# Rankine cycle

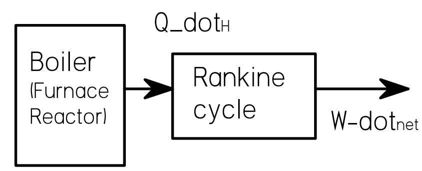
*rev 2 added s = constant interpolation area to determine state 2 enthalpy and corrected $T_2$ calc*

this file calculates reversible Rankine cycle with following parameters:
condenser 40 deg C
steam pressure 30 bars (3 MPa)
superheat 460 deg_C

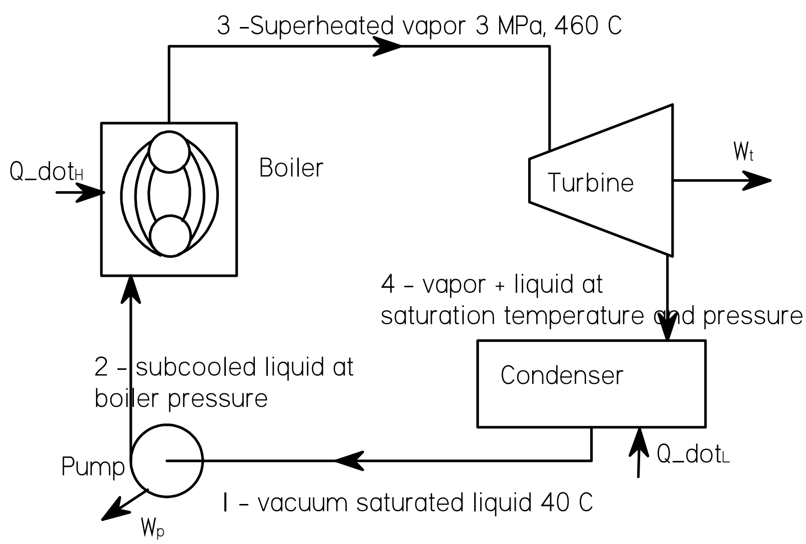
define some units $kJ := 10^3 \cdot J$

$kN := 10^3 \cdot N$ $kPa := 10^3 \cdot Pa$

$MPa := 10^6 Pa$ $bar := 0.1MPa$




conceptual Rankine cycle




1 - vacuum; saturated liquid

2 - sub cooled liquid at boiler pressure

3 - superheated vapor

4 - vapor + liquid @ saturation temperature and pressure

refer to T-s and H-s diagrams at end of file

## state 1: condenser outlet

$T_1 := 40$ $p_1 := 7.384kPa$ $v_{f\_1} := 0.0010078 \frac{m^3}{kg}$ $v_1 := v_{f\_1}$

Table 1 or Table A.1.1

$s_{f\_1} := 0.5725 \frac{kJ}{kg \cdot K}$ $s_{fg\_1} := 7.6845 \frac{kJ}{kg \cdot K}$ $h_{f\_1} := 167.57 \frac{kJ}{kg}$ $h_{fg\_1} := 2406.7 \frac{kJ}{kg}$

$s_1 := s_{f\_1}$ $h_1 := h_{f\_1}$

## state 2: pump outlet

assume $v_f = v_1$ constant, isentropic, ds = 0 =>T*ds= 0 => h2 = h1+v1*dp from relationships Tds = dh + v*dp integrated with constant v and Tds = 0

$s_2 := s_1$

$p_2 := 30\text{bar}$ $\quad h_2 := h_1 + v_1 \cdot (p_2 - p_1)$ $\quad h_2 = 170.586 \frac{kJ}{kg}$

$w_p := h_1 - h_2$ $\quad w_p = -3.016 \frac{kJ}{kg}$

calc of T in earlier version incorrect see VW&S 5.18 with C = 4.184 kJ/(kg*K) Table A.7

using $C_p$ $\quad Cp := 4.184 \frac{kJ}{kg}$ $\quad \frac{kJ}{kg \cdot K}$ actual units

