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Experimental investigation of a transcritical Organic Rankine Cycle with scroll expander for low temperature waste heat recovery

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PRESENTATION OUTLINE

- Context & objectives
- Experimental setup
- Components performances
- ORC performances
- Conclusion

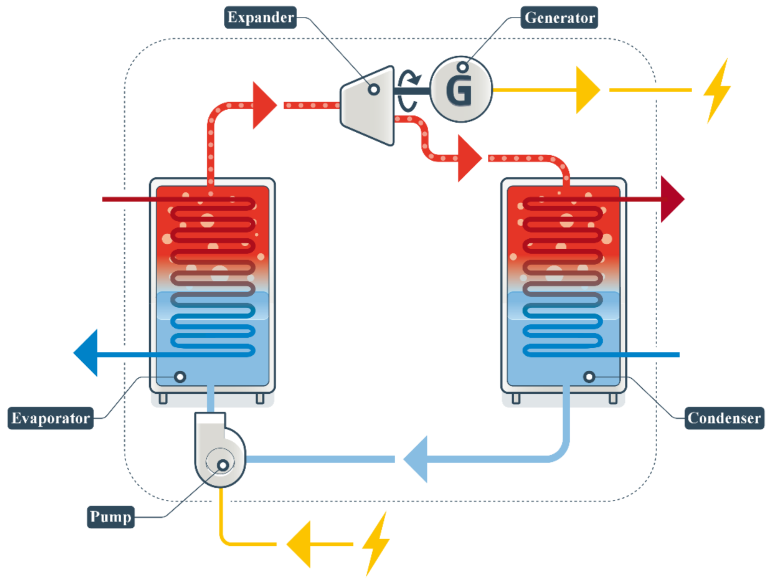
Transcritical Organic Rankine Cycle:

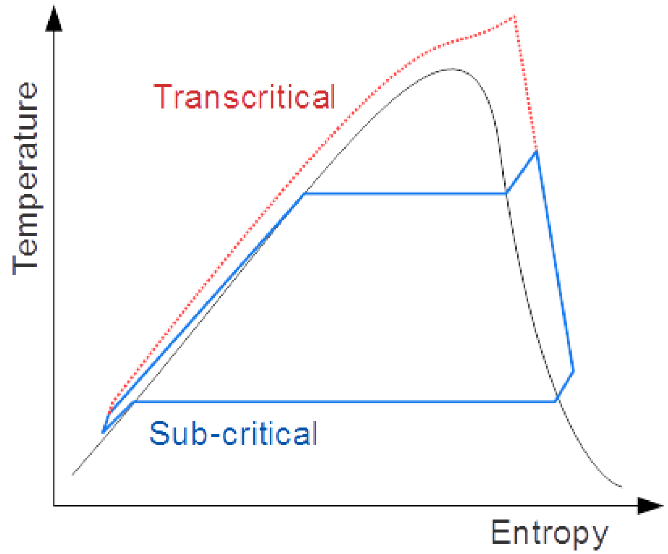
+ Higher energetic & exergetic efficiency

+ Approach of the triangular cycle

- High operating pressure

- Higher back work ratio





Transcritical Organic Rankine Cycle for small scale heat recovery applications :

