# Waste heat recovery of combustion engines using ORC: potential and testing

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# Content

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- Waste heat recovery in general
- Operational principle of WHR ORC
- Operational experiences on micro ORC test setup at LUT

# Waste heat

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- A large portion of the fuel power is lost in a form of heat in engine systems.
- The lost heat could be utilized by using heat recovery.
- Waste heat can be utilized as heat power or part of the waste heat can be converted to electricity.
- The use of WHR increases the power output and efficiency of the system, and reduces emissions.

# Waste heat recovery technologies



- Different technologies are available or under intensive development for converting heat to electricity:
  - Steam turbine cycles (large-scale combined cycles)
  - Organic Rankine Cycles
  - Thermoelectric generators, Stirling engines, Kalina cycle, closed Brayton cycles, supercritical CO2 cycles…

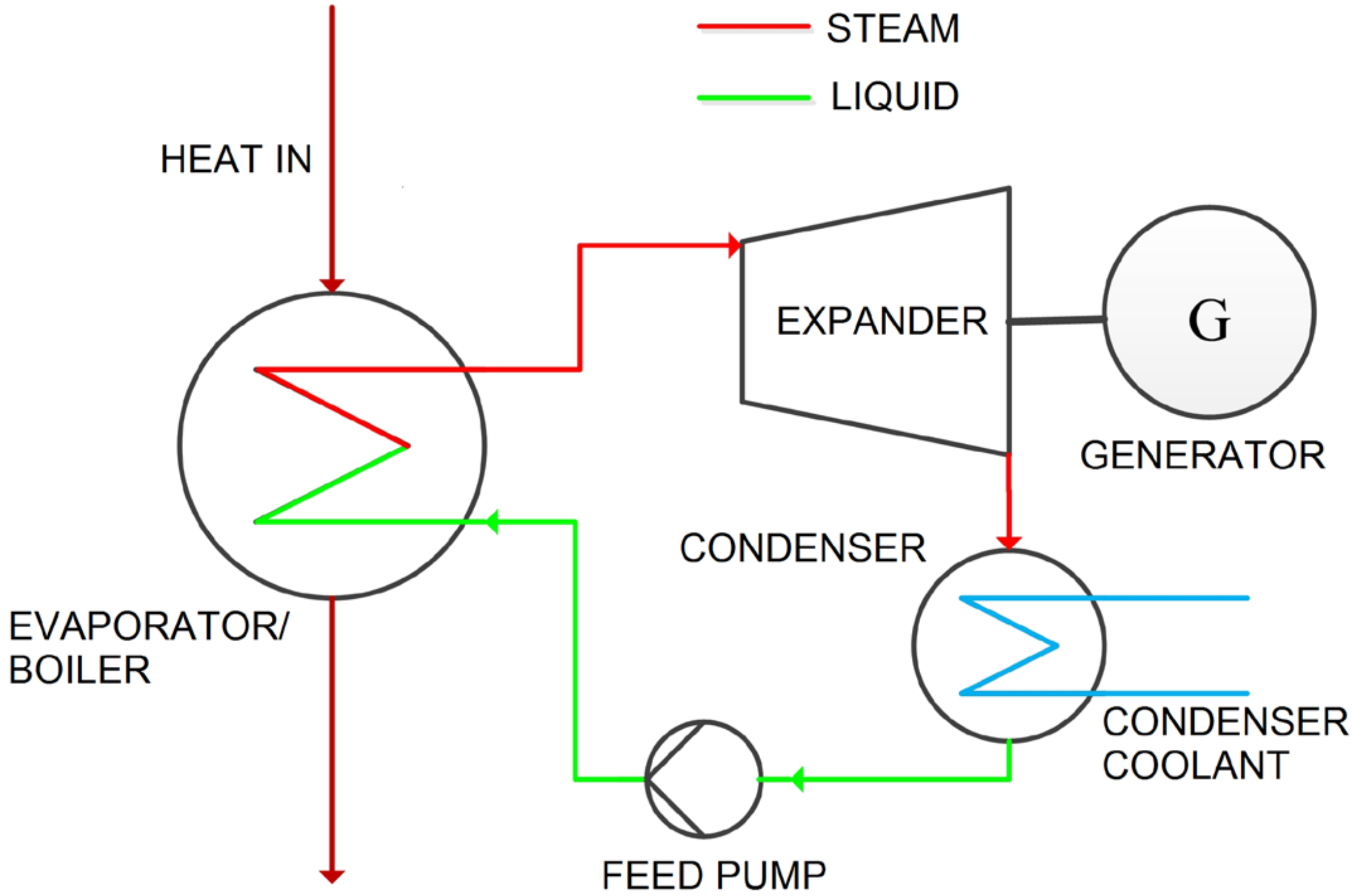
# Organic Rankine Cycle (ORC)



