Chemical Engineering 612

Reactor Design and Analysis

Lecture 20

Thermodynamics II

Brayton Cycle

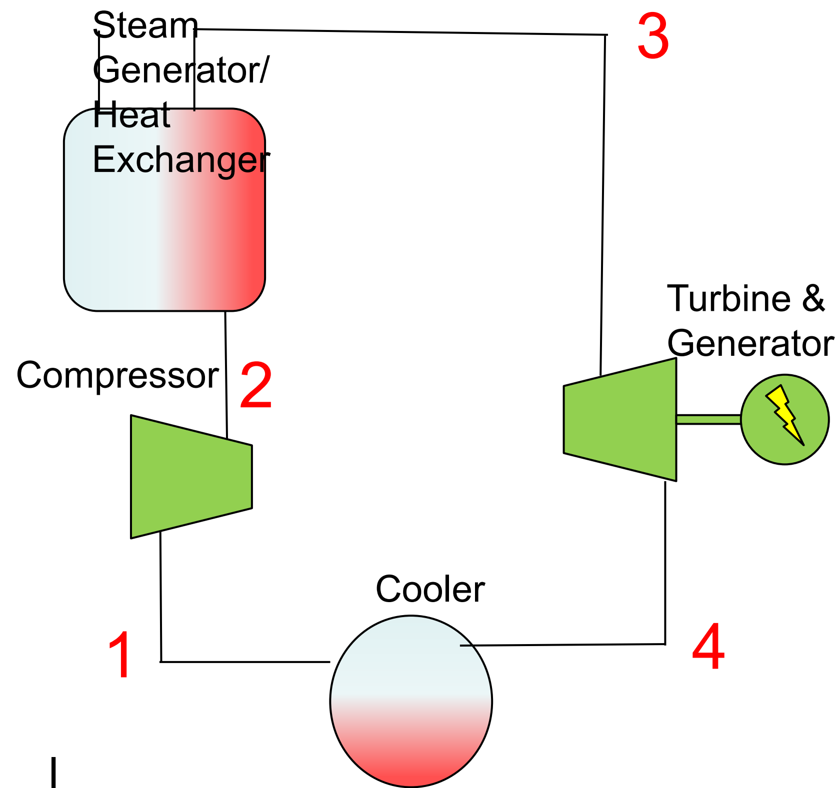
Spiritual Thought

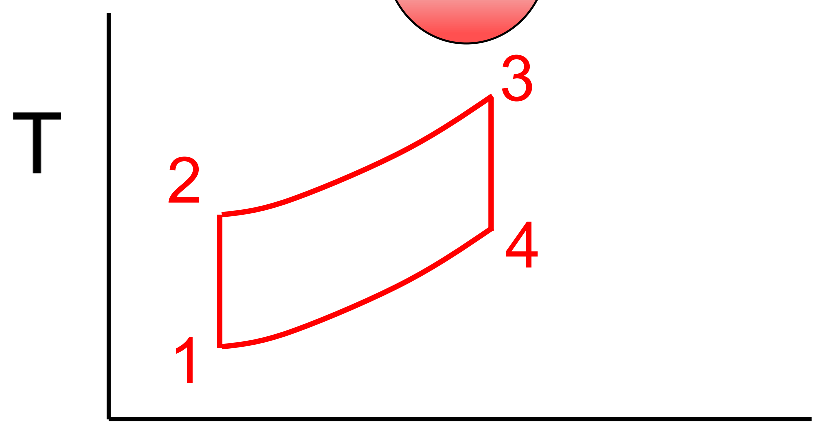
"We have failed the youth of the church, because they don't understand the role of marriage in the plan of salvation!"

