Thermodynamic Calculations of Vapor Compression Refrigeration Cycle with Regeneration

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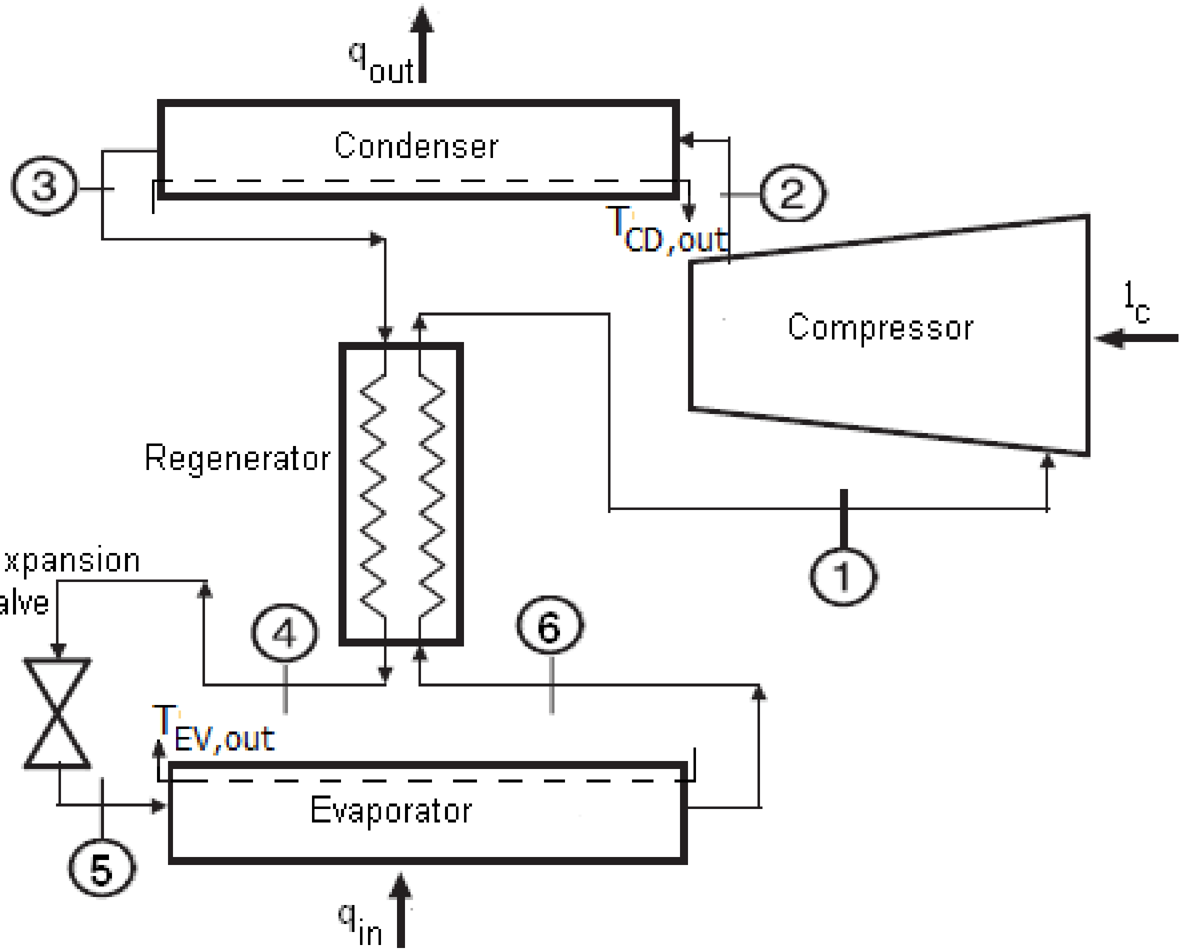
Introduction

