THE CARBON CYCLE

What Is Carbon?

- An element
- The basis of life of earth
- Found in rocks, oceans, atmosphere

Carbon Cycle

- The same carbon atoms are used repeatedly on earth. They cycle between the earth and the atmosphere.

Plants Use Carbon Dioxide

- Plants pull carbon dioxide from the atmosphere and use it to make food –– photosynthesis.
- The carbon becomes part of the plant (stored food).

Animals Eat Plants

- When organisms eat plants, they take in the carbon a becomes part of the

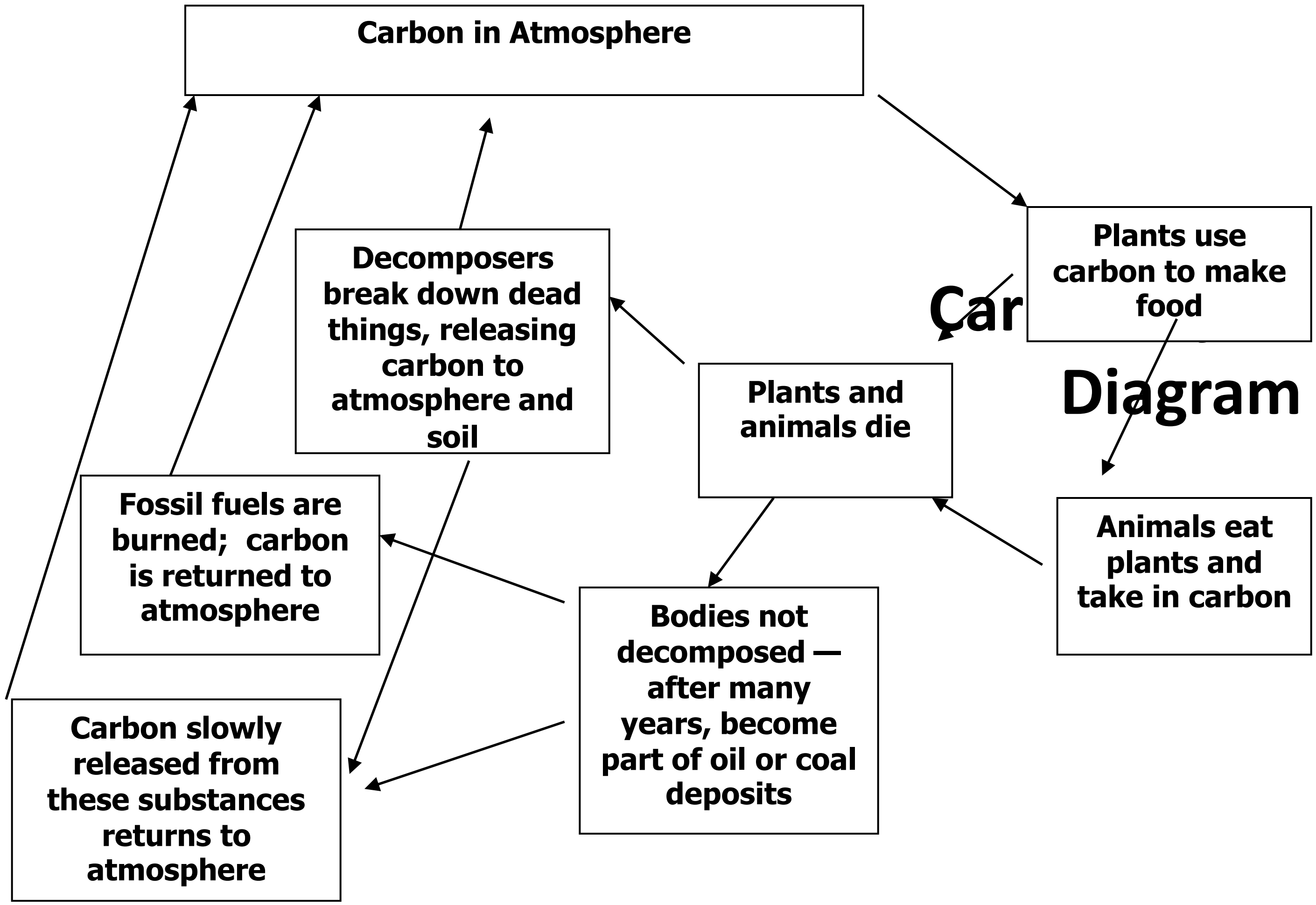
Plants and Animal Die

- When plants and animals die, most of their bodies are decomposed and carbon atoms are returned to the atmosphere.
- Some are not decomposed fully and end up in deposits underground (oil, coal, etc.).

Carbon Slowly Returns to Atmosphere

- Carbon in rocks and underground deposits is released very slowly into the atmosphere.
- This process takes many years.

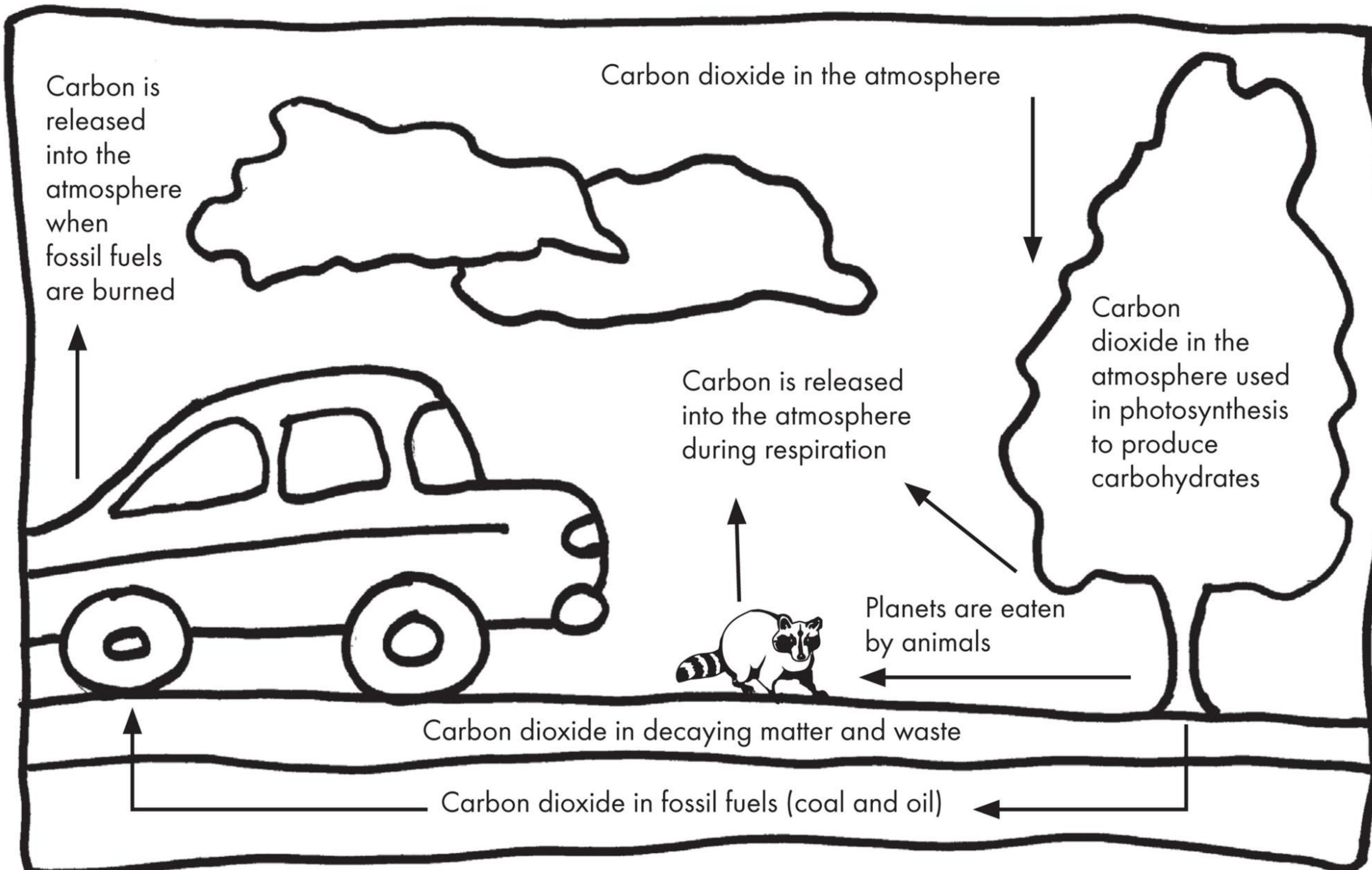
Cycle – Repeats Over and Over and Over and Over …


Car
Diagram
Carbon in Atmosphere
Plants use carbon to make food
Decomposers break down dead things, releasing carbon to atmosphere and soil
Plants and animals die
Animals eat plants and take in carbon
Fossil fuels are burned; carbon is returned to atmosphere
Bodies not decomposed — after many years, become part of oil or coal deposits
Carbon slowly released from these substances returns to atmosphere

Carbon in Oceans

- Additional carbon is stored in the ocean.
- Many animals pull carbon from water to use in shells, etc.
- Animals die and carbon substances are deposited at the bottom of the ocean.
- Oceans contain earth’s largest store of carbon.

The Carbon Cycle



Human Impact

- Fossil fuels release carbon stores very slowly
- Burning anything releases more carbon into atmosphere — especially fossil fuels
- Increased carbon dioxide in atmosphere increases global warming
- Fewer plants mean less CO_2 removed from atmosphere