- Organic Rankine Cycle (ORC) is a power system that works in principle like steam power plants, but uses organic working fluid instead of water.
- Enables power production in small scale applications (few kW to several MW), whereas conventional steam turbine cycles are more feasible in larger scale.
- Enables the utilization of low temperature heat sources.
- Several applications and technical solutions: Waste heat, biomass, geothermal, solar…

# Simple Rankine cycle





# Selection of working fluid



- Thermodynamic properties:
  - High electric power output for the cycle
  - Critical pressure and temperature, molecular weight
  - Pressure levels, flow rates
  - Component design (expander, heat exchangers, pumps etc..)

Design requires the use of accurate thermodynamic properties of the working fluid. The gas dynamic phenomena and thermodynamics differs significantly from ideal gases.

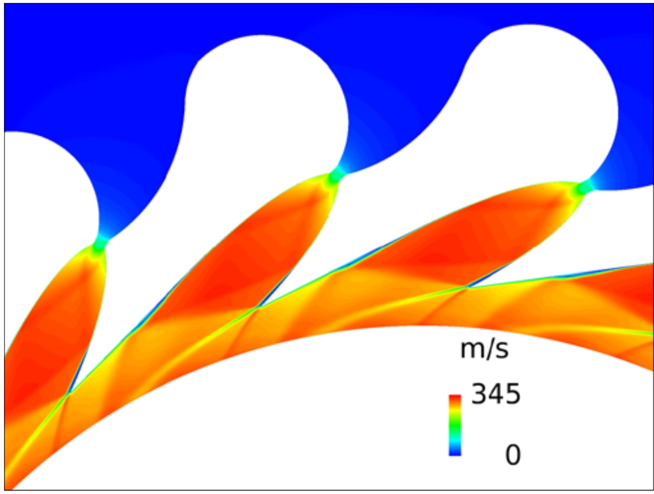
# Selection of working fluid



- Flammabilty and/or toxicity
- Global warming (GWP) and ozone depletion potential (ODP)
- Price