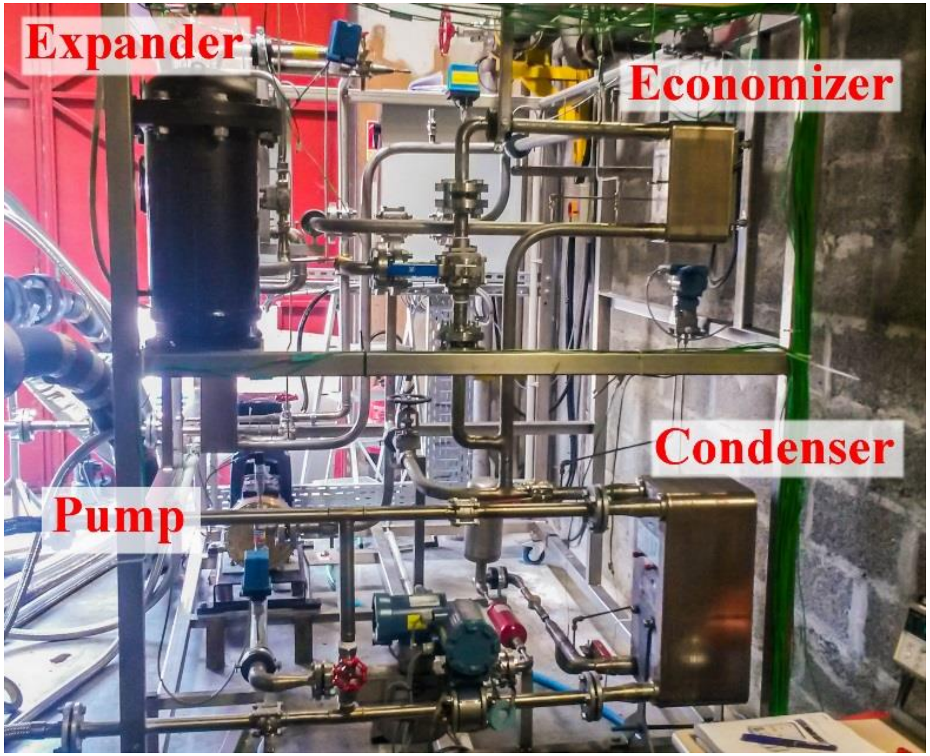
- Feasibility ?
- Real performances ?

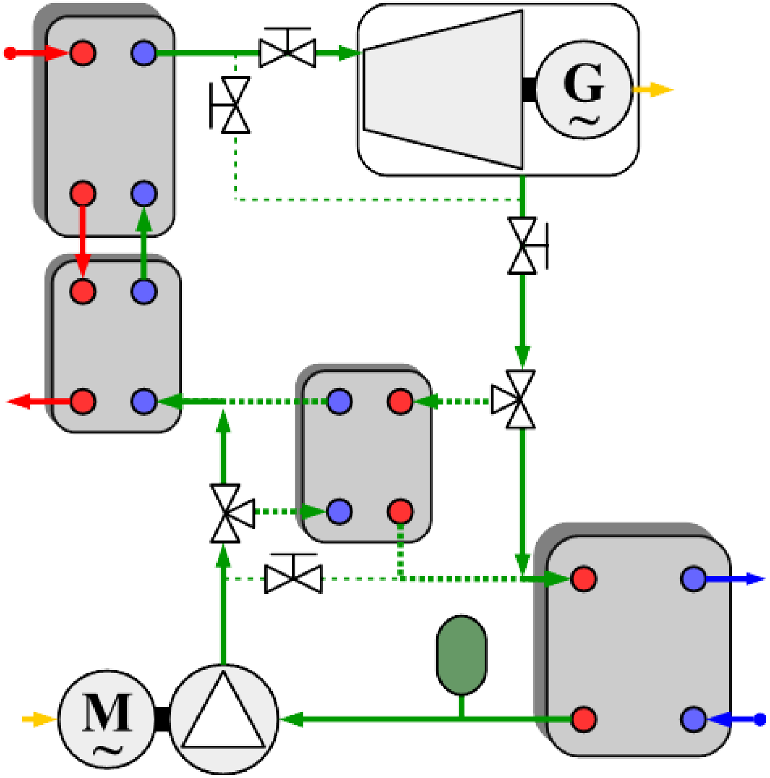
Transcritical ORC prototype

10 kWe scroll expander

250 kWth at 150°C pressurized water heat source

R-134a working fluid (*crit. pt. 40,6 bar / 101°C*)

