LELME2150 - Thermal Cycles

Homework 3.0 - Cycle design based on pinch

Introduction

The objective of this homework is to design and analyse an Organic Rankine Cycle (ORC) evaporator fed by industrial waste heat.

Through this work, students will be able to:

- Apply iterative numerical solving (with `fsolve`) to thermodynamic design problems;
- Use the pinch-point method to determine an optimal evaporation pressure for a working fluid;
- Compute the exergetic efficiency of a heat exchanger.

This homework is completely optional; it will not be taken into account in your final grade. However, we strongly encourage you to do it, as it will be very useful for the upcoming assignments. If you would like to receive feedback, you can submit your work before Sunday, October 19 at 23:59. Before submitting, we recommend testing your code ! Please submit your `Python` script and a one-page report in the designated area on Moodle.

Pinch Point in Heat Exchangers

The pinch in a heat exchanger refers to the smallest temperature difference between the hot and cold fluid streams along the exchanger. It is a critical design parameter because it represents the most restrictive point for heat transfer: no more heat can be exchanged without reducing this minimum temperature difference.

A small pinch (e.g., 5 K) means the two streams come very close in temperature, which allows maximum heat recovery and improves thermodynamic efficiency. However, it requires larger heat transfer surfaces and thus higher investment costs. A large pinch (e.g., 20 K or more) reduces the heat recovered, decreasing cycle efficiency, but results in a more compact and less expensive exchanger.

The minimum achievable pinch is not universal: it depends on the fluid pair (hot and cold streams), their thermal properties (such as specific heat variation with temperature), and the chosen phase-change conditions. For instance, condensation or evaporation processes often create long isothermal plateaus that constrain the temperature approach, while single-phase fluids allow smoother matching.

In energy systems design (e.g., Organic Rankine Cycles), the pinch therefore sets a balance between heat recovery performance (higher efficiency) and economic feasibility (capital cost). Designers often impose a target pinch to size the system consistently.

T−q diagram

A T−q diagram (temperature−heat transfer diagram) is a graphical representation of the temperature evolution of two fluids as heat is exchanged between them (typically one hot stream releasing heat and one cold stream absorbing it). The horizontal axis represents the cumulative heat transferred (q), while the vertical axis represents the temperature of each stream. This diagram provides a clear visual of how the temperature profiles of both fluids approach each other along the exchanger. It is especially useful to identify the pinch point. The value of this pinch directly indicates the thermodynamic quality and sizing constraints of the heat exchanger: a smaller pinch means better thermal matching but a larger required heat exchange area. Therefore, T−q diagrams are essential tools for analysing and optimizing heat exchangers, as they highlight irreversibilities, guide design decisions, and help evaluate exergy efficiency and recoverable energy potential.

Tasks

1. Download the signature (`pinch_group_xx.py`);
2. Rename the script with your group number (0x if number lower than 10);
3. Implement the function to compute the optimal evaporation pressure of Heptane ensuring a pinch of 5 K;
4. Test your code using the provided test script (`pinch_test.py`);
5. Prepare a **max 1-page report** to summarise your methodology and present your findings. This report should include:
   - the key equations (definition of pinch, exergy analysis);
   - your numerical approach and assumptions (including the use of `fsolve`);
   - the optimal working fluid pressure ensuring the required pinch;
   - a T-q diagram of the heat exchange process;
   - a calculation of the heat exchanger exergy efficiency and a discussion of irreversibilities;

Statement

Organic Rankine Cycles (ORCs) are widely recognized as an effective technology to convert low- and medium-grade waste heat into useful power. They enable industries to improve their overall energy efficiency while reducing CO_2 emissions by utilizing heat streams that would otherwise be lost to the environment (See Figure 1). Among the many industrial sectors, the cement industry is particularly well suited for such recovery, as its clinker production process releases large quantities of exhaust gases at temperatures in the range of $150 - 250°C$.

In this homework, you will design part of an ORC system to exploit this waste heat source, focusing on the optimal choice of evaporation pressure in the ORC evaporator under a given pinch constraint. Consider a hot waste heat stream at 220°C from a cement plant, outlet at at 150°C. The heat is provided trough a thermal oil medium : Therminol 72. This waste heat stream is used to evaporate an Organic Rankine Cycle (ORC) working fluid, heptane, in a simple evaporator. The pinch-point temperature difference between heat transfer fluid and the working fluid must be 5 K. The evaporation pressure of the working fluid is therefore a design variable that must be determined by iteration.

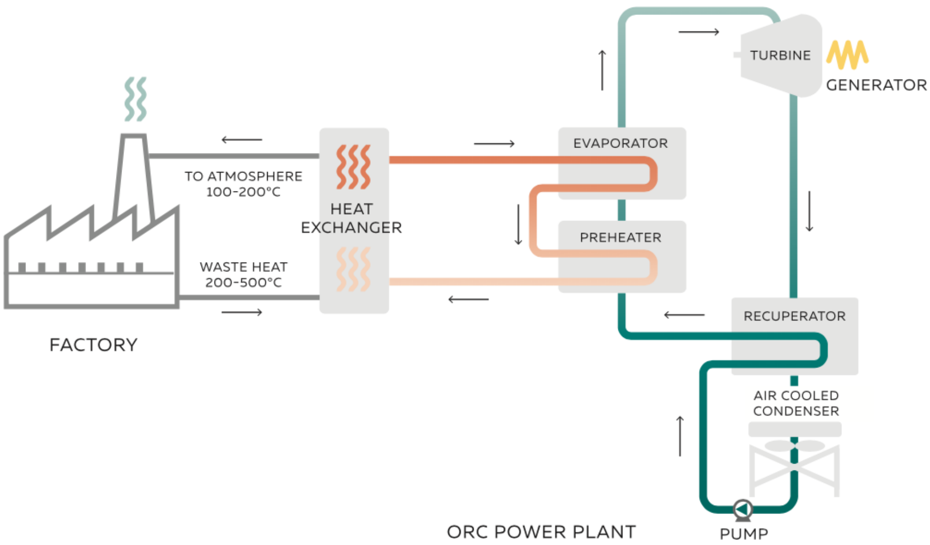

Figure 1: Organic Rankine cycle integrated with a waste heat stream from an industrial process. Source: Exergy ORC