Know parameters

$R \equiv 8.314 \frac{J}{mol \cdot K}$ $MJ := 10^6 J$ $kJ := 10^3 J$ $kmol := 10^3 mol$

Mass flow rate of fuel $m_{fuel} := 11.5 \frac{kg}{s}$ Air surplus coefficient $\alpha := 2.1$

Composition of fuel (molar ratio)

$y_{H2} := 27.17\%$ $y_{CH4} := 41.91\%$ $y_{C3H8} := 0.50\%$ $y_{CO} := 15.50\%$ $y_{C2H4} := 1.79\%$

$y_{CO2} := 7.22\%$ $y_{C2H6} := 6.92\%$ ==> $LHV := 35930 \frac{kJ}{kg}$

Molecular weights of different compositions

$M_{H2} := 2 \frac{kg}{kmol}$ $M_{CH4} := 16 \frac{kg}{kmol}$ $M_{C3H8} := 44 \frac{kg}{kmol}$ $M_{CO} := 28 \frac{kg}{kmol}$ $M_{C2H4} := 28 \frac{kg}{kmol}$

$M_{CO2} := 44 \frac{kg}{kmol}$ $M_{C2H6} := 30 \frac{kg}{kmol}$ $M_{H2O} := 18 \frac{kg}{kmol}$ $M_{O2} := 32 \frac{kg}{kmol}$ $M_{N2} := 28 \frac{kg}{kmol}$

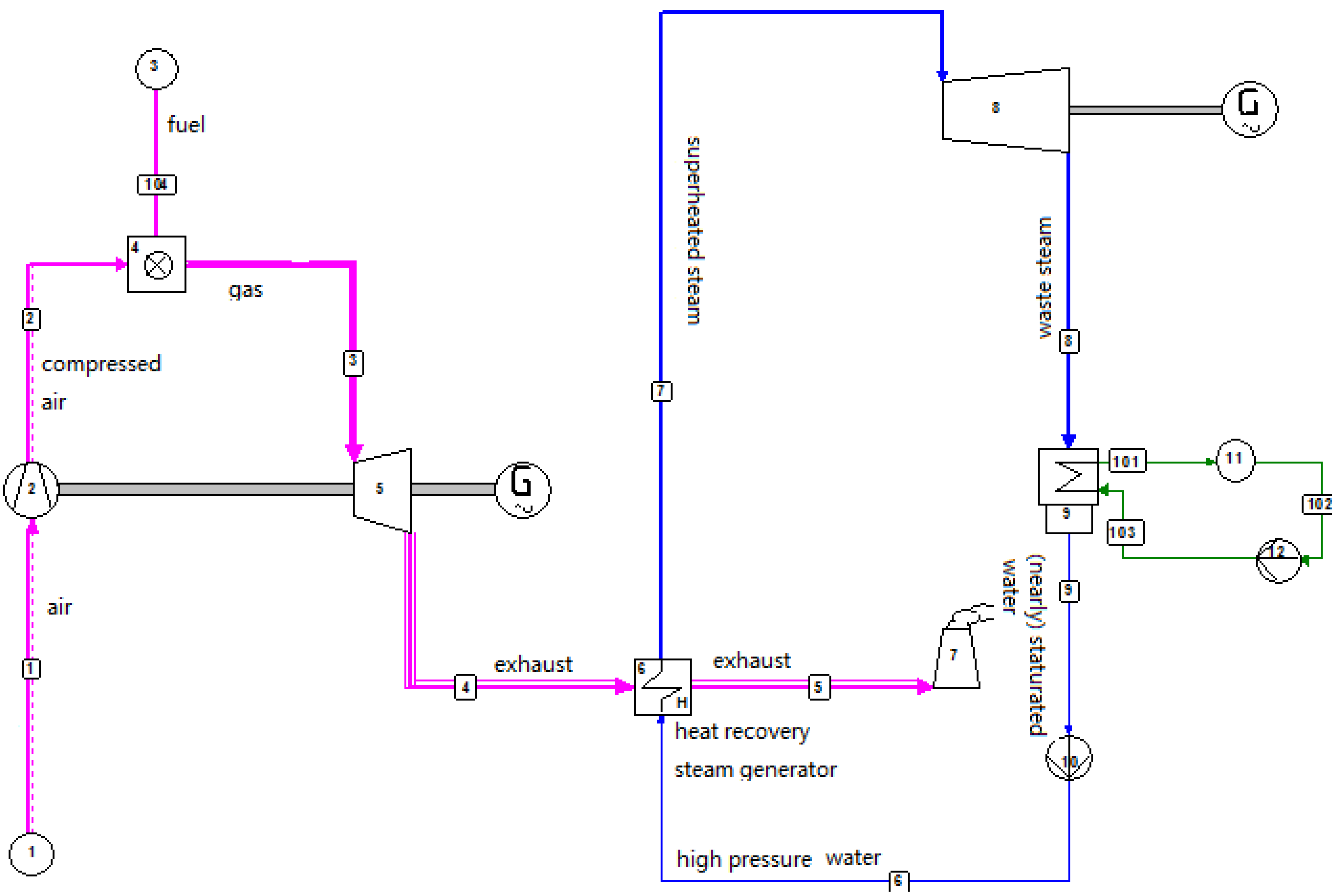
State variables in the cycle (the subscripts are related with the #s enclosed in the squares in the following flowchart)

