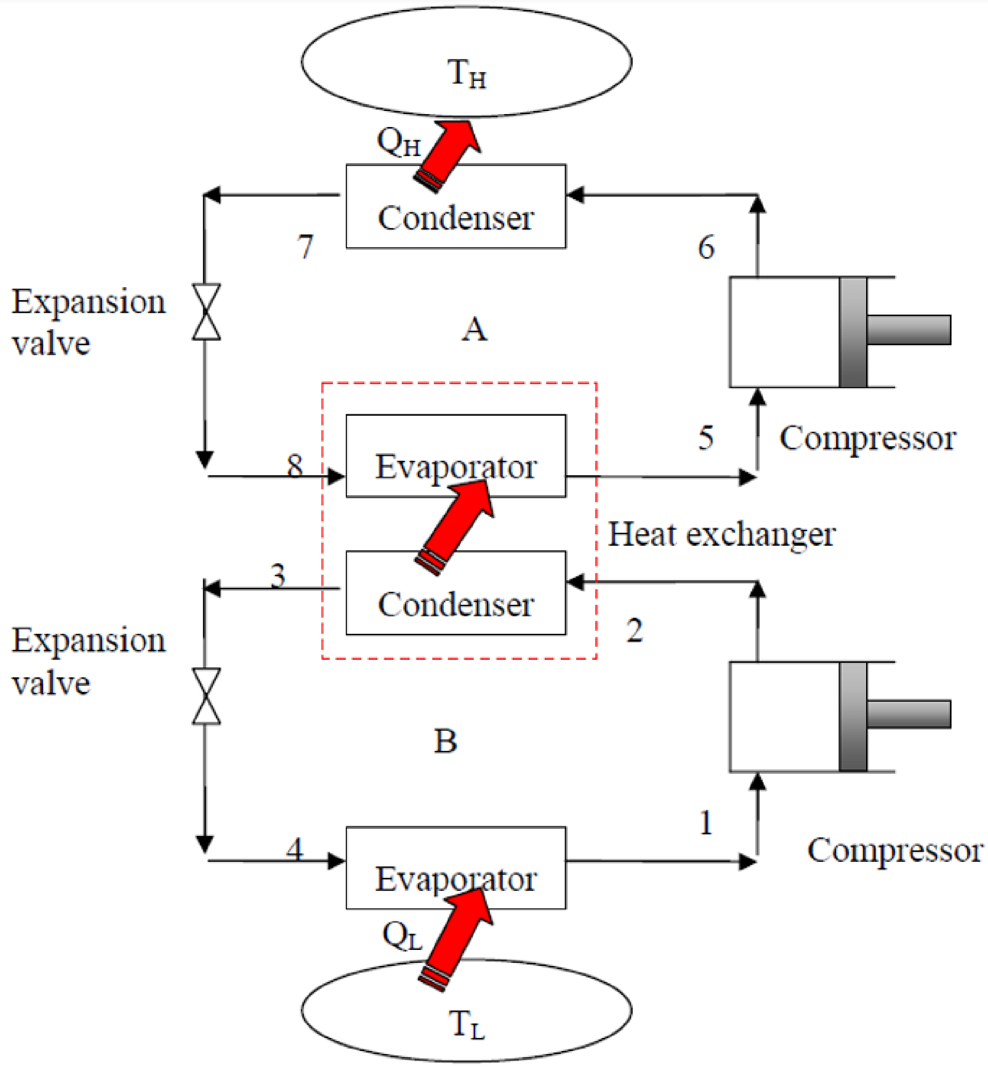
Cascade Refrigeration Cycle

Systems that have 2 (or more) refrigeration cycles operating in series.



A 2-stage cascade refrigeration cycle.

Cascade cycle is used where a very wide range of temperature between TL and TH is required. As shown in above, the condenser for the low temperature refrigerator is used as the evaporator for the high temperature refrigerator.

