Experimental testing of a small-scale supercritical ORC at low-temperature and variable conditions

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Presentation Outline

- Concept and objectives
- Description of the installed ORC engine
- Test results at subcritical operation
- Test results at supercritical operation
- Conclusions

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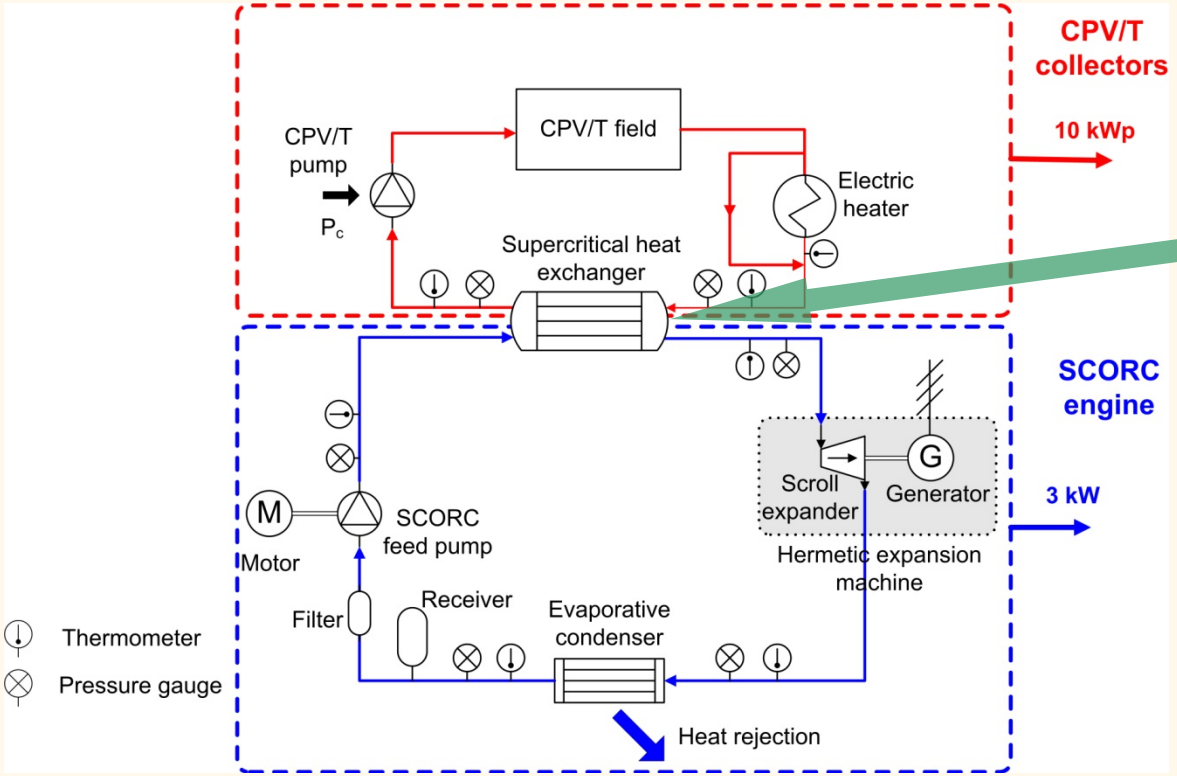
Concept and objectives

Research project FP7-SME: CPV/Rankine (duration: 2013-2014), www.cpvrankine.aua.gr



CPV/T field (100 m², 10 kWp, 41 kWth)

Supercritical heat exchanger (41 kW_{th})

Supercritical ORC engine (~3 kW)