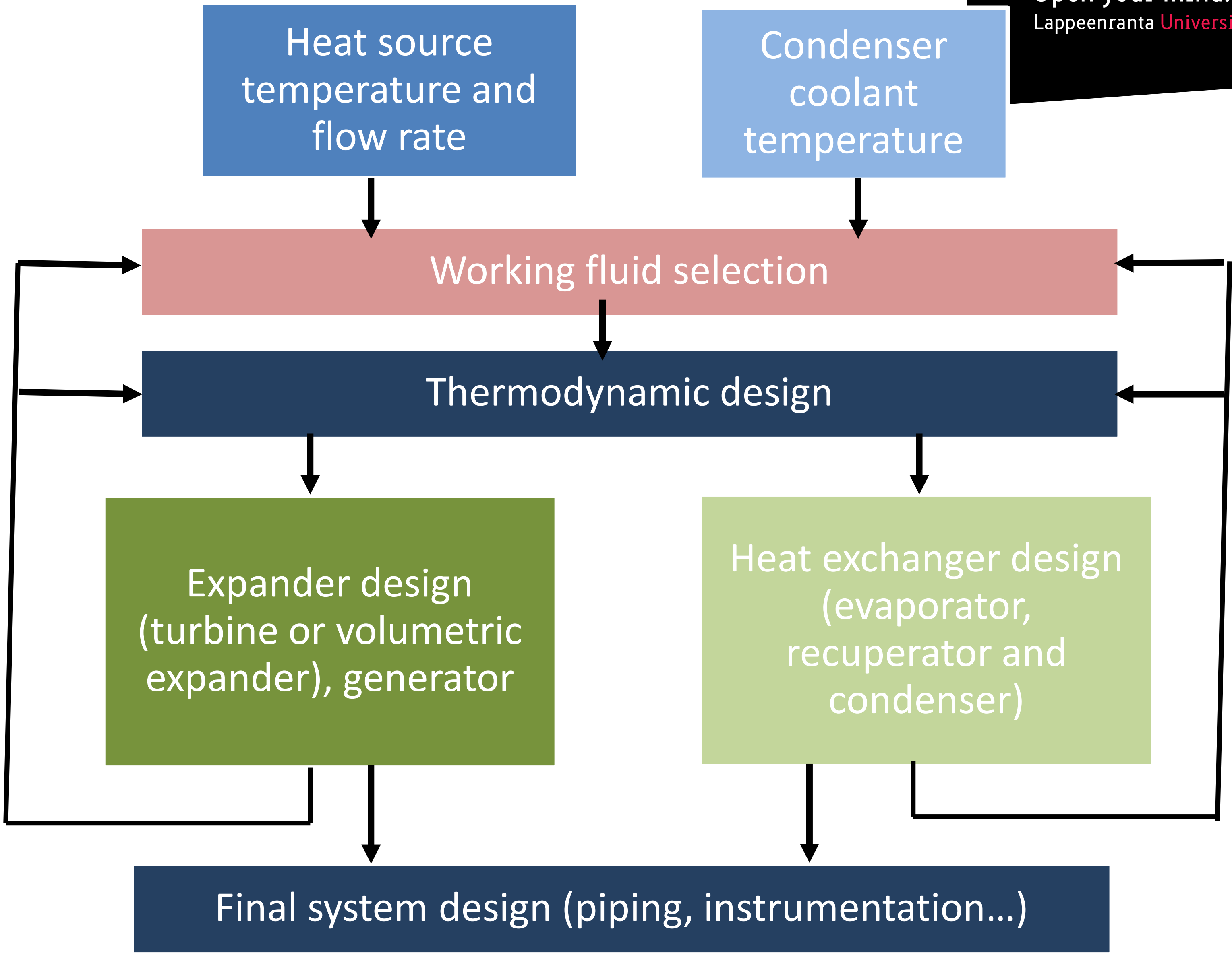
- Low speed of sound -> supersonic flows in turbines

- Thermal and chemical stability
  - limited turbine inlet temperature
  - compatibility with materials
  - use of lubrication oil might lead to decomposition




NO SINGLE FLUID CAN BE IDENTIFIED AS OPTIMAL FOR ALL THE APPLICATIONS AND TEMPERATURE LEVELS!

# Design of an ORC



# ORCs in recovering waste heat from engines



- Exhaust gas heat recovery as the most potential heat source, electric power increase of the engine system up to 10 %
    - High temperature (300-400 $^{o}$C) -> high cycle efficiency
- Engine cooling water utilization
    - Low cycle efficiency due to the temperature level
    - Simple ORC configuration
- Charge air utilization
    - Moderate cycle efficiency
    - Experimental setup tested at VTT in 2013 related to FCEP-project