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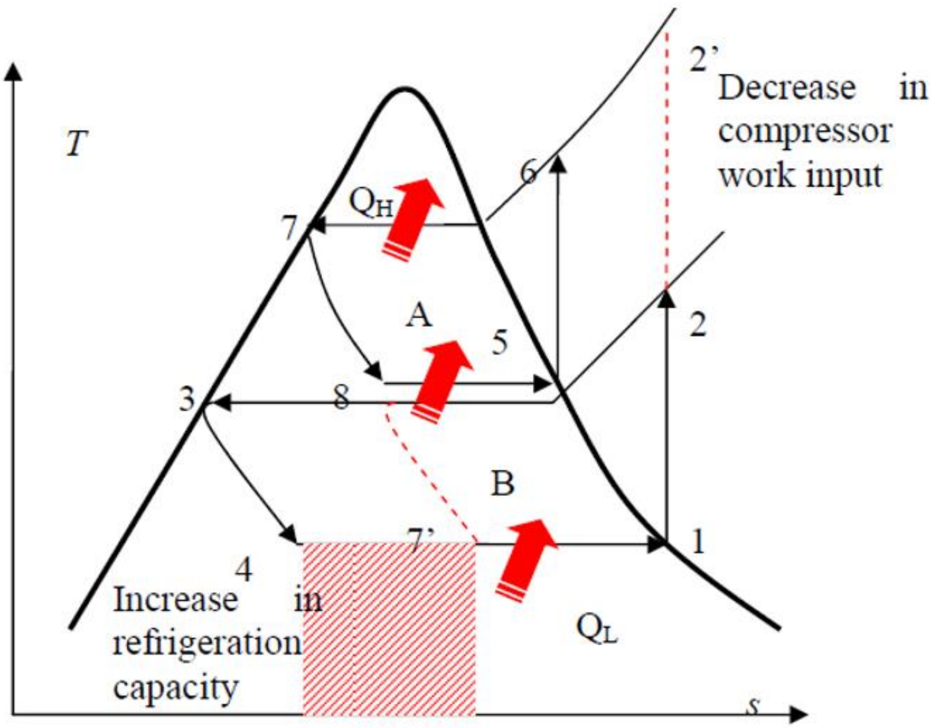
Cascading improves the COP of a refrigeration cycle. Moreover, the refrigerants can be selected to have reasonable evaporator and condenser pressures in the two or more temperature ranges.



T-s diagram for 2-stage cascade system.

The two cycles are connected through the heat exchanger in the middle, which serves as evaporator (cycle A) and condenser (cycle B). One can write:

$\dot{m}_A\,(h_5 - h_8) = \dot{m}_B\,(h_2 - h_3)$

$$COP_{R,cascade} = \frac{\dot{m}_B\,(h1 - h4)}{\dot{m}_A\,(h6 - h5) + \dot{m}_B\,(h2 - h1)}$$

Figure above shows the increase in refrigeration capacity (area under 4-7') and decrease in compressor work (2-2'-6-5).

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Example: A two-stage Refrigeration cycle

Consider a two-stage cascade refrigeration system operating between pressure limits of 0.8 and 0.14 MPa. Each stage operates on an ideal vapor-compression refrigeration cycle with refrigerant R-134a as working fluid. Heat rejection from the lower cycle to the upper cycle takes place in an adiabatic counter flow heat exchanger where both streams enter at about 0.3 MPa. If the mass flow rate of the refrigerant through the upper cycle is 0.05 kg/s, determine:

a) the mass flow rate of the refrigerant through the lower cycle.

b) the rate of heat removal from the refrigerated space and the power input to the compressor.

c) COP.

Assumptions:

1) Steady operation
2) ΔKE=ΔPE=0
3) Adiabatic heat exchanger.

Figure above shows the *T-s* diagram for the cascade cycle. Enthalpies for all 8 states of refrigerant R-134a can be read off Tables.

h_1 =239.16 kJ/kg, saturated vapour enthalpy at P=0.14 MPa.

h_2 = 259.2kJ/kg, super-heated vapour at P=0.3MPa.

h_3 = 55.16kJ/kg, saturated liquid enthalpy at P=0.3 MPa.

$h_4 = h_3$

h_5 =251.88 kJ/kg, saturated vapour enthalpy at P=0.3 MPa.

h_6 =276.5 saturated vapour enthalpy at P=0.8 MPa.

$h_8 = h_7$ = 95.47 kJ/kg, saturated liquid enthalpy at P=0.8 MPa.

Writing energy balance for the heat exchanger, the mass flow rate of the refrigerant through the lower cycle can be found:

$\dot{m}_A$ (h_5- h_8)= $\dot{m}_B$ (h_2- h_3)

0.05 kg (251.88 – 95.47) kJ/kg = $\dot{m}_B$(259.2 – 55.16) kJ/kg

$\dot{m}_B$= 0.038 kg/sec.

b) the heat removal by the cascade cycle can be determined from:

$\dot{Q}_L = \dot{m}_B$ (h_1- h_4) =0.038 kg/s (239.16 – 55.16) kJ/kg =6.992kW.

$\dot{w}_{in} = w_{Comp1,in} + w_{Comp2,in} = \dot{m}_A$ (h_6- h_5)+ $\dot{m}_B$ (h_2- h_1) = 1.992kW.

c) the COP of the cycle will be:

$COP_R = \frac{\dot{Q}_L}{\dot{W}_{net,in}} = \frac{6.992kW}{1.992kW}$ =3.51

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