@ T = 40 C
p = 3 MPa

and ... eqn 5.18 $\quad h_2 - h_1 = Cp \cdot (T_2 - T_1)$

$p_2 = 3\,MPa$

$h_{22} := 170.21 \cdot \frac{kJ}{kg}$ $\quad h_2 = 170.586 \frac{kJ}{kg}$ $\quad T_{22} := 40$ $\quad T_2 := T_{22} + \frac{h_2 - h_{22}}{Cp}$ $\quad T_2 = 40.09$

s = constant interpolation

$h_2 = 170.586 \frac{kJ}{kg}$ using $h_2 = h_1 + v_1 \cdot (p_2 - p_1)$ and then $C_p$ $\quad T_2 = 40.09$

interpolation results ...

$h_{2a} = 170.609 \frac{kJ}{kg}$ interpolation Table 2 page 7 subcooled region $\quad T_{2a} = 40.096$

$h_{2b} = 170.598 \frac{kJ}{kg}$ interpolation K&K 40 - 60 T range but p= 2.5 and p = 5 MPa interpolation for p = 3 MPa required first $\quad T_{2b} = 40.093$

$h_{2c} = 170.6 \frac{kJ}{kg}$ interpolation VW&S Table A.1.4 40 - 60 T range but p= 10 and p = 5 MPa extrapolation for p = 3 MPa required first $\quad T_{2c} = 40.096$

## state 3: boiler outlet

$p_3 := p_2$ $\quad T_3 := 460$ $\quad p_3 = 3\,MPa$

from table 2 handout: $\quad h_3 := 3366.7 \cdot \frac{kJ}{kg}$ $\quad s_3 := 7.114 \cdot \frac{kJ}{kg \cdot K}$

interpolation

from interpolation Table A.1.3 P=3MPa page 622 $\quad h_{3a} = 3366.5 \frac{kJ}{kg}$ $\quad s_{3a} = 7.113 \frac{kJ}{kg \cdot K}$

## state 4: turbine outlet

isentropic expansion to 40 deg C
determine $h_4$ from x

$s_4 := s_3$

$s_4 = s_{f\_1} + x \cdot s_{fg\_1}$ => $\quad x := \frac{s_4 - s_{f\_1}}{s_{fg\_1}}$ $\quad x = 0.851$

$h_4 := h_{f\_1} + h_{fg\_1} \cdot x$ $\quad h_4 = 2216 \frac{kJ}{kg}$

$w_t := h_3 - h_4$ $\quad w_t = 1150 \frac{kJ}{kg}$

thermal efficiency

$$\eta_{th} = \frac{work\_net}{Q_H} = \frac{Q_H + Q_L}{Q_H} = \frac{w_t + w_p}{Q_H} = \frac{(h_3 - h_4) + (h_1 - h_2)}{h_3 - h_2}$$

