Transient 1D heat exchanger model for the simulation of domestic cooling cycles working with R600a

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1. Introduction

Motivation

- Between 5% to 29% of the domestic electrical energy is used to operate refrigerators and freezers (IEA, 2009), e.g.:

- In future the demand for cooling appliances will be increasing
1. Introduction

Domestic refrigeration

- State of the art on/off controlled refrigerator based on the vapor compression loop

Diagram:
- isolated cabinet
- condenser
- evaporator
- compressor
- capillary tube
1. Introduction

Domestic refrigeration: Outlook

State of the art systems: Not as energy efficient as theoretically possible

Major task for engineers: Reduction of the energy consumption by

- Optimizing conventional systems (short term)
- Research and development of alternative, more energy efficient cooling technologies (long term)
1. Introduction

Aim of the overall research project

- Development of a transient vapor compression cycle simulation tool
  - Implementation of R600a properties
  - Modelling the single components (e.g. reciprocating compressor)
  - Assembling to get the whole system
  - Simple extendable and modifiable tool
- Focus of this paper is the modeling of the HXs (Condenser, Evaporator)
1. Introduction

Modeling basics – kick it

Two modeling approaches

Component level

- Applied Methods:
  - Moving Boundary Approach
  - Distributed Parameter Approach

- Discussion:
  - Very detailed and complex
  - Time consuming but accurate
  - Difficult to get appropriate BC

System level

- Applied Methods:
  - Lumped Parameter Approach
  - Moving Boundary Approach
  - Distributed Parameter Approach

- Discussion:
  - Simplified models
  - Component interactions can be captured
2. Simulation Model

Transient heat exchanger model

Finite Volume Approach

Simplifying assumptions for geometry, physics

Solving governing equations for
- mass
- energy
  conservation

Working Media R600a (Isobutane)

BC from sub models
2. Simulation Model

Computation algorithm

1. Input data
2. Initialization
3. Get BC for new time step
4. Guess new pressure in 1st cell
5. Solve conservation equations iteratively and cell by cell
   - \( \Delta \text{energy balance} < \varepsilon_{\text{energy}}? \)
     - YES
     - \( \Delta \text{mass flow rate last cell} < \varepsilon_{\text{mass\_flow}}? \)
       - YES
       - Final time step?
         - YES
         - Calculation finished
       - NO
     - NO
   - NO
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3. Experimental Validation

Experimental setup

- Research coil condenser

- Wall temperature middle
- Absolute pressure inlet
- Condenser pressure drop
- Inlet temperature
- Mass flow meter
- Outlet temperature
- Sight glass
3. Experimental Validation

Results – Mass flow rates, refrigerant mass

![Graph showing mass flow rates and refrigerant mass over time]

- **mp inlet EXP**
- **mp outlet SIM**
- **m refrigerant**

**Axes:**
- **Y-axis:** Mass flow rate / kg/s
- **X-axis:** Time / s
- **Y-scale:** 0 to 0.01 kg
- **X-scale:** 0 to 1400 s
3. Experimental Validation

Results – Temperature trends
3. Experimental Validation

Results – Transient pressure trends
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Content
4. Conclusion

- A detailed transient heat exchanger model based on the distributed parameter approach was presented.
- The model is going to be implemented in a cooling cycle simulation tool.
- The model framework can be used for condenser simulations as well as for evaporator simulations.
- Convergence of the simulation is mainly influenced by the highly transient state changes during start-up and shut-down.
- The comparison of experimental data and predicted data has shown truly satisfying agreement.
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