Off-design modelling of an Organic Rankine Cycle micro-CHP: Modular Framework, Calibration and Validation

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KEYWORDS
micro-CHP; Organic Rankine Cycle; Model; Off-design

ABSTRACT
A modular framework to model the steady off-design behavior of micro-CHP natural gas boilers based on Rankine technology is presented. The system charge integration into the model eliminates the use of any assumptions (i.e. subcooling, superheating, condensing pressure,…) which makes the presented model completely predictive. It is illustrated in the modelling a micro-CHP that satisfies the hot waters and central heating domestic needs (35 kW) and produces electricity (≤1.5 kW). A library of sub models of components with empirical (rotary vane pump and vapor scroll expander), semi-empirical (compact plates condenser) and spatially detailed physical (gas burner and evaporator) models is used to construct a model, using R-245fa as thermal fluid.

The model is calibrated and validated in tests in which 0.1 kg/s of water was heated from 20 ºC to 30–36 ºC, and 80–500 W mechanical power was delivered at the expander shaft, sweeping restrict ranges of three control variables: burner thermal power of combustion (10–14.5 kW), pump (500–740 rpm) and expander (2500–2750 rpm) rotation speeds. The model predicts most output variables with acceptable errors, e.g., less than ±10% for the expander outlet pressure (190–220 kPa, abs) or the temperatures at the outlet of the evaporator (80–150 ºC) or the expander (60–120 ºC).

NOMENCLATURE:

Symbols:

- A: Area (m²)
- C: Heat capacity rate (W/K)
- c_p: Specific heat (J/kg·K)
- D: Diameter (m)
- F: F Factor
- f: Friction factor
- g: Constant gravity acceleration (m/s²)
- G: Mass velocity (kg/s·m²)
- h: Specific enthalpy, (kJ/kg)
- K: Thermal conductivity (W/m·K)
- L_p: Length of plates of the CHE (m)
- M: Molar mass (kg/kmol)
- m: Mass flow rate (kg/s)
- N: Rotational Speed (rpm)
- N_p: Number of plates of the CHE
- N_u: Nusselt Number
- p: Pressure (kPa, abs.)
- P: Power (W)
- p_w: Wavelets step distance of CHE plates (m)
- Pr: Prandtl Number

Greek Letters:

- α: Pump displacement (m³)
- β: Chevron angle of the plates of the CHE
- δ: Excess air ratio of combustion
- ε: Heat exchanger efficiency
- η: Efficiency (various types)
- ρ: Density (kg/m³)
- μ: Dynamic viscosity (Pa·s)

Subscripts:

- a: ambient
- ad: adiabatic
- b: burner
- c: combustion
- e: electric
- f: thermal fluid
- g: natural gas
- gq: burnt gases
- h: hydraulic
- in: inlet
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