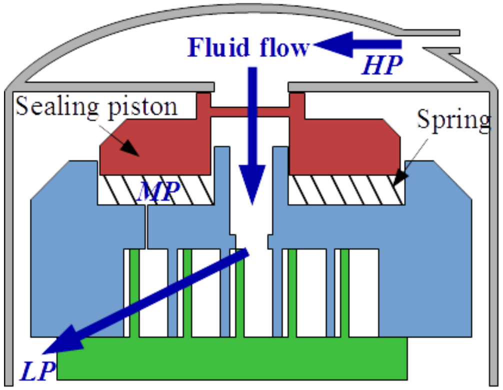


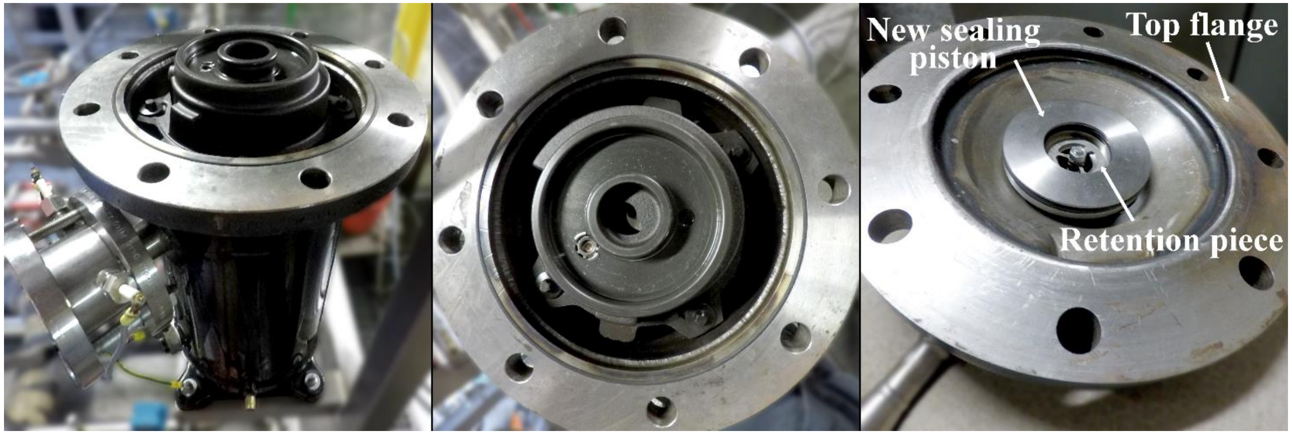


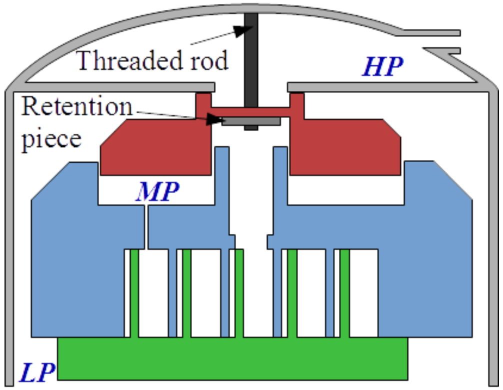
EXPERIMENTAL SETUP

Modified scroll expander:

- Copeland-Emerson® modified compressor (*BVR ~ 3*)
- 1st modifications: casing cutting, non-return valve removal, piston spring addition
- Spring removal, floating seal fixed to top flange
- Hermetic electric connectors failure & replacement
- Sealing piston replacement