There are a variety of ways that the refrigeration cycle can be tailored to suit an application in a better way (not always necessarily resulting in a higher COP) than the simple (basic) vapor compression cycle.
Addition of a single heat exchanger to the basic vapor compression cycle, exchanging heat between the fluid leaving the evaporator and the fluid leaving the condenser benefits of this cycle modification.
First, since the specific enthalpy remains constant during expansion, a reduction of the specific enthalpy prior to expansion results in a reduction of specific enthalpy prior to evaporation. Therefore the unit will have more evaporative heat transfer to provide more evaporator cooling capacity. Second, the state prior to compression is further away from the saturated vapor line. For most compressors, it is imperative that the state of the refrigerant prior to compression does not have any liquid in the form of droplets or mist, since liquid entrained in a vapor undergoing compression tends to damage the fast moving parts of a compressor, seriously degrading the performance and working life span of the compressor. For this reason, it is usually desirable for the refrigerant to enter the compressor as a superheated vapor, several degrees above the saturation temperature at the pre-compression pressure. The internal heat exchanger, by increasing the enthalpy and temperature of the pre-compression refrigerant, assists in ensuring that a superheated vapor with no liquid droplets enters the compressor.
This application is for thermodynamic calculations of vapor compression refrigeration cycle with regeneration



Creation functions on properties and processes of working fluids

```
> restart
> with(ThermophysicalData) :
  with(Units[Standard]) :
  with(plots) :
```

Vapor pressure on the saturated line as a function of temperature

```
> PSVTwf := (T, wf) → Property(P, temperature = T, Q = 1, wf) :
```

Liquid pressure on the saturated line as a function of temperature

```
> PSLTwf := (T, wf) → Property(P, temperature = T, Q = 0, wf) :
```

Liquid temperature on the saturated line as a function of pressure

```
> TSLPwf := (p, wf) → Property(T, pressure = p, Q = 0, wf) :
```

Vapor temperature on the saturated line as a function of pressure

```
> TSVPwf := (p, wf) → Property(T, pressure = p, Q = 1, wf) :
```

Liquid specific enthalpy on the saturated line as a function of temperature

```
> HSLTwf := (T, wf) → Property(enthalpy, temperature = T, Q = 0, wf) :
```

Liquid specific enthalpy on the saturated line as a function of pressure

```
> HSLPwf := (p, wf) → Property(enthalpy, pressure = p, Q = 0, wf) :
```

Vapor specific enthalpy on the saturated line as a function of pressure

```
> HSVPwf := (p, wf) → Property(enthalpy, pressure = p, Q = 1, wf) :
```

Liquid specific entropy on the saturated line as a function of temperature

```
> SSLTwf := (T, wf) → Property(entropy, temperature = T, Q = 0, wf) :
```

Liquid specific entropy on the saturated line as a function of pressure

```
> SSLPwf := (p, wf) → Property(entropy, pressure = p, Q = 0, wf) :
```

Vapor specific entropy on the saturated line as a function of pressure

```
> SSVPwf := (p, wf) → Property(entropy, pressure = p, Q = 1, wf) :
```

Temperature as a function of pressure and specific entropy

```
> TPSwf := (p, s, wf) → Property(T, pressure = p, entropy = s, wf) :
```

Temperature as a function of pressure and specific enthalpy

```
> TPHwf := (p, h, wf) → Property(T, pressure = p, enthalpy = h, wf) :
```

Specific enthalpy as a function of pressure and temperature

```
> HPTwf := (p, T, wf) → Property(H, pressure = p, temperature = T, wf) :
```

Specific entropy as a function of pressure and temperature

```
> SPTwf := (p, T, wf) → Property(S, pressure = p, temperature = T, wf) :
```

```
> HCOMPRESSIONPTPEFFwf := proc( p1, T1, p2, eff, wf)
  #Specific enthalpy of working fluid at the end of compression process as function of pressure p1 and
      temperature T1 at initial point 1 (superheated vapor), pressure at final point p2,
      internal efficiency of the compressor eff, type of working fluid
  local h1, s1, s2_is, T2_is, h2_is;
  h1 := HPTwf(p1, T1, wf) :
  s1 := SPTwf(p1, T1, wf) :
  s2_is := s1 :
  T2_is := TPSwf(p2, s2_is, wf) : h2_is := HPTwf(p2, T2_is, wf) :
  return h1 + (h2_is - h1)/eff
  end proc:
```

