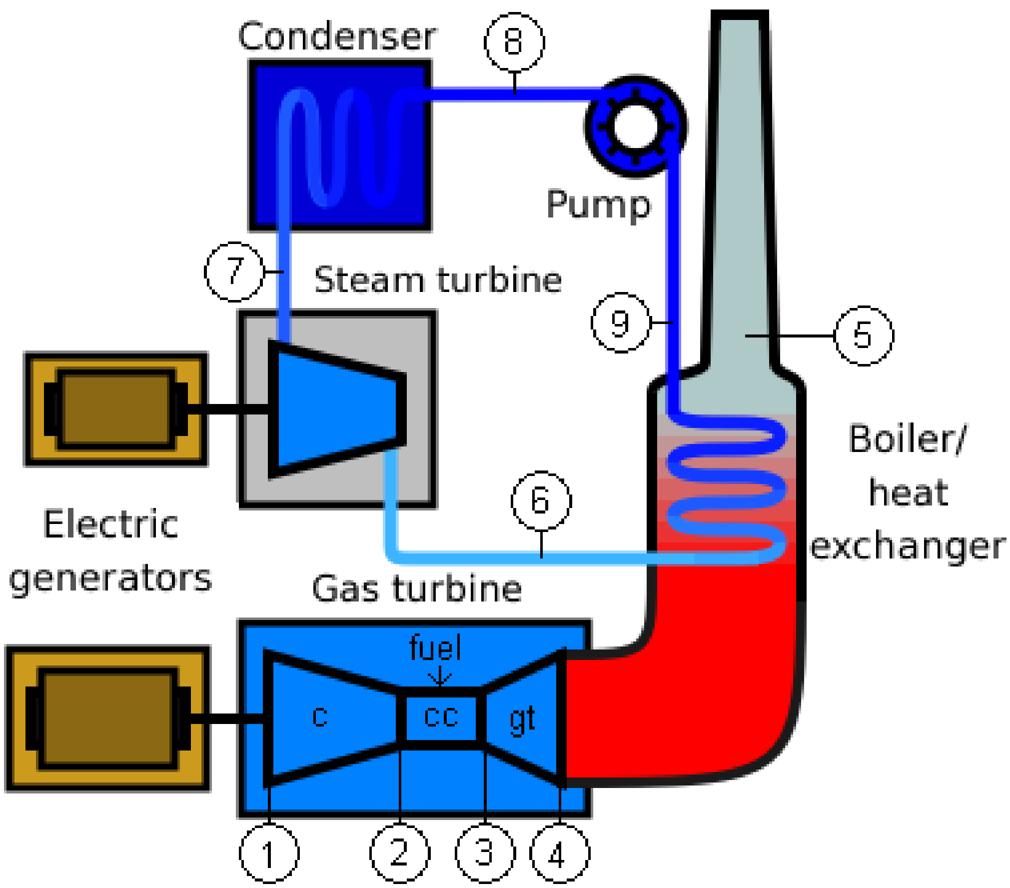
Thermal Efficiency of the combined (binary) cycle

Author: Valery Ochkov (http://twt.mpei.ac.ru/ochkov/v_ochkov.htm)

Introduction

The figure shows the scheme of a simplest ideal combined (binary) cycle, i.e. steam turbine (6-7) cycle with use of superheated water steam. At this plant the boiler (6-9) burner is replaced with gas turbine unit (Brayton cycle: 1-4) equipped with air compressor (1-2), combustion chamber (2-3), gas turbine (3-4) and one more electric generator.



