EPFL

Heat Pump Systems

Summary W5

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Analysis of Heating and Refrigeration HP Cycle

- Graphical representation of exergy losses

$$l_{qh} = \frac{T_a}{T_h}\left(T_h^{'} - T_h\right)(s_2 - s_3)$$

$$T_a(s_4 - s_3) = l_e$$

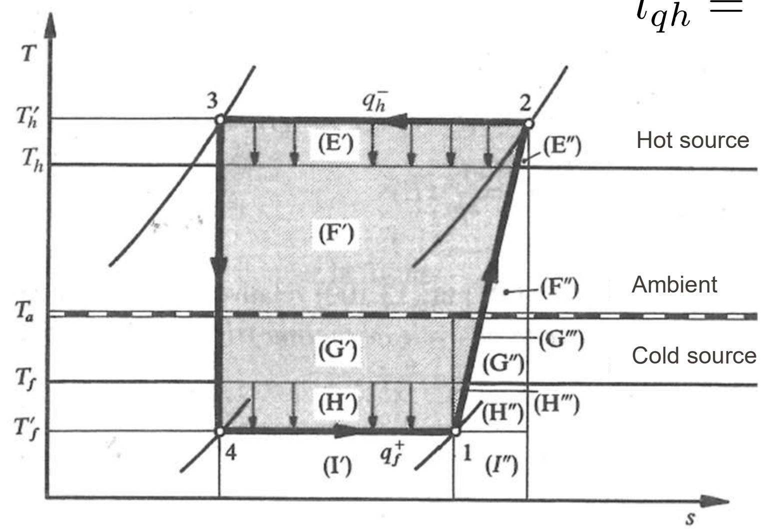


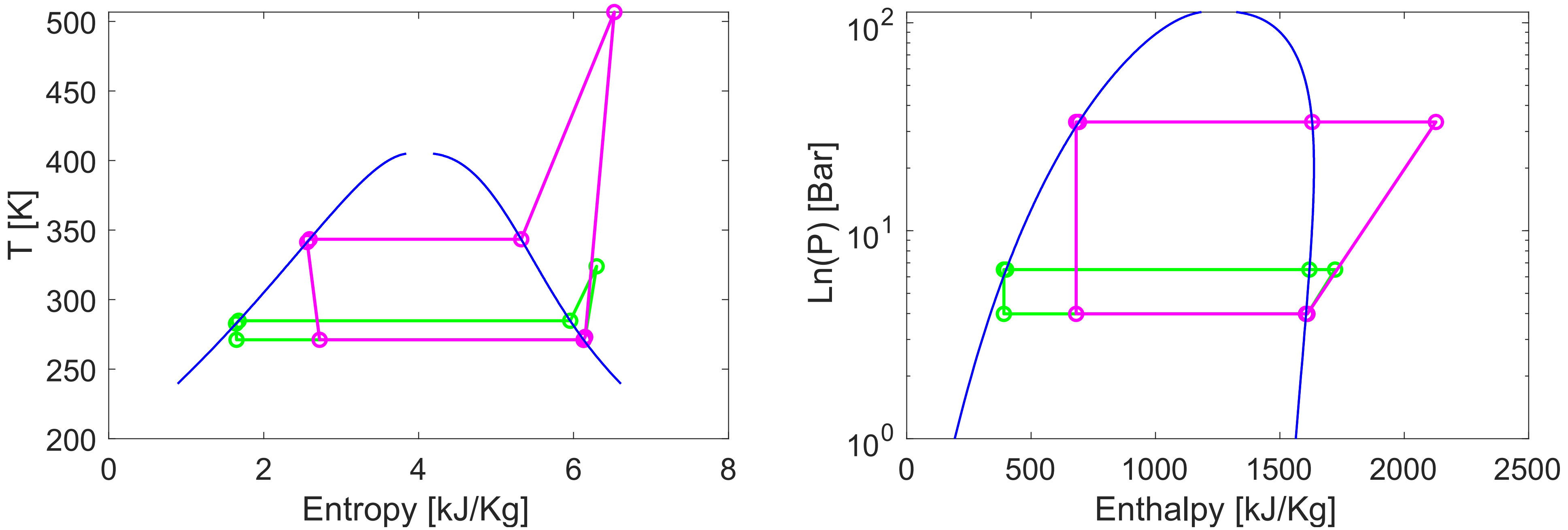
Fig 13.26 Favrat

$$l_{qf} = \frac{T_a}{T_f}\left(T_f - T_f^{'}\right)(s_1 - s_4)$$