Input Data

Temperature of heat source fluid at evaporator outlet

> $T_{EV,out} := (-12 + 273.15)\,K$

$$261.15\ K \tag{3.1}$$

Temperature of heat consumption fluid at condenser outlet

> $T_{CD,out} := (50 + 273.15)\,K$

$$323.15\ K \tag{3.2}$$

Temperature difference at the cold end of the evaporator

> $\delta T_{EV,c} := 4K$

$$4\ K \tag{3.3}$$

Temperature difference at the hot end of the condenser

> $\delta T_{CD,h} := 4K$

$$4\ K \tag{3.4}$$

Temperature difference at hot end of the regenerator

> $\delta T_{R,h} := 10K$

$$10\ K \tag{3.5}$$

Isentropic efficiency of the compressor

> $\eta_{comp} := 0.8$

$$80,\% \tag{3.6}$$

Working fluid

> $wf := R134a$

$$wf := R134a \tag{3.7}$$

Calculations

Temperature of the working fluid at the evaporator intlet

> $T_5 := T_{EV,out} - \delta T_{EV,c}$

$$257,15\ K \tag{4.1}$$

Pressure of the working fluid at the evaporator intlet

> $p_5 := \mathrm{PSLTwf}(T_5, \mathrm{wf})$

$$157,28 \times 10^3\ Pa \tag{4.2}$$

Pressure of the working fluid at the compressor outlet

> $p_2 := \mathrm{PSVTwf}(T_{CD,out} + \delta T_{CD,h}, \mathrm{wf})$

$$1,46 \times 10^6\ Pa \tag{4.3}$$

Pressure of the working fluid at the condenser outlet

> $p_3 := p_2$

$$1,46 \times 10^6\ Pa \tag{4.4}$$

Temperature of the working fluid at the condenser outlet

> $T_3 := \mathrm{TSLPwf}(p_3, \mathrm{wf})$

$$327,15\ K \tag{4.5}$$

Specific enthalpy of the working fluid at the condenser outlet

> $h_3 := \mathrm{HSLTwf}(T_3, \mathrm{wf})$

$$277,89 \times 10^3\ \frac{J}{kg} \tag{4.6}$$

Specific entropy of the working fluid at the condenser outlet

> $s_3 := \mathrm{SSLTwf}(T_3, \mathrm{wf})$

$$1,26 \times 10^3\ \frac{J}{kg\ K} \tag{4.7}$$

Pressure of the working fluid at the compressor intlet

> $p_1 := p_5$

$$157{,}28 \times 10^3 \text{ Pa} \quad \textbf{(4.8)}$$

Temperature of the working fluid at the compressor intlet

> $T_1 := T_3 - \delta T_{R,h}$

$$317{,}15 \text{ K} \quad \textbf{(4.9)}$$

Specific enthalpy of the working fluid at the compressor intlet

> $h_1 := \text{HPTwf}(p_1, T_1, \text{wf})$

$$440{,}11 \times 10^3 \frac{\text{J}}{\text{kg}} \quad \textbf{(4.10)}$$

Specific entropy of the working fluid at the compressor intlet

> $s_1 := \text{SPTwf}(p_1, T_1, \text{wf})$

$$1{,}92 \times 10^3 \frac{\text{J}}{\text{kg K}} \quad \textbf{(4.11)}$$

Specific enthalpy of the working fluid at the compressor outlet

> $h_2 := \text{HCOMPRESSIONPTPEFFwf}(p_1, T_1, p_2, \eta_{comp}, \text{wf})$

$$515{,}51 \times 10^3 \frac{\text{J}}{\text{kg}} \quad \textbf{(4.12)}$$

Enhtalpy change in the compressor after actual compression

> $l_c := h_2 - h_1$

$$75{,}40 \times 10^3 \frac{\text{J}}{\text{kg}} \quad \textbf{(4.13)}$$

Temperature of the working fluid at the compressor outlet

> $T_2 := \text{TPHwf}(p_2, h_2, \text{wf})$

$$407{,}57 \text{ K} \quad \textbf{(4.14)}$$

Specific entropy of the working fluid at the compressor outlet

> $s_2 := \text{SPTwf}(p_2, T_2, \text{wf})$

$$1{,}95 \times 10^3 \frac{\text{J}}{\text{kg K}} \quad \textbf{(4.15)}$$

Temperature of saturated liquid of the working fluid at the evaporator inlet

> $T_{sl,5} := \text{TSLPwf}(p_5, \text{wf})$

$$257{,}15 \text{ K} \quad \textbf{(4.16)}$$

Specific enthalpy of saturated liquid of the working fluid at the evaporator inlet