$T_1 := 25\ °C$ $T_3 := 1200\ °C$ $T_5 := 175\ °C$ $T_7 := 400\ °C$

$p_1 := 1atm$ $p_2 := 15atm$ $p_4 := 1atm$ $p_5 := 1atm$

$p_6 := 4.5MPa$ $p_7 := 4MPa$ $p_8 := 0.008MPa$ $p_9 := 0.008MPa$ 暂定轮机和泵（风机）效率都为100%

The isentropic efficiencies of the turbines, pumps and blowers are assumed to be 100%



Calulating the materials entering into combustor of gas turbine

Molecular weight of fuel

$$M_{fuel} := y_{H2} \cdot M_{H2} + y_{CO} \cdot M_{CO} + y_{CO2} \cdot M_{CO2} + y_{CH4} \cdot M_{CH4} + y_{C2H4} \cdot M_{C2H4} + y_{C2H6} \cdot M_{C2H6} + y_{C3H8} \cdot M_{C3H8}$$

Molar flowrate of fuel

$$n_{fuel} := \frac{m_{fuel}}{M_{fuel}}$$

Molar flowrates of different fuel compositions

$$n_{H2} := n_{fuel} \cdot y_{H2} \qquad n_{CO} := n_{fuel} \cdot y_{CO} \qquad n_{CO2} := n_{fuel} \cdot y_{CO2}$$

$$n_{CH4} := n_{fuel} \cdot y_{CH4} \qquad n_{C2H4} := n_{fuel} \cdot y_{C2H4} \qquad n_{C2H6} := n_{fuel} \cdot y_{C2H6}$$

$$n_{C3H8} := n_{fuel} \cdot y_{C3H8}$$

Reactions within the combustor of gas turbine

$H_2 + 1/2\ O_2 = H_2O$

$CO + O_2 = CO_2$

$CH_4 + 2\ O_2 = CO_2 + 2\ H_2O$

$C_2H_6 + 7/2\ O_2 = 2\ CO_2 + 3\ H_2O$

$C_3H_8 + 5\ O2 = 3\ CO_2 + 4\ H_2O$

$C_2H_4 + 3\ O2 = 2\ CO_2 + 4\ H_2O$

Molar flowrates of air entering into the combustor

$$n_{O2} := \alpha \cdot \left(\frac{1}{2} n_{H2} + n_{CO} + 2n_{CH4} + \frac{7}{2} n_{C2H6} + 5 \cdot n_{C3H8} + 3 \cdot n_{C2H4} \right)$$

$$n_{N2} := n_{O2} \cdot \frac{79}{21}$$

$$n_{air} := n_{O2} + n_{N2}$$

$$n_1 := n_{air} \qquad n_2 := n_{air}$$

Calulating the materials flowing out of the combustor of gas turbine

$$n_{CO2\_new} := n_{CO2} + n_{CO} + n_{CH4} + 2n_{C2H6} + 3n_{C3H8} + 2n_{C2H4}$$

$$n_{H2O} := n_{H2} + 2n_{CH4} + 3n_{C2H6} + 4n_{C3H8} + 2n_{C2H4}$$

$$n_{N2} = 7500.31\,\frac{mol}{s}$$

$$n_{O2\_new} := n_{O2} - n_{CO} - \frac{1}{2}n_{H2} - 2n_{CH4} - \frac{7}{2}n_{C2H6} - 5n_{C3H8} - 3n_{C2H4}$$