$$T_a(s_2 - s_1) = l_c$$

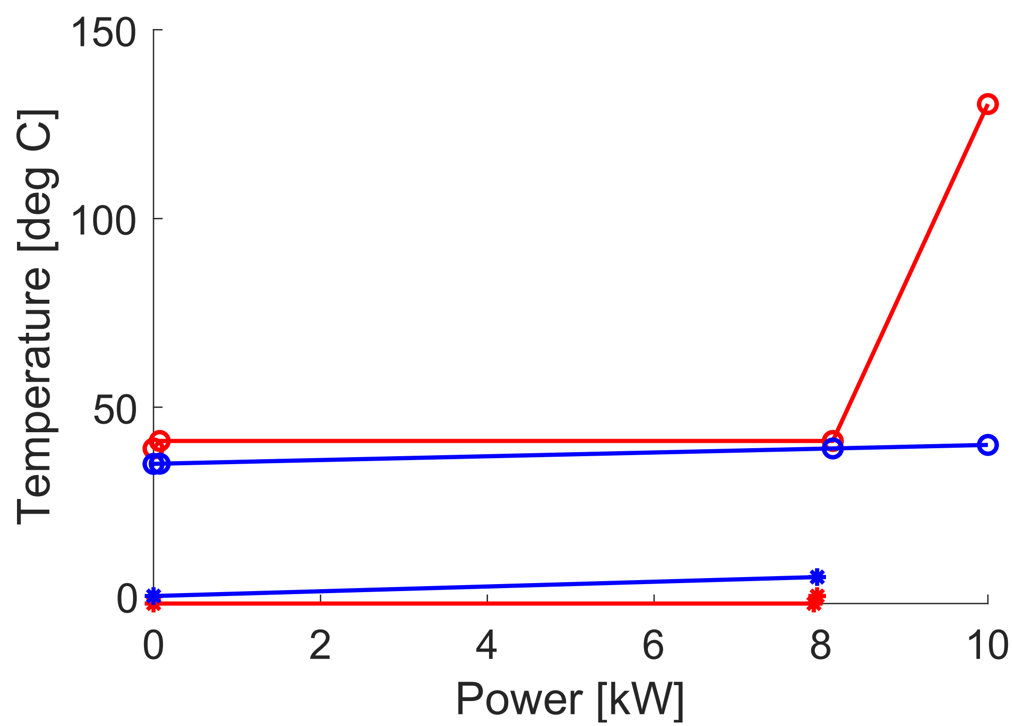
Typical Heat Pump Cycle Representation

- Vapor compression heat pump in T-s and P-h diagrams



Heat Pump Cycle Composites in Heat Exchangers

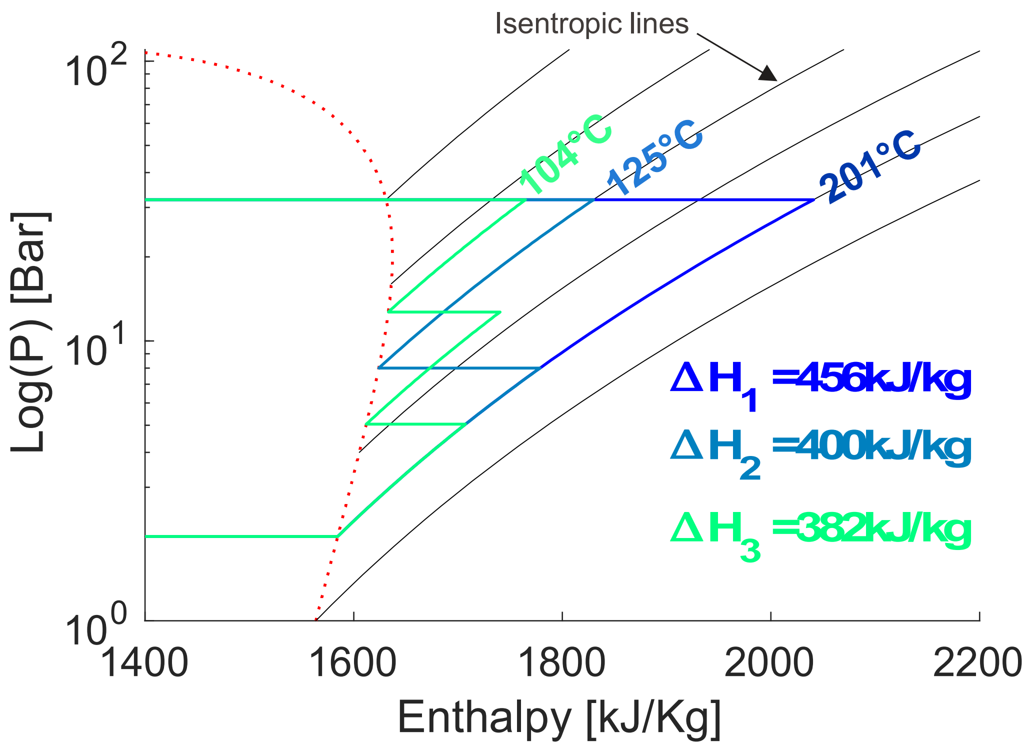
- Condenser and evaporator composites
  - 2K superheat & subcooling
  - Cold source is air at 5°C
  - Temperature difference on water and air 5K
  - Pinch in condenser and evaporator 2K