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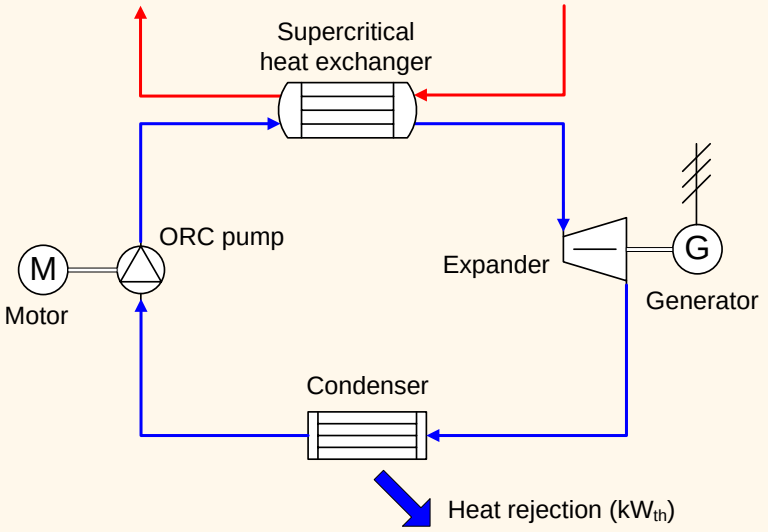
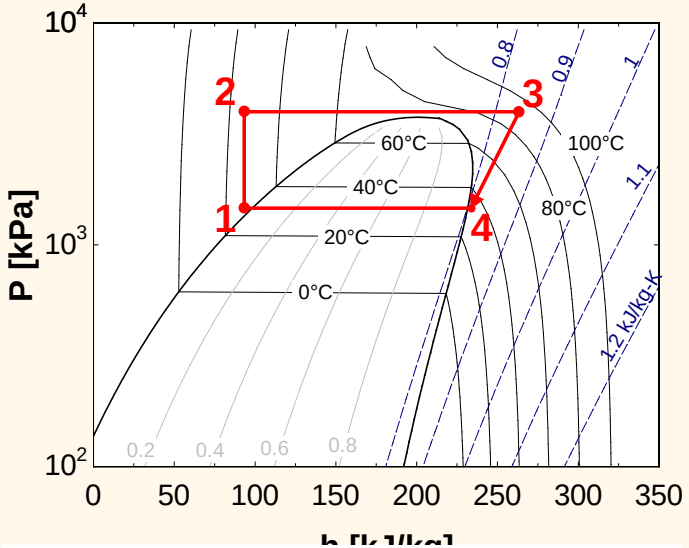
Description of the installed ORC engine

ORC engine – design (single-stage)

- Selection of appropriate organic fluid: R-404a.
- Heat input: 41 kW_{th} with max. pressure almost 40 bar (~1.04 P/P_{cr}).
- Thermal efficiency at design conditions: 6.8% with net power production 2.9 kW.
- Condensation temperature ~30 ^{o}C and pressure ~15 bar, depending on the condenser operation.
- The pump and expander are equipped with frequency inverters for controlling their rotational speeds.
- Maximum temperature ~85 ^{o}C with a 10 K pinch-point temperature difference (at the outlet side).
- Further details about the HEX are provided by UGent.





Description of the installed ORC engine

- The scroll expander is a hermetic scroll compressor in reverse operation, manufactured by Copeland (ZP series: ZP137KCE-TFD with swept volume 127.15 cm^3/rev), suitable for high-pressure A/C applications (usually with R-410a).
- Max. isentropic efficiency at compressor mode is 75.2% at pressure ratio ~2.8.
- A new casing was installed and some internal parts have been re-designed for higher performance (e.g. the inlet volume before the fluid enters the steady scroll).



Hermetic scroll compressor (Copeland: ZP137-KCE-TFD)