> *restart* : *with*(*ThermophysicalData*) : *with*(*Units*[*Standard*]) :

Calculations

Steam turbine cycle

Input data:

> $t\_6 := 480\text{degC}; p\_6 := 9\text{MPa}; p\_7 := 4.76\text{kPa}$

$$t\_6 := 480\ °C$$

$$p\_6 := 9\ MPa$$

$$p\_7 := 4.76\ kPa \quad (2.1.1)$$

Specific entropy of fresh (live) steam (the turbine inlet):

> $s\_6 := Property(\text{entropy}, \text{pressure} = p\_6, \text{temperature} = t\_6, water)$

$$6.593\ \frac{kJ}{kg\ K} \quad (2.1.2)$$

Specific enthalpy of fresh (live) steam (the turbine inlet):

> $h\_6 := Property(\text{enthalpy}, \text{pressure} = p\_6, \text{temperature} = t\_6, water)$

$$3{,}336.4\ \frac{kJ}{kg} \quad (2.1.3)$$

Outlet steam specific entropy from the turbine (an ideal process of the steam extension)

> $s\_7 := s\_6 :$

Dryness of steam in outlet of the turbine:

> $x\_7 := Property(Q, P = p\_7, entropy = s\_7, water)$

$$77.13\% \quad (2.1.4)$$

Outlet wet steam temperature from the turbine

> $t\_7 := Property(\text{temperature}, \text{pressure} = p\_7, Q = 1, \text{water}) : t\_7 - 273.15K$

$$32.0\ °C \quad (2.1.5)$$

Outlet wet steam specific enthalpy from of the turbine:

> $h\_7 := Property(enthalpy, T = t\_7, Q = x\_7, water)$

$$2{,}004.4\ \frac{kJ}{kg} \quad (2.1.6)$$

Specific work of steam in the turbine:

> $w\_st := h\_6 - h\_7$

$$1{,}332.0\ \frac{kJ}{kg} \quad (2.1.7)$$

Specific enthalpy of water at saturated line at temperature in the condenser

> $hw\_7 := Property(enthalpy, T = t\_7, Q = 0, water)$

$$134.1\ \frac{kJ}{kg} \quad (2.1.8)$$

Specific entropy of water at saturated line at temperature in the condenser

> $sw\_7 := Property(entropy, T = t\_7, Q = 0, water)$

$$.4643\ \frac{kJ}{kg\ K} \quad (2.1.9)$$

Specific enthalpy of condensate

> $h\_8 := hw\_7 :$

Pressure of feed water

> $p\_9 := p\_6 :$

Specific entropy of feed water (an ideal process in the pump):

> $s\_9 := sw\_7$:

Temperature of feed water:

> $t\_9 := Property(temperature, pressure = p\_9, entropy = s\_9, water) : t\_9 - 273.15\mathrm{K}$

$$32.2\ °\mathrm{C} \tag{2.1.10}$$

Specific enthalpy of feed water:

> $h\_9 := Property(enthalpy, pressure = p\_9, temperature = t\_9, water)$

$$143.1\ \frac{\mathrm{kJ}}{\mathrm{kg}} \tag{2.1.11}$$

Specific useful work of the feed pump:

> $w\_p := h\_9 - hw\_7$

$$9.02\ \frac{\mathrm{kJ}}{\mathrm{kg}} \tag{2.1.12}$$

Specific heat supplied to the boiler:

> $q\_b := h\_6 - h\_9$

$$3193.3\ \frac{\mathrm{kJ}}{\mathrm{kg}} \tag{2.1.13}$$

Hence the thermal efficiency of the steam turbine cycle:

> $\eta\_tst := \frac{w\_st - w\_p}{q\_b}$

$$41.43\% \tag{2.1.14}$$

Gas turbine cycle

Input data:

> $t\_1 := 15\mathrm{degC}; p\_1 := 0.1\mathrm{MPa}; p\_2 := 1\mathrm{MPa}; t\_3 := 1100\mathrm{degC}; t\_5 := 130\mathrm{degC}$

$$t\_1 := 15\ °\mathrm{C}$$
$$p\_1 := 0.1\ \mathrm{MPa}$$
$$p\_2 := \mathrm{MPa}$$
$$t\_3 := 1100\ °\mathrm{C}$$
$$t\_5 := 130\ °\mathrm{C} \tag{2.2.1}$$