Improving Compression Process

- Splitting compression process with intercooling reduces power to achieve same pressure ratio

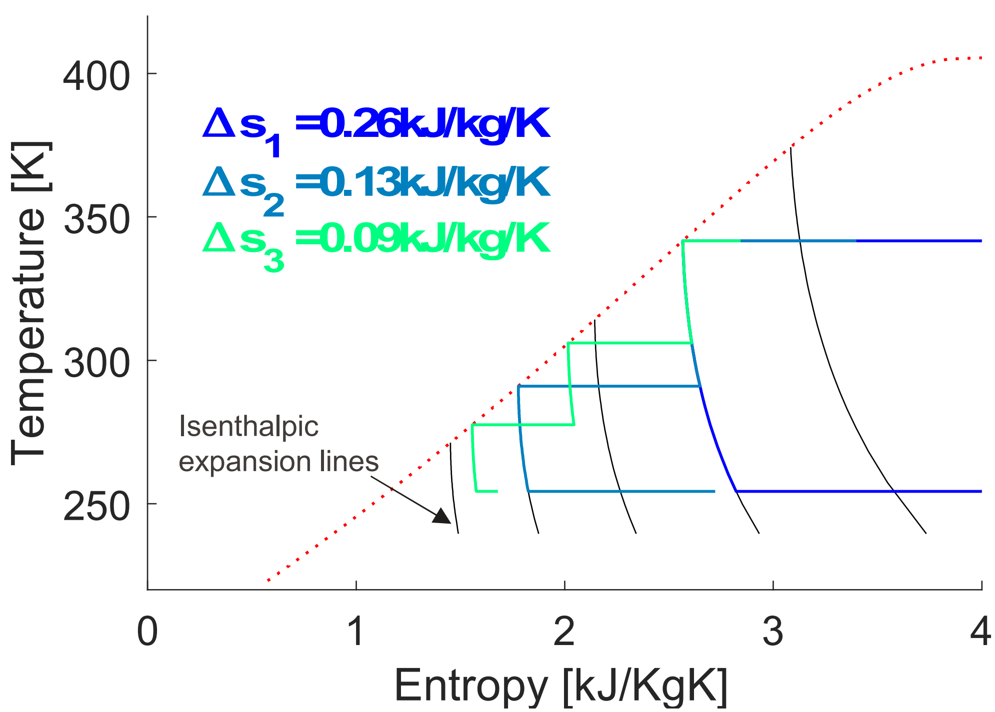
- Splitting and intercooling reduces exhaust temperature



Improving Expansion Process

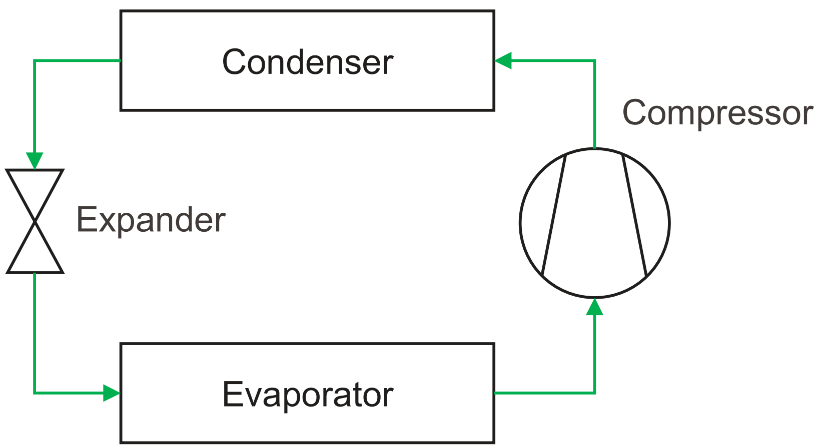
- Splitting expansion process reduces losses and increases latent heat pickup in evaporator

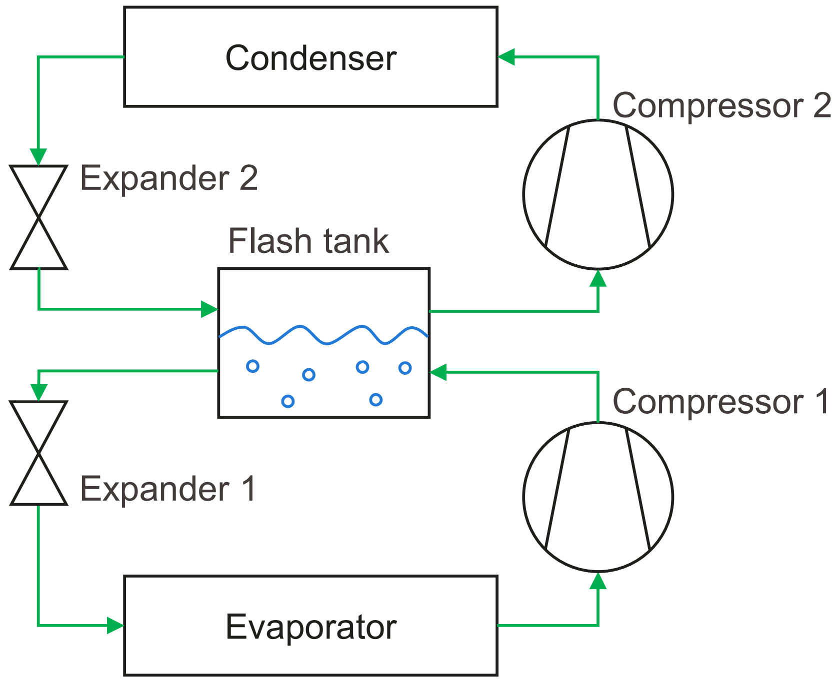
- Considering exergy losses savings can be significant in particular for high temperature lift cycles