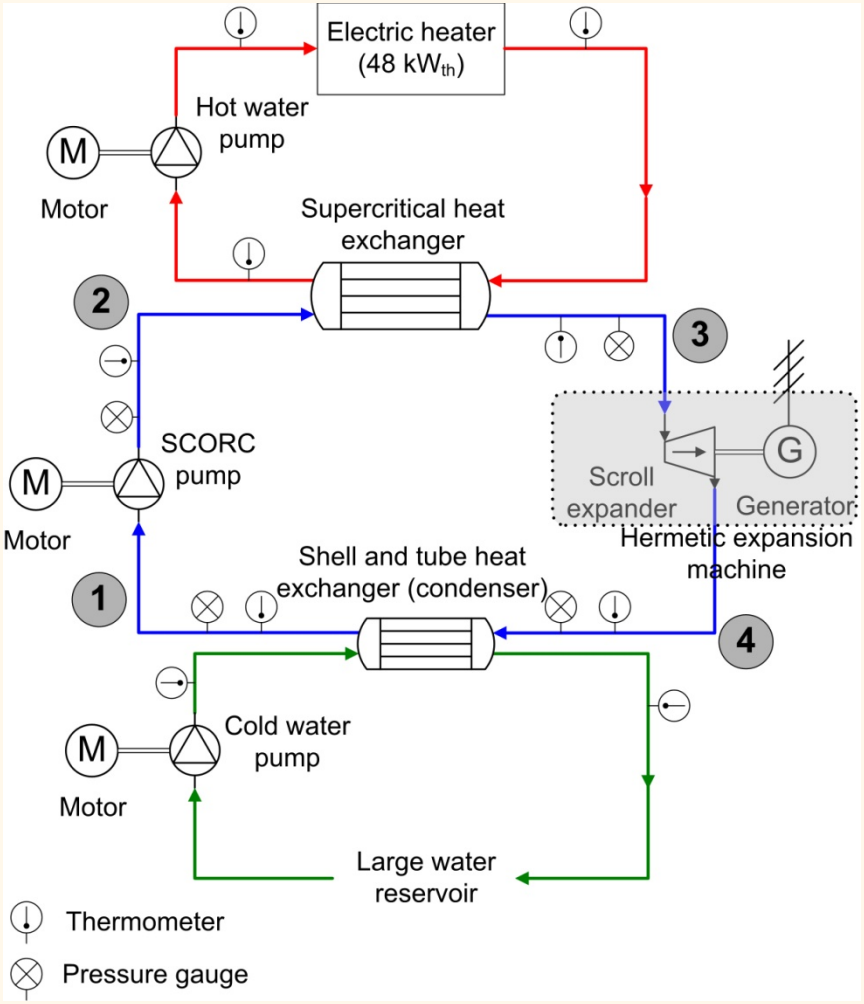

Description of the installed ORC engine

Top: Hermetic scroll expander and side view of ORC

Right: ORC engine

Description of the installed ORC engine

- ORC engine installed in the laboratory.
- Heat input from a controllable electric heater (10-48 kW_{th}).
- HTF temperature adjusted to the desired set point (65-100 ^{o}C).
- HTF pump at constant speed (2900 rpm - 50 Hz). ORC pump and expander speed can be controlled (10-50 Hz).
- Pump: diaphragm pump (20 l/min) by Wanner/Hydra Cell (G-10), with an inlet pressure limit of 17 bar.
- Condenser: shell and tube HEX using cold water (~15 ^{o}C) from a 320 m^3 reservoir.