- Elder Marcus B. Nash

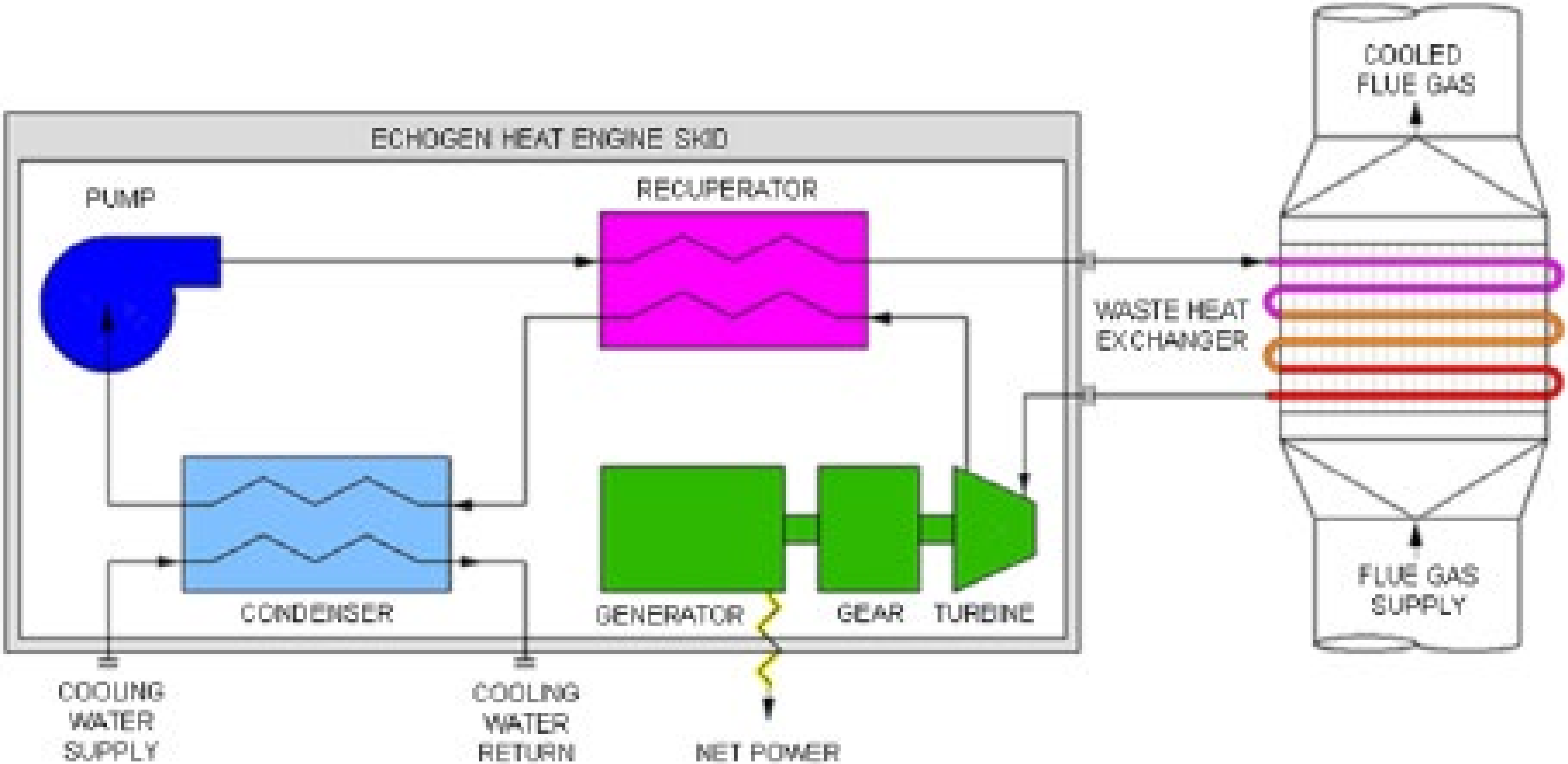
Brayton Cycle

- Gas Cycle
  - Isobars
    - 1-2 → isentropic compression
    - 2-3 → isobaric heating
    - 3-4 → isentropic expansion (turbine)
    - 4-1 → Isobaric cooling