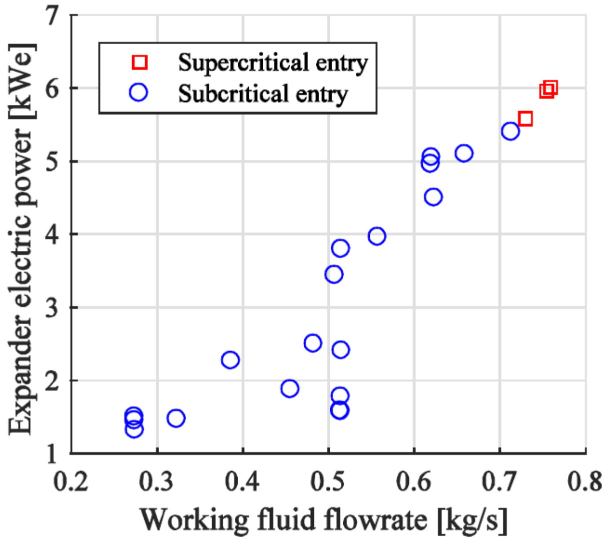


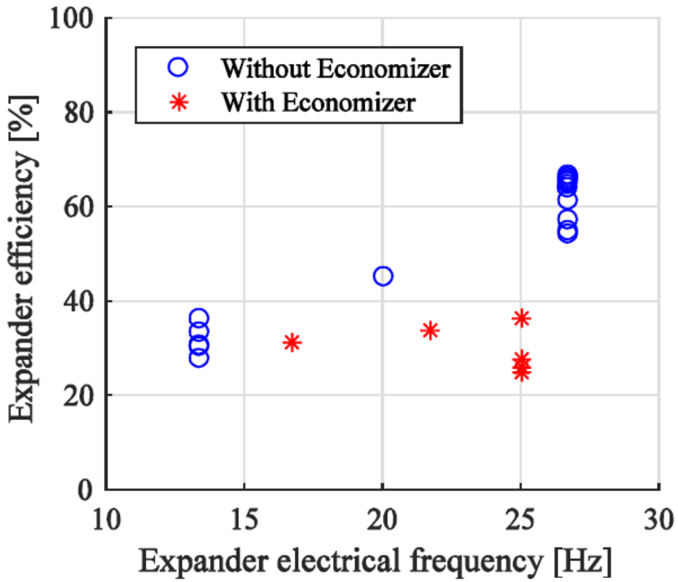


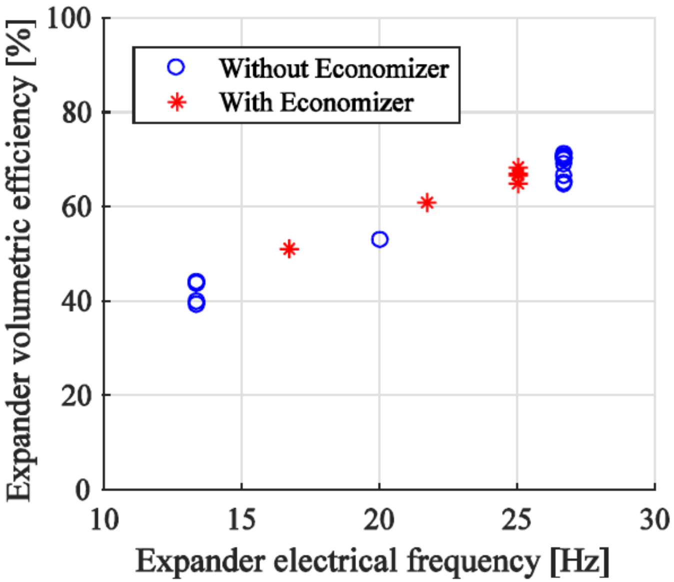


Expander performances:

- Up to 6 kWe, with a 66,5 % efficiency, in supercritical conditions
- Efficiency decline mainly due to leakage at low speed
- Efficiency decline with economizer due to low P_{ratio}
- Potential for higher efficiency at nominal conditions