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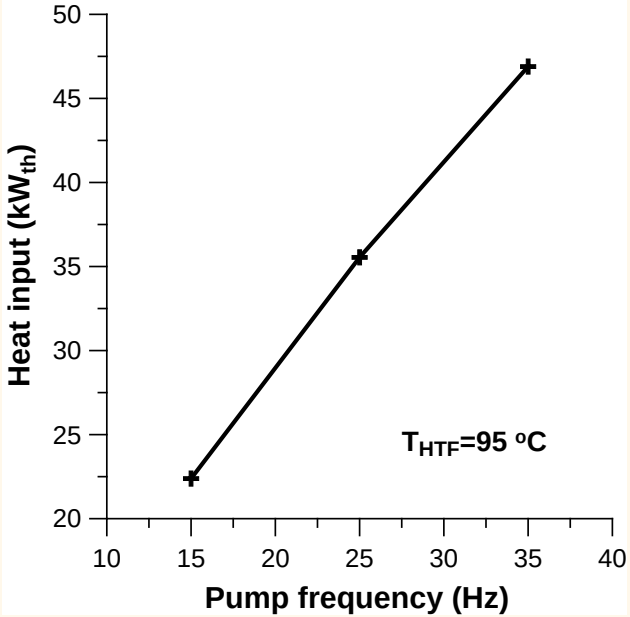
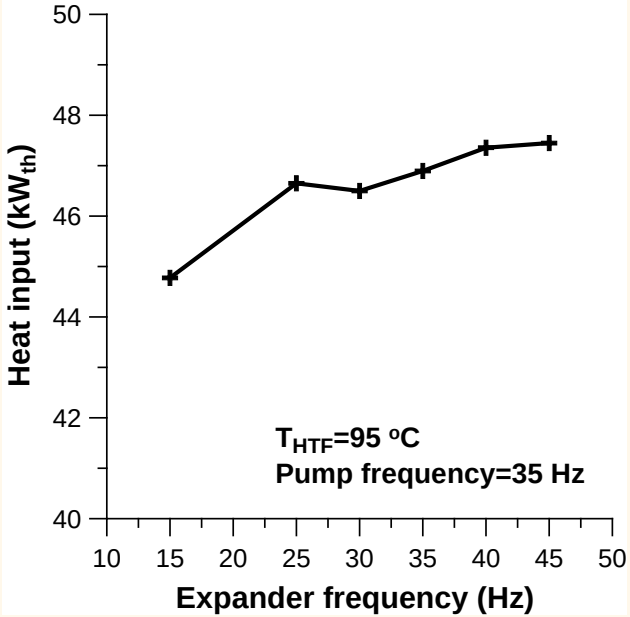
Test results at subcritical operation

All test results presented concern a HTF temperature of 95 °C.

Main parameters varied during operation:

- Pump speed (-> heat input)
- Expander speed (-> max. pressure and pressure ratio)



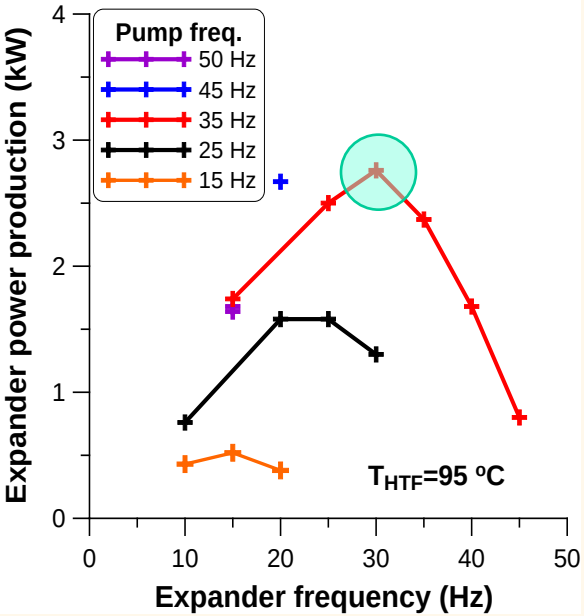


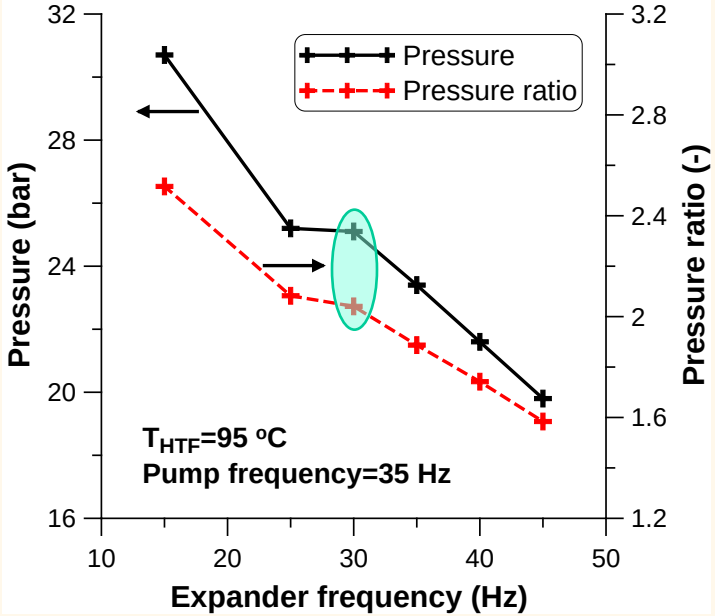
Effect of pump and expander speeds on heat input

