Thermal Efficiency of Steam Turbine Cycle with 2 Pre-heaters

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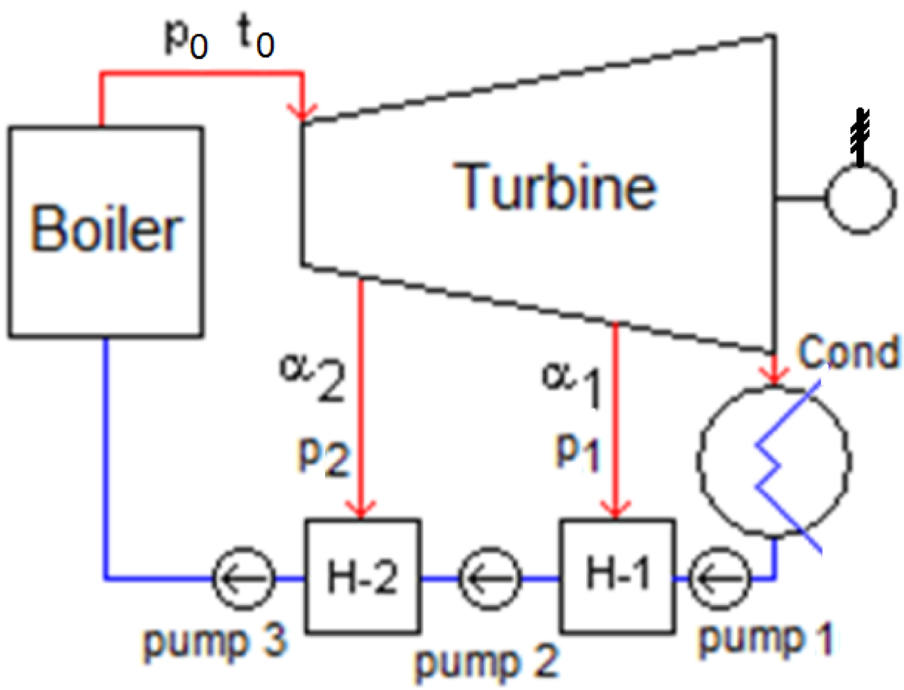
Introduction

This application calculates the thermal efficiency of a steam turbine cycle with two pre-heaters



Water Properties

```
> restart :
  with(ThermophysicalData) :
```

Specific entropy of water or steam as function of pressure and temperature

```
> wspSPT := (P, T) → Property(entropy, pressure = P, temperature = T, water) :
```

Specific enthalpy of water or steam as function of pressure and temperature

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> wspHPT := (P, T) → Property(enthalpy, pressure = P, temperature = T, water) :
```

Vapor fraction of steam as function of pressure and specific entropy

```
> wspXPS := (P, S) → Property(Q, pressure = P, entropy = S, water) :
```

Specific enthalpy of water or steam as function of temperature and vapor fraction

```
> wspHSTX := (T, X) → Property(enthalpy, temperature = T, Q = X, water) :
```

Specific enthalpy of water at the saturated line as function of pressure

```
> wspHSWP := P→Property(enthalpy, pressure = P, Q = 0, water) :
```

Specific entropy of water at the saturated line as function of pressure

```
> wspSSWP := P→Property(entropy, pressure = P, Q = 0, water) :
```

Specific enthalpy of water or steam as function of pressure and specific entropy

```
> wspHPS := (P, S) → Property(enthalpy, pressure = P, entropy = S, water) :
```

Temperature of water or steam as function of pressure and specific entropy

```
> wspTPS := (P, S) → Property(temperature, pressure = P, entropy = S, water) :
```

Functions for processes steam expansion and water compression

```
> wspHEXPANSIONPTPEFF := proc( p0, t0, p1, eff)
  # Specific enthalpy of steam at the end of steam expansion process as function of pressure at initial
      point p0, temperature at initial point t0, pressure at final point p1, internal efficiency of  the
      turbine eff
  local h0, s0, s1, t1, x1, h1;
  h0 := wspHPT(p0, t0) :
  s0 := wspSPT(p0, t0) :
   s1 := s0 :
   t1 := wspTPS(p1, s1) :
  if Property(PhaseString, pressure = p1, entropy = s1, water) ="twophase"
  then
    x1 := wspXPS(p1, s1) :
    h1 := wspHSTX(t1, x1)
  else
    h1 := wspHPT(p1, t1)
  end if:
  return h0 − (h0 − h1)·eff
  end proc:
```

```
> wspHCOMPRESSIONPPEFF := proc( p0, p1, eff)