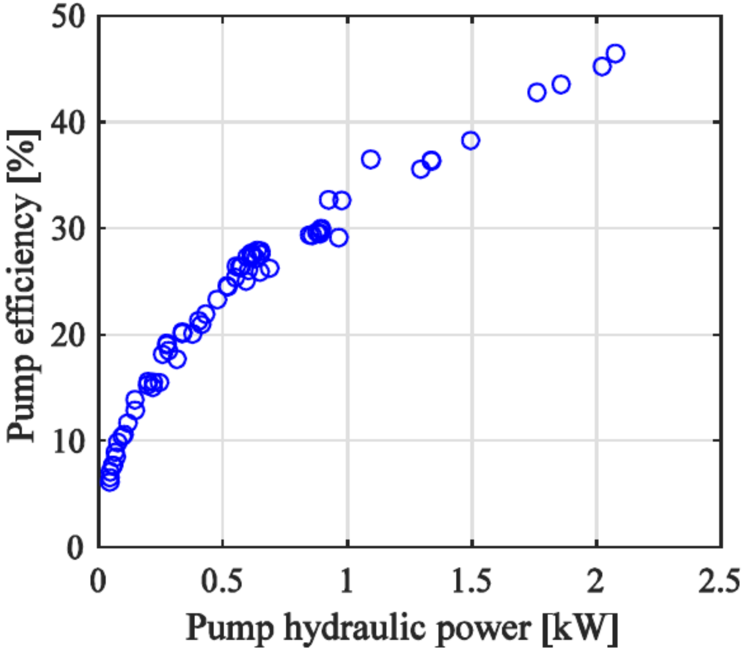


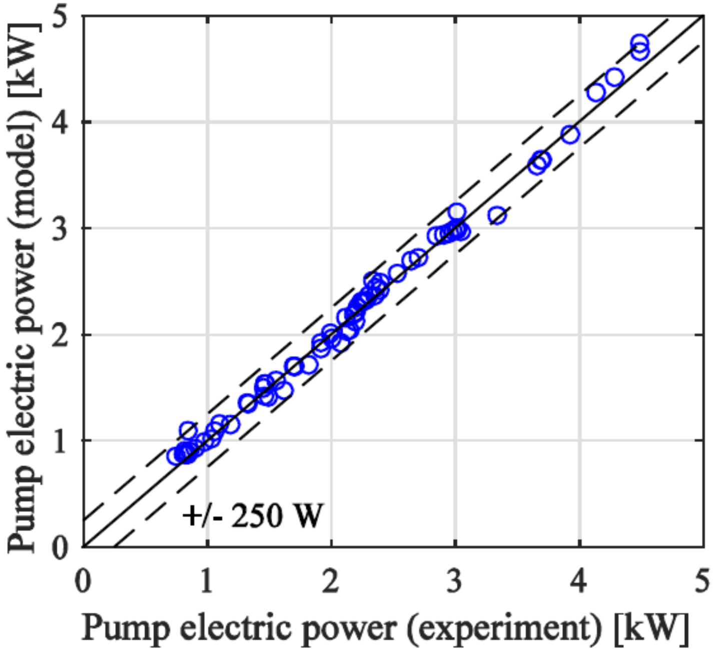




Pump performances:

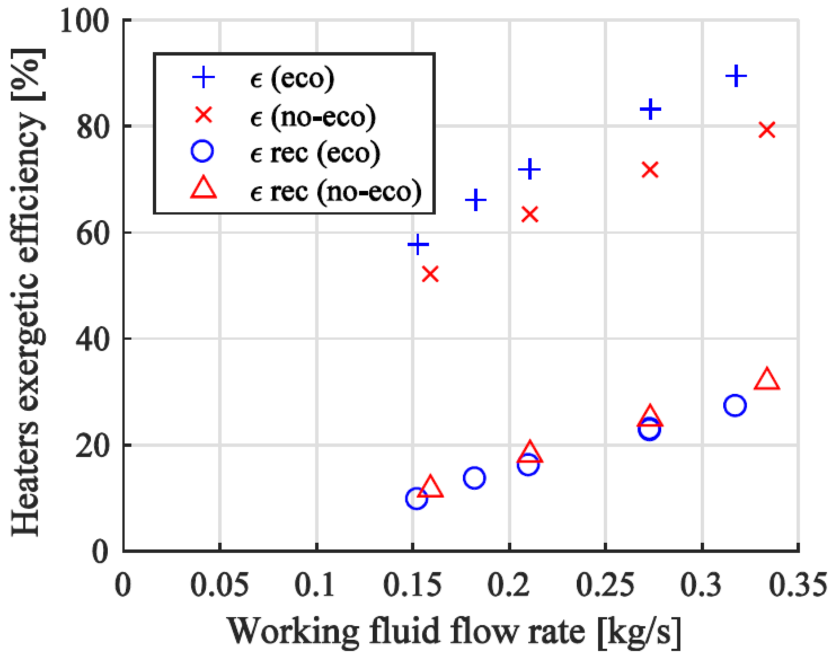
- Maximum efficiency of 46,3 %
- Reciprocating pump semi-empirical model fitting & validation
- Pump mechanical efficiency of 70 %, according to manufacturer efficiency
- Motor and speed drive efficiency of 66 %.