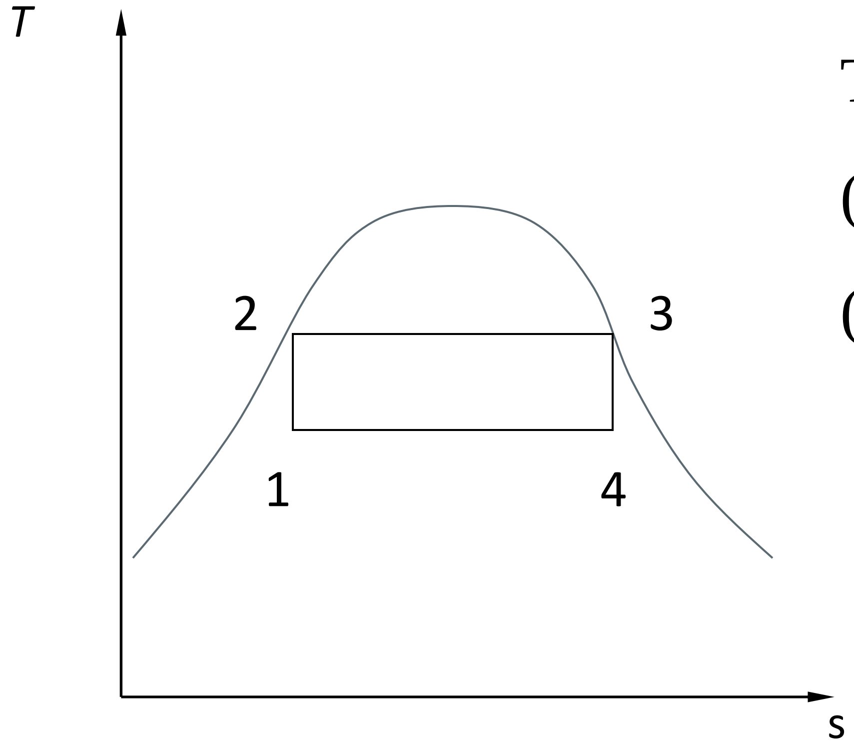
What We Need to Do

- Burn less, especially fossil fuels
- Promote plant life, especially trees

chapter 9 Steam Power Cycle

9-1 The Rankine Cycle

9-1-1. Vapor Carnot cycle

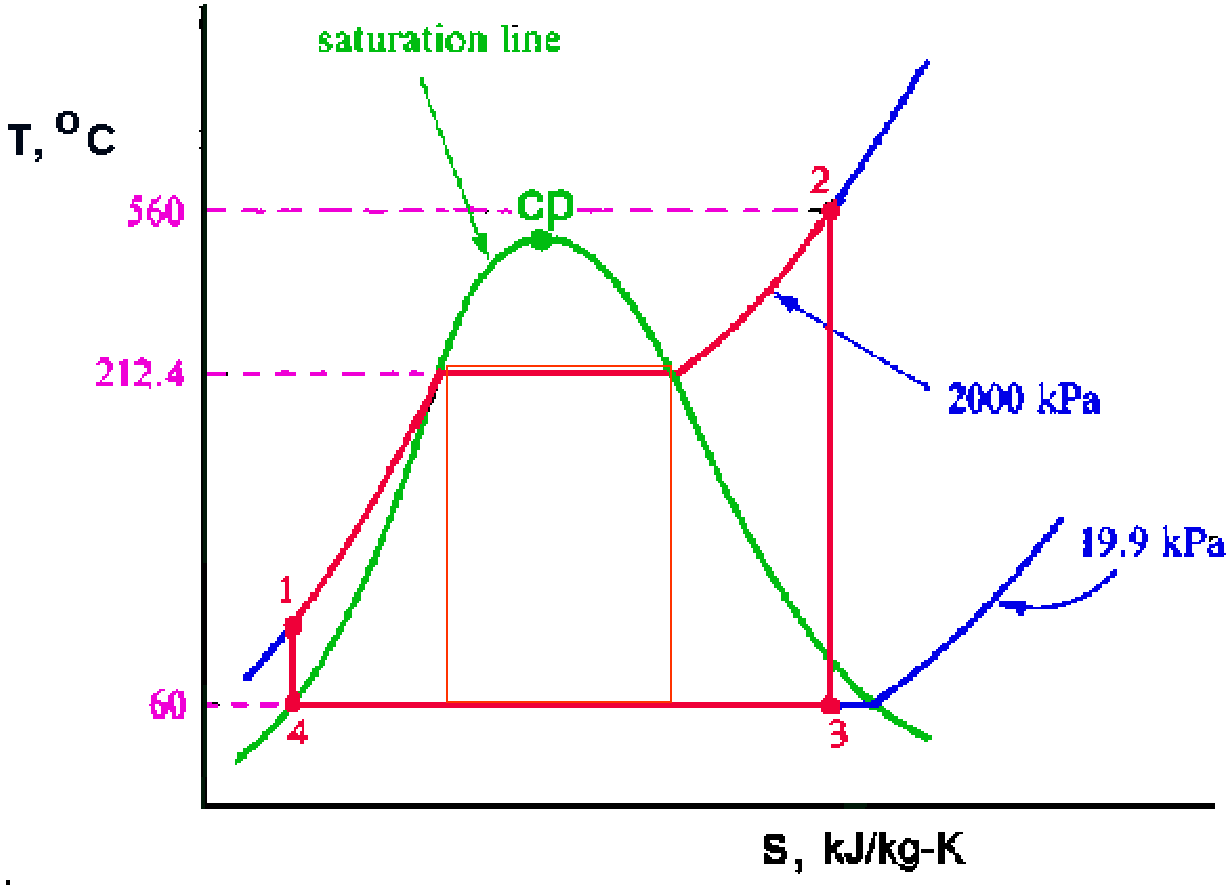


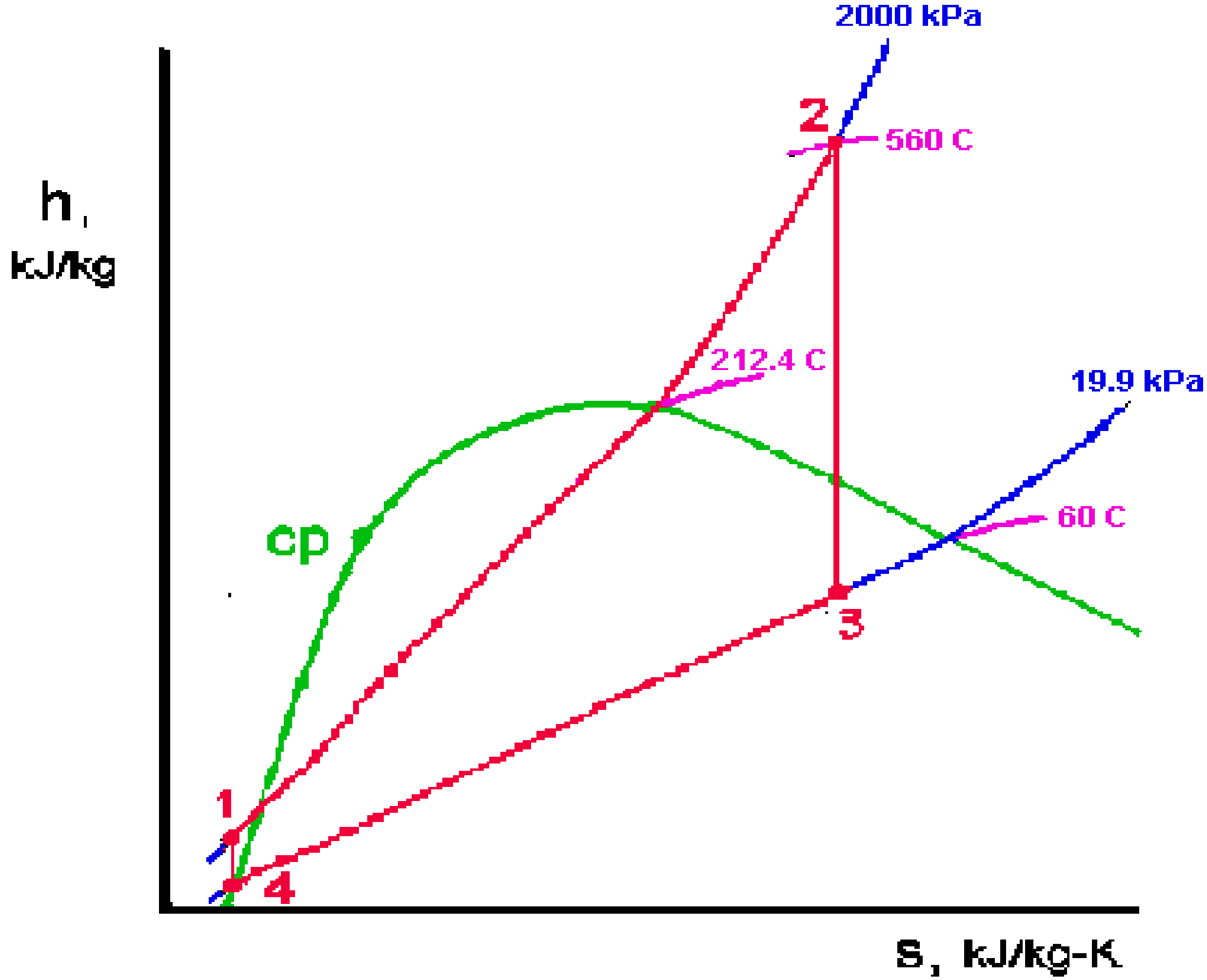
There are some problems:

(1) Compressor

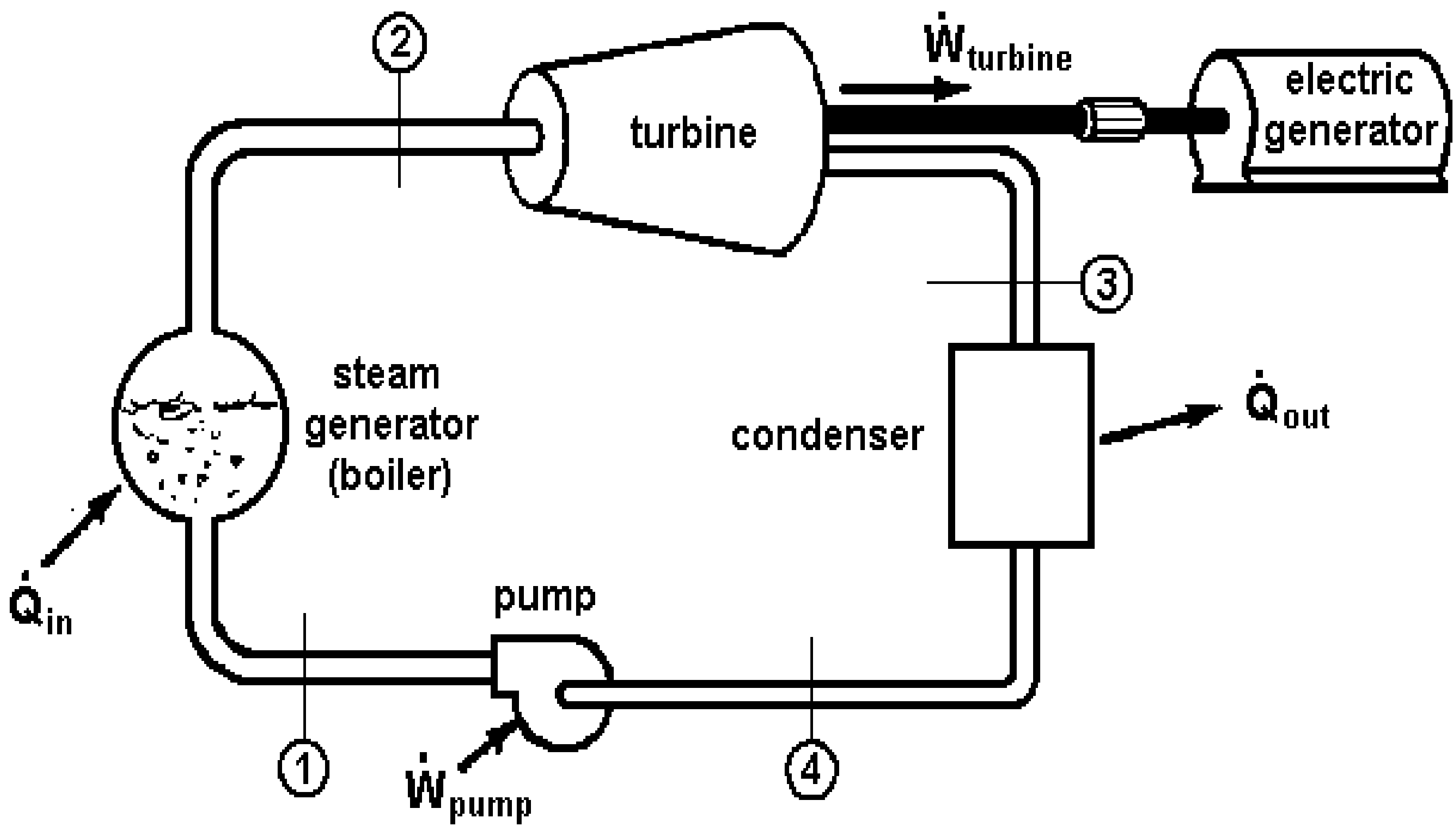
(2) turbine

9-1-2. Rankine cycle

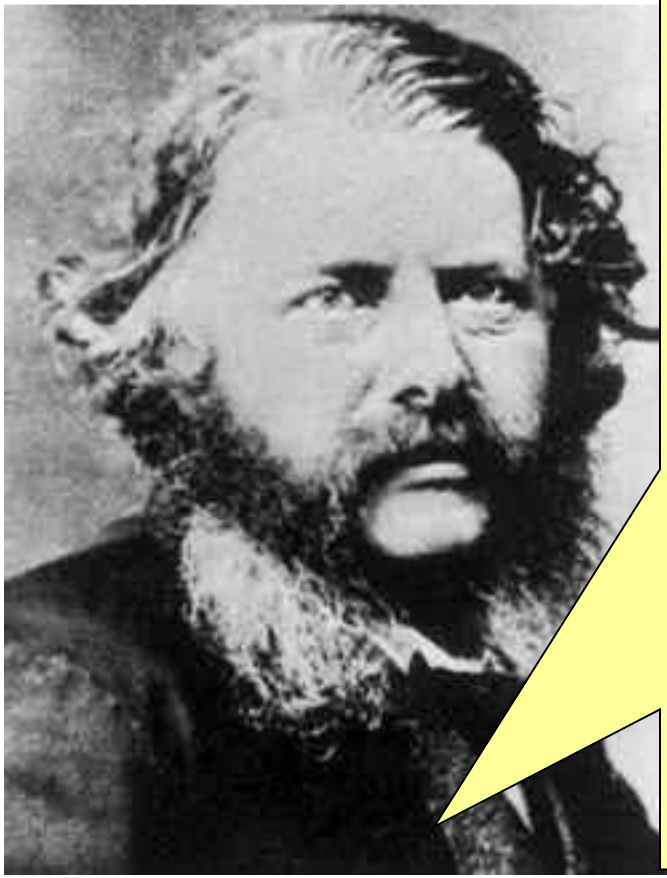




2000 kPa
2
560 C
h,
kJ/kg
212.4 C
19.9 kPa
cp
60 C
3
1
4
s, kJ/kg-K

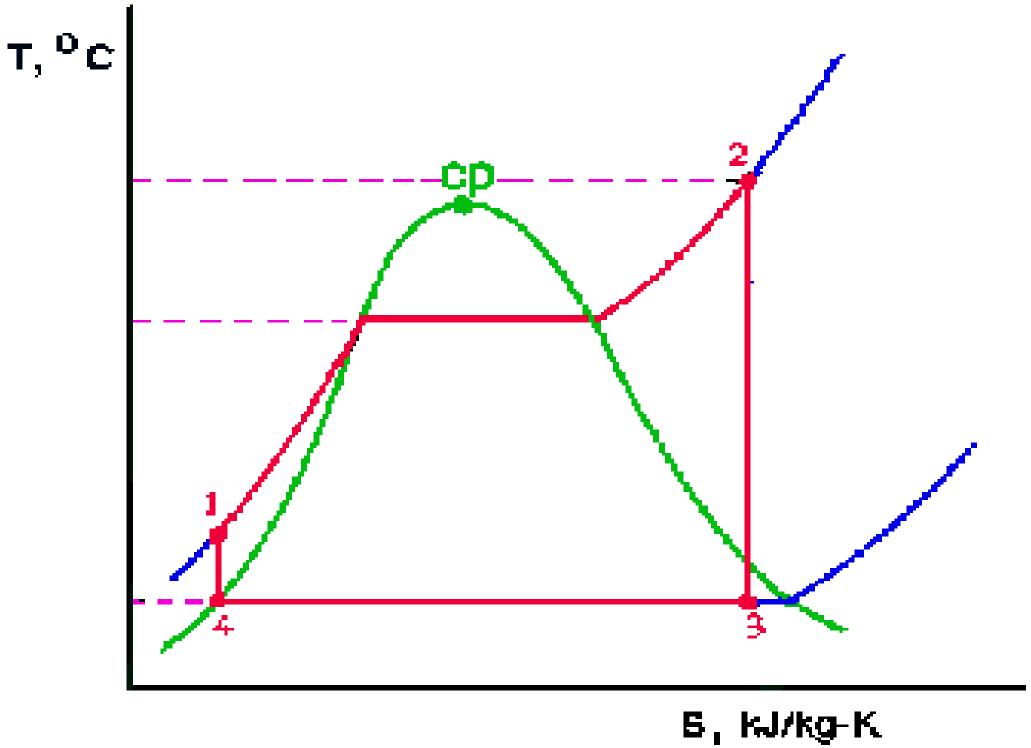


2
turbine
$\dot{W}_{turbine}$
electric generator
3
steam generator (boiler)
condenser
$\dot{Q}_{out}$
$\dot{Q}_{in}$
pump
1
$\dot{W}_{pump}$
4



Trained as a civil engineer, **William Rankine** (1820-1872)was appointed to the chairman of civil engineering and mechanics at Glasgow in 1855. He worked on heat, and attempted to derive Sadi Carnot's law from his own hypothesis. He was elected a Fellow of the Royal Society in 1853. Among his most important works are *Manual of Applied Mechanics* (1858), *Manual of the Steam Engine and Other Prime Movers* (1859) .

