Sustainable Heating and Cooling Technologies
Spring Semester 2025
Student Project
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Heat pump for cooking pasta in a restaurant

In modern, high-throughput restaurant environments pasta is cooked fresh in full view of customers using batch-based pasta cookers (Figure 1). This process is repeated multiple times per day. Each cooking cycle requires significant thermal energy to keep large volumes of water at or near boiling watering temperature. Traditionally, this energy is supplied using gas or electric heaters. This project proposes a more sustainable and energy-efficient solution: the design of a heat pump system capable of meeting the thermal demands of such a cooking process while reducing energy consumption. As the responsible design engineer, your task is to design a technically reasonable and efficient heating system that is suitable for a high-throughput restaurant environment, including the compressor and the heat exchanger size optimized for batch pasta cooking.

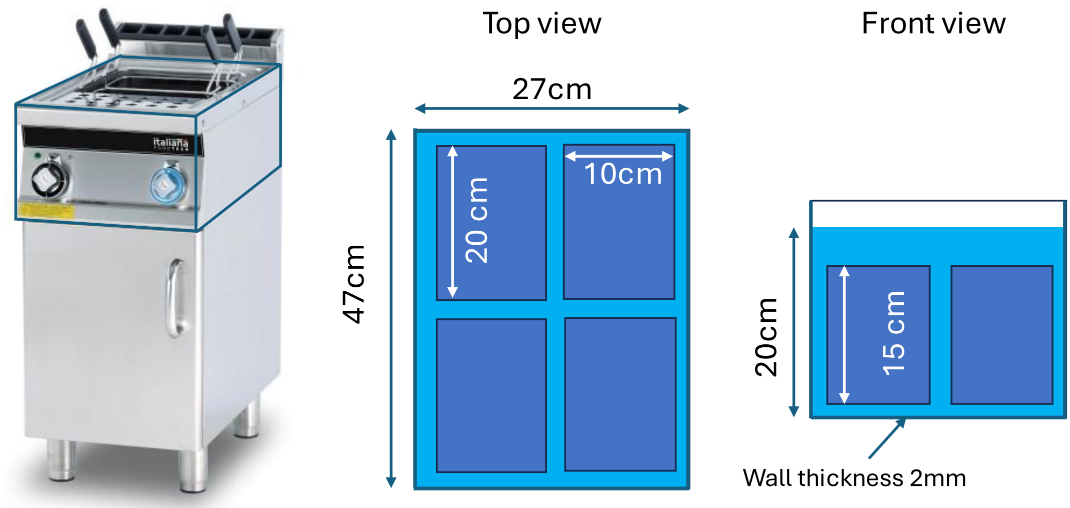

Figure 1: Pasta cooker for high-throughput restaurants [https://italianafoodtech.com/] (left), pasta cooker geometry (right)

<u>Your task:</u>

1. Simulate the pasta cooking step of the pasta cooker to determine the required specifications of the heat pump
    - Determine the required heating power during the pasta cooking phase.
    - Determine the maximum condenser heat transfer area, considering space limitations in the pasta cooker.
    - Develop an on/off control strategy for the heat pump that keeps the water temperature within the allowed range.
2. Design the heat pump process to meet the requirements of the pasta cooker
    - Design the heat pump process as a function of compressor size and refrigerant type
    - Take into account the pasta cooker's thermal requirements in the cooking phase, the maximum condenser size that can be integrated into the pasta cooker, and typical technical constraints.
3. Simulate the operation of the pasta cooker, including the heat pump process, and select the most suitable combination of compressor diameter and refrigerant
    - Consider a full day of operation, including the heating-up phase

- When selecting the best design, consider daily energy demand, the number of start/stop cycles of the heat pump compressor, and the time needed for heating up the water in the morning
- Visualize the operation of the complete system (pasta, water, heat pump) over one day using appropriate plots.

4. Compare the heat pump-based pasta cooker with a conventionally electrically heated one
    - Calculate the energy savings, electricity cost savings, and CO_2 emission reductions of your selected design compared to an electric heater.
    - Use Zurich's electricity cost and emission factor for the comparison.

Design requirements

System modeling:

The system's performance should be evaluated for a full day (12 hours), including heating up the water in the morning and continuously cooking the pasta throughout the day.

Heating up the water:

- The water in the water basin is at ambient temperature (20°C) in the morning.

Cooking pasta:

- Before cooking, the pasta is kept in the fridge at 7°C.
- The pasta is cooked in 2.0 kg batches (0.5kg per basket), each for 7 minutes.
- In each cooking cycle, the pasta should reach 85°C.
- Between pasta batches, there is a 5-minute break.
- The water temperature must be kept between 85°C and 93°C during operation.