Comparison of Single and Double Stage HP Cycles

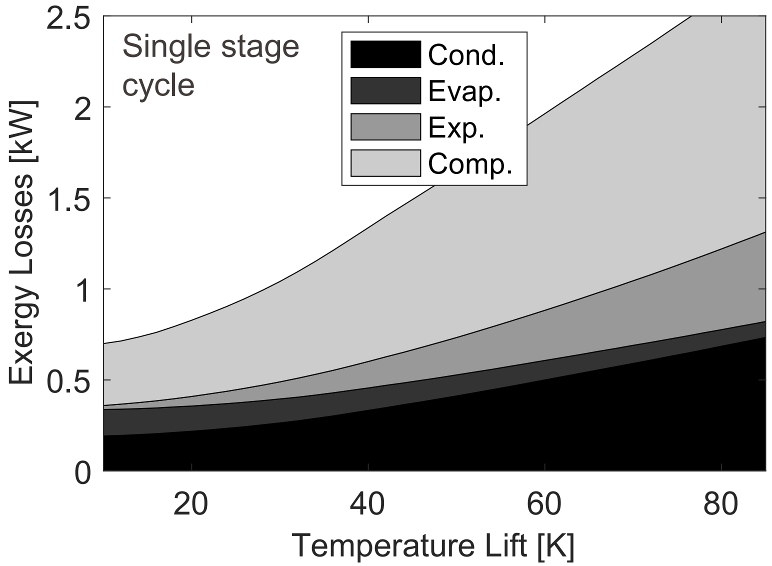
- Comparison based on realistic components and assumptions

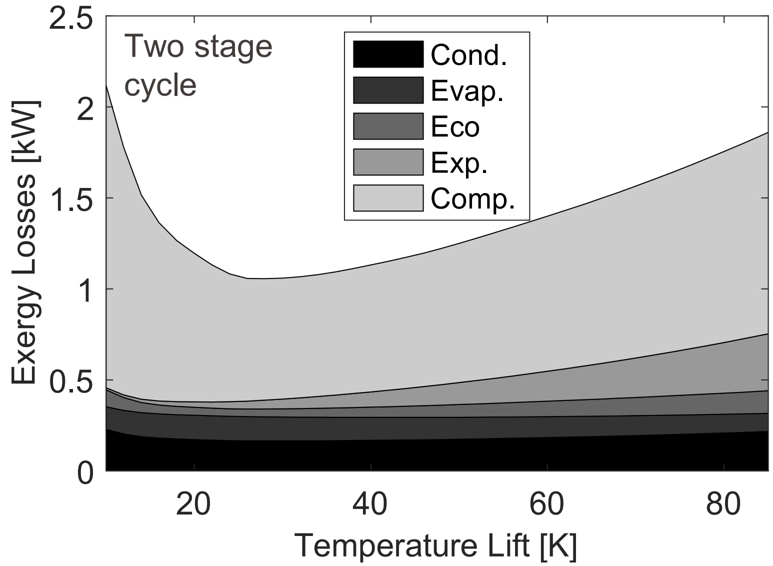




Comparison of Single and Double Stage HP Cycles

- Condenser losses decreased with twin stage cycle due to lower temperatures at compressor exhaust
- Expansion losses reduced with two stage cycle
- Two stage cycle compression losses decrease only at high lifts