9-1-3. The efficiency of Rankine cycle



$$q_{\text{absorb}} = h_2 - h_1$$

$$q_{exhaust} = h_3 - h_4$$

$$\eta = \frac{q_{absorb} - q_{exhaust}}{q_{absorb}}$$

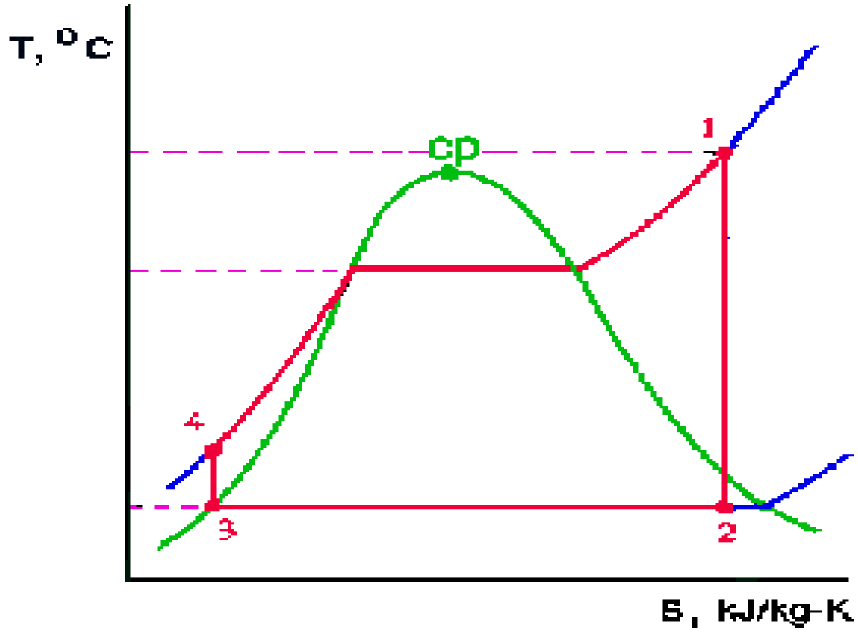
$$= \frac{h_2 - h_1 - (h_3 - h_4)}{h_2 - h_1}$$

$$= \frac{h_2 - h_1 - h_3 + h_4)}{h_2 - h_1}$$

Usually, The properties: p_1, t_1 and p_2 are available for a power plant,then:

h_1:

From p_1, t_1 , get h_1 , s_1



h_2: From p_2 , get s_2' , s_3''
h_2' , h_2''

$$s_2 = s_1 = xs_2'' + (1-x)s_2'$$

So, X can be known

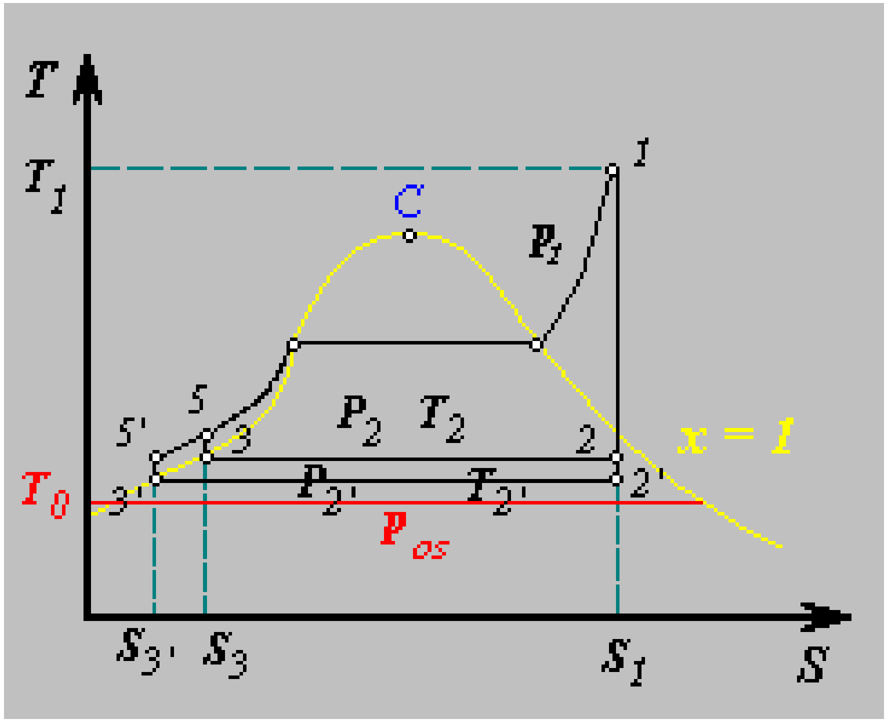
$$h_2 = xh_2'' + (1-x)h_2'$$

h_3: From p_2 , get h_2' , s_2' .
$h_3 = h_3'$ $s_3 = s_3'$

h_4: From p_1 , $s_1 = s_4$ get h_4

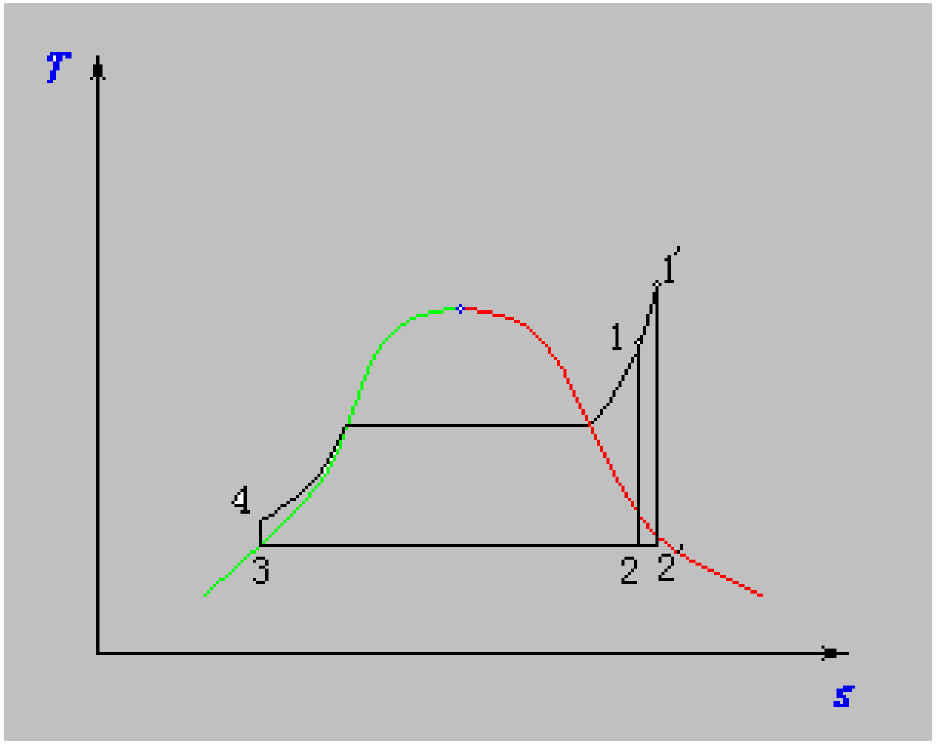
9-2 The Influence of Steam Property

9-2-1. Exhaust Pressure



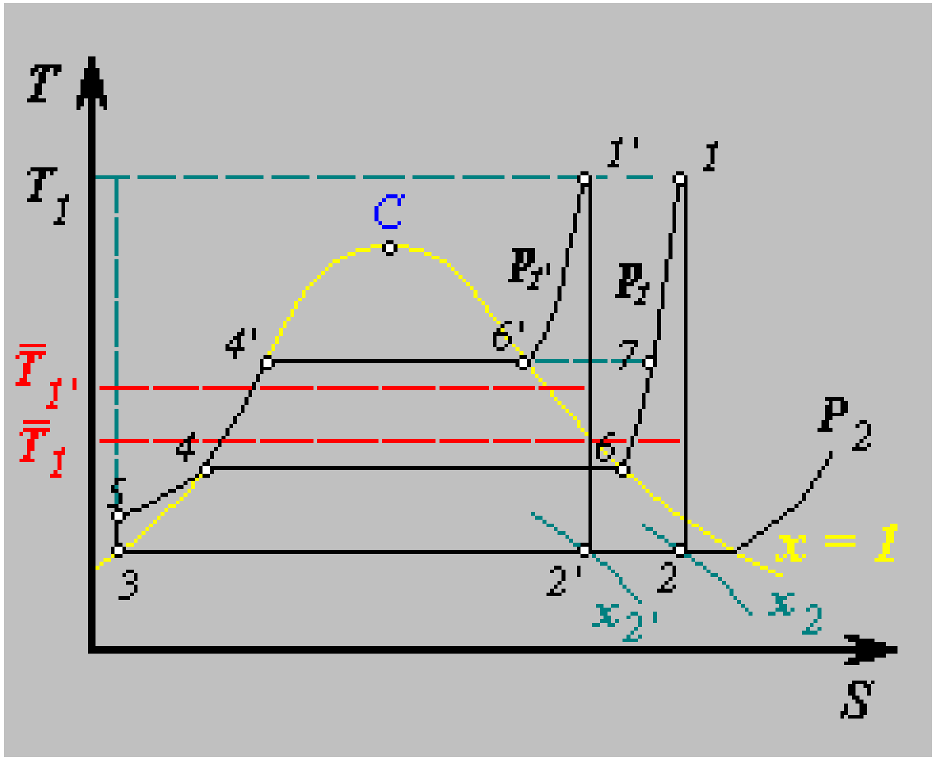
To decrease the exhaust pressure can increase the efficiency of Rankine cycle.
But the dryness fraction will increase too. This can lead some damage to steam turbine

9-2-2. Inlet temperature



To decrease the inlet temperature can increase the efficiency of Rankine cycle.
But this increase depends on boiler material

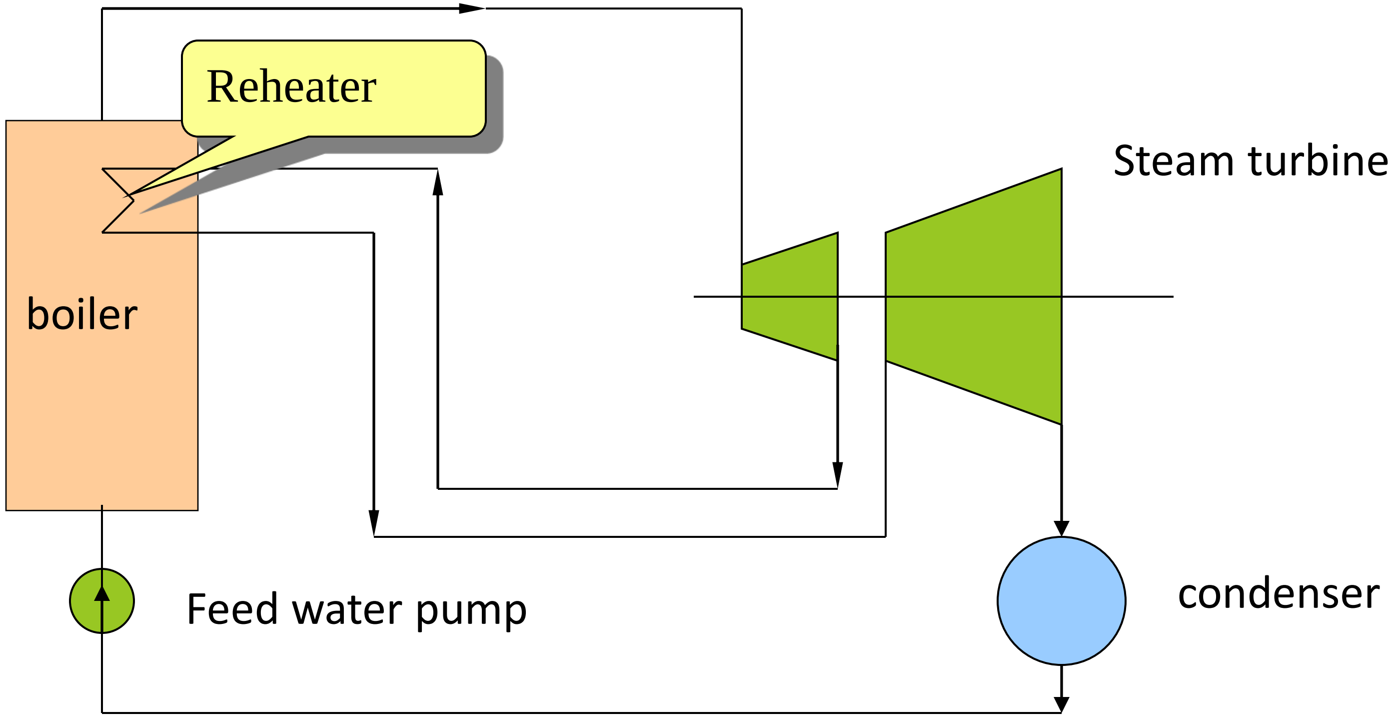
9-2-3. Inlet pressure



To increase the inlet pressure can increase the efficiency of Rankine cycle greatly.
But this increase also depends on boiler material

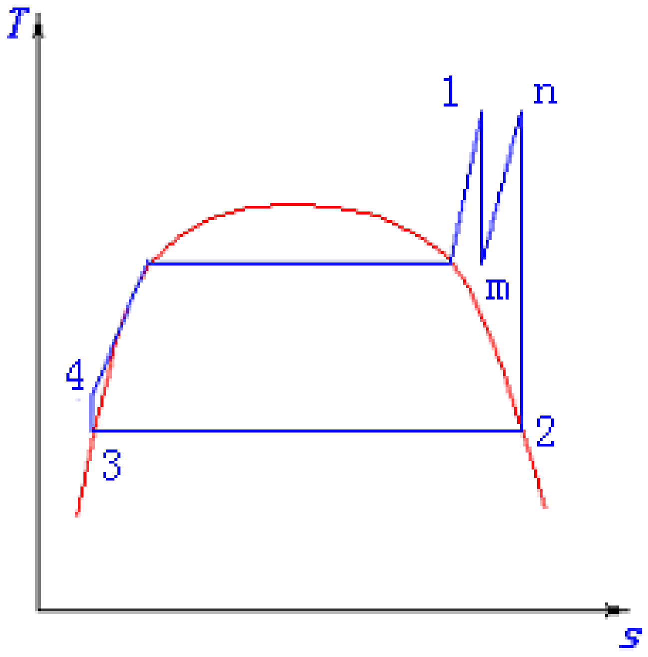
9-3 Reheat Cycle

9-3-1 Equipments of Reheat Cycle



9-3-2 Efficiency

T-s diagram



Efficiency

$$q_{in} = (h_1 - h_4) + (h_n - h_m)$$

$$q_{exhaust} = h_2 - h_3$$

$$w = q_{in} - q_{exhaust}$$

$$\eta = \frac{w}{q_{in}}$$

$$= \frac{(h_1 - h_4) + (h_n - h_m) - (h_2 - h_3)}{(h_m - h_1) + (h_1 - h_n)}$$

The properties: p_1, t_1, p_m, t_n (equals t_1 usually), p_2 are available for a reheat power plant,then:

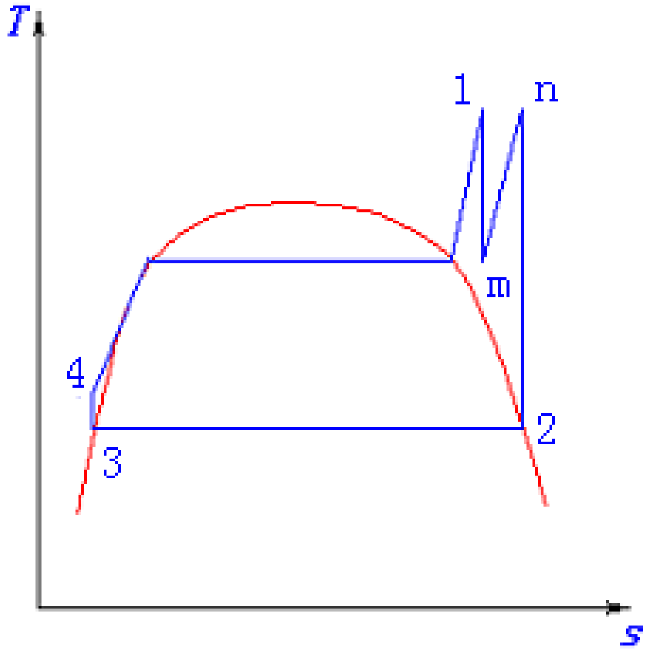
h_1:

From p_1, t_1, get h_1, s_1

h_m: From p_2, $s_2 = s_1$, get h_m

h_n: From p_m, t_n, get h_n

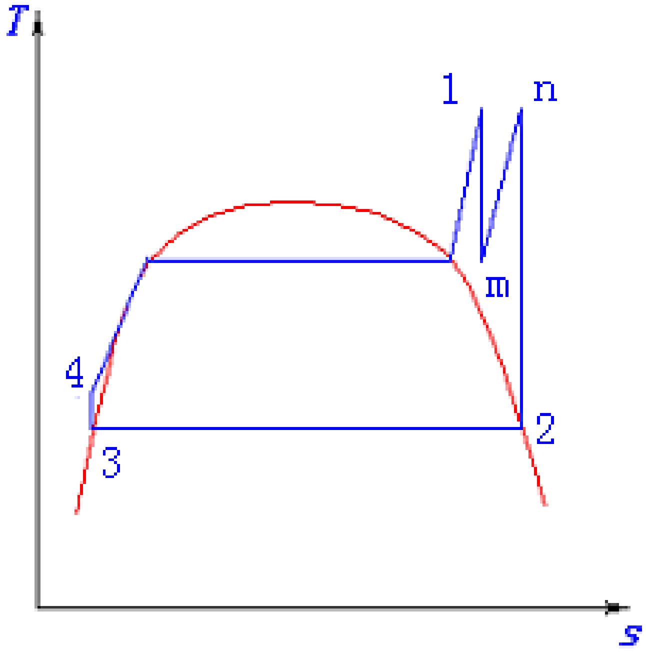
h_2: From p_2, get s_2', s_3''
h_2', h_2''



$$s_2 = s_n = xs_2'' + (1-x)s_2'$$

So, X can be known

$$h_2 = xh_2'' + (1-x)h_2'$$



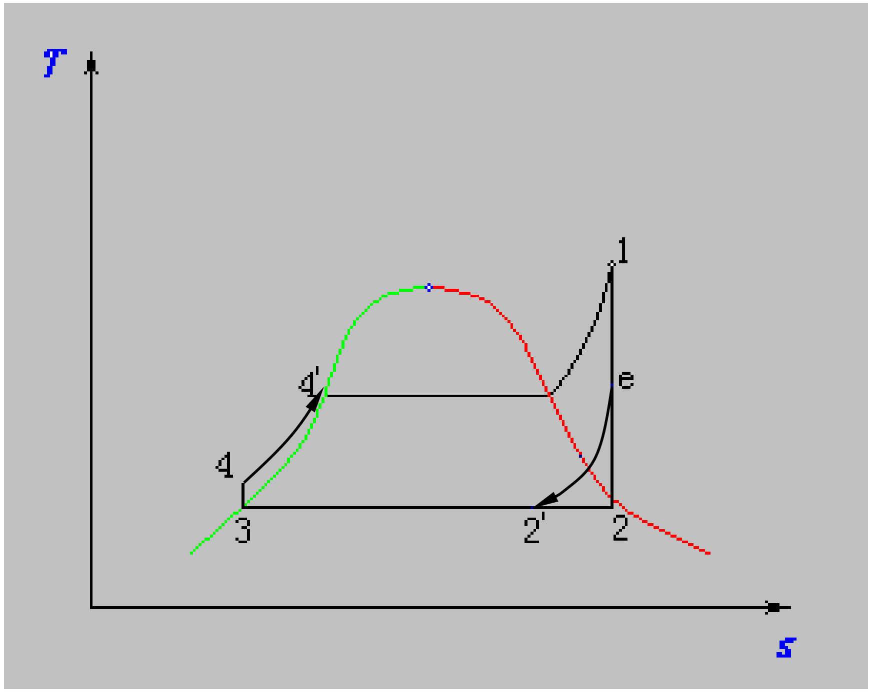
h_3: From p_2, get h_2', s_2'.

