ORC waste-heat recovery: integration challenges for existing medium size fossil fuel powered engines

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Introduction - Basics of Organic Rankine Cycles
Introduction

• Most common choice source for ORC Waste Heat Recovery on engines: Hot exhaust gases of stationary gas engine
  - High temperature thus high efficiency
  - High power available
  - Stationary applications generally means less design constraints

• Most common technology of expanders:
  - Single or multi-stage turbine for high power → high specific power but high speed
  - Screw or scroll for low to medium power → lower speed, easier for small scales

However, another approach is possible!
Low temperature heat recovery

ENOGIA pushes forward heat recovery on engine water jacket

**ORC system more reliable and safer:**
- No contact between ORC and engine exhaust gas
- No exhaust back pressure
- ORC components at T < 100°C
- No hot spot => no risk of damaging the working fluid
- Hot source at constant T => easier system control
- No evaporator fouling

**ORC system less costly:**
- No high temperature material
- No special material to resist to acid compounds
- Integration to customer’s process easier (hot water loop)
- Lower pressure ratio, cheaper expander and pump

We think integration on hot water make a more sensible choice for customer:
- Lower CAPEX and OPEX
- Higher flexibility, can be fitted to any engine

*ENOGIA built its success on low temperature ORC microplants on water loops*
Presentation of Enogia

ENOGIA designs and produces Organic Rankine Cycle micro-powerplants that convert waste heat into electrical power.

- **Innovative** company founded in 2009. Head office and facilities in **Marseille, France**
- 35 employees
- Production with **local partners**
- More than 50 references in **19 countries**
- **Fastest growth** of turnover amongst all French cleantechs, winner of Deloitte Technology Fast 50
- **Strategic partnership** with the famous research group
- Welcomes a **strategic shareholder** in 2018
ENOGIA’S expander technology

- Enogia’s approach for compact expanders
  - Single-stage high-speed axial turbine, supersonic injector
  - Brushless generator directly on the shaft, immersed in the working fluid
  - High precision balancing of the whole shaft assembly
  - Lubrication with the working fluid

- Benefits vs volumetric expanders:
  - More reliable
  - More compact
  - More flexible
Case study 1: ORC100

- Specifications:
  - Heat recovery in engine water jacket of large gensets (typically over 1MW<sub>el</sub>)
  - Heat source from 70 to 95°C, up to 1.4 MW<sub>th</sub>
  - Easy to integrate (water loop with standard ISO flanges)
  - Remote control and monitoring
  - Grid feeding and grid operator compliant
  - Target price: 2 000 €/kW
Case study 1: ORC100

• Targeted market:
  – Diesel gensets
  – Biogas plants (core business of Enogia)
  – Natural gas engines
  – Examples of manufacturers: Jenbacher, Caterpillar, Liebherr…
Case study 1: ORC100

- Turbine design
  - Radial inflow turbine selected:
    - High pressure drop
    - Part-load operation
    - Compactness
  - Two symmetric turbines to equilibrate axial efforts
  - Immersed brushless generator
  - Lubrication with working fluid
  - Expected performance: 0.80 isentropic efficiency
Case study 1: ORC100

System design: maximizing electric output

- High efficiency, high speed brushless generator → 97% efficiency
- Dedicated high efficiency inverter, 30-100KW output → 94% efficiency

→ Overall, 91% of the mechanical power is transformed to electricity

Designed by Mavel, tested at IFPEN test-bench:
Case study 1: ORC100

Prototype built
- Integration into a flexible trailer
- Hot side: brazed plate exchangers with ISO flanges
- Control and command with network access for remote monitoring
- Cold loop integrated:
  - Dry cooler
  - Circulator
  - Heat exchanger
→ Stand alone module
Case study 1: ORC100

• First tests – landfill biogas power plant
  – Heat source: hot water from several biogas- fueled CHP engines
  – Experimental results: at mid-load (50kW_e)
    • Evaporator efficiency: 90 %
    • Turbine stage efficiency: 75 %
    • Generator and inverter global efficiency: 91 %
    • Condenser thermal efficiency: 90 %
    • Overall heat-to-grid efficiency of 5 %
    • Results at partial load and warm weather, even better can be expected
Case study 1: ORC100

- **Current status**
  - Currently installed in IFPEN Solaize for in-depth characterization
  - Retrofitting under progress to incorporate Enogia’s recent technological upgrades
  - Changing fluid to R1233zd
  - **Update**: 53 kW produced with 80% of isentropic efficiency, retrofitting still under progress!
  - Toward the commercial ENO100LT
Case study 2: Efficientship

• Context and objectives
  – Life+ European project
  – Contribute to the on-board electricity production
  – Reduce the fuel consumption and operational cost / extend range
  – Qualify the cycle and parts for marine applications

• Specifications
  – 20 kWel ORC
  – Integrated on an existing 22 m fishing vessel
  – Hot exhaust gases as heat source
  – Sea water as cold source
Case study 2: Efficiency

• Constraints
  – Corrosive environment (piping)
  – Corrosive hot source (hot exhaust gases, sulphur)
  – Corrosion and clogging on the cold source heat exchanger (sea water)
  – Space
  – Wave-induced shocks and movements, list
  – Special certifications
  – …
Case study 2: Efficientship

- Technical solutions
  - “Dismantling” of the machine
  - Choice and sizing of heat exchangers (flooding, cleaning)
  - Choice, sizing and integration of the working fluid pump (discharge and cavitation issues)
Case study 2: Efficientship

• Results of the first test campaign
  – Under assessment for further publication
  – Integration successful despite physical constraints
  – Significant fuel saving measured
  – Up to 30% of the on-board electricity needs covered
  – Technical developments validated, know-how developed

• Next step
  – Larger ships – more room for series solution
  – Larger engines – water jacket as hot source
  – Thus, larger electricity production
Case study 3: ORC200

• Specifications
  – “Marine-proof” product
  – Water jacket as the heat source
  – Sea water as the cold source
  – Up to 2.4 MWth heat source (cargo ships, tankers…)
  – 200 kWel production
  – 2 x 2 x 2 m size, stackable for easy up scaling
  – Cooperation with AVID Technology for the generator

• Target price : 1 500 €/kW
Case study 3: ORC200

- Status:
  - Prototype constructed
  - Under on-land test at ENOGIA facility
Conclusions

• All components have a size! Even pipes and working fluid → ENOGIA’s small turbines allow compact design only if the whole cycle is carefully designed

• Spatial arrangement must be carefully considered

• The specificities of the final use of the product must be taken into account early in the design

• Cost, electricity output and integration objectives must be balanced to maximize the benefits of the installation

• Synergies can sometimes be found between objectives → Low temperature approach: affordable and easy integration
Thank you for your attention

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