      # Specific enthalpy of water at the end of water compression process as function of pressure at
      initial point p0 (satutated line), pressure at final point p1, internal efficiency of the pump eff
  local h0, s0, s1, h1;
  h0 := wspHSWP(p0) :
  s0 := wspSSWP(p0) :
   s1 := s0 :
  h1 := wspHPS(p1, s1) :
  return h0 + (h1 − h0)/eff
  end proc:
```

Input Data

```
> t_0 := 540degC :
   p_0 := 13MPa :
   p_2 := 7MPa :
   p_1 := 3MPa :
```

$p\_cond := 4kPa :$
$\eta\_i\_t := 0.85 :$ # Internal efficiency of the turbine
$\eta\_i\_p := 0.75 :$ # Internal efficiency of pumps

Calculations

Heat balance of in H-1 and H-2 pre-heaters:

> $equ1 := (1 - \alpha\_1 - \alpha\_2) \cdot h\_p1out + \alpha\_1 \cdot h\_1 = (1 - \alpha\_2) \cdot h\_p2in :$

> $equ2 := (1 - \alpha\_2) \cdot h\_p2out + \alpha\_2 \cdot h\_2 = h\_p3in :$

Specific enthalpy of steam in the inlet of the turbine

> $h\_0 := wspHPT(p\_0, t\_0)$

$$3\,445{,}0 \ \frac{kJ}{kg} \tag{4.1}$$

Specific enthalpy of steam in the inlet of the pre-heater 2

> $h\_2 := wspHEXPANSIONPTPEFF(p\_0, t\_0, p\_2, \eta\_i\_t)$

$$3\,276{,}1 \ \frac{kJ}{kg} \tag{4.2}$$

Specific enthalpy of steam in the inlet of the pre-heater 1

> $h\_1 := wspHEXPANSIONPTPEFF(p\_0, t\_0, p\_1, \eta\_i\_t)$

$$3\,079{,}3 \ \frac{kJ}{kg} \tag{4.3}$$

Specific enthalpy of wet steam in the outlet of the turbine

> $h\_cond := wspHEXPANSIONPTPEFF(p\_0, t\_0, p\_cond, \eta\_i\_t)$

$$2\,200{,}3 \ \frac{kJ}{kg} \tag{4.4}$$

Specific enthalpy of water in the inlet of the pump 1

> $h\_p1in := wspHSWP(p\_cond)$

$$121{,}4 \ \frac{kJ}{kg} \tag{4.5}$$

Specific enthalpy of water in the outlet of the pump 1

> $h\_p1out := wspHCOMPRESSIONPPEFF(p\_cond, p\_1, \eta\_i\_p)$

$$125{,}40 \ \frac{kJ}{kg} \tag{4.6}$$

Specific enthalpy of water in the inlet of the pump 2

> $h\_p2in := wspHSWP(p\_1)$

$$1\,008{,}3 \ \frac{kJ}{kg} \tag{4.7}$$

Specific enthalpy of water in the outlet of the pump 2

> $h\_p2out := wspHCOMPRESSIONPPEFF(p\_1, p\_2, \eta\_i\_p)$

$$1\,014{,}8 \ \frac{kJ}{kg} \tag{4.8}$$

Specific enthalpy of water in the inlet of the pump 3

> h_p3in := wspHSWP(p_2)

$$1\,267{,}7\ \frac{kJ}{kg} \tag{4.9}$$

Specific enthalpy of water in the outlet of the pump 3 (feed water for the boiler)

> h_p3out := wspHCOMPRESSIONPPEFF(p_2, p_0, η_i_p)

$$1\,278{,}4\ \frac{kJ}{kg} \tag{4.10}$$

Solution of the system of equations (see above) of the heat balance in H-1 and H-2 pre-heaters:

> res := solve({equ1, equ2}, {α_1, α_2})

$$res := \{\alpha\_1 = 26{,}55\%, \alpha\_2 = 11{,}18\%\} \tag{4.11}$$

Specific work of the turbine

> w_t := eval((h_0 − h_2) + (1 − α_2)·(h_2 − h_1) + (1 − α_1 − α_2)·(h_1 − h_cond), res)

$$891{,}08\ \frac{kJ}{kg} \tag{4.12}$$

Specific work of pumps

> w_p := eval((1 − α_1 − α_2)·(h_p1out − h_p1in) + (1 − α_2)·(h_p2out − h_p2in) + (h_p3out − h_p3in), res)

$$19{,}021\ \frac{kJ}{kg} \tag{4.13}$$

Specific heat of the boiler

> q_b := h_0 − h_p3out

$$2\,166{,}6\ \frac{kJ}{kg} \tag{4.14}$$

Hence the thermal efficiency

> η_T := eval((w_t − w_p)/q_b, res)

$$40{,}25\% \tag{4.15}$$