$h_3 = h_3'$ $s_3 = s_3'$

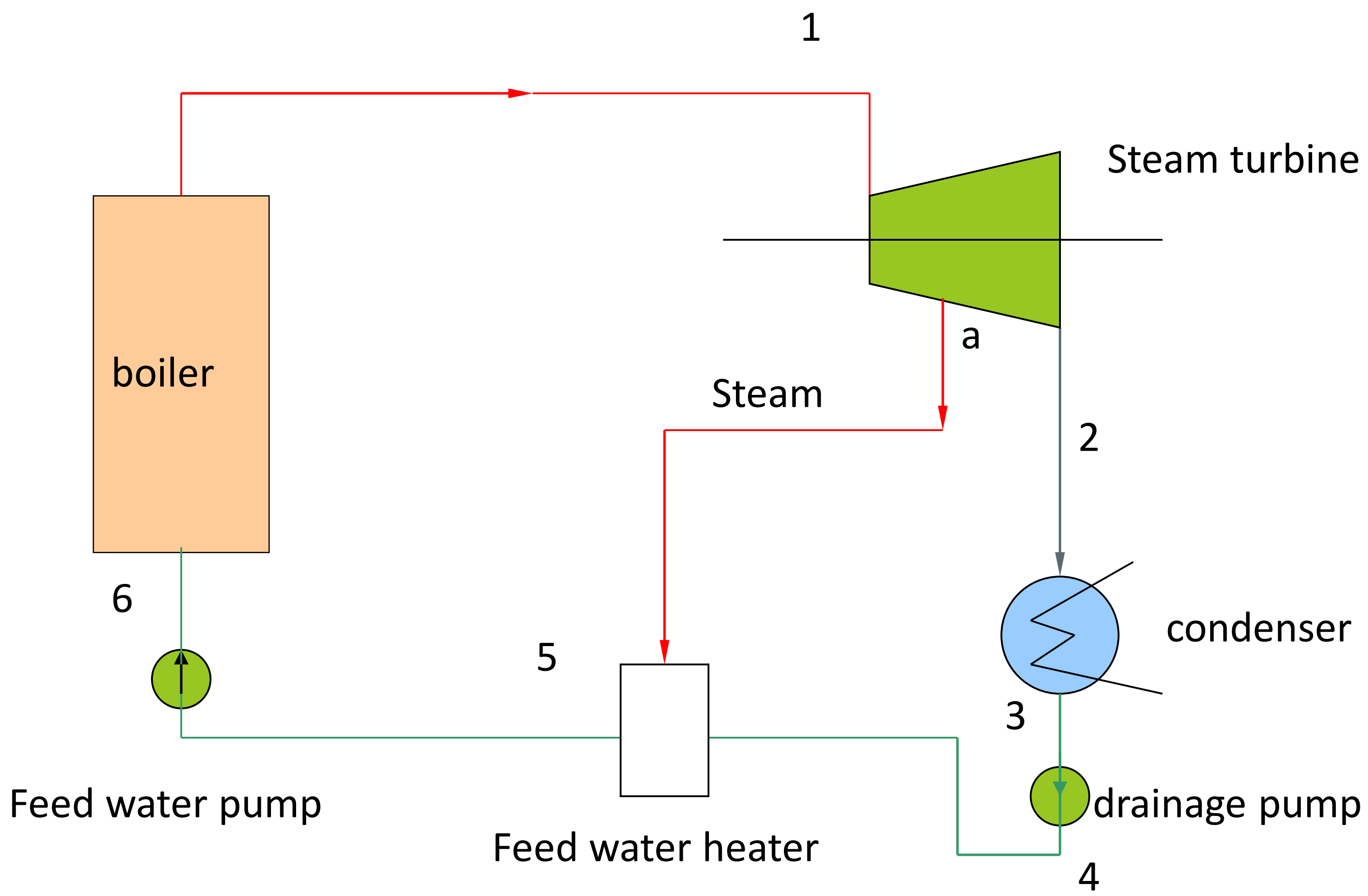
h_4: From p_1, $s_1 = s_4$ get h_4

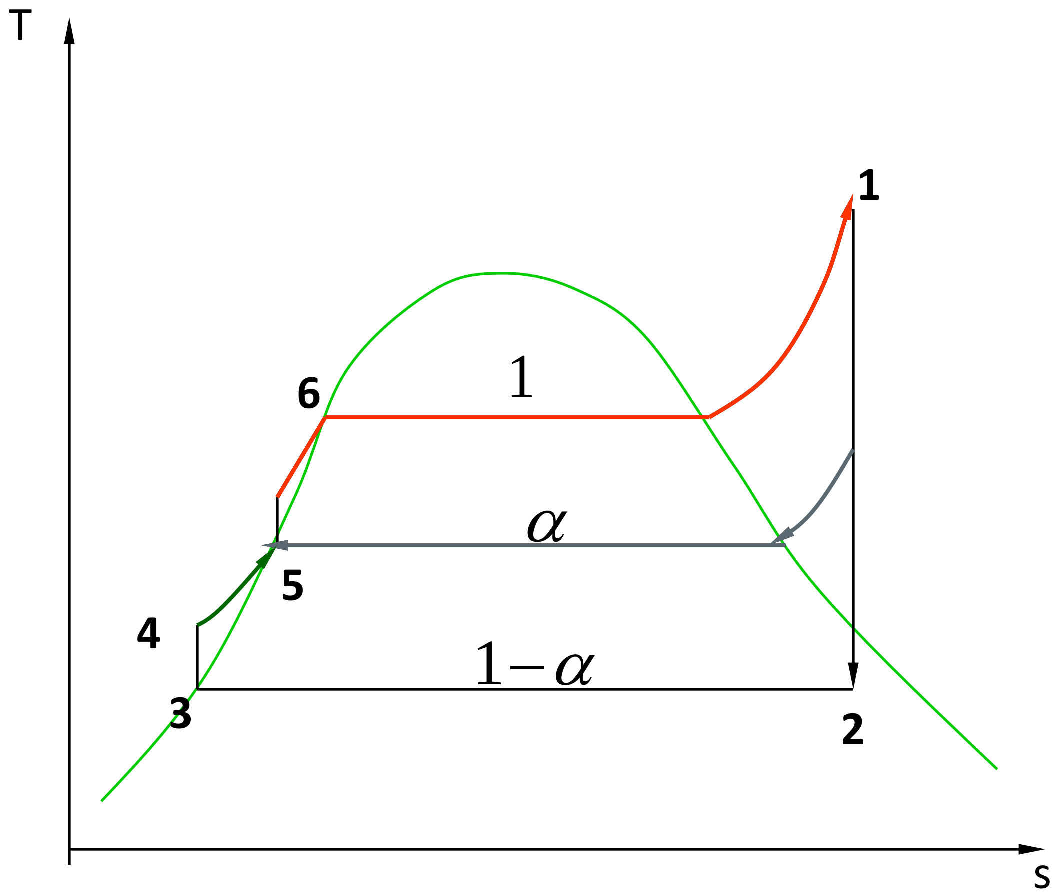
9-4 Regenerative Cycle

9-4-1 Ideal Regenerative Cycle



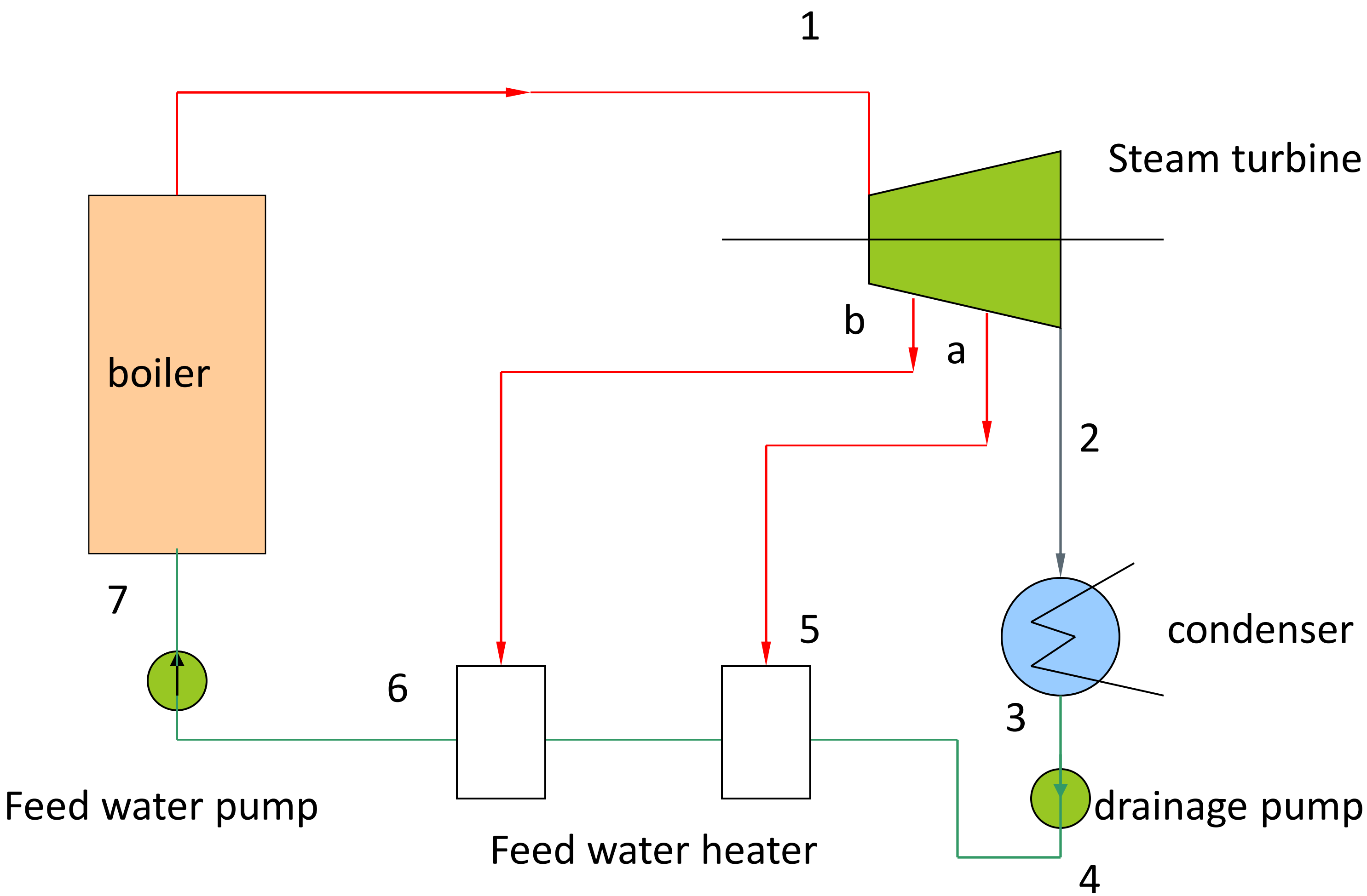
9-4-2 Regenerative Cycle

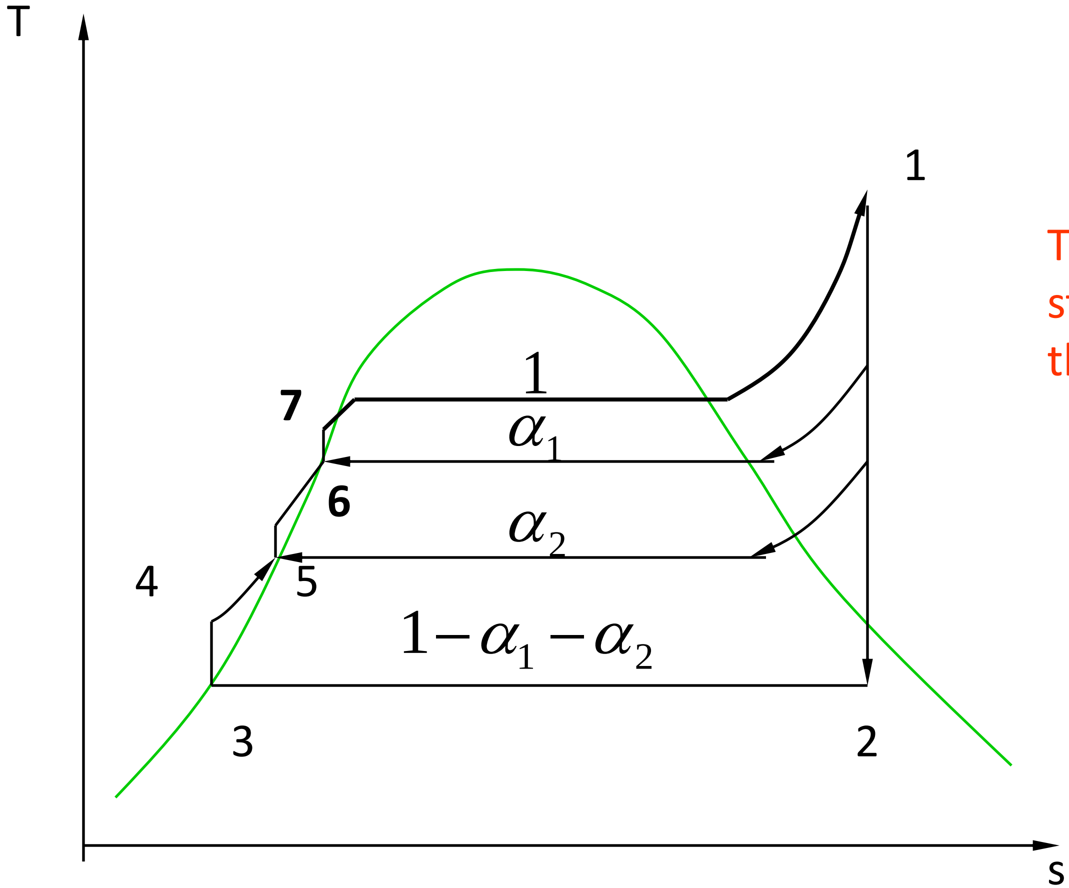




The feed water is heated by steam bleeding out from steam turbine. The average temperature of heat absorption process increases then.

$$\alpha = \frac{\text{The flow of steam bleeding out from the turbine}}{\text{The flow of steam entering the turbine}} \times 100\%$$

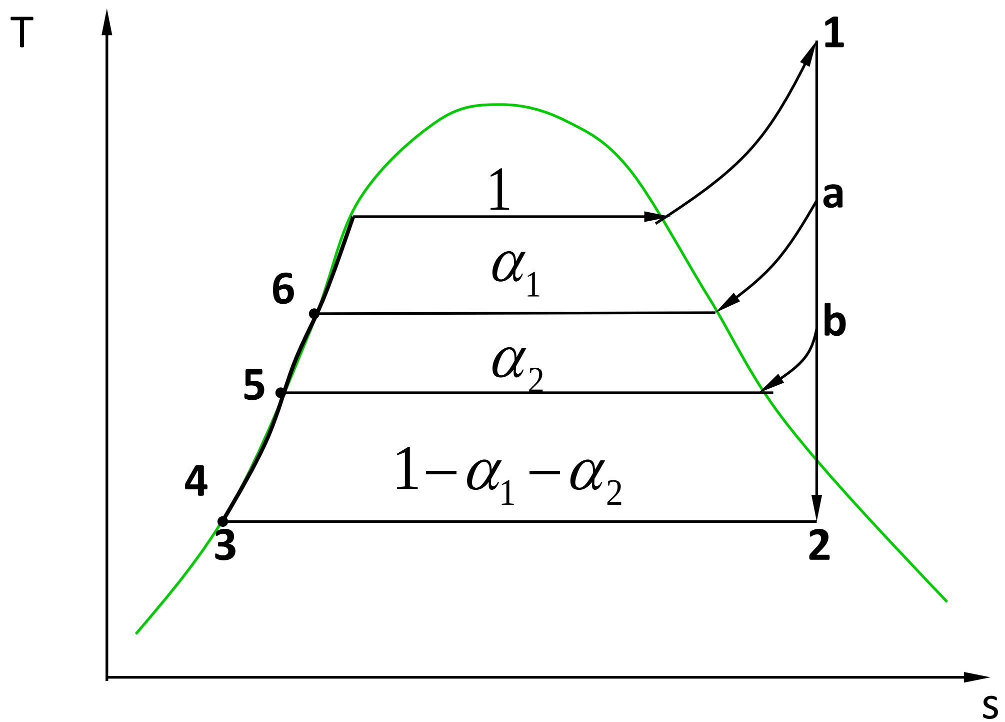

1
Steam turbine
boiler
b
a
2
7
5
condenser
6
3
Feed water pump
drainage pump
Feed water heater
4



The more stages of bleeding steam, the higher efficiency the cycle has

9-4-2 The efficiency of regenerative Cycle

As to a two stages regenerative cycle,the properties: p_1, t_1 , p_a , p_b , p_2 are available. If neglect the pump work, the T-s diagram should be as following.



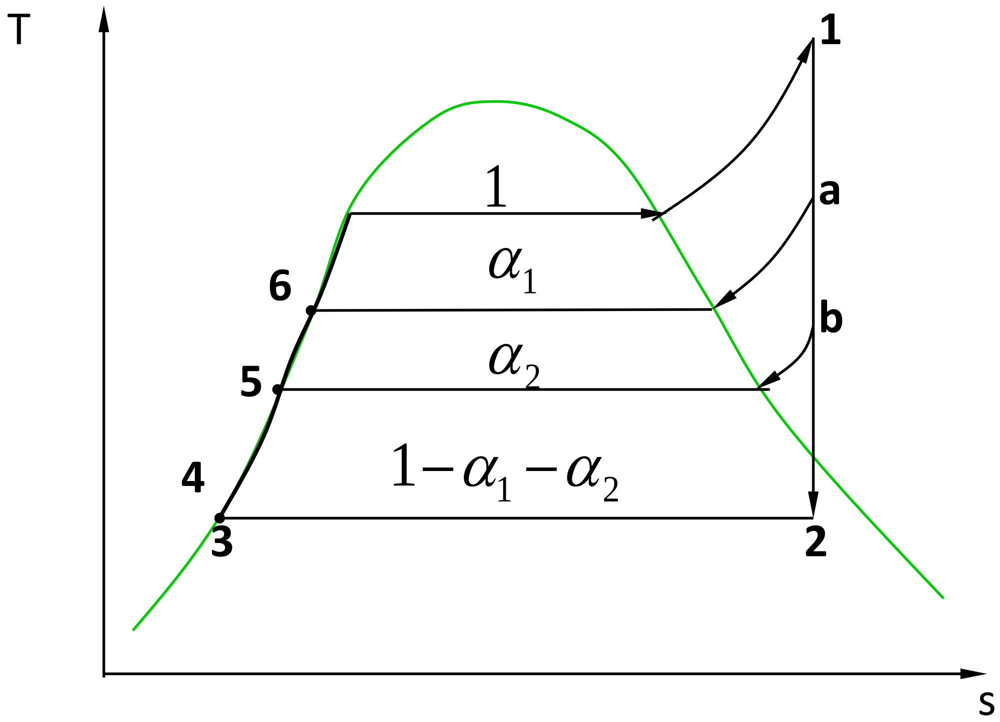
$$q_{in} = h_1 - h_6$$

$$q_{exhaust} = (h_2 - h_3)(1 - \alpha_1 - \alpha_2)$$

$$w = q_{in} - q_{exhaust}$$

$$\eta = \frac{q_{in} - q_{exhaust}}{q_{in}}$$

The enthalpy of each point



h_1: From p_1, t_1, get h_1, s_1

h_a: From p_a, s_1, get h_a

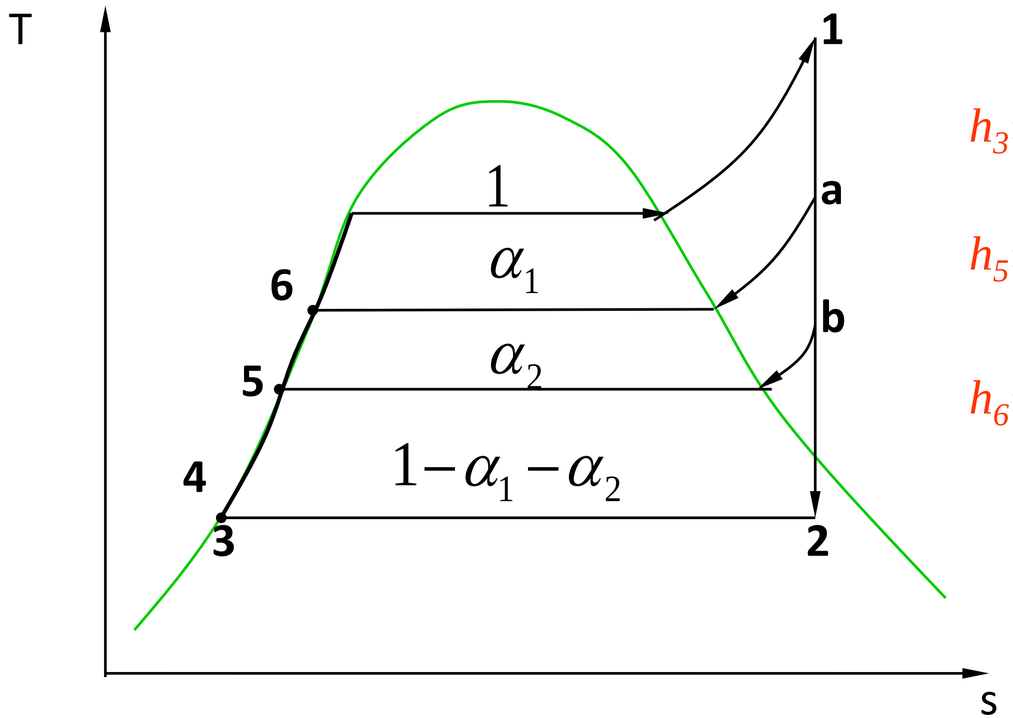
h_b: From p_b, s_1, get h_b

h_2: From p_2, get s_2', s_3''
h_2', h_2''

$$s_2 = s_1 = xs_2'' + (1-x)s_2'$$

So, x can be known

$$h_2 = xh_2'' + (1-x)h_2'$$



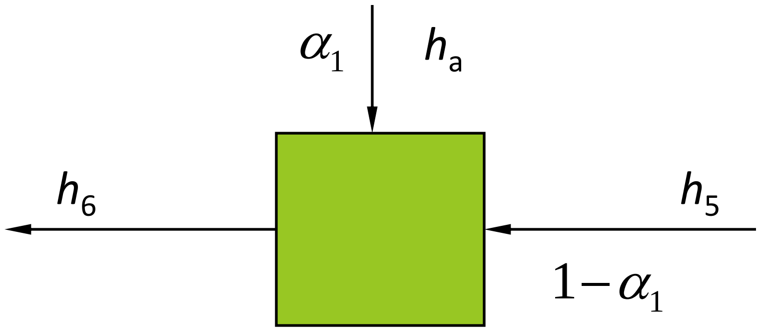
h_3: From p_2, get h_2', $h_3 = h_2'$

h_5: From p_b, get h_b', $h_5 = h_b'$

h_6: From p_a, get h_a', $h_6 = h_a'$

α_1 and α_2

As to the 1st stage heater

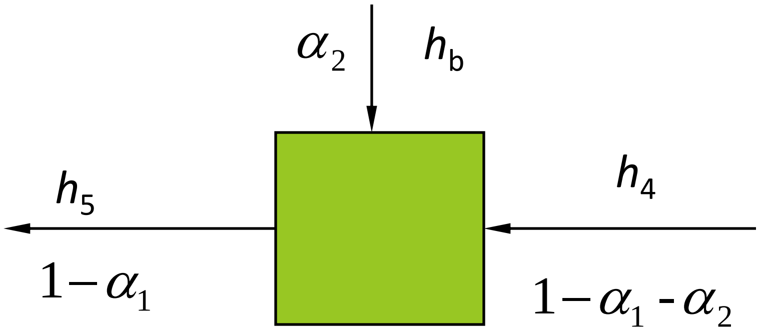


According to the first law of thermodynamics

$$h_6 = h_5(1-\alpha_1) + \alpha_1 h_a$$

$$\alpha_1 = \frac{h_6 - h_5}{h_a - h_5}$$

As to the 2nd stage heater



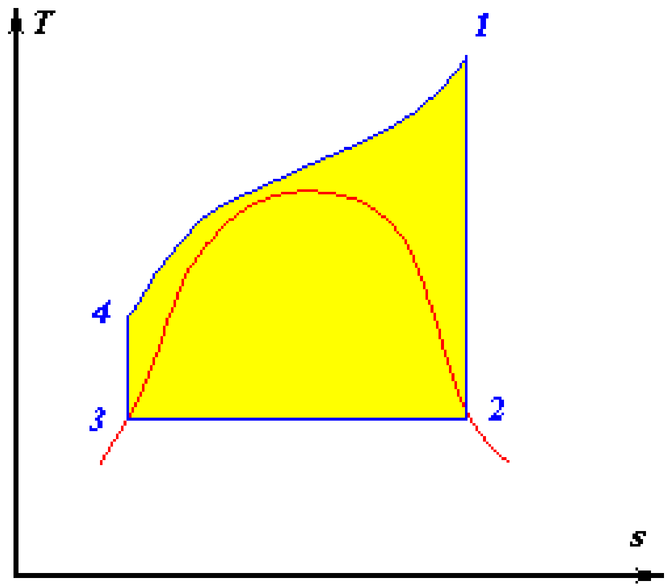
According to the first law of thermodynamics

$$h_5(1-\alpha_1) = h_4(1-\alpha_1-\alpha_2)+\alpha_2 h_b$$

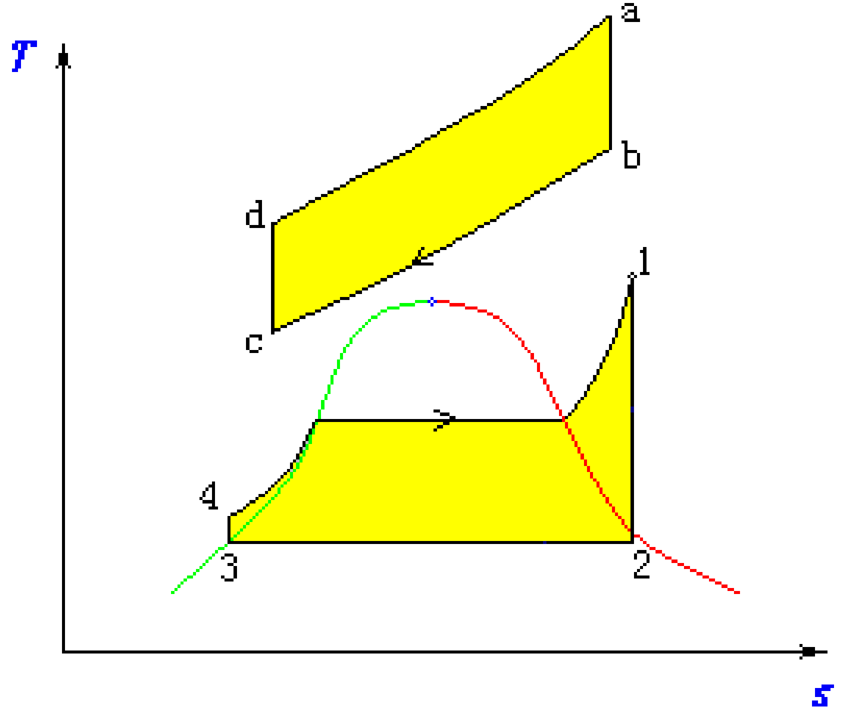
$$\alpha_2 = \frac{(1-\alpha_1)(h_5-h_4)}{h_b-h_4}$$