Test results at subcritical operation

Scroll expander operation and performance

- Max. expander power: 3 kW for moderate speeds (pump: 35 Hz, expander: 30 Hz)
- Max. power production is observed for pressure ratio of 2 with max. pressure ~24 bar (almost constant condenser pressure of 12 bar)





Effect of expander speed on power, pressure and pressure ratio

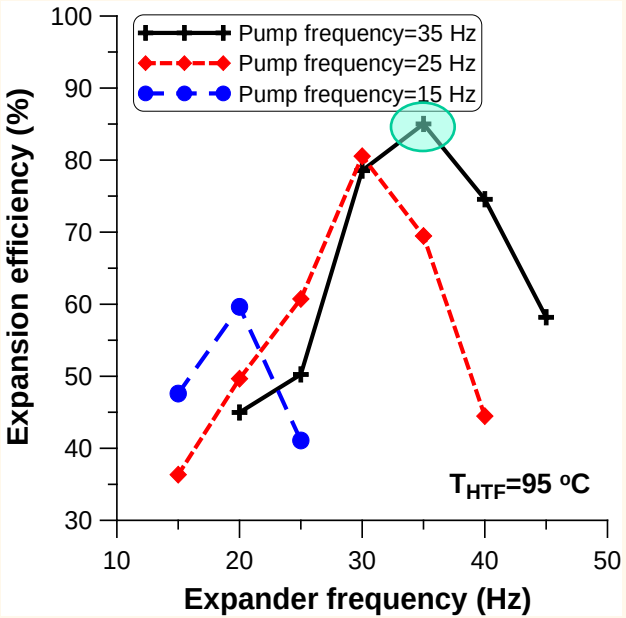
Test results at subcritical operation

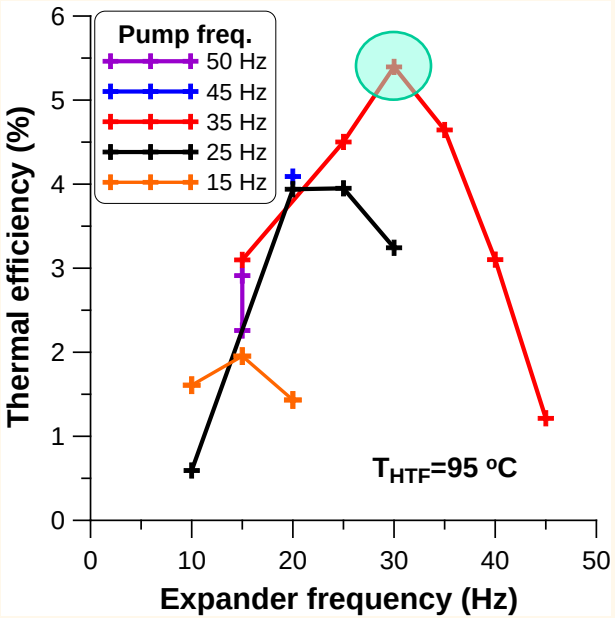
ORC engine performance

- Max. expansion efficiency: 85% for moderate speeds (pump: 35 Hz, expander: 35 Hz)
- Max. thermal efficiency: 5.5%, observed for the conditions with max. expansion efficiency

$$\eta_{exp} = \frac{\text{Electricity production}\,(kW_e)}{\dot{m}(h_{in} - h_{out,is})}$$

$$\eta_{th} = \frac{\text{Electricity production}\,(kW_e)}{\text{Heat input}\,(kW_{th})}$$