> $h_{sl,5} := \text{HSLPwf}(p_5, \text{wf})$

$$178{,}83 \times 10^3 \frac{\text{J}}{\text{kg}} \quad \textbf{(4.17)}$$

Pressure of the working fluid at the compressor intlet

> $p_6 := p_1$

$$157{,}28 \times 10^3 \text{ Pa} \quad \textbf{(4.18)}$$

Temperature of saturated vapor of the working fluid at the evaporator outlet

> $T_6 := TSVPwf(p_6, wf)$

$$257, K \quad (4.19)$$

Specific enthalpy of saturated vapor of the working fluid at the evaporator outlet

> $h_6 := HSVPwf(p_6, wf)$

$$389{,}02 \times 10^3 \frac{J}{kg} \quad (4.20)$$

Specific enthalpy of the working fluid at the regenerator outlet

> $h_4 := h_3 - (h_1 - h_6)$

$$226{,}79 \times 10^3 \frac{J}{kg} \quad (4.21)$$

Pressure of the working fluid at the regenerator outlet

> $p_4 := p_3$

$$1{,}46 \times 10^6 \, Pa \quad (4.22)$$

Temperature of the working fluid at the regenerator outlet

> $T_4 := TPHwf(p_4, h_4, wf)$

$$292{,}61 \, K \quad (4.23)$$

Specific entropy of the working fluid at the regenerator outlet

> $s_4 := SPTwf(p_4, T_4, wf)$

$$1{,}09 \times 10^3 \frac{J}{kg\,K} \quad (4.24)$$

Specific enthalpy of the working fluid at the evaporator intlet

> $h_5 := h_4$

$$226{,}79 \times 10^3 \frac{J}{kg} \quad (4.25)$$

Quality of the working fluid at the evaporator intlet

> $x_5 := \frac{h_5 - h_{sl,5}}{h_6 - h_{sl,5}}$

$$22{,}82\% \quad (4.26)$$

Specific entropy of saturated liquid of the working fluid at the evaporator inlet

> $s_{sl,5} := SSLPwf(p_5, wf)$

$$920{,}54 \frac{J}{kg\,K} \quad (4.27)$$

Specific entropy of saturated vapor of the working fluid at the evaporator outlet