Parameters:

- The water in the water basin and the pasta can be modeled as 0D (no temperature gradients inside water and pasta).
- Temperature and pressure dependency of the properties of the water and the pasta can be neglected.
- The thermal resistance between the environment and the water inside the basin is $R_{env,water}$ =30. K/kW. Neglect any evaporation of the cooking water.
- The thermal resistance between the water inside the basin and the pasta is $R_{water,pasta}$= 15 K/kW
- The heat capacity of the water is $c_{p,water}$= 4.18 kJ/kgK
- The heat capacity of the pasta is $c_{p,pasta}$= 3.5 kJ/kgK

Heat pump design:

Process

- Consider a subcritical heat pump process.
- Heat source: Ambient air in cross flow @ T_{so} = 20 °C
- Heat sink: Pasta water
- Make sure the heat pump meets usual technical constraints (e.g., superheating) and is in COP-optimal operation at each point in time.

Refrigerant
Investigate the following refrigerants: Isobutane, Butane, Isobutene, DimethyEther
Equipment
Compressor:

- Use the function **`recip_comp_corr_SP`** to determine the isentropic compressor efficiency and the refrigerant mass flow (see description below).
- The compressor model considers a 4-cylinder reciprocating compressor that is available in different sizes D = {35 mm, 40 mm, 45 mm, 50 mm}.

Heat exchanger

- The heat pump's condenser consists of pipes (outer diameter = 6.35 mm, tube wall thickness=0.8 mm) that run directly through the water basin. The number and positioning of the pipes, as well as the material, is a design aspect that you need to consider (please note: the space for pipes inside the water basin is limited by the baskets).
- You can assume that the evaporator has no such size constraints, and you do not have to calculate the evaporator heat exchanger area.
- When calculating the heat exchanger area, take the different phases of the refrigerant into account. For simplicity, it can be assumed that the heat transfer coefficients are not refrigerant-specific and independent of temperature.

Fluid	Heat transfer coefficient, W/(m²K)		
	Liquid	Vapor/liquid (2-phase)	Vapor
Refrigerant	1000	2000	200
Water	1000	---	---

Controlling:

The heat pump is on/off controlled. The controlling unit only knows the water temperature to decide if the heat pump should be switched on/off. Here, you need to consider threshold values (consider min and max water temperatures). Further, the heat pump's COP is degraded if the heat pump delivers more heat than required (COP decreases due to repeated on/off cycles). The resulting heat pump $\mathrm{COP}_{\mathrm{res}}$ can be calculated as a function of the inner heat pump $\mathrm{COP}_{\mathrm{inner}}$ (from the process model without repeated switching on/off) through the following empirical equation:

$$\mathrm{COP}_{\mathrm{res}} = COP_{\mathrm{inner}} \left(\frac{\frac{\dot{Q}_{\mathrm{demand}}}{\dot{Q}_{\mathrm{heat\ pump}}}}{0.9 \frac{\dot{Q}_{\mathrm{demand}}}{\dot{Q}_{\mathrm{heat\ pump}}} + 0.1} \right)$$

Hint :
In modeling the heat pump operation, optimizing the heat pump states for changing sink temperatures is time-limiting and takes significant time when simulating a whole day. Thus, we recommend creating a function that approximates the heat pump's inner $\mathrm{COP}_{\mathrm{inner}}$ and the heating capacity for a defined range of sink temperatures (off-design), based on the detailed process optimizations. Instead of calling the optimization routine for each timestep, you can use the data resulting from this function to represent the heat pump's performance in your simulation, e.g., through interpolation.

`recip_comp_SP(param, refrigerant, transcrit=False)`

Estimates the **isentropic efficiency** and **mass flow rate** of a **reciprocating compressor** under **subcritical conditions** using empirical correlations.

Parameters

- **`param`** (tuple):
  Input parameters as a 5-element list:
  (T_ev, T_co, DeltaT_sh, DeltaT_sc, D)
  - T_ev (float): Evaporating temperature [°C]
  - T_co (float): Condensing temperature [°C]
  - DeltaT_sh (float): Superheat at suction [K]
  - DeltaT_sc (float): Subcooling before throttle [K]
  - D (float): Cylinder diameter [mm]
- **`refrigerant`** (str):
  Refrigerant name (Coolprop).
- **`transcrit`** (bool, optional):
  Indicates whether the operation is transcritical. Should be False for subcritical use (default).

Returns

- `eta_is` (float): Isentropic efficiency (dimensionless)
- `m_dot` (float): Mass flow rate [kg/s]