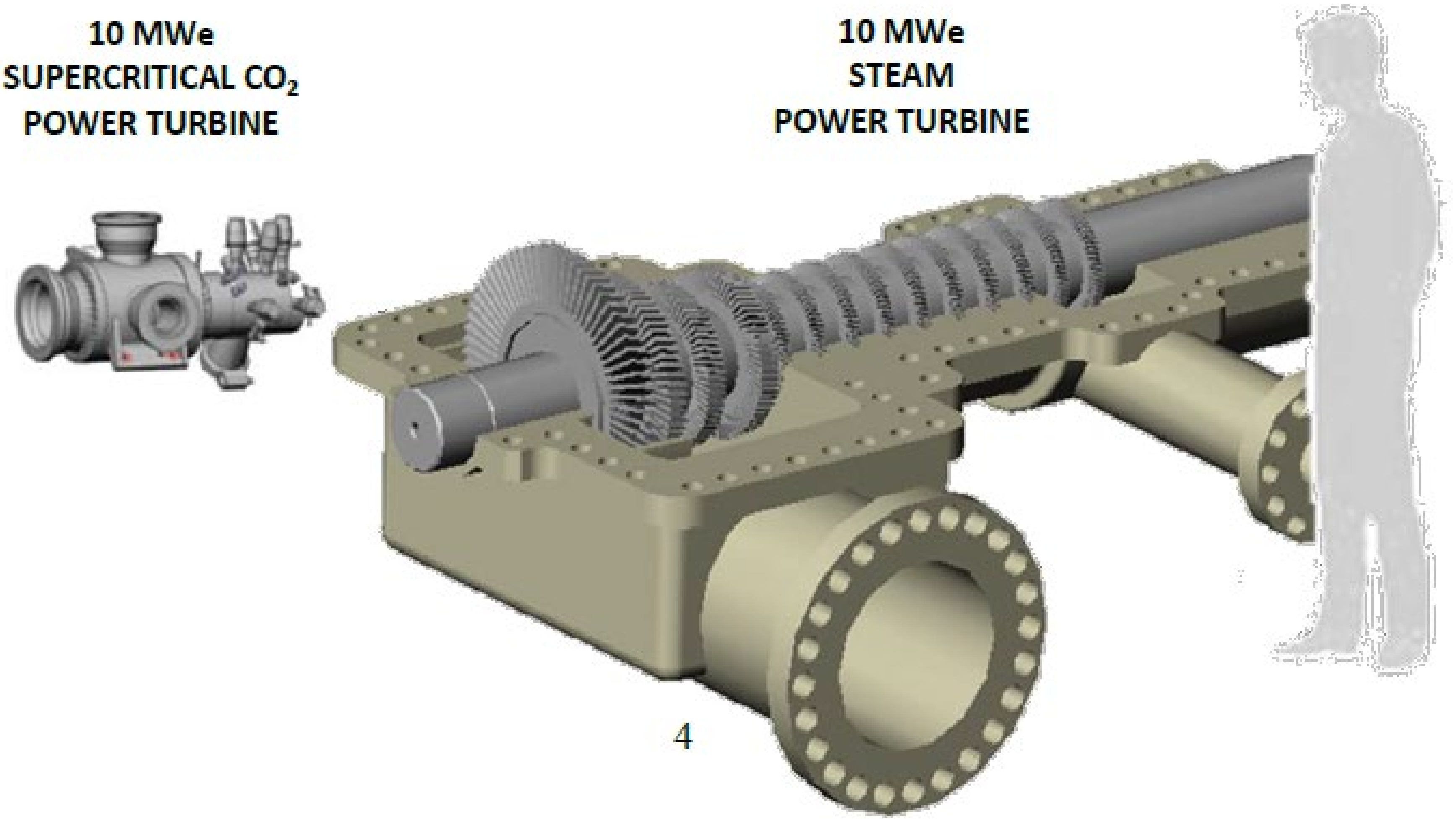


EchoGen S-CO_2 Brayton Cycle



From: M. Persichilli, A. Kacludis, E. Zdankiewicz, T. Held, “Supercritical CO2 Power Cycle Develpments and Commercilaiztation: WhycCP2 can Displace Steam” Poer-Gen Inida & Central Asia, April 2012.