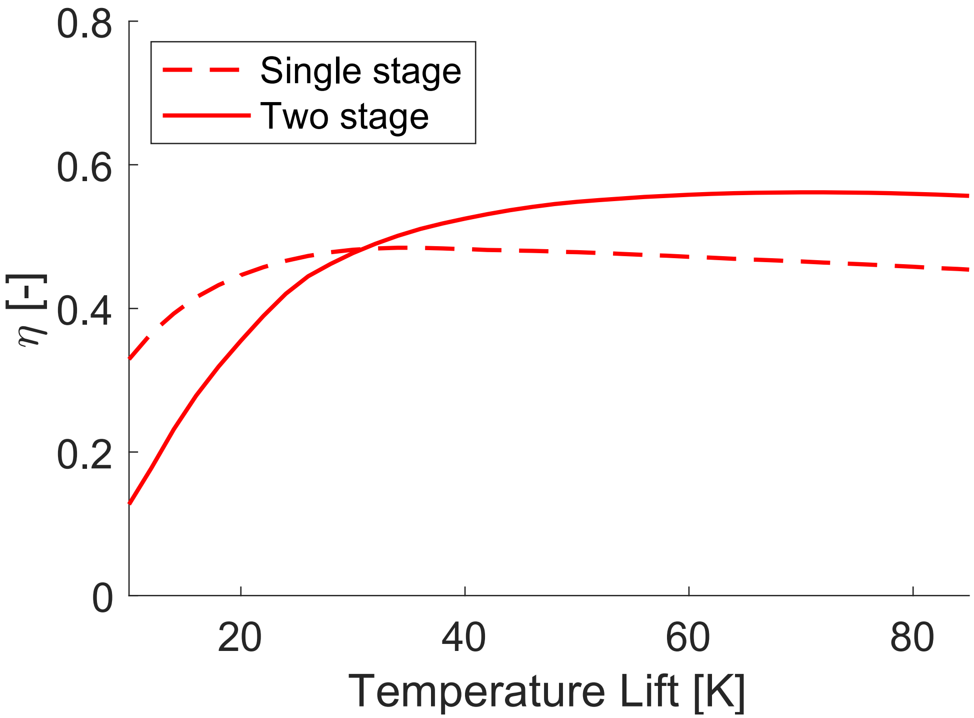




Benefits of Two Stage Compression HP Cycle

- Efficiency improves by ~20% compared to single stage HP cycle at high temperature lifts

- Two stage cycle makes no sense at low lifts due to low compressor efficiency (over-compression)



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Heat Pump Systems

Heat pump cycle improvements II

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Cycle Improvements

- Improvements can be achieved by improving individual component performance or by implementing more advanced thermodynamic cycles
  - Subcooling after condenser
  - Multistage compression with intercooling
  - Splitting expansion process
  - Cascades

- Cycles design to reduce compression exhaust temperature and/or to improve efficiency

Practical Aspects I

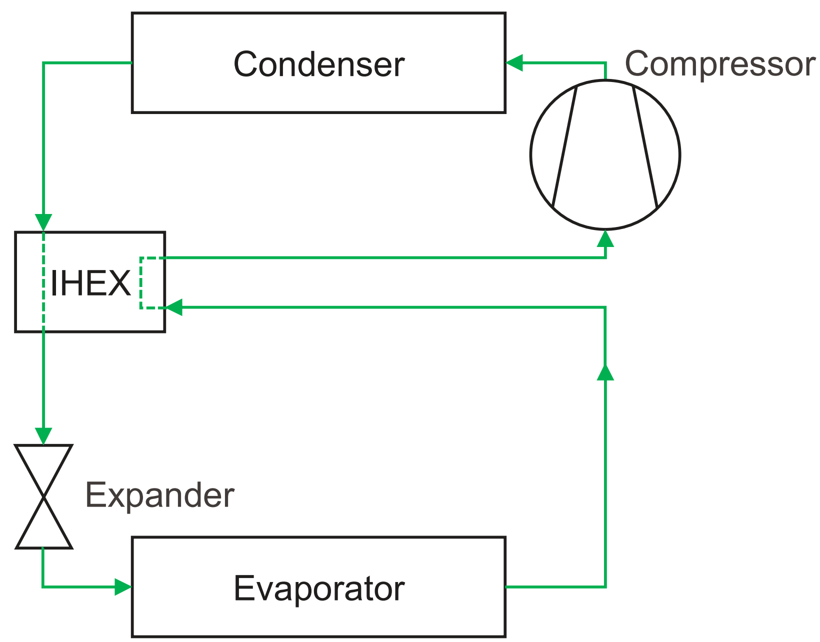
- High exhaust temperatures may damage lubricant (oil), deteriorate working fluid molecules and induce mechanical damage to compressor
- High exhaust temperatures occur when high temperature lifts are required
- Often primary objective is to reduce compressor exhaust temperature to enable high temperature lifts

Practical Aspects II

- Compressor must run with vapor → sufficient superheat at inlet
- Compressor exhaust temperature below threshold
- Expansion valve requires liquid fluid → vapor bubbles increase flow resistance
- Heat pump cycles rarely run at nominal condition → wide operating range needed (temperature lift & power modulation)