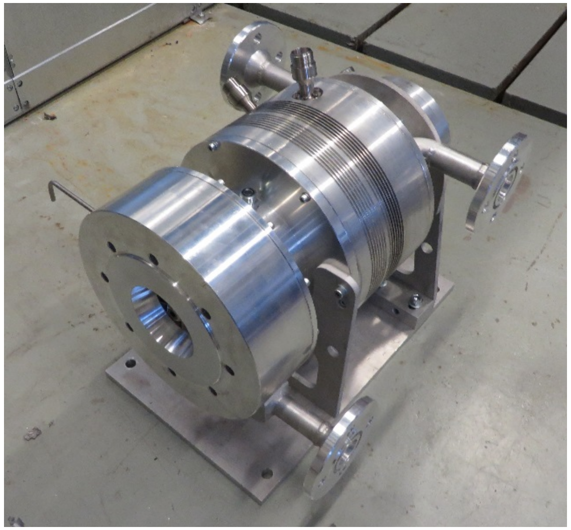
# ORC research at LUT

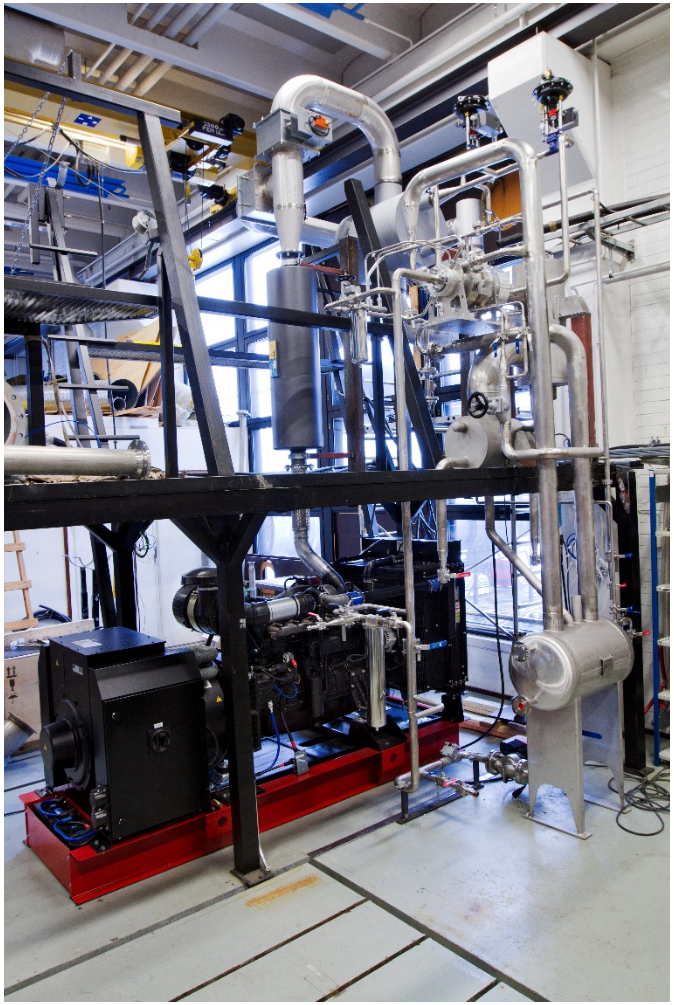


- ORC systems based on high-speed turbines
- Thermodynamic design, working fluid selection, process optimization, turbine and generator design
- Several prototypes and test setups1980-2017
- Power scale 10 kW – 160 kW of electric power
- 160 kW high temperature ORC has been commercialized by Tri-O-Gen. Main application is exhaust gas recovery of 1-2 MW scale biogas engines.