9-5 Other Steam Power Cycle

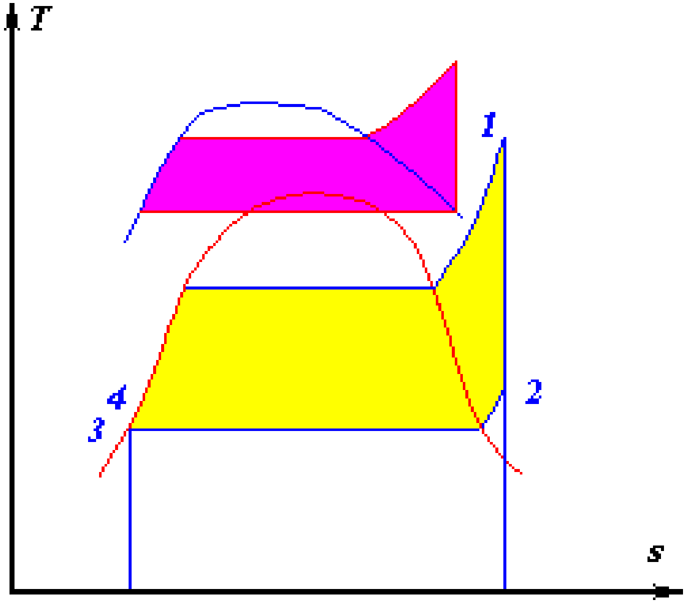
9-5-1 Super-critical Cycle



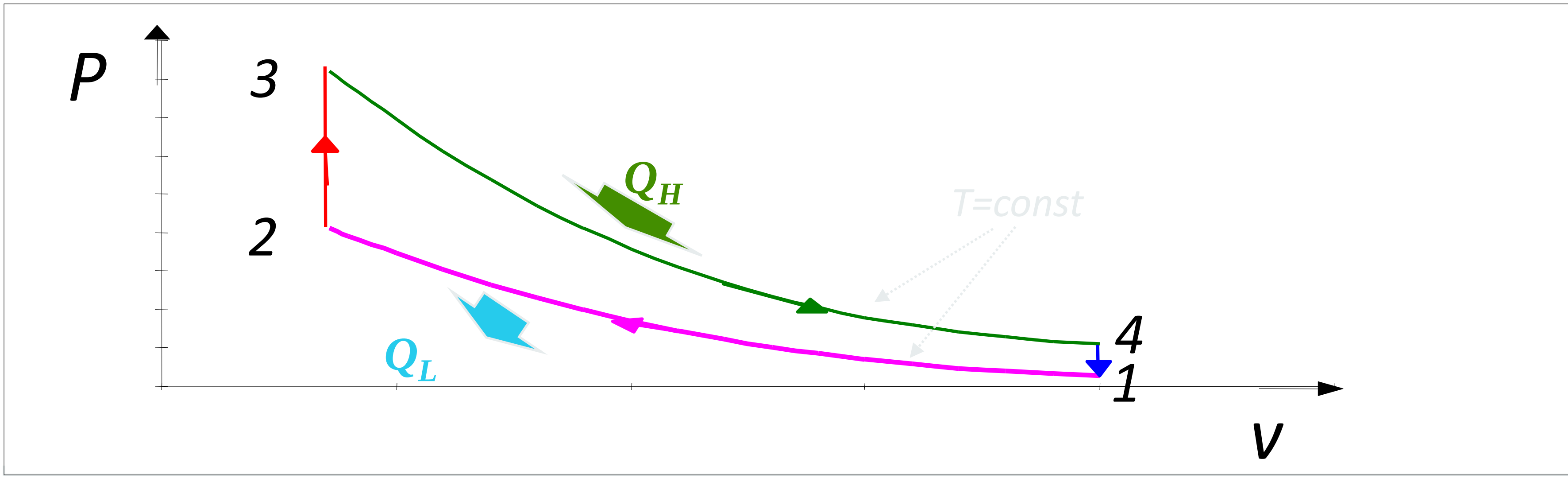
9-5-2 The Combined Gas-Vapor Power Cycle



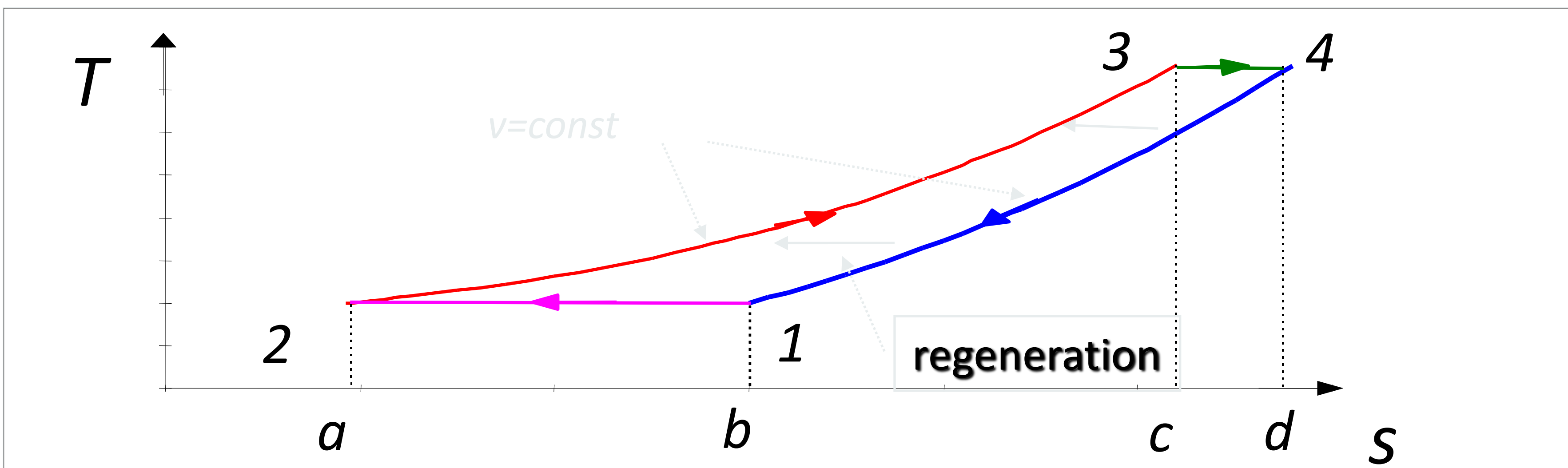
9-5-2 Binary-vapor Cycle



Reciprocating engines (internal combustion)



P
3
2
4
1
v
Q_H
Q_L
T=const

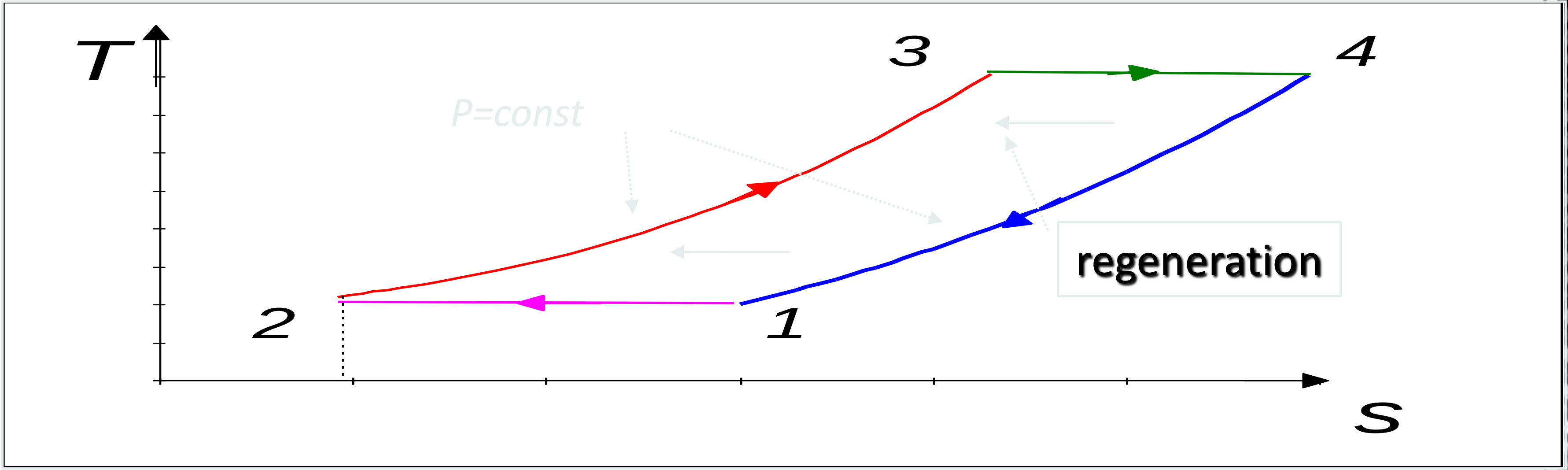


T
3
4
v=const
2
1
regeneration
a
b
c
d
s

- same as Stirling cycle with the P=const processes substituted for v=const
- should involve regeneration
- impractical

Ericsson cycle

Example 9.9



Efficiency of Stirling and Ericsson cycles with regeneration

1st law for this cycle:

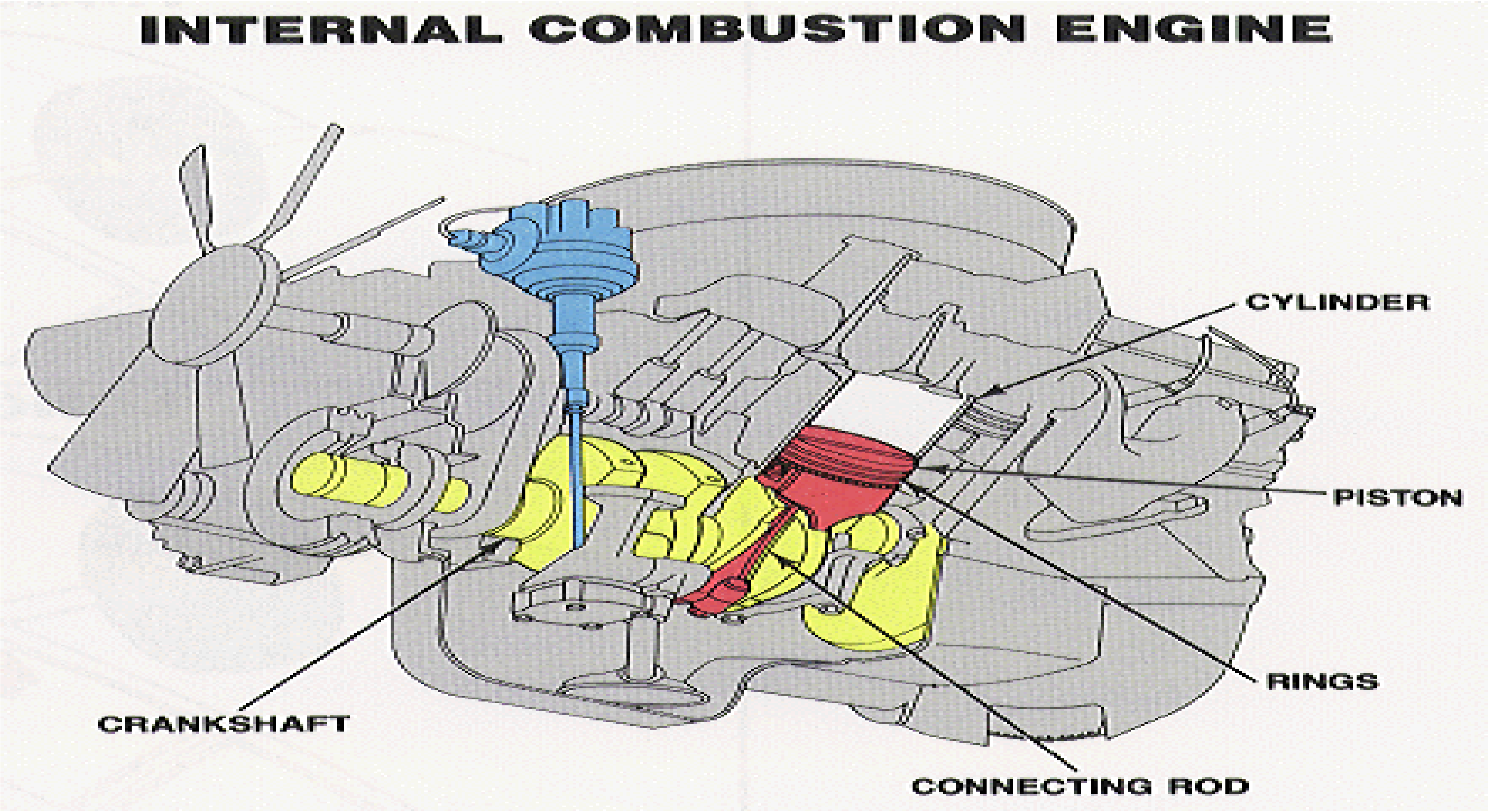
$$W = Q_H - Q_L$$

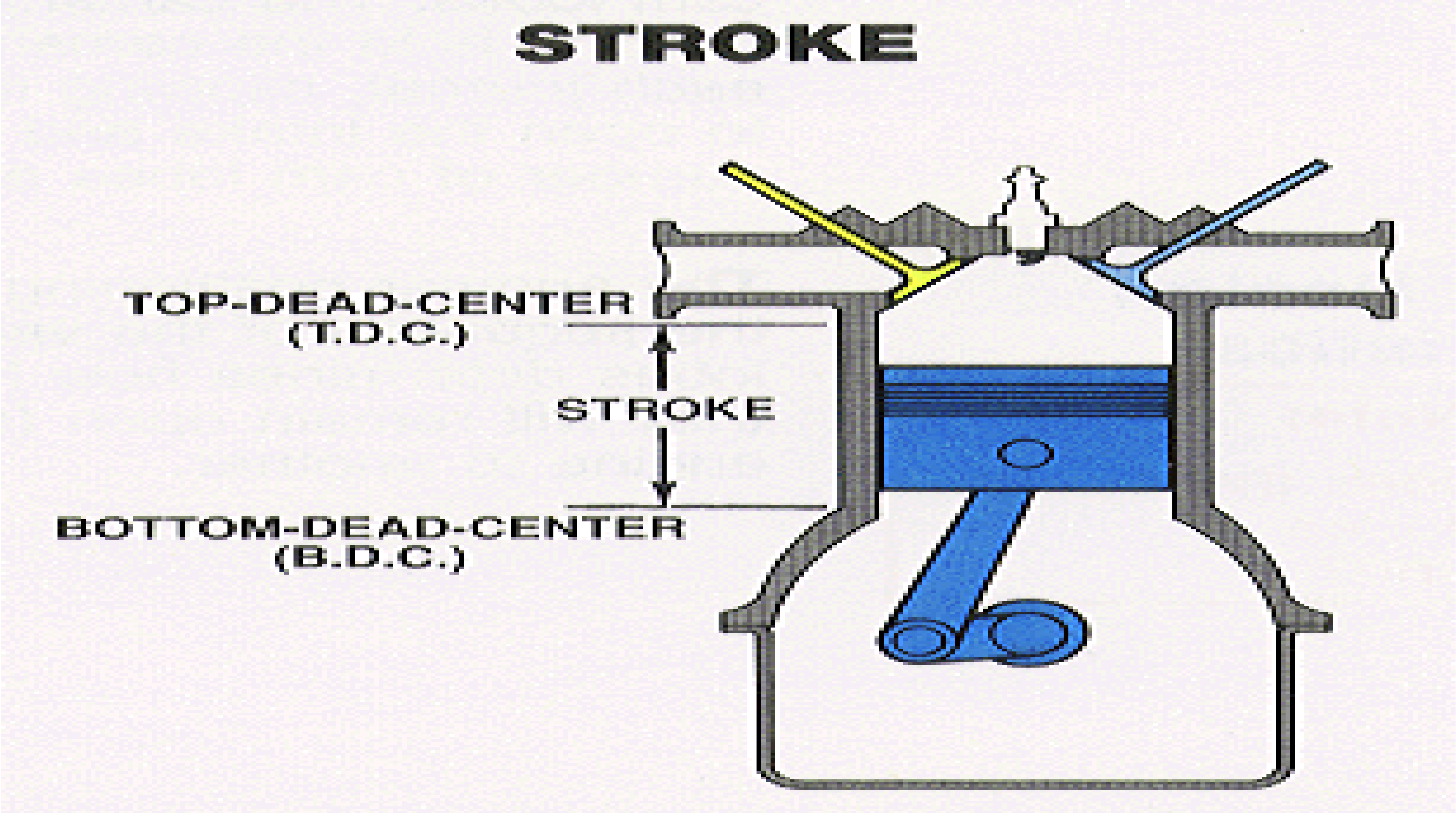
energy conversion efficiency is:

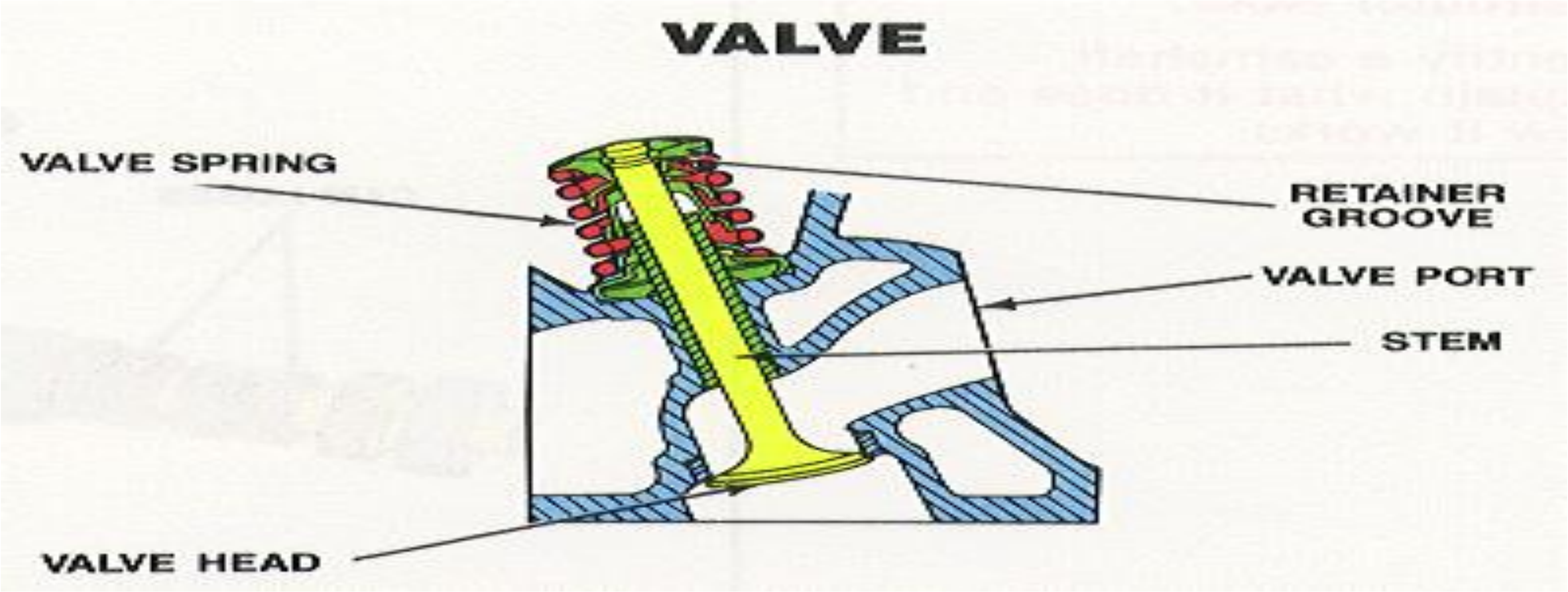
$$\eta = \frac{\text{useful work}}{\text{heat input}} = \frac{W}{Q_H} = \frac{Q_H - Q_L}{Q_H}$$

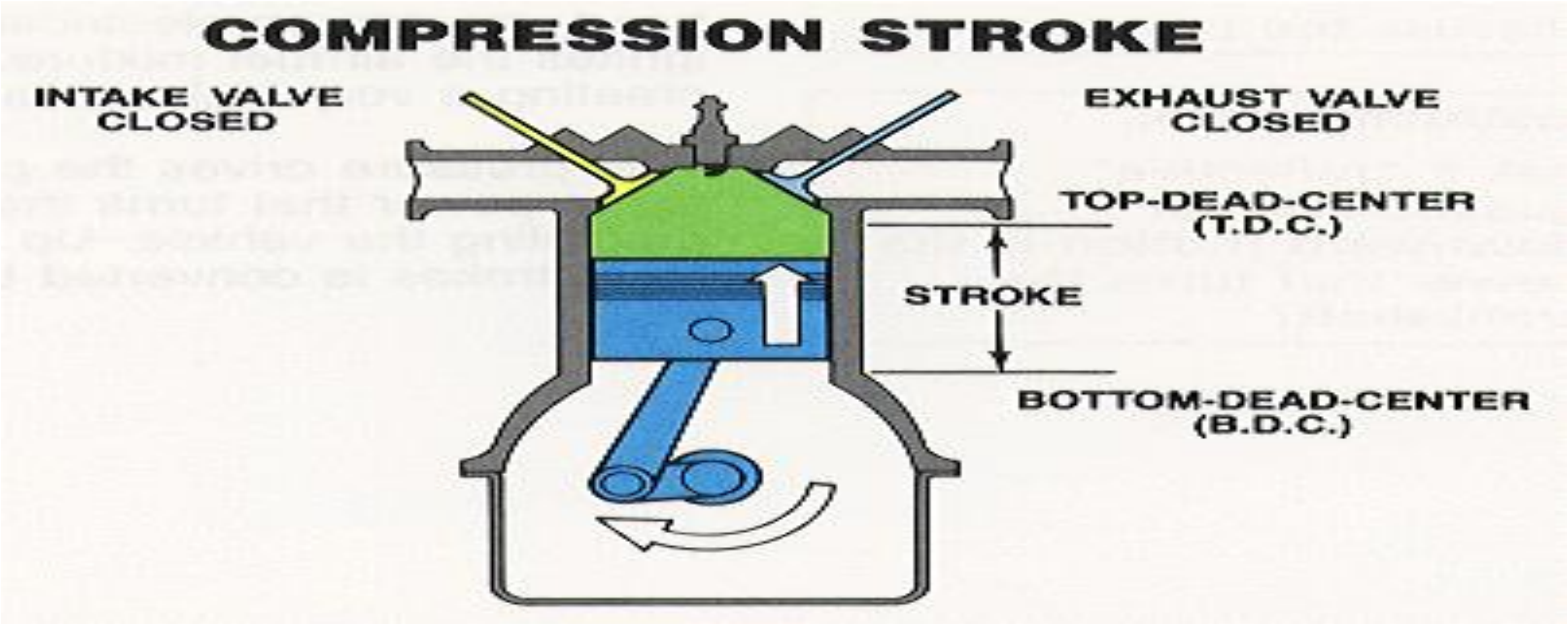
$$\eta = 1 - \frac{Q_L}{Q_H} = 1 - \frac{T_L}{T_H}$$

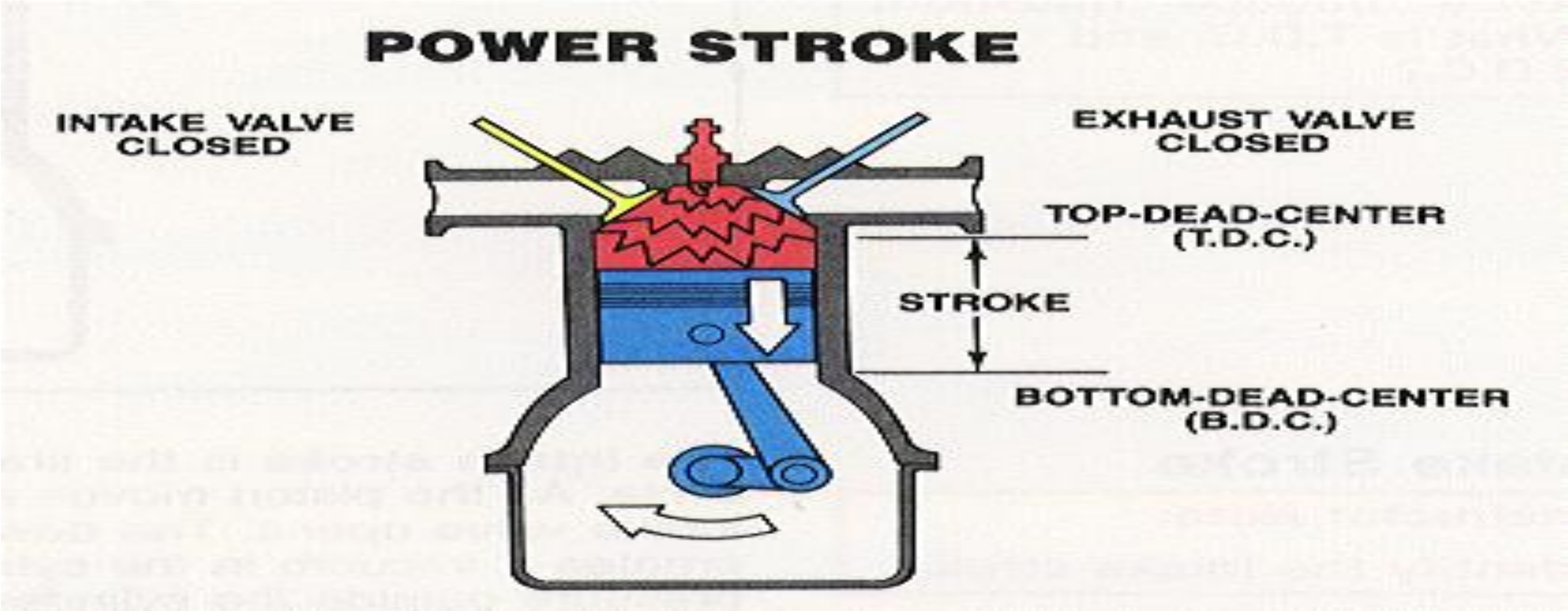
Efficiency is the same as for Carnot Cycle but it would be much lower if regeneration were not present