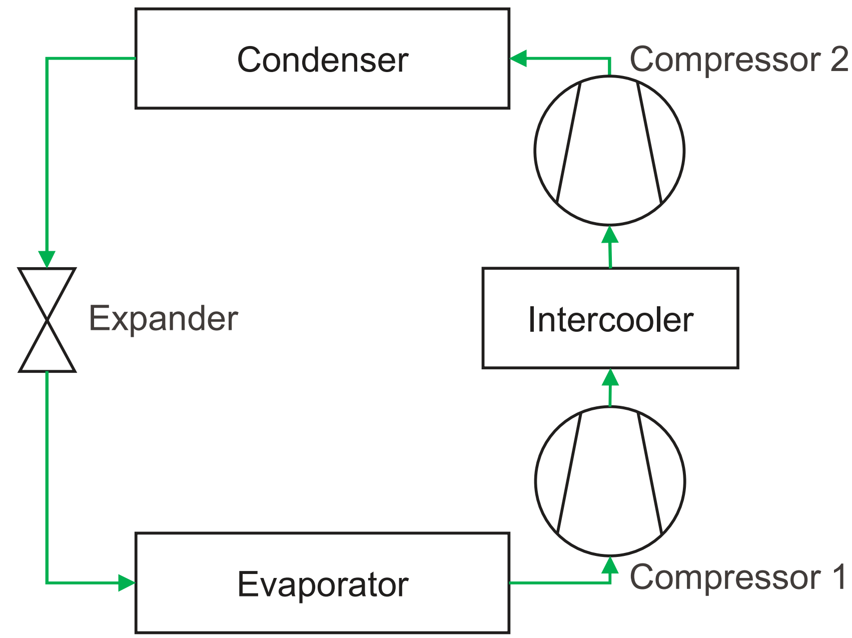
Suction Superheater Cycle

- Use of suction superheater offers operational benefits and safety and may improve cycle efficiency



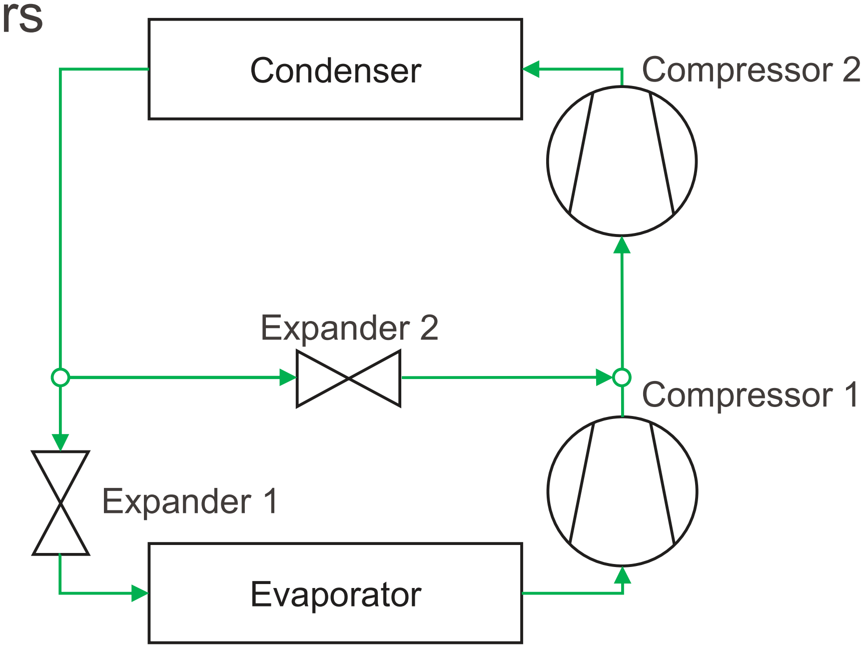
External Intercooling

- Intercooling between compressor stages by rejecting heat to ambient through air or water cooler
- Single stage expansion cycle



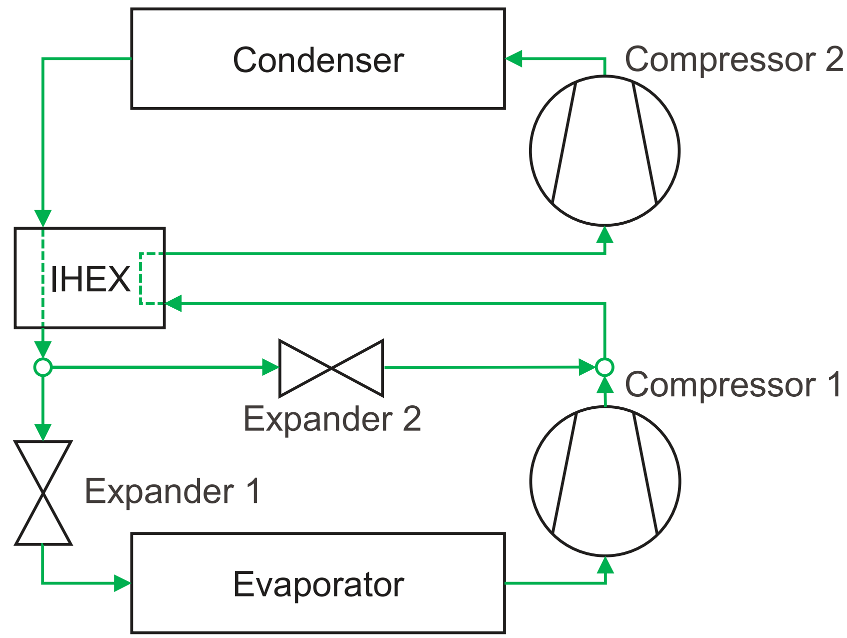
Partial Expansion with Intermediate Injection

