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

Antti Uusitalo
Post Doctoral Researcher
Lappeenranta University of Technology (LUT)
School of Energy Systems
antti.uusitalo@lut.fi

8th CIMAC CASCADES, Smart, Clean and Efficient Energy Conversion Solutions
4-5.5.2017, Helsinki
Content

– Waste heat recovery in general

– Operational principle of WHR ORC

– Operational experiences on micro ORC test setup at LUT
Waste heat

- 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

- Evaporator/Boiler
- Condenser
- Feed Pump
- Expander
- Generator

Flow paths:
- Red: Steam
- Green: Liquid

Heat In
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

- Flammability 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

Heat source temperature and flow rate

Condenser coolant temperature

Working fluid selection

Thermodynamic design

Expander design (turbine or volumetric expander), generator

Heat exchanger design (evaporator, recuperator and condenser)

Final system design (piping, instrumentation...)

Open your mind. LUT.
Lappeenranta University of Technology
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 °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 setups 1980-2017
- 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.

Experiences from test runs

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

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.
THANK YOU FOR
YOUR ATTENTION!