Why S-CO_2?



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Brayton Theory (I)

- Perfect Gas: Equation of State PV=nRT
- $\Delta h = C_p \Delta T,\ h = C_p \Delta T + h_o$
- $C_p = C_v + R^*,\ R^* = \frac{R}{A}$ $\qquad r_p = \frac{p_{high}}{p_{low}} = \frac{p_2}{p_1} = \frac{p_3}{p_4}$
- $\gamma = \frac{C_p}{C_v} = \frac{n+2}{n}\ (n = molecular\ dof)$
  - $n = 3, monatomic \quad n = 5, diatomic$
- As with Rankine, $\eta_T = \frac{\dot{W}_t - \dot{W}_p}{\dot{Q}}$

Brayton Theory (II)

- Isentropic
- $Tv^{\gamma-1} = constant$
- $\frac{T}{P^{\frac{\gamma-1}{\gamma}}} = constant$
- $\dot{W}_t = \dot{m}(h_3 - h_4)$
- $\dot{W}_c = \dot{m}(h_2 - h_1)$
- $\dot{Q}_{in} = \dot{m}(h_3 - h_2)$
- Pressure losses (to friction)
  - $P_3<P_2$, $P_1<P_4$, $\beta = \left(\frac{P_4}{P_1}\frac{P_2}{P_3}\right)^{\frac{\gamma-1}{\gamma}}$

$$\dot{W}_t = \dot{m}c_p(T_3 - T_4)$$

$$\dot{W}_t = \dot{m}c_pT_3\left(1 - \frac{T_4}{T_3}\right)$$

$$\dot{W}_t = \dot{m}c_pT_3\left(1 - \frac{1}{r_p^{\frac{\gamma-1}{\gamma}}}\right)$$

$$\dot{W}_c = \dot{m}c_pT_1\left(r_p^{\frac{\gamma-1}{\gamma}} - 1\right)$$

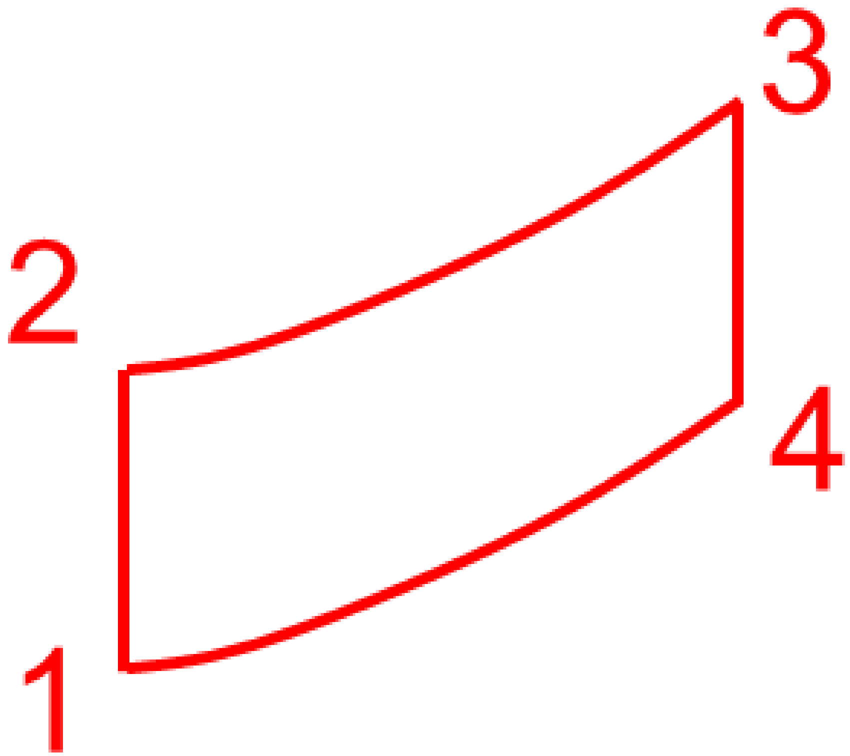
$$\dot{Q}_{in} = \dot{m}c_pT_1\left(\frac{T_3}{T_1} - r_p^{\frac{\gamma-1}{\gamma}}\right)$$