- Intercooling between compressor stages by mixing of partially expanded fluid
- Different mass-flow seen by compressors



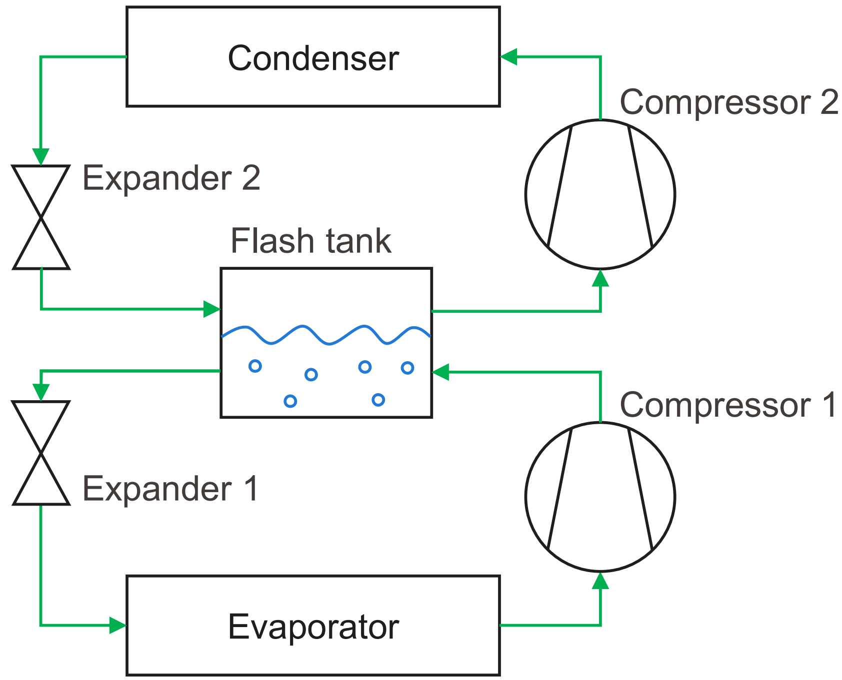
Partial Expansion with Intermediate Injection & Heat Exchanger

- Intercooling between compressor stages by mixing of partially expanded and reheated fluid
- Improved cooling performance



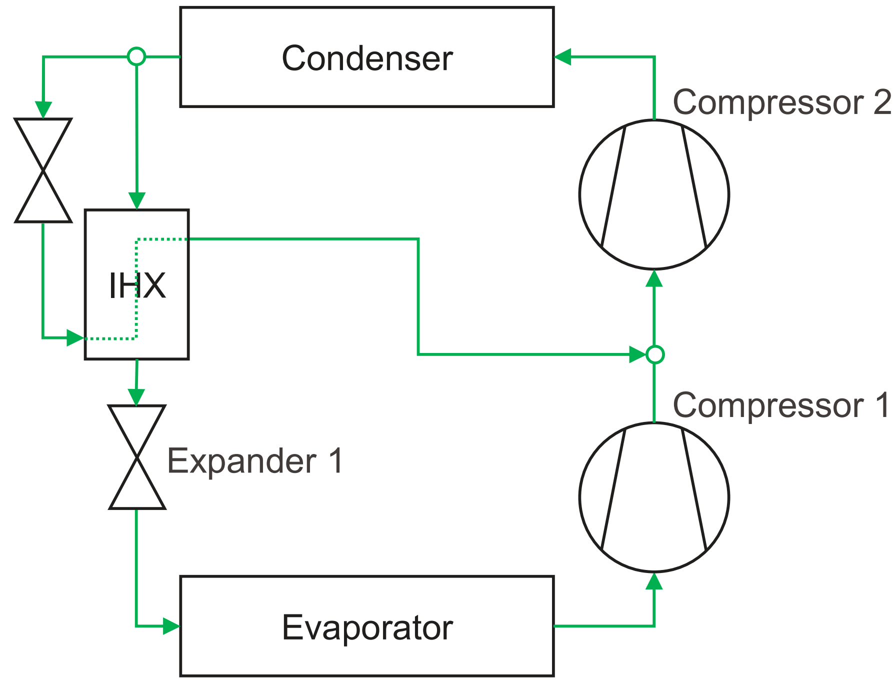
Two Stage Cycle with Open Flash Tank

- Cycle benefits from reduced expansion losses, decreased compression work and better compressor efficiency