# ORC test setup at LUT

- Objective to design and study a small-scale and high efficiency ORC for high temperature heat sources
- High speed turbogenerator, 30 000 rpm
- Working fluid siloxane MDM
- First test runs 2015-2016

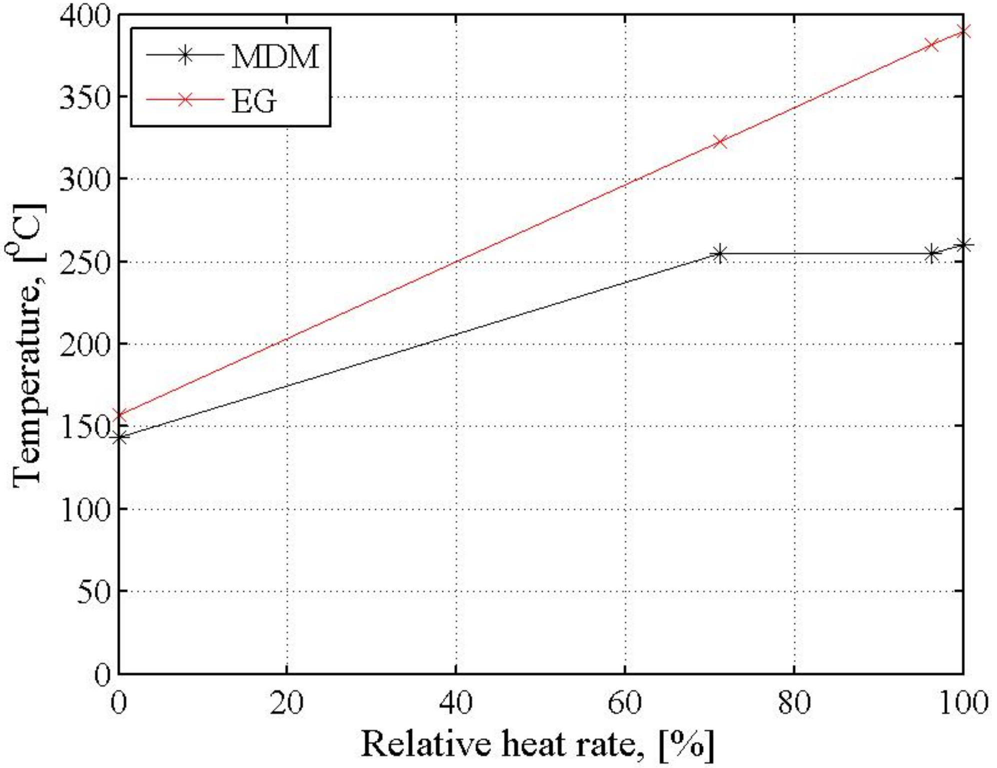




# Experiences from test runs



- Turbogenerator test runs carried out by using working fluid lubricated bearings. Test runs with ball bearings will be carried out next.
- The system is able to efficiently extract the exhaust heat to the ORC working fluid.
- Maximum electric power output of about 6 kW has been reached during the tests (about 80 % of TG design speed)
- Target is to reach about 10 kW output in the future with diesel engine power of about 150 kW.




Ref. Uusitalo, A., Honkatukia, J., & Turunen-Saaresti, T. (2017). Evaluation of a small scale waste heat recovery organic Rankine cycle. *Applied Energy*, *192*, 146-158.