Heat exchangers performances:

- Pinches of 10 K at the design flow rate
- Evaporator: global heat transfer +50 % in supercritical state vs liquid state
- Economizer: improves exergetic efficiency of the evaporator for closed sources applications (solar/biomass), but not for open sources (heat recovery)



Evaporator exergetic efficiency: Closed source

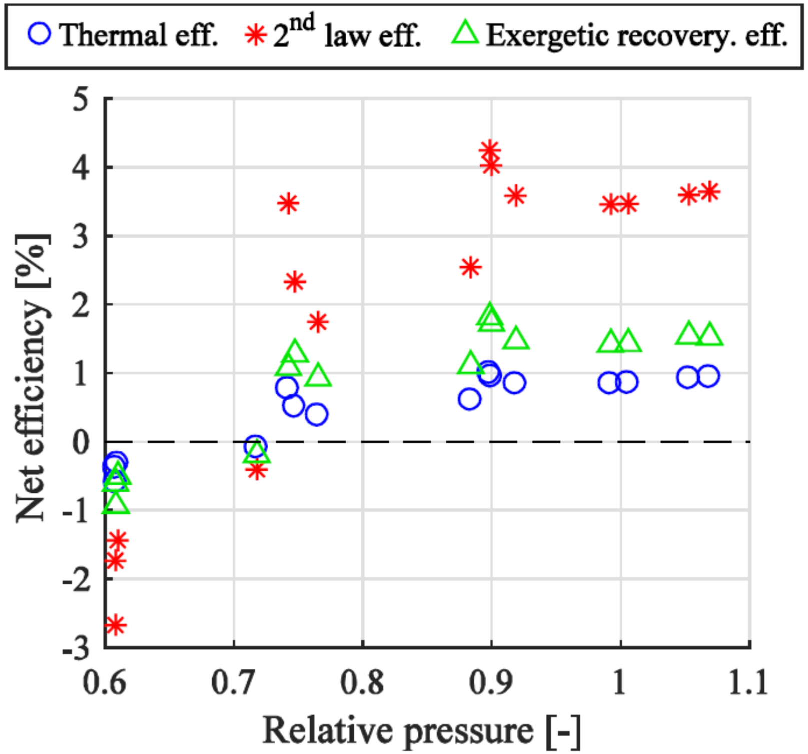
$$\varepsilon_{evap} = \frac{m_{working\ fluid} \cdot (e_{out,wf} - e_{in,wf})}{m_{hot\ fluid} \cdot (e_{in,hf} - e_{out,hf})}$$

Evaporator exergetic efficiency : Open source

$$\varepsilon_{ev,recovery} = \frac{m_{wf} \cdot (e_{out,wf} - e_{in,wf})}{m_{hf} \cdot (e_{in,hf} - e\{T_0; P_{out}\}_{hf})}$$

Performance criteria:

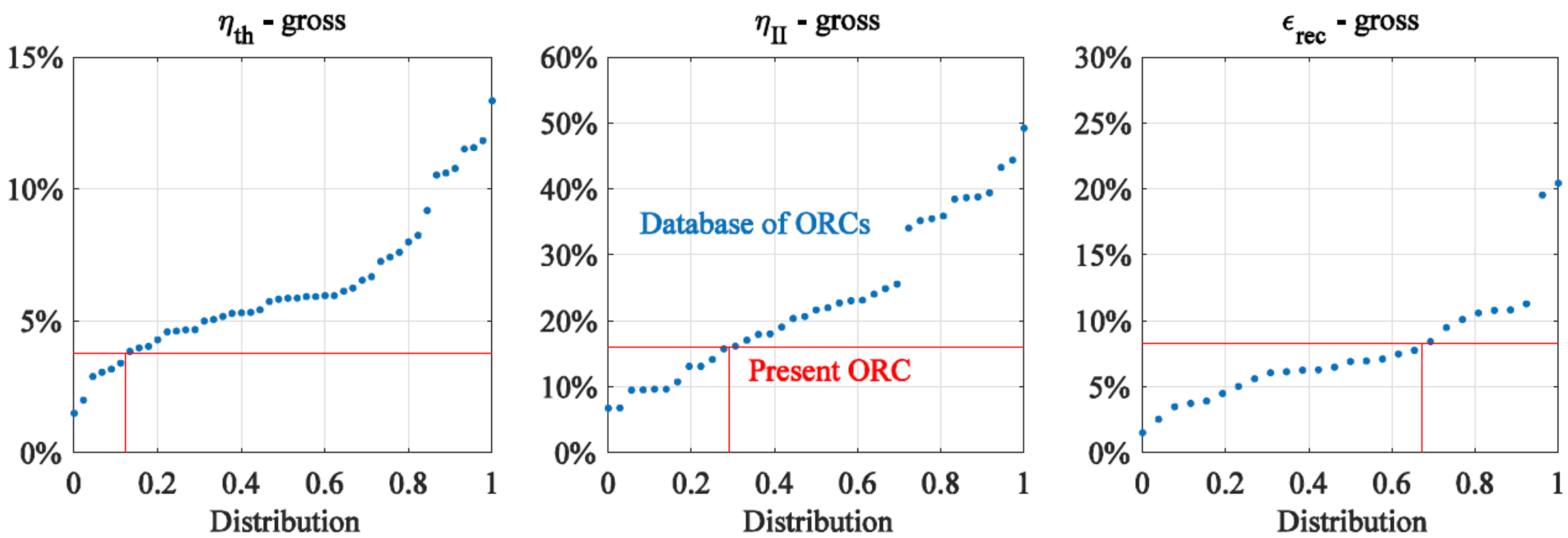
- Thermal efficiency : $$\eta_{th} = \frac{W_{ORC}}{m_{hf} \cdot (h_{in,hf} - h_{out,hf})}$$
- Second law efficiency : $$\eta_{II} = \frac{\eta_{th}}{\eta_{Carnot}} = \frac{W_{ORC}}{m_{hf} \cdot (h_{in,hf} - h_{out,hf})} \cdot \frac{T_{in,hf}}{T_{in,hf} - T_{in,cf}}$$
- Exergetic recovery efficiency : $$\varepsilon_{rec} = \frac{W_{ORC}}{m_{hf} \cdot (e_{in,hf} - e(T_0; P_{out})_{hf})}$$



- ORC efficiency increase with evaporating pressure
- Maximum net thermal efficiency of only 1.0 %
- Large Back Work Ratio (minimum of 74 %)

Comparison with same scale ORC prototypes:

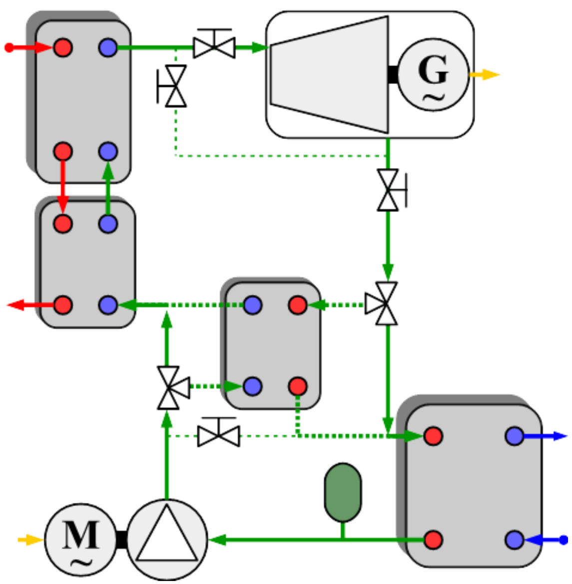
Comparison of the ORC gross efficiencies with other 1-10 kWe ORC units*