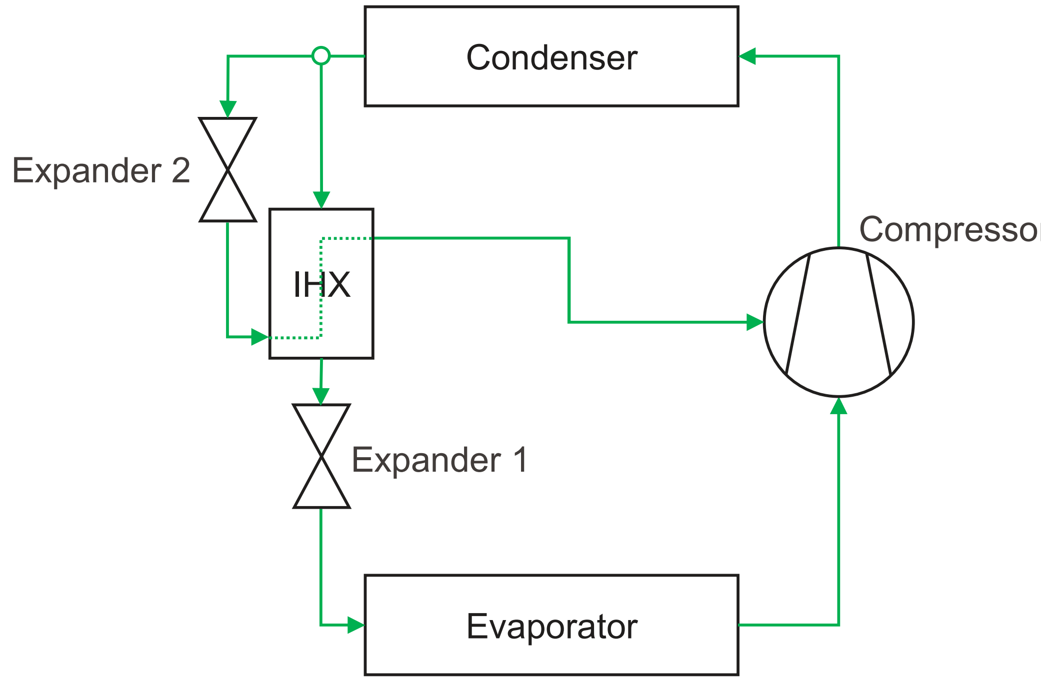
Two Stage Cycle with Internal Heat Exchanger

- To avoid distillation for working fluid mixtures internal heat exchanger with double expansion is applied



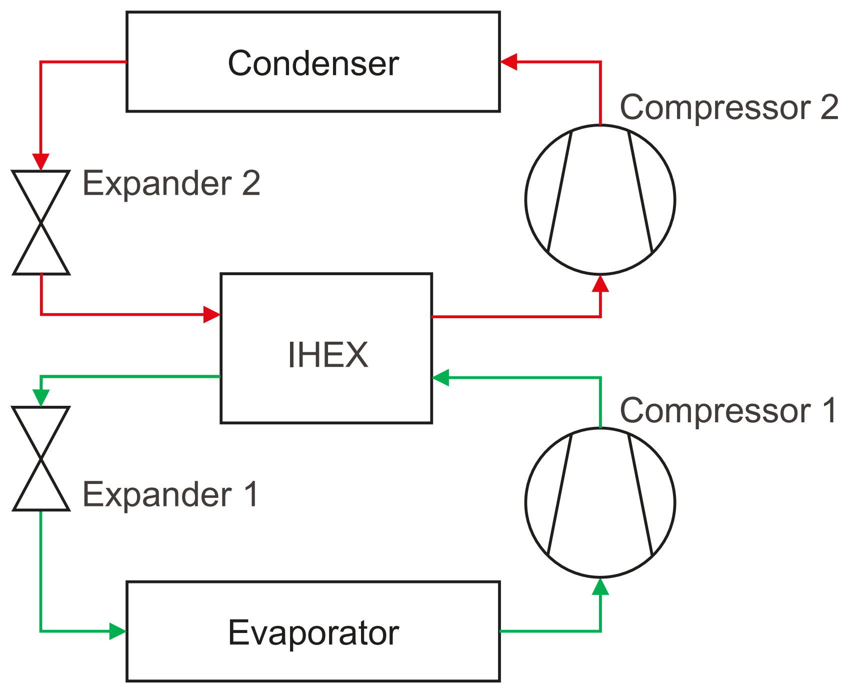
Injected Single Stage Compressor with Internal Heat Exchanger

- Use single stage compressor with intermediate injection port to avoid investment of two compressors



Cascade

- Single stage cycles are superposed and linked with heat exchanger
- Individual working fluids can be used for each cycle



Summary

- Performance improvement can be achieved by working on components and thermodynamic cycle
- Large variety of cycle improvements between single and two-(multi) stage cycles
- Moderate improvements can be achieved by combining slight modifications with operational limitations
- Ideal cycle and working fluid highly depend on application and its specifications

Outlook for W7

- Working fluids
- Introduction to compressor technologies

Exercises W6

- Theory questions
- A compressor driven heat pump installation