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ACT-ORC - Advanced Control of Organic Rankine Cycle Systems for Increased Efficiency of Heavy-Duty Transport

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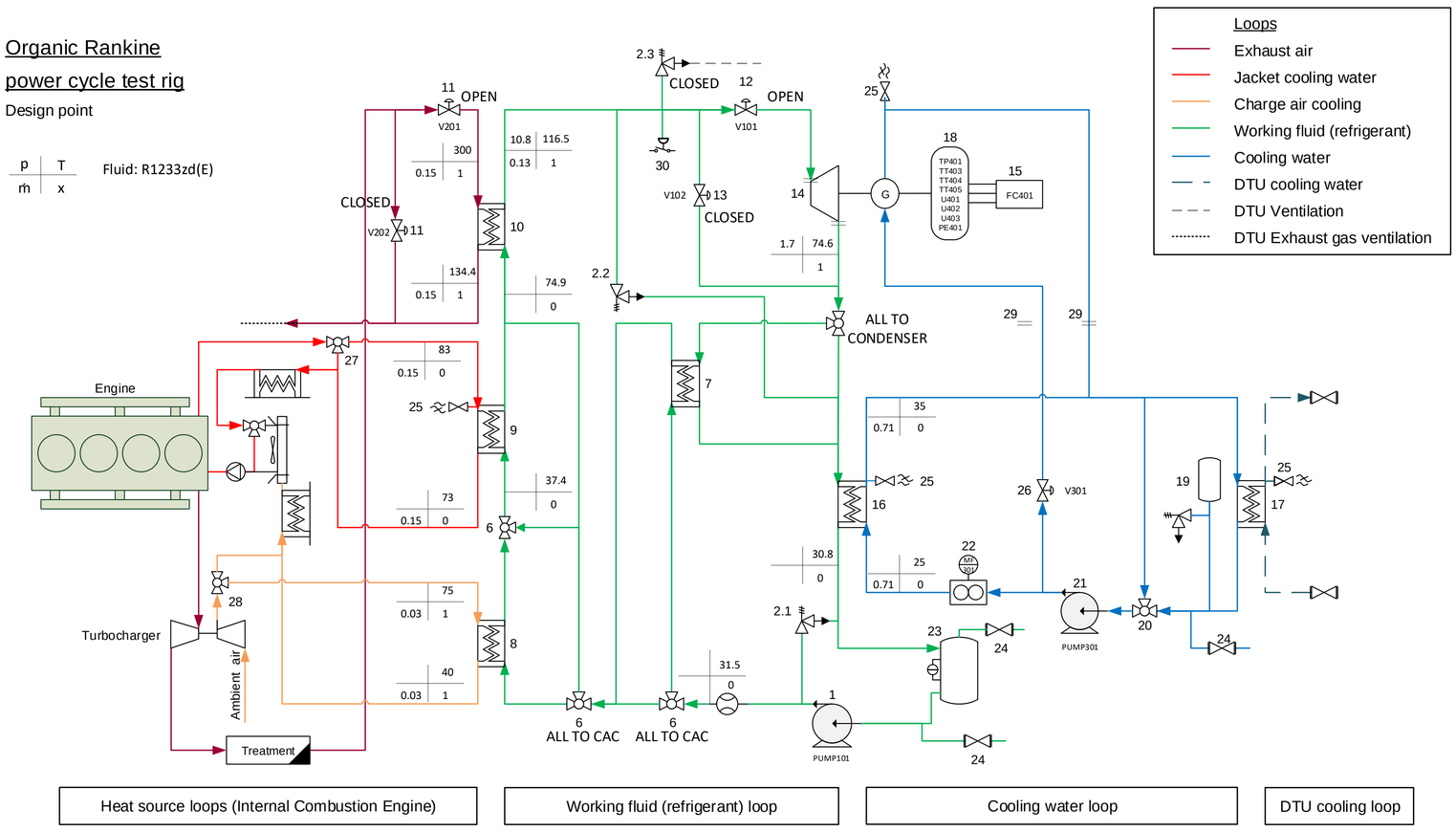
Internal combustion engines of heavy-duty vehicle powertrains have limited efficiency and are responsible for 27 % of the CO_2 emissions as well as 5 % of greenhouse gas emissions in the EU (2016). This project aims to achieve more efficient powertrains to contribute to **green transport.** The unused energy of the internal combustion engine can be recovered by **organic Rankine cycle** power systems to increase the efficiency up to 8 %. During the project, **advanced control solutions** to optimize the power production and guarantee safe operation of the improved engine-ORC power unit are investigated and tested on a lab test rig.