$$\dot{Q}_{HX} = \dot{m}c_pT_3\left(\frac{1}{r_p^{\frac{\gamma-1}{\gamma}}} - \frac{T_1}{T_3}\right)$$

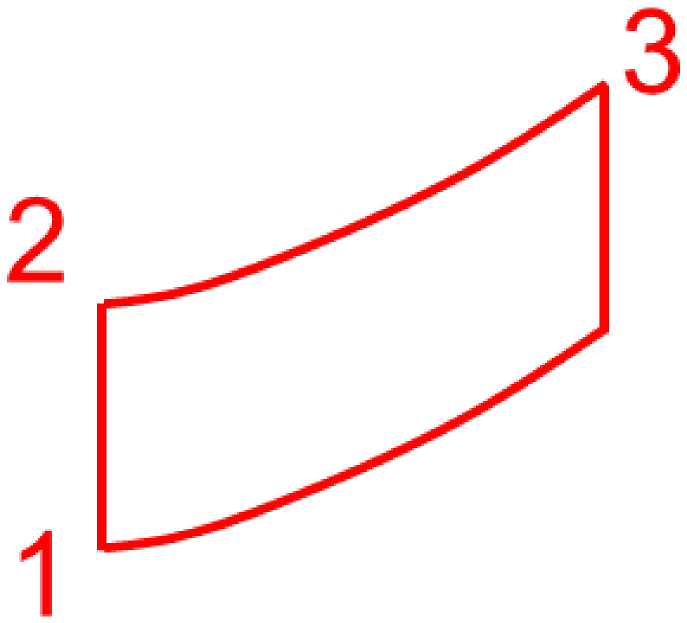
Efficiency Improvements

- Similar to Rankine:
  - Regeneration (heat from hot to cold)
    - Decrease Q_{in}
  - Reheat (add additional Heat)
    - Increases area (thus work)
  - Intercooling (remove additional heat)
    - Two compressors
    - Lower efficiency, work increses
  - Increase component efficiency