# Experiences from test runs

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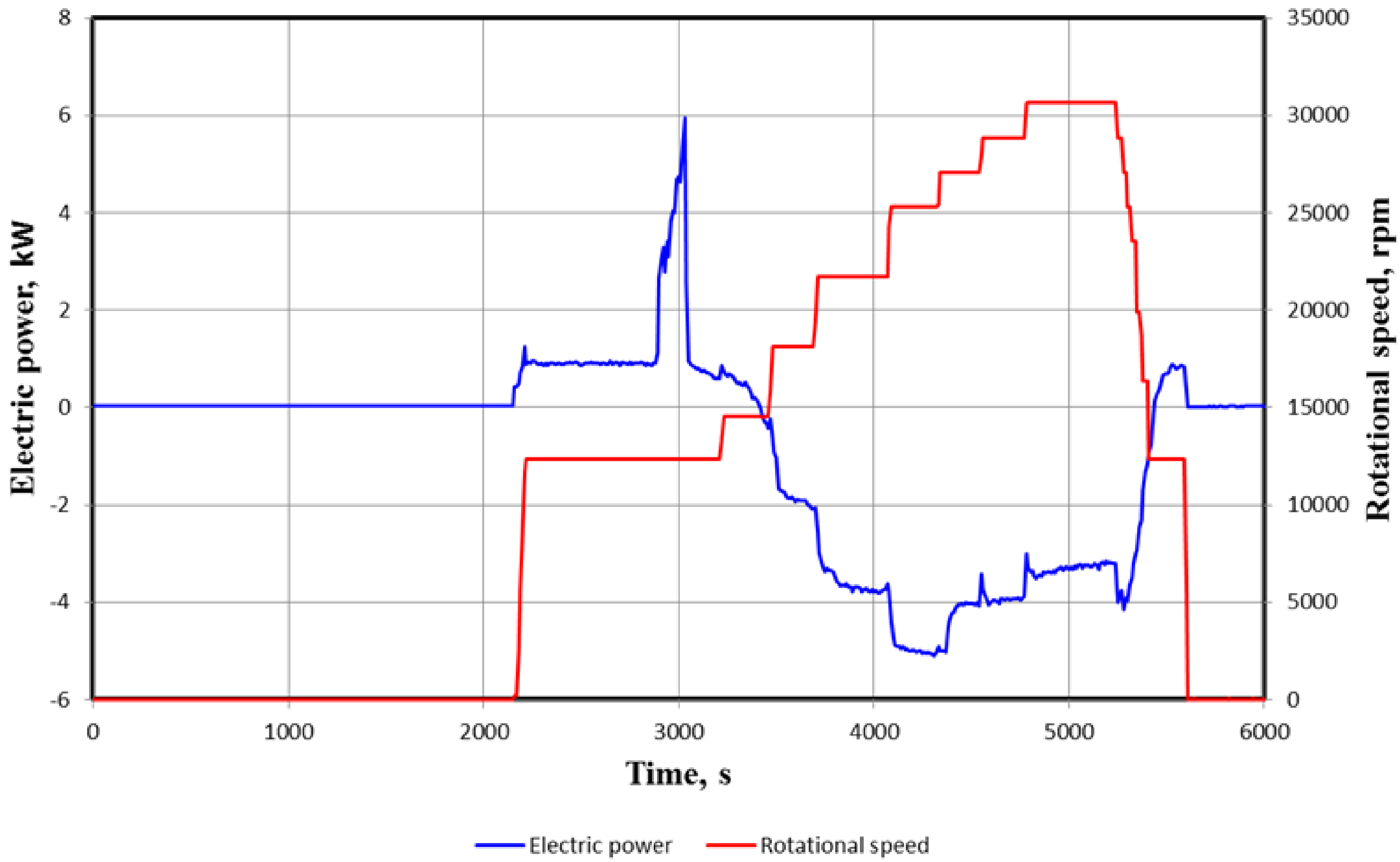


Ref. Design and testing of high temperature micro-ORC test stand using Siloxane as working fluid, T Turunen-Saaresti, A Uusitalo, J Honkatukia – *IOP Journal of Physics: Conference Series*, 2017