1 Working fluid (refrigerant) pump
2.1 Pressure release valve (15 bar, T > 150°C)
2.2 Pressure release valve (18 bar, T > 150°C)
2.3 Pressure release valve (20 bar, T > 150°C)
3 Pressure Transducers
4 Thermocouples (K-type)
5 Coriolis mass flow meter
6 3-way valve (manual)
7 Brazed plate heat exchanger (recuperator)
8 Brazed plate heat exchanger (pre-evaporator)
9 Brazed plate heat exchanger (pre-evaporator)
10 Brazed plate heat exchanger (evaporator)
11 Exhaust gas bypass and on/off valve (motorized)
12 Turbine on/off valve (motorized)
13 Turbine bypass valve (motorized)
14 Turbine generator unit (axial flow turbine)
15 Resistive load bank for generator
16 Brazed plate heat exchanger (condenser)
17 Brazed plate heat exchanger (cooling water)
18 Terminal Box of Turbine generator unit
19 Water tank (expansion and storage)
20 3-way mixing valve (manual)
21 Cooling water pump
22 Magnetic mass flow meter
23 Refrigerant liquid receiver tank
24 Charging & Discharging port
25 Air release valve
26 Throttle valve
27 3-way valve (manual)
28 3-way valve (manual)
29 Bolted flange
30 Pressure switch to engine

Figure 1: P&I diagram of experimental set-up.

Waste heat from heavy-duty vehicle powertrains

The efficiency of internal combustion engines is limited to 30-46 %, and the remaining energy is released to the atmosphere through the exhaust pipe, engine cooling water, EGR cooler and charge air cooler. The waste heat fluctuates very quickly over time, depending on the driver action and operational map of the internal combustion engine.

Waste heat recovery with organic Rankine cycle

Organic Rankine cycle power systems can recover waste heat at low/medium temperature in an efficient way, providing extra mechanical power that can be used directly on the engine shaft, or converted into electricity for the vehicle electric demand or to charge a battery in hybrid powertrains. **Efficiency improvements up to 8 %** are predicted by previous works.

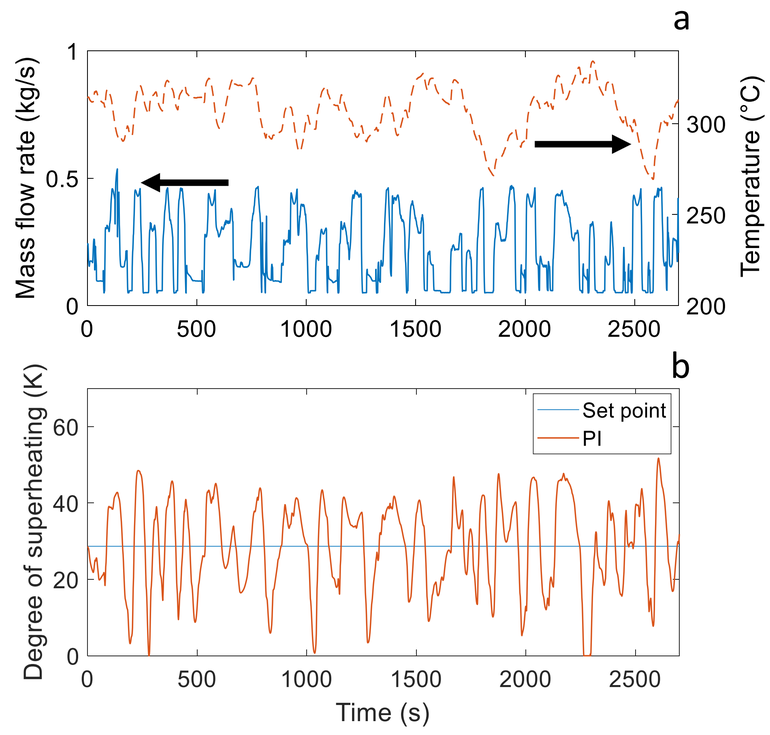


Fig. 2. Control of ORC units under driving cycle: (a) heat source fluctuations; (b) control of superheating at turbine inlet with traditional proportional-integral controllers.

Dynamics and control of organic Rankine cycle units.

Several challenges are posed to the **control and safe operation** of the organic Rankine cycle power systems. In particular, two important factors have to be ensured:
- if the expander is a turbine, the fluid has to be fully vaporized before entering the turbine;
- the maximal allowable temperature of the working fluid has not to be exceeded.

At the same the control objective is to maximize the **net power output**.

Main project objectives

- Develop advanced controllers (MPC) for the control of a 3 kW-ORC unit with axial-flow turbine;
- Test the controller performance on realistic driving cycle;
- Develop guidelines for start-up and shutdown.

Partners

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