> $s_{sv,6} := SSVPwf(p_6, wf)$

$$1{,}74 \times 10^3 \frac{J}{kg\,K} \quad (4.28)$$

Specific entropy of the working fluid at the evaporator inlet

> $s_5 := s_{sl,5} + x_5 \cdot (s_{sv,6} - s_{sl,5})$

$$1{,}11 \times 10^3 \frac{J}{kg\,K} \quad (4.29)$$

Heat rejection in the condenser

> $q_{out} := h_2 - h_3$

$$237{,}63 \times 10^{3}\ \frac{\mathrm{J}}{\mathrm{kg}} \qquad (4.30)$$

Heat addition in the evaporator

> $q_{in} := h_6 - h_5$

$$162{,}22 \times 10^{3}\ \frac{\mathrm{J}}{\mathrm{kg}} \qquad (4.31)$$

Coefficent of performance of a refrigerator

> $COP_R := \frac{q_{in}}{l_c}$

$$2{,}15 \qquad (4.32)$$

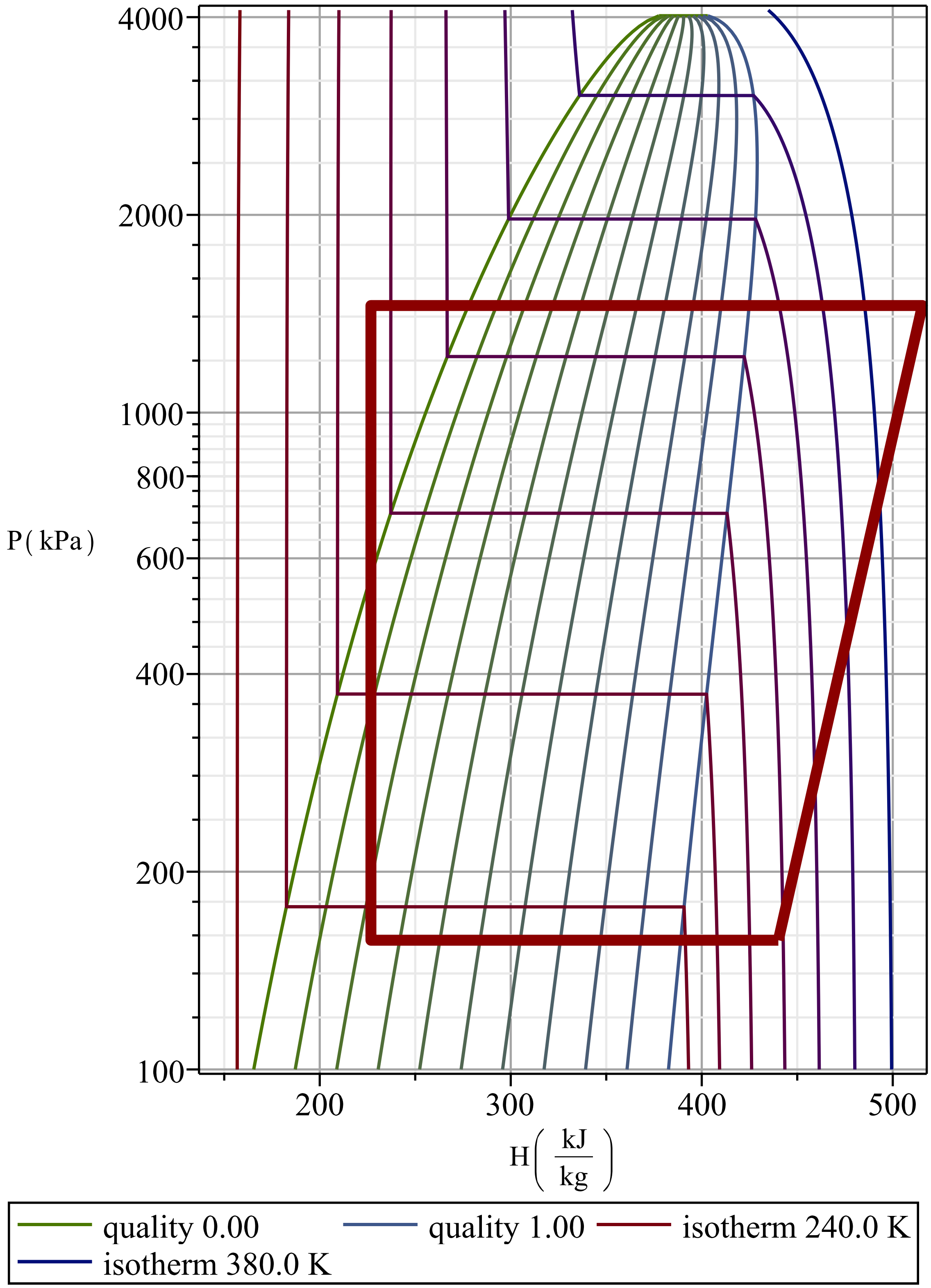
Coefficent of performance of a heat pump

> $COP_{HP} := \frac{q_{out}}{l_c}$

$$3{,}15 \qquad (4.33)$$

Plot the Refrigeration Cycle on a P-h-T Chart

```
> phtChart := PHTChart(wf, 100 kPa ..4100 kPa) :
> pts := convert~~([[([h1, p1]), [h2, p2], [h3, p3], [h4, p4], [h5, p5], [h6, p6], [h1, p1]], unit_free) :
> cycle := pointplot(0.001·~pts, connect = true, color = "DarkRed", thickness = 5) :
> display(phtChart, cycle)
```


4000
2000
1000
800
600
400
200
100
P(kPa)
200
300
400
500
H(kJ/kg)
quality 0.00
quality 1.00
isotherm 240.0 K
isotherm 380.0 K

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