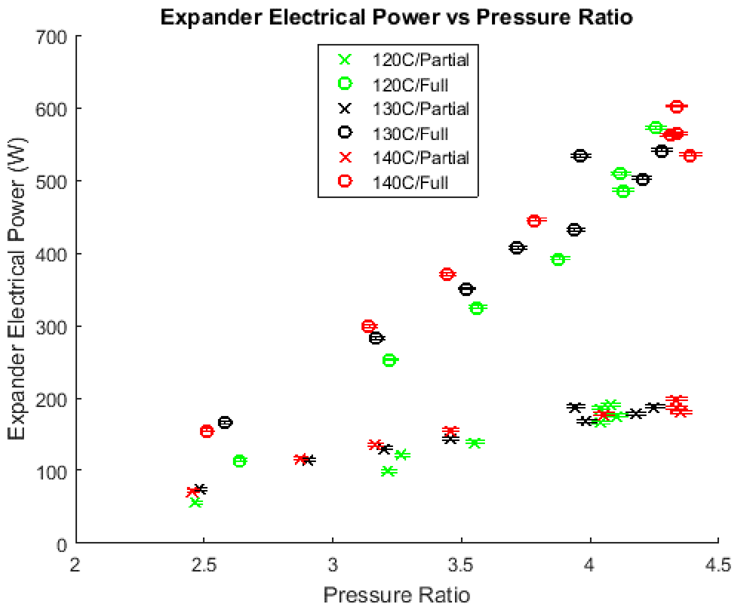
Experimental results

ORC test result – mass flow rate



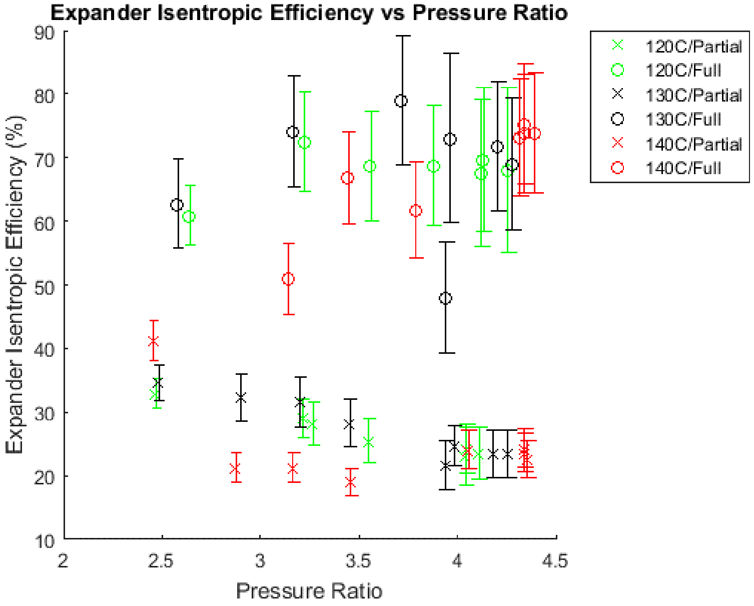
- Positive correlation between mass flow rate and pump speed

ORC test result – expander electrical power



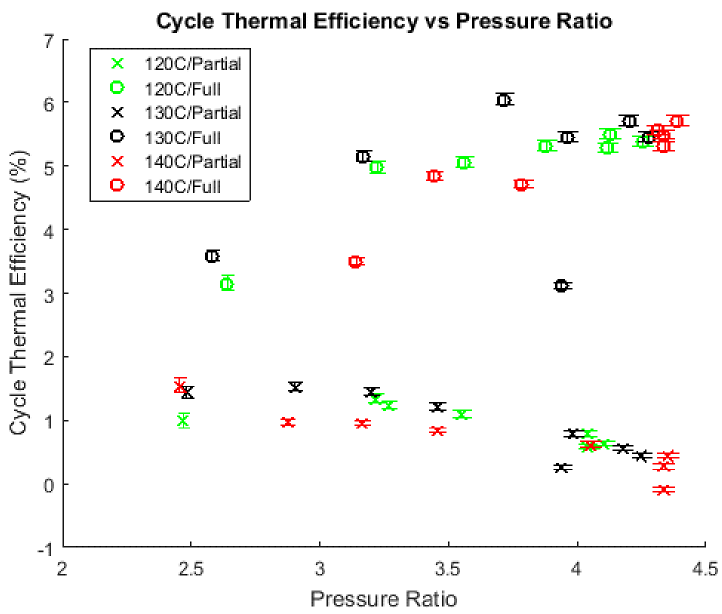
- Positive correlation between expander electrical power and pressure ratio
- The expander electrical power output quadrupled from partial load (150W) to full load (600 W)