Specific enthalpy of fresh air

> $h\_1 := Property(\mathrm{enthalpy, pressure = p\_1, temperature = t\_1, air})$

$$414.38\ \frac{\mathrm{kJ}}{\mathrm{kg}} \tag{2.2.2}$$

Specific entropy of fresh air

> $s\_1 := Property(\mathrm{entropy, pressure = p\_1, temperature = t\_1, air})$

$$3.8500\ \frac{\mathrm{kJ}}{\mathrm{kg\ K}} \tag{2.2.3}$$

Outlet air specific entropy, temperature and spacific enthalpy from the compessor

> $s\_2 := s\_1$:

> $t\_2 := Property(temperature, pressure = p\_2, entropy = s\_2, air) : t\_2 - 273.15\mathrm{K}$

$$279.46\ °\mathrm{C} \tag{2.2.4}$$

> $h\_2 := Property(\mathrm{enthalpy, pressure = p\_2, temperature = t\_2, air})$

$$683.60 \frac{kJ}{kg} \quad (2.2.5)$$

Inlet gas pressure, specific entropy and specific enthalpy to the gas turbine

> $p\_3 := p\_2:$

> $s\_3 := Property(\text{entropy, pressure} = p\_3, \text{temperature} = t\_3, \text{air})$

$$4.867 \frac{kJ}{kg\,K} \quad (2.2.6)$$

> $h\_3 := Property(\text{enthalpy, pressure} = p\_3, \text{temperature} = t\_3, \text{air})$

$$1,610.34 \frac{kJ}{kg} \quad (2.2.7)$$

Outlet gas pressure, specific entropy, temperature and specific enthalpy from the gas turbine

> $p\_4 := p\_1:$

> $s\_4 := s\_3:$

> $t\_4 := Property(temperature, pressure = p\_4, entropy = s\_4, air) : t\_4 - 273.15K$

$$498.01\ °C \quad (2.2.8)$$

> $h\_4 := Property(\text{enthalpy, pressure} = p\_4, \text{temperature} = t\_4, \text{air})$

$$916.82 \frac{kJ}{kg} \quad (2.2.9)$$

Specific heat supplied to the combustion chamber:

> $q\_1 := h\_3 - h\_2$

$$926.74 \frac{kJ}{kg} \quad (2.2.10)$$

Specific work of the gas turbine

> $w\_gt := h\_3 - h\_4$

$$693.52 \frac{kJ}{kg} \quad (2.2.11)$$

Specific work of the air compressor

> $w\_c := h\_2 - h\_1$

$$269.23 \frac{kJ}{kg} \quad (2.2.12)$$

Hence the thermal efficiency of the gas turbine cycle:

> $\eta\_tgt := \frac{w\_gt - w\_c}{q\_1}$

$$45.78\% \quad (2.2.13)$$

Combined (binary) cycle

Outlet gas pressure and specific enthalpy from the steam boiler

> $p\_5 := p\_4:$

> $h\_5 := Property(\text{enthalpy, pressure} = p\_5, \text{temperature} = t\_5, \text{air})$

$$530.5 \frac{kJ}{kg} \quad (2.3.1)$$

Ratio of gas and steam mass flow

> $m := \frac{h\_6 - h\_9}{h\_4 - h\_5}$

$$8.265 \qquad (2.3.2)$$

Specific heat supplied to the combustion chamber:

> $q\_1 := m \cdot (h\_3 - h\_2)$

$$7659.4 \frac{kJ}{kg} \qquad (2.3.3)$$

Specific work of the gas turbine cycle

> $w\_gtc := (h\_3 - h\_4) - (h\_2 - h\_1)$

$$424.3 \frac{kJ}{kg} \qquad (2.3.4)$$

Specific work of the steam turbine cycle

> $w\_stc := (h\_6 - h\_7) - (h\_9 - h\_8)$

$$1323.0 \frac{kJ}{kg} \qquad (2.3.5)$$

Hence the thermal efficiency of the Combined (binary) cycle is higher than separate steam or gas turbine cycles:

> $\eta\_tbc := \frac{m \cdot w\_gtc + w\_stc}{q\_1}$

$$63.06\% \qquad (2.3.6)$$

>