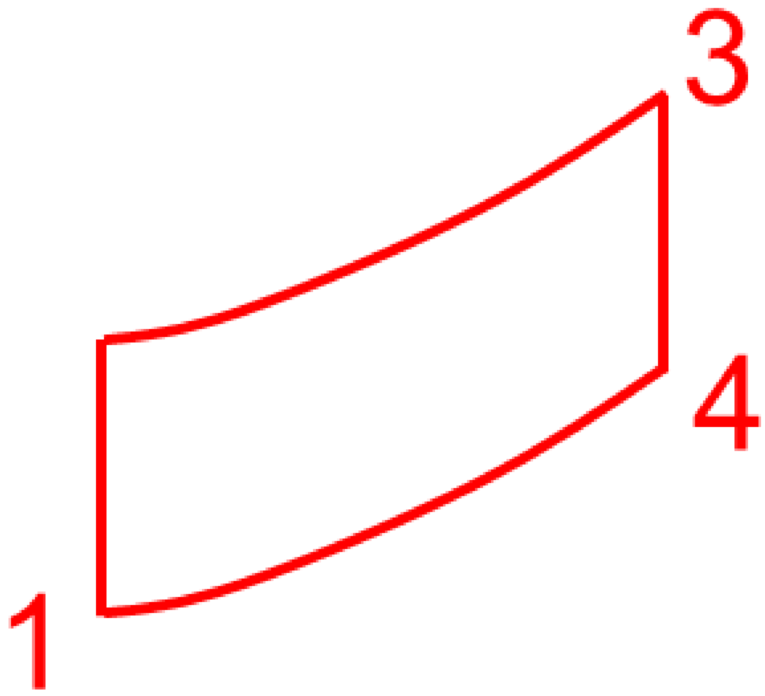
Regeneration



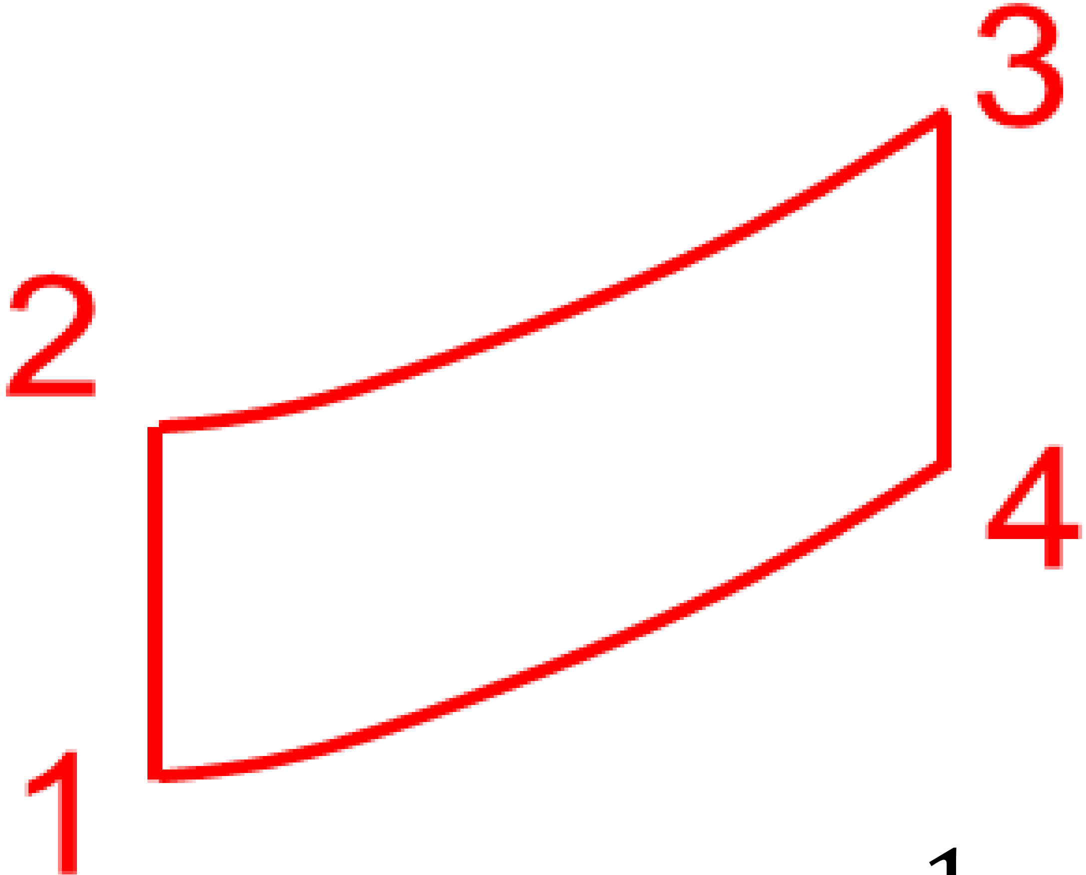
Reheat



Intercooling



Actual Efficiencies



$$\zeta = \eta = 1 - \frac{1}{\left(r_p\right)^{\frac{\gamma-1}{\gamma}}}$$