$$n_{comb} := n_{CO2\_new} + n_{H2O} + n_{O2\_new} + n_{N2}$$

Hence, the molar flowrates at points 3~5 in the flowchart

$n_3 := n_{comb}$ $\quad n_4 := n_{comb}$ $\quad n_5 := n_{comb}$

molar ratios of the compostions of the gas and molar weight of the gas

$x_{CO2} := n_{CO2\_new} \div n_{comb}$ $\quad x_{H2O} := n_{H2O} \div n_{comb}$

$x_{O2} := n_{O2\_new} \div n_{comb}$ $\quad x_{N2} := n_{N2} \div n_{comb}$

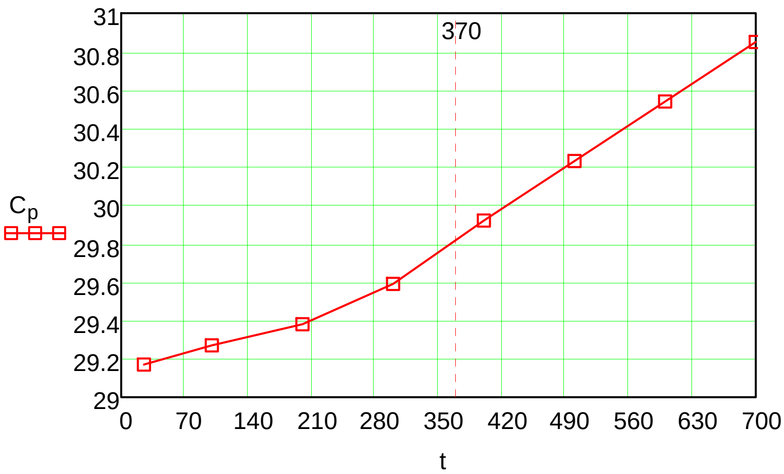
$$M_{gas} := x_{CO2} \cdot M_{CO2} + x_{H2O} \cdot M_{H2O} + x_{O2} \cdot M_{O2} + x_{N2} \cdot M_{N2}$$

Calulating the unknown state variables in "gas-cycle" side

$p_3 := p_2$

thermal capcity data of air

$$t \equiv \begin{pmatrix} 25 \\ 100 \\ 200 \\ 300 \\ 400 \\ 500 \\ 600 \\ 700 \end{pmatrix} \qquad C_p \equiv \begin{pmatrix} 29.17 \\ 29.27 \\ 29.38 \\ 29.59 \\ 29.92 \\ 30.23 \\ 30.54 \\ 30.85 \end{pmatrix}$$



1->2 adiabatic process ,
determing temperature of compressed air (T_2) with "trial-and-error" method

$T_{2\_try} := 370\ °C$ $\qquad C_{p\_2} := 29.192\,\frac{J}{mol \cdot K}$

$$k_2 := \frac{C_{p\_2}}{C_{p\_2} - R} \qquad T_2 := T_1 \cdot \left(\frac{p_2}{p_1}\right)^{\frac{k_2 - 1}{k_2}} \qquad \left|T_2 - T_{2\_try}\right| = 1.6\,K$$

3->4 adiabatic process ,
determing T_4 with the similar prcedure to that for T_2

Try value $T_{4\_try} := 440\ °C$

thermal capcity data the compositions at this temperature

$C_{pCO2\_4} := 44.30 \frac{J}{mol \cdot K}$ $C_{pH2O\_4} := 35.40 \frac{J}{mol \cdot K}$ $C_{pO2\_4} := 31.17 \frac{J}{mol \cdot K}$ $C_{pN2\_4} := 29.78 \frac{J}{mol \cdot K}$

$C_{p\_4} := x_{CO2} \cdot C_{pCO2\_4} + x_{H2O} \cdot C_{pH2O\_4} + x_{O2} \cdot C_{pO2\_4} + x_{N2} \cdot C_{pN2\_4}$

$k_4 := \frac{C_{p\_4}}{C_{p\_4} - R}$ $T_4 := T_3 \cdot \left(\frac{p_4}{p_3}\right)^{\frac{k_4 - 1}{k_4}}$ $\left|T_4 - T_{4\_try}\right| = 3.18\,K$

Calulating the enthalpies in "gas-cycle" side

$h_1 := 0 \frac{J}{mol}$ Base point

enthalpy at point #2

$h_2 := C_{p\_2} \cdot \left(T_2 - T_1\right)$ $h_2 \div M_{gas} = 356.34 \frac{kJ}{kg}$

enthalpy at point #3

1200℃时 (status #3) , the mean thermal capacities of different compositions of gas

$C_{pCO2\_3} := 51.25 \frac{J}{mol \cdot K}$ $C_{pH2O\_3} := 39.85 \frac{J}{mol \cdot K}$ $C_{pO2\_3} := 33.76 \frac{J}{mol \cdot K}$ $C_{pN2\_3} := 31.94 \frac{J}{mol \cdot K}$