Effect of expander speed on efficiency of expander and thermal efficiency

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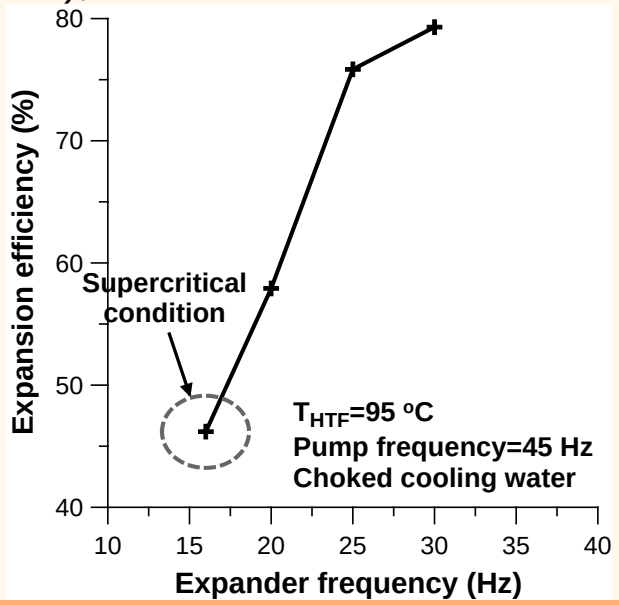
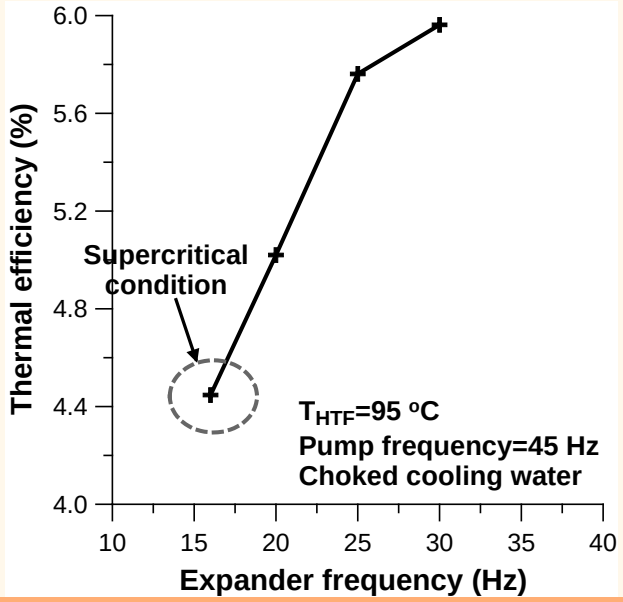
Test results at supercritical operation

For reaching supercritical operation, the flow rate of the cooling water was decreased, increasing the low pressure to around 16-17 bar.

- Pressure ratio: around 2.3 at such conditions
- Expansion efficiency at supercritical conditions: 45% (for expander frequency of 16 Hz), resulting to low thermal efficiency (4.4%)
- For higher expander speeds, the expansion efficiency increases up to ~80% (subcritical operation), as well as the thermal efficiency





Effect of expander speed on expansion efficiency and thermal efficiency (choked cooling water)

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Main conclusions from the laboratory tests

- The small-scale ORC engine operates without any problem and produces power with good performance at subcritical conditions (max. thermal efficiency almost 6%).
- The modified scroll expander shows high performance and much higher than any other expander tests of the AUA research group. Max. expansion efficiency: 85% for a single operating condition, while values around 70% were common for a large range of operation.
- Stable supercritical operation could be reached for choked cooling water only (increase of condenser pressure/temperature).
- At such conditions, operation at low expander speed resulted to high pressure with expansion efficiency ~45% and thermal efficiency of 4.4% (lower than subcritical operation).
- For continuous operation at supercritical conditions, the size of the expander (its swept volume) should be reduced, increasing its speed as well closer to 50 Hz, leading to higher pressure operation at high expansion speeds with increased electric efficiency of the generator.

Main conclusions from the laboratory tests

- By extrapolating the results so far and using a smaller expander, the expansion efficiency could reach values around 70% at supercritical operation, ending up to a thermal efficiency around 7% (higher than subcritical operation).
- Such value is higher than any value recorded at subcritical operation during the tests, which is just an indication that supercritical operation can have a good potential at such low-temperature applications, even at small-scale.

Next steps

- The ORC engine has been installed at the field and connected with the CPV/T collectors.
- First test results have been achieved, showing that such concept is feasible and leads to a total higher production.
- More tests are planned in the future.




Thank you for your attention

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