ORC test result – expander isentropic efficiency



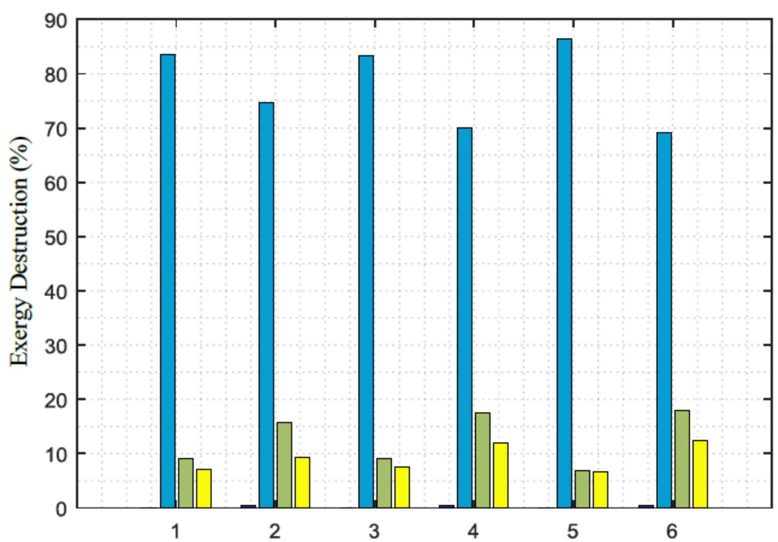
- Higher pressure ratios led to higher expander isentropic efficiencies reaching values up to ~80%.

ORC test result – cycle thermal efficiency

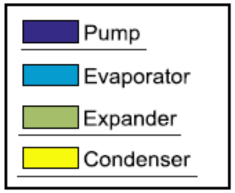


- Maximum ORC thermal efficiency by Carnot is: 29.3%
- T_{hot} = 140 ºC T_{cold} = 19 ºC
- Maximum efficiency realized ~6% at full load with intermediate heat source of 130 ºC

ORC test result – exergy analysis (partial expander load)



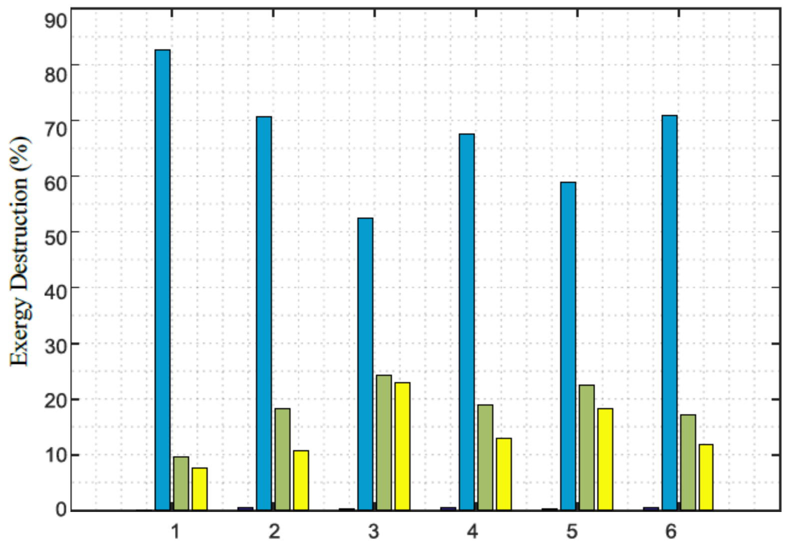
- Average expander exergy loss ~15% at partial load

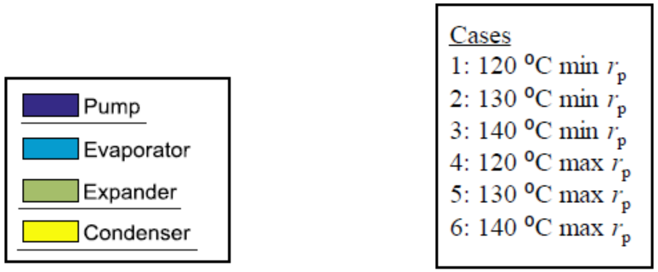


Cases
1: 120 ^{o}C min r_p
2: 130 ^{o}C min r_p
3: 140 ^{o}C min r_p
4: 120 ^{o}C max r_p
5: 130 ^{o}C max r_p
6: 140 ^{o}C max r_p

ORC test result – exergy analysis (full expander load)

- Average expander exergy loss ~20% at full load





Conclusions and outlook

- Performance characteristics of scroll expander can me mapped by changes in evaporating temperature, pump speed and expander load
- Over a range of heat-source temperatures (120 – 140 °C), higher pressure ratios led to higher expander outputs, with expander efficiencies reaching values up to ~80%.
- Overall ORC system thermal efficiencies of up to 6% were attained at an intermediate heat-source temperature (130 °C), pressure ratio (3.6) and at full generator load
- An exergy analysis showed that the expander accounted for the second largest exergy destruction after the evaporator
- Efficiency changes with reciprocating piston expanders

Acknowledgement

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Thank you for listening.

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