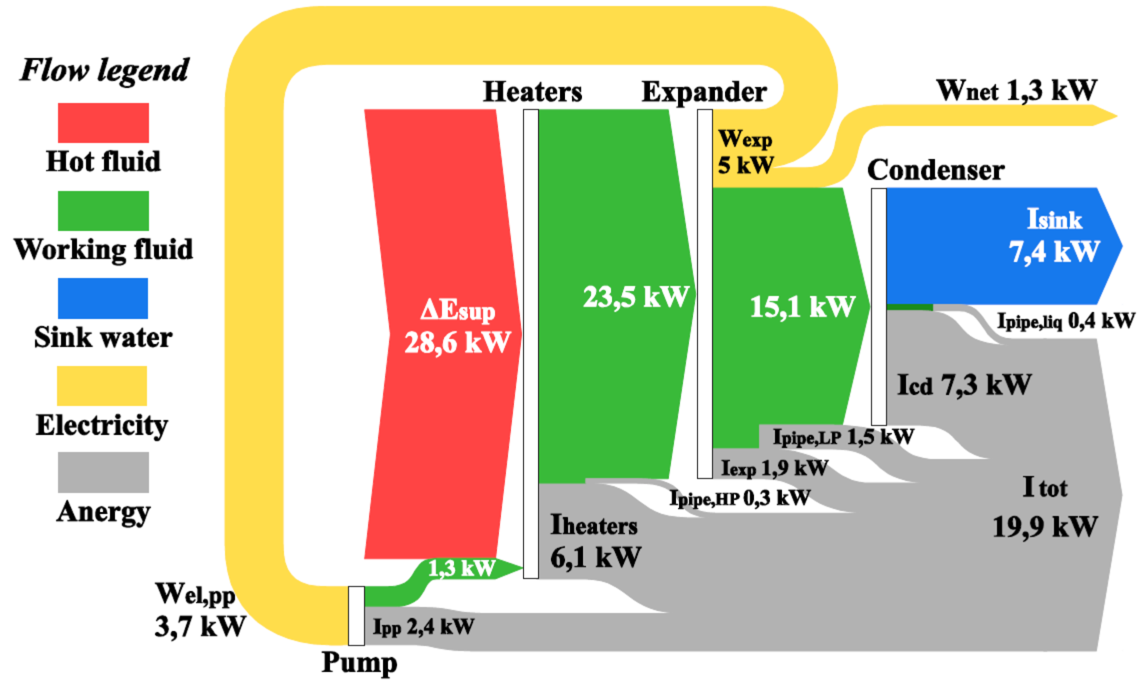


- Low performances for power production from closed sources (see η_{II})
- Greater performances for heat recovery applications (see ε_{rec})
- Part load operation: potential for improvement

* Landelle & Tauveron, *Experimental ORC database v2016.12* – Zenodo.org

ORC exergetic analysis: Losses and potential improvements identification





- High exergy destruction at condenser : reduce condensing pressure
- Pipe losses : improve path and diameter to decrease pressure losses
- High level of auto-consumption by the pump : direct pump driving

* Landelle & Tauveron, *Experimental ORC database v2016.12* – Zenodo.org

CONCLUSION

- Production up to 6 kWe under transcritical conditions
- Scroll expander efficiency up to 66.5 % while running at part load
- Mechanical resistance of modified scroll compressor should be evaluated
- Pump efficiency has a major impact on the transcritical ORC efficiency
- Control of condensing pressure could substantially increase ORC performances

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THANKS FOR YOUR ATTENTION !

ANY QUESTION ?