# Example of cycle temperatures during operation

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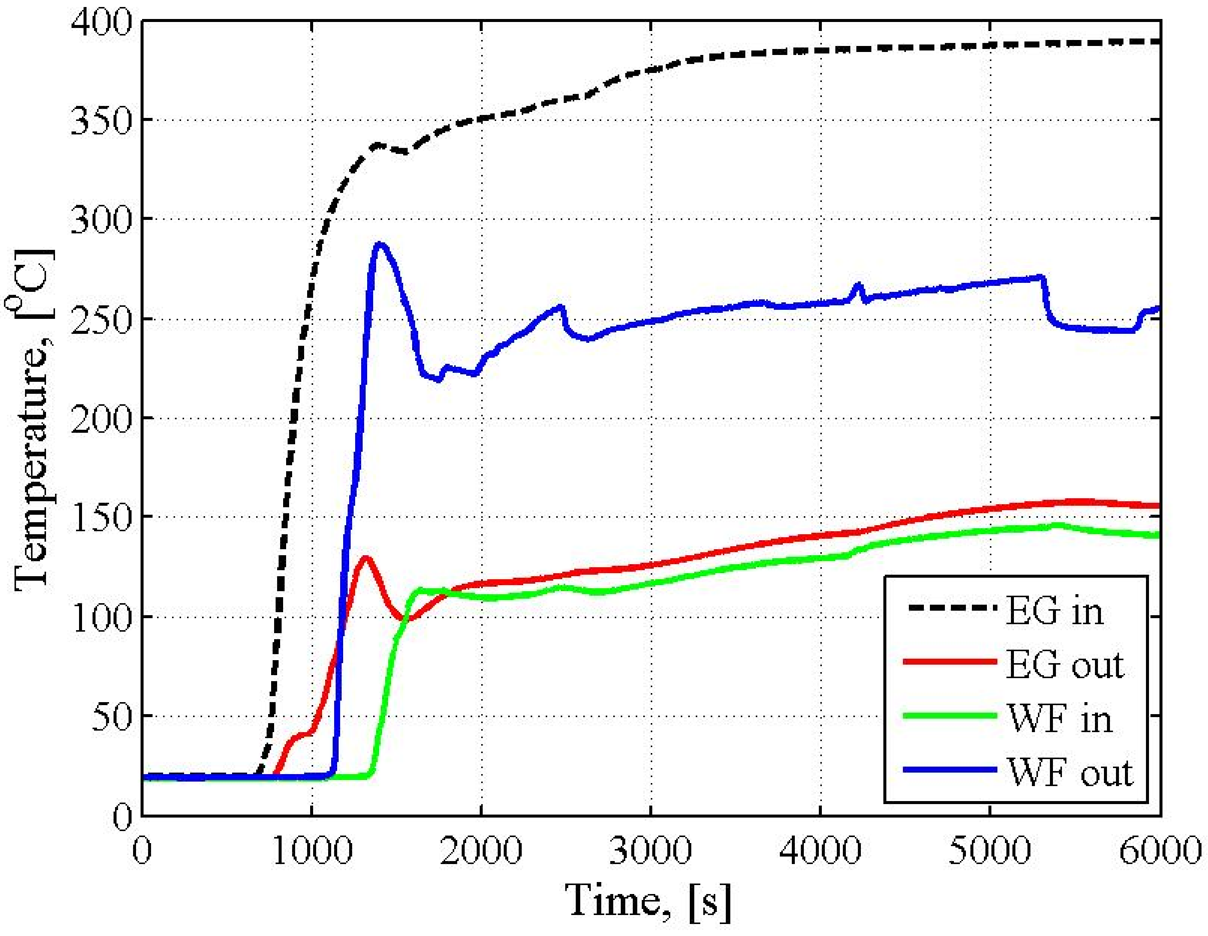


Ref. Uusitalo, A., Honkatukia, J., & Turunen-Saaresti, T. (2017). Evaluation of a small-scale waste heat recovery organic Rankine cycle. *Applied Energy*, *192*, 146-158.

# Experiences from the test runs

- Turbine, generator and high speed feed pump are performing close to what was predicted in the design phase.
- Detailed research on loss mechanisms and distribution of losses in the turbogenerator will be carried out in the future.
- Bearings and control of the ORC system will be further studied and improved.
- Experiments have shown the technical potential of using high temperature ORCs for exhaust gas recovery also in small-scale engine applications.

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