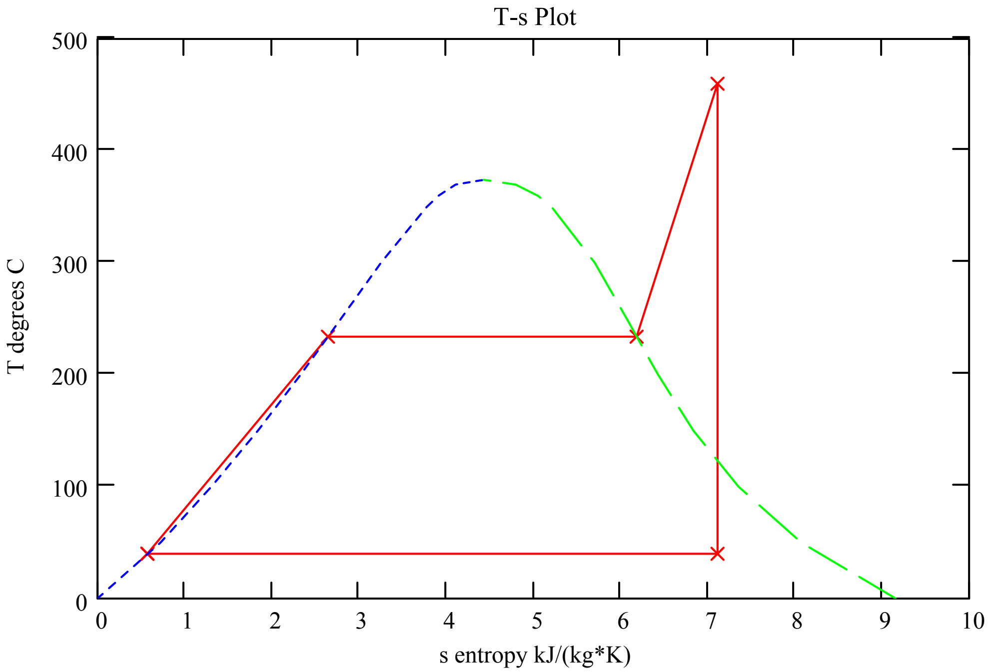
$$\eta_{th} := \frac{(h_3 - h_4) - (h_2 - h_1)}{h_3 - h_2} \qquad \eta_{th} = 0.359 \qquad \eta_{th} := \frac{w_t + w_p}{h_3 - h_2} \qquad \eta_{th} = 0.359$$

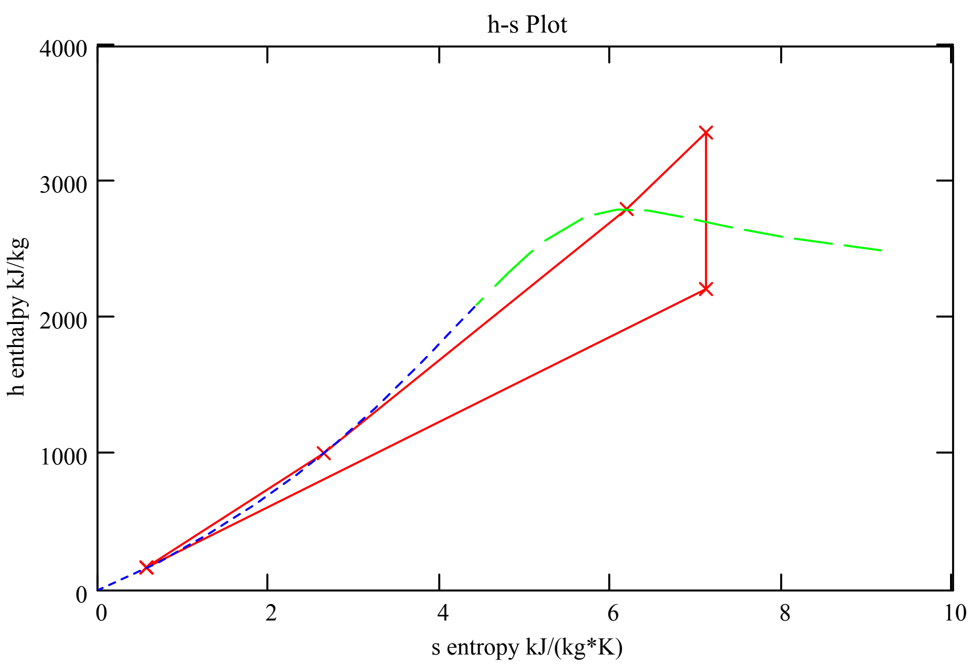
$$Q_H := h_3 - h_2 \qquad Q_L := h_1 - h_4$$

$$\eta_{th\_1} := \frac{Q_H + Q_L}{Q_H} \qquad \eta_{th\_1} = 0.359$$

▸ data for saturation curve

▸ data for T s and H s plots


T-s Plot
T degrees C
s entropy kJ/(kg*K)
0
100
200
300
400
500
0
1
2
3
4
5
6
7
8
9
10


h-s Plot
h enthalpy kJ/kg
s entropy kJ/(kg*K)
0
1000
2000
3000
4000
0
2
4
6
8
10

close up of points 1 and 2