$C_{p\_3} := x_{CO2} \cdot C_{pCO2\_3} + x_{H2O} \cdot C_{pH2O\_3} + x_{O2} \cdot C_{pO2\_3} + x_{N2} \cdot C_{pN2\_3}$

$h_3 := C_{p\_3} \cdot \left(T_3 - T_1\right)$ $h_3 \div M_{gas} = 1402.82 \frac{kJ}{kg}$

enthalpy at point #4

$h_4 := C_{p\_4} \cdot \left(T_4 - T_1\right)$ $h_4 \div M_{gas} = 459.89 \frac{kJ}{kg}$

enthalpy at point #5

mean capacity of compositions of gas at 175℃时 (status #5)

$C_{pCO2\_5} := 40.12 \frac{J}{mol \cdot K}$ $C_{pH2O\_5} := 34.11 \frac{J}{mol \cdot K}$ $C_{pO2\_5} := 29.95 \frac{J}{mol \cdot K}$ $C_{pN2\_5} := 29.25 \frac{J}{mol \cdot K}$

$C_{p\_5} := x_{CO2} \cdot C_{pCO2\_5} + x_{H2O} \cdot C_{pH2O\_5} + x_{O2} \cdot C_{pO2\_5} + x_{N2} \cdot C_{pN2\_5}$

$h_5 := C_{p\_5} \cdot (T_5 - T_1)$ $h_5 \div M_{gas} = 160.36 \frac{kJ}{kg}$

Together with what we got above

$n_1 = 9494.06 \frac{mol}{s}$ $n_2 = 9494.06 \frac{mol}{s}$ $n_3 = 9990.95 \frac{mol}{s}$ $n_4 = 9990.95 \frac{mol}{s}$ $n_5 = 9990.95 \frac{mol}{s}$

Energy in the fuel: $Q_{fuel} := m_{fuel} \cdot LHV$

Energy difference between points 2 and 3: $Q_{2\_3} := n_3 \cdot h_3 - n_2 \cdot h_2$

Energy consumed by air compressor $W_1 := n_1 \cdot (h_1 - h_2)$

Shaft work of gas turbine $W_2 := n_3 \cdot (h_3 - h_4)$

Calulating the unknown state variables in "steam-cycle" side

Calculating molar flow rate of steam via energy balance of heat recovery steam generator

$$n_6 \cdot h_6 + n_4 \cdot h_4 = n_7 \cdot h_7 + n_5 \cdot h_5 \qquad n_6 = n_7 \qquad n_5 = n_4$$

$$n_7 \cdot h_6 + n_4 \cdot h_4 = n_7 \cdot h_7 + n_4 \cdot h_5$$

$$n_7 = \frac{n_4 \cdot (h_4 - h_5)}{h_7 - h_6}$$

Reading the enthalpies of steam at different temperatures from H-S diagram or T-S diagram

$$h_7 := 3214 \frac{kJ}{kg} \cdot M_{H2O}$$

$$h_8 := 2118 \frac{kJ}{kg} \cdot M_{H2O}$$ 7 -> 8 adiabatic process

$$h_9 := 173.85 \frac{kJ}{kg} \cdot M_{H2O}$$

$$h_6 := 178.37 \frac{kJ}{kg} \cdot M_{H2O}$$ 9 -> 6 adiabatic process

$$n_7 := n_4 \cdot \frac{h_4 - h_5}{h_7 - h_6}$$

Shaft work of steam turbine

$$W_3 := n_7 \cdot (h_7 - h_8)$$

Net work of combined cycles

$$W_{net} := W_1 + W_2 + W_3$$

Efficiencies calculation (fuel production efficiency=0.95)

$$\eta_{1\_gross} := \frac{W_2 + W_3}{Q_{fuel}} \times 0.95 \qquad \eta_{1\_net} := \frac{W_{net}}{Q_{fuel}} \times 0.95$$

$$\eta_2 := \frac{W_{net}}{Q_{2\_3}} \qquad n_8 := n_7 \qquad n_9 := n_7$$

$$1 - \frac{(n_8 \cdot h_8 - n_9 \cdot h_9) + (n_5 \cdot h_5 - n_1 \cdot h_1)}{Q_{2\_3}} = 66.9\%$$

If the isentropic efficiencies of the turbines, pumps and blowers are 90%, there will be,

$$\eta_{1\_gross} \times 0.9 \times 0.95 = 59\% \qquad \eta_{1\_net} \times 0.9 \times 0.95 = 40\%$$