Development and Operation of a High Temperature High Speed Organic Rankine Cycle System

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WHAT IS ORC?

• ORC = Organic Rankine Cycle
• A Rankine cycle is a closed thermodynamic process in two phases to convert heat into electricity, usually operating with water / steam
• Organic: organic working fluid, like:
  – Coolants (CFK),
  – Hydro-carbons (pentane, butane, toluene)
  – silicon oils (siloxanes)
  – ammonia

Why ORC?

• Temperature level of the heat source
• Amount of heat to convert
Residual or waste heat can be found in:

- Exhaust gasses from:
  - gas engines
  - Diesel engines
  - gas turbines
  
- Various industrial processes:
  - petro-chemical
  - food & dairy
  - base-metal
  - glass, cement, brick manufacturing

- Combustion of fuels not suitable for use in internal combustion engines and turbines (off-spec fuels):
  - Residuals and waste
  - Biomass, wood
  - Flare gas (a.o. landfill gas, industrial flares)

Running on fossil fuels or: Landfill gas, biogas, bio-diesel
HIGH SPEED TURBO GENERATOR (HTG)

- Turbine, high speed generator and main pump on one shaft, no gearbox
- Rugged induction type generator
- High speed (~25,000 rpm), for optimum turbine and pump efficiency
- Hermetically closed system: no leakage of working fluid
- No external shaft connections, so no shaft seals
- Lubrication of hydrodynamic bearings by working fluid, so no lubricants
- Generator internal cooling through working fluid
- HTG exchangeable as a module (< 1 day)
HIGH SPEED TURBO GENERATOR
PROCESS DATA

- Net output 60 - 170 kWₑ, depending heat source and condenser cooling
- Turbine inlet conditions T = 325 °C, p = 32 bar
- Condenser conditions: T = 55 °C, p = 0,175 bar
- Net heat input ~900 kWₜh @ 180 °C in the ORC exhaust
- Inlet temperature minimal ~ 350 °C
- Exhaust and condenser heat useable for co-generation
- Efficiency:
  - net power out / net heat input: up to 20 %
  - total efficiency in co-generation > 90 % possible
APPLICATIONS for IC ENGINES

- IC engines are widely used for distributed and renewable power generation
- Engines inherently produce waste heat in exhaust gas and cooling water
- The energetic value of this heat is a function of temperature
- High temperature exhaust heat can be converted into extra electricity
- Low temperature residual heat is still available for heating and drying purposes
IC ENGINE APPLICATION

Diagram showing the flow of fuel through an engine, exhaust gases going through an ORC (Organic Rankine Cycle) device, and then to a generator, ultimately producing electricity. The percentages indicate the efficiency at each step: fuel input is 100%, engine output is 45%, ORC output is 5%, and generator output is 50%.
APPLICATION ENVELOPE

Bio-Gas Engines
1 – 2 MW_{e}

Engine Exhaust Gas
600 – 1200 kW_{heat}
350 – 550 °C

ORC Exhaust Gas
180 – 220 °C

ORC Power
60 – 170 kW_{e}

T_{in}: 35-60 °C
T_{out}: 55-80 °C

Condesor Cooling Water
400 – 700 kW_{heat}
CHP flexibility

Triogen Offers the ORC in 2 different models:

- **The WB1 model**, Ideal to generate the most electrical power from the heat source. The temperature of the condenser load is typically 35-55°C (in/out).

- **The version WB1-VARIO** offers you the flexibility to choose the temperature of the condenser cooling. The temperature can vary between 55°C and 80°C (out), allowing you to get the most out of your heat!
THE TRIOGEN ORC
PACKAGE DATA

• Dimensions within standards for road transport

• Two separated compartments for ORC process and heat supply (evaporator) on one skid

• Gross weight 12 tons, Foot print approx. 15 m²

• Electrical output at 380/400 V, 3 phases, direct grid connection

• Internet connection for remote monitoring and operation

• Operates smoothly under different input heat conditions

• CE marked including FMEA and HAZOP studies under supervision of Lloyds
MODULARIZED PLANT DESIGN

Four Modules:

1. Standard evaporator, sized to take the available heat-energy

2. Standard Process Module, containing turbogenerator, recuperator, condenser, working fluid inventory, pre-feed pump, valves & piping, instrumentation

3. Standard heat rejection module, to cool the condenser continuously or sized as a back-up for other heat users

4. Electrical power module, for grid connection (inverter) and unit control

Turn key delivery also contains flue gas ducts and valves, electrical connections and flue gas ducting.
APPLICATIONS for Electricity from Biomass

- Solid biomass cannot be used directly for generation of electricity.
- Biomass can be combusted in furnaces and boilers.
- Flue gases from furnaces can be fed to ORC evaporator.
- Triogen system can absorb high temperature (< 600°C) flue gas.
- High temperature flue gas heat suitable for conversion into electricity.
- Low temperature residual heat is still available for heating and drying purposes.
- To plants in operation/commissioning in Italy, three plants on order in Italy, Czech Republic and Slovakia.
- Evaporator with special cleaning device to remove flue gas dust.
REFERENCES

- AD Digester gas engines:
  - 7 plants in operation in The Netherlands
- Landfill gas engines:
  - 2 plants in France (Suez)
  - 2 plants in Portugal (AdP)
  - 1 plant in Germany
- Landfill gas direct combustion:
  - Netherlands (prototype)
  - France: supplementary firing next to gas engines
- Natural gas engine:
  - 1 plant for greenhouse co-generation in The Netherlands
- Bio-diesel engine:
  - 1 plant in The Netherlands
- Direct combustion of solid bio-mass:
  - 1 plant operating in Italy
- Order back-log:
  - 10 plants in Belgium, Czech Republic, Slovakia, Latvia, Italy, Finland

- Achievements:
  - Total number of operating hours: > 250,000
  - Total Electricity produced: > 30,000 MWh
  - Demonstrated availability: > 97 %
Corn Fermentation plant
Since 2009, 34,000 hours
Heat source: 2 x 835 kW<sub>e</sub> biogas engine
Electric power ORC: 155 kW<sub>e</sub>
Manure Co-Fermentation plant
Since 2009, 25,000 hours
Heat source: 2 x 646 kW\textsubscript{e} biogas engine
Electric power ORC: 125 kW\textsubscript{e}
Fermentation of municipal organic waste
Since 2011, 19,000 hours
Heat source: 2 x 1.1 MW\textsubscript{e} biogas engine
Electric power ORC: 155 kW\textsubscript{e}
GERMANY: Landfill site

Landfill Gas Utilization plant
Since October 2011, 14,000 hours
Heat source: 2 gas engines (835 kW<sub>e</sub> + 1000 kW<sub>e</sub>)
Electric power ORC: 150 kW<sub>e</sub>
FRANCE: 2 Landfill sites (GdF – Suez)

Landfill Gas Utilization plants

Since July 2011, 10,800 + 9,500 hours

Heat sources: 2 gas engines @ 1 MWₑ + flaregas burner each

Electric power ORC: 150 kWₑ each
Landfill Gas Utilization plant
Since September 2011, 15,000 + 14,000 hours
Heat sources: 2 gas engines @ 1 MW\textsubscript{e} each
Electric power ORC: 150 kW\textsubscript{e} each
BELGIUM: BiogasTec

Manure Co-Fermentation plant
To be commissioned: August 2013
Heat sources: 2 gas engines @ 1,4 MW_e each
Electric power ORC: 150 kW_e
Wood burning plant in Italy