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Option: Renewable Energy and Environment

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Tutorial Session No. 4.

Exercise 1 :

We study an open Brayton cycle (air as the working fluid) in which the compressed air is heated in a solar receiver (direct air heating) before entering the turbine. Recovery (heat recuperation) is assumed negligible for simplicity.

Data:

- Mass flow rate of air: $\dot{m}$=20.00 kg/s
- Ambient temperature: T0=300.00 K
- Compressor pressure ratio: rp=10.00
- Compressor isentropic efficiency: ηc=0.85
- Turbine isentropic efficiency: ηt=0.88
- Turbine inlet temperature after the solar receiver: Tturb_in=1123.00 K (≈ 850 °C)
- Air (assumed ideal gas): cp=1.005 kJ/kg ,γ=1.4

Questions:

1. Calculate the specific work of the compressor wc (kJ/kg)
2. Calculate the specific work of the turbine wt (kJ/kg).
3. Calculate the net power Pnet (kW) and the thermal efficiency of the simple cycle
4. Estimate the required solar thermal input (kW) to keep Tturb_in=1123 K at the given mass flow.

Exercise 2 :

We want to design a field of parabolic trough collectors capable of delivering **1.0 MW** of useful thermal power to feed an ORC system or a heat exchanger. Each collector has an **aperture area** of **100 m²**. We assume a **Direct Normal Irradiance (DNI)** of **800 W·m⁻²** (clear-sky conditions) and a **global optical efficiency** (including geometry, reflectivity, intercept factor, and absorber properties) of **ηcol= 0.62**.

The Heat Transfer Fluid (HTF) circulates between **300 °C** and **390 °C** (ΔT=90 K), with a specific heat **cp = 1.50 kJ·kg^{-1}·K^{-1}**.

Molten salts are used for thermal storage with **cp= 1.50 kJ·kg^{-1}·K^{-1}** and an operating temperature range of ΔT_{salt}=290 K (e.g. 290 → 580 °C).

We also want to size a thermal storage system able to supply **4 hours** of operation at full load (1.0 MW) during nighttime. Compute:

1. the useful thermal power delivered by a single collector (kW),
2. the minimum number of collectors required (round up),
3. the mass flow rate of the HTF needed for a temperature rise of 90 K (kg·s^{-1}),
4. the energy to be stored (MWh) for 4 h and the **required mass of molten salts** (tonnes),
5. the total estimated field losses (kW) and a short comment on safety margins.

Exercise 3 :

A Stirling engine is used to convert solar energy into electricity. The engine is installed at the focal point of a parabolic concentrator with a diameter D=10 m. The system operates at a hot temperature T_h=923 K (≈650∘C) and a cold temperature T_c=350 K (≈77∘C).

Given data:

- Direct Normal Irradiance (DNI): 900 W/m²
- Mirror reflectivity: ρ=0.90
- Overall optical efficiency (reflectivity × geometry × cleanliness): η_{opt}=0.80
- Thermal efficiency of the Stirling engine: η_{th}=0.35 (actual)
- Mechanical/electrical efficiency of the alternator: η_{elec}=0.90
- The theoretical Stirling cycle has a Carnot efficiency:
  $\eta_{Carnot}=1-T_c/T_h$

Tasks / Questions:

1. Calculate the theoretical maximum efficiency of the engine (Carnot efficiency).
2. Calculate the solar power captured by the concentrator.
3. Calculate the thermal power effectively transferred to the Stirling engine.
4. Calculate the electrical power produced by the system.
5. Compare the actual overall efficiency to the Carnot efficiency.
6. If 50 kWh per day is desired, how many hours of sunlight are required?