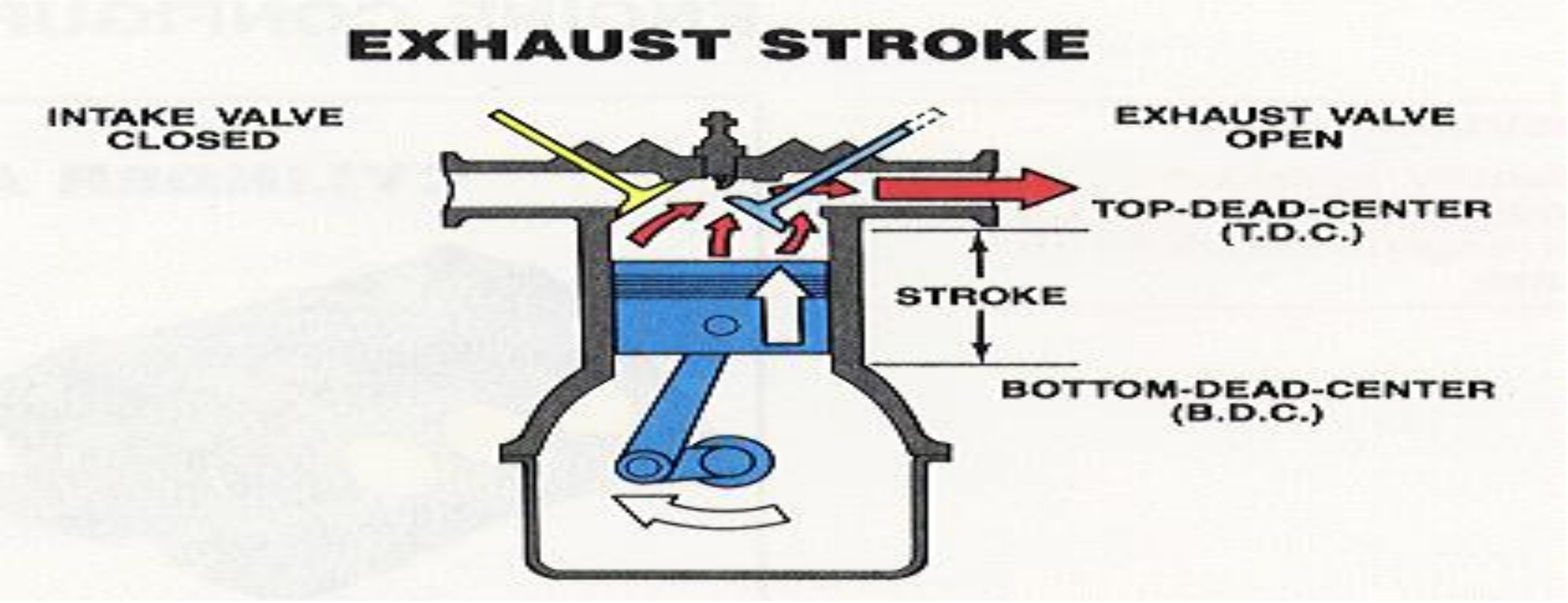

INTERNAL COMBUSTION ENGINE
CYLINDER
PISTON
RINGS
CRANKSHAFT
CONNECTING ROD

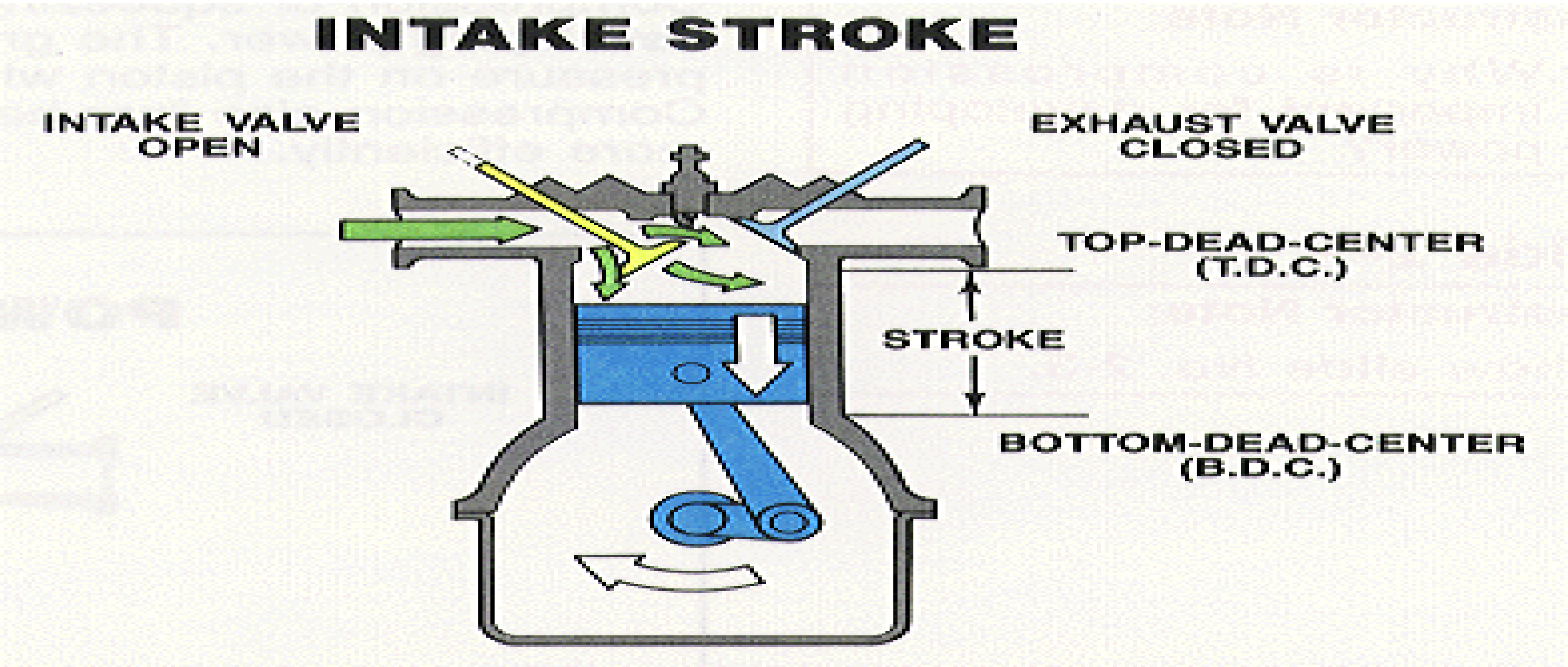

STROKE
TOP-DEAD-CENTER
(T.D.C.)
STROKE
BOTTOM-DEAD-CENTER
(B.D.C.)

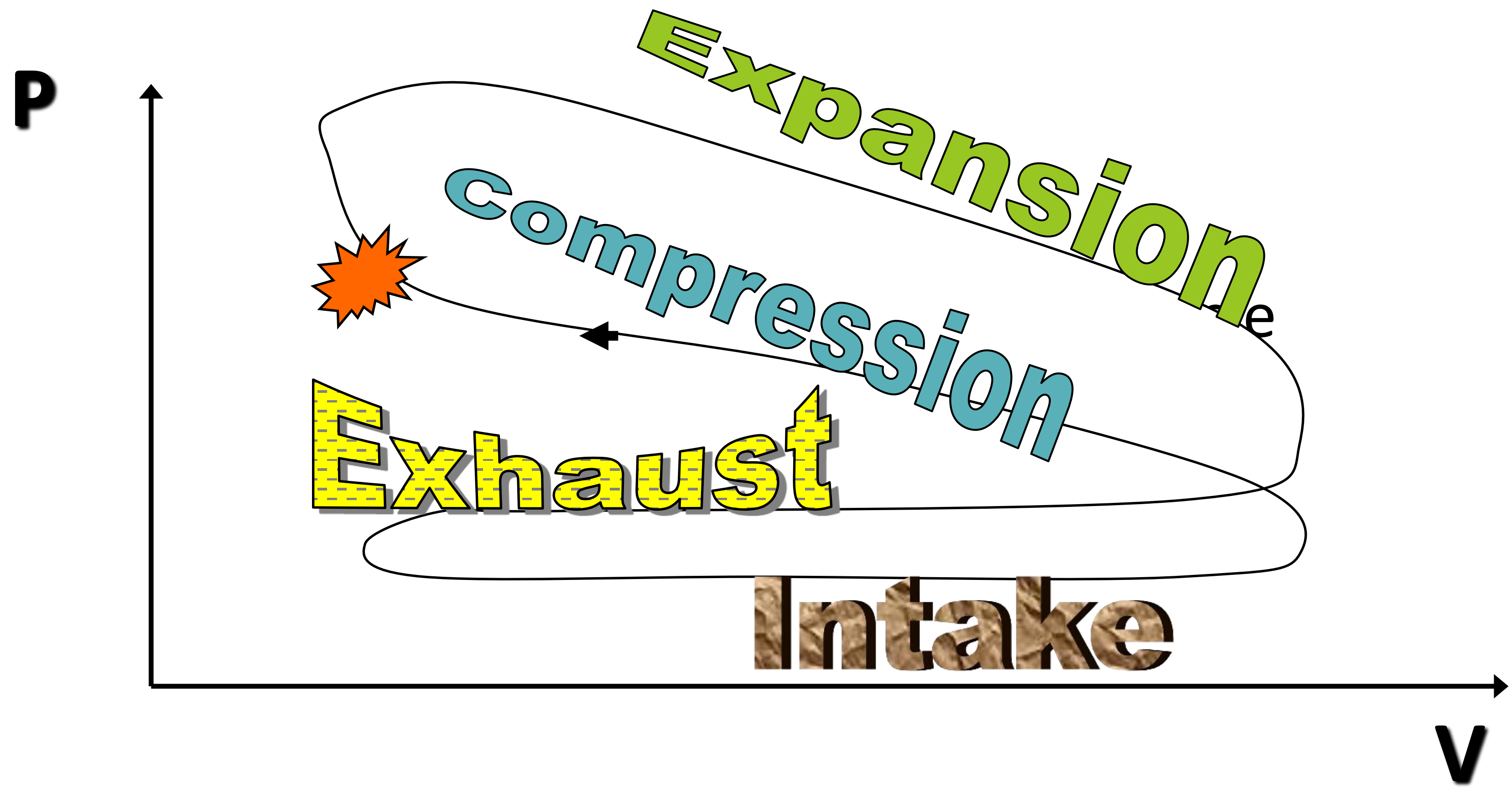

VALVE
VALVE SPRING
RETAINER
GROOVE
VALVE PORT
STEM
VALVE HEAD


COMPRESSION STROKE
INTAKE VALVE CLOSED
EXHAUST VALVE CLOSED
TOP-DEAD-CENTER (T.D.C.)
STROKE
BOTTOM-DEAD-CENTER (B.D.C.)


POWER STROKE
INTAKE VALVE CLOSED
EXHAUST VALVE CLOSED
TOP-DEAD-CENTER (T.D.C.)
STROKE
BOTTOM-DEAD-CENTER (B.D.C.)

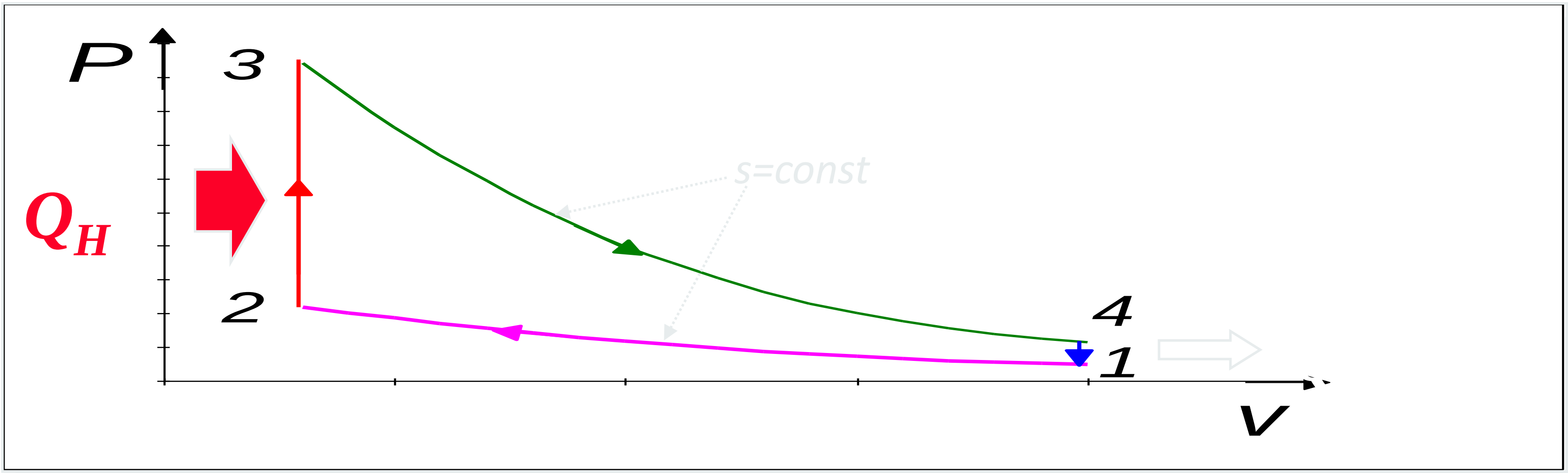

EXHAUST STROKE
INTAKE VALVE CLOSED
EXHAUST VALVE OPEN
TOP-DEAD-CENTER (T.D.C.)
STROKE
BOTTOM-DEAD-CENTER (B.D.C.)

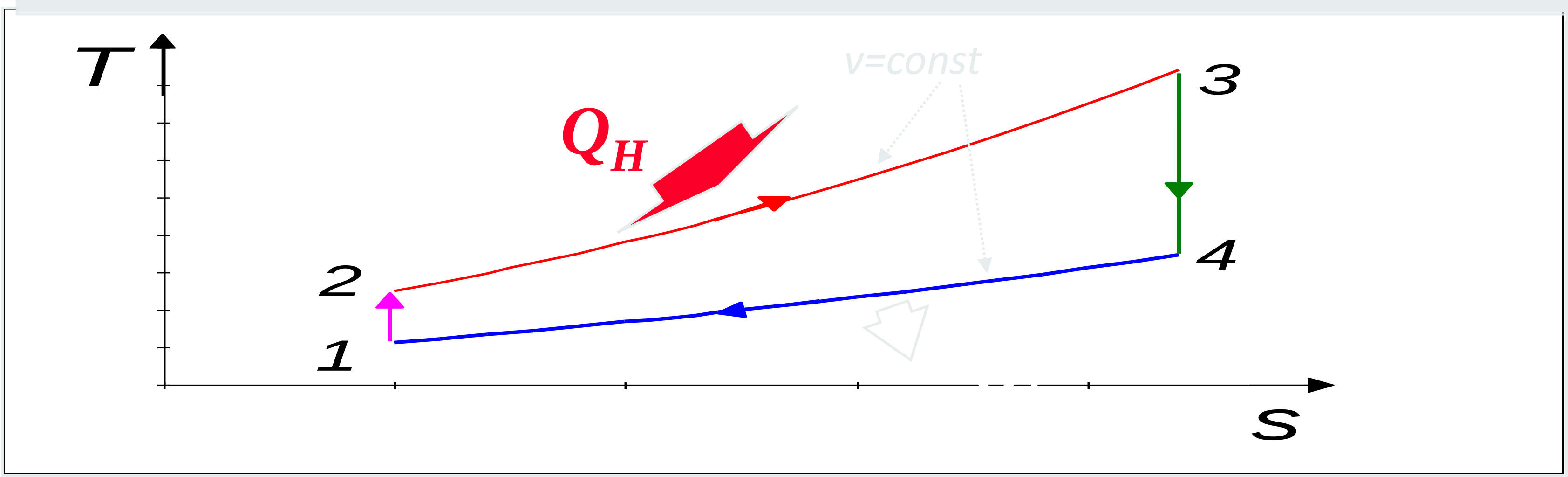

INTAKE STROKE
INTAKE VALVE
OPEN
EXHAUST VALVE
CLOSED
TOP-DEAD-CENTER
(T.D.C.)
STROKE
BOTTOM-DEAD-CENTER
(B.D.C.)


P
Expansion
compression
Exhaust
Intake
V

Air-Standard Power Cycles

- Assumptions:
  - we analyse a control mass of an ideal gas, meaning.....
  - exhaust and air intake are substituted with heat transfer from the system to the surroundings
  - combustion is replaced by heat transfer from an external source to the system
  - all processes are internally reversible, meaning....
  - gas specific heat is constant


P
3
Q_H
2
s=const
4
1
V


T
v=const
3
Q_H
2
4
1
S

Ideal Otto Cycle (cont.)

1st law for this cycle:

$$W = Q_H - Q_L$$

energy conversion efficiency is:

$$\eta = \frac{\text{useful work}}{\text{heat input}} = \frac{W}{Q_H} = \frac{Q_H - Q_L}{Q_H}$$

$$\eta = 1 - \frac{Q_L}{Q_H} = 1 - \frac{mC_v(T_4 - T_1)}{mC_v(T_3 - T_2)}$$

$$\eta = 1 - \frac{T_1(T_4/T_1 - 1)}{T_2(T_3/T_2 - 1)}$$

Ideal Otto Cycle (cont.)

for an isentropic process:

$$Pv^k = const$$

$$P_1 v_1^{\,k} = P_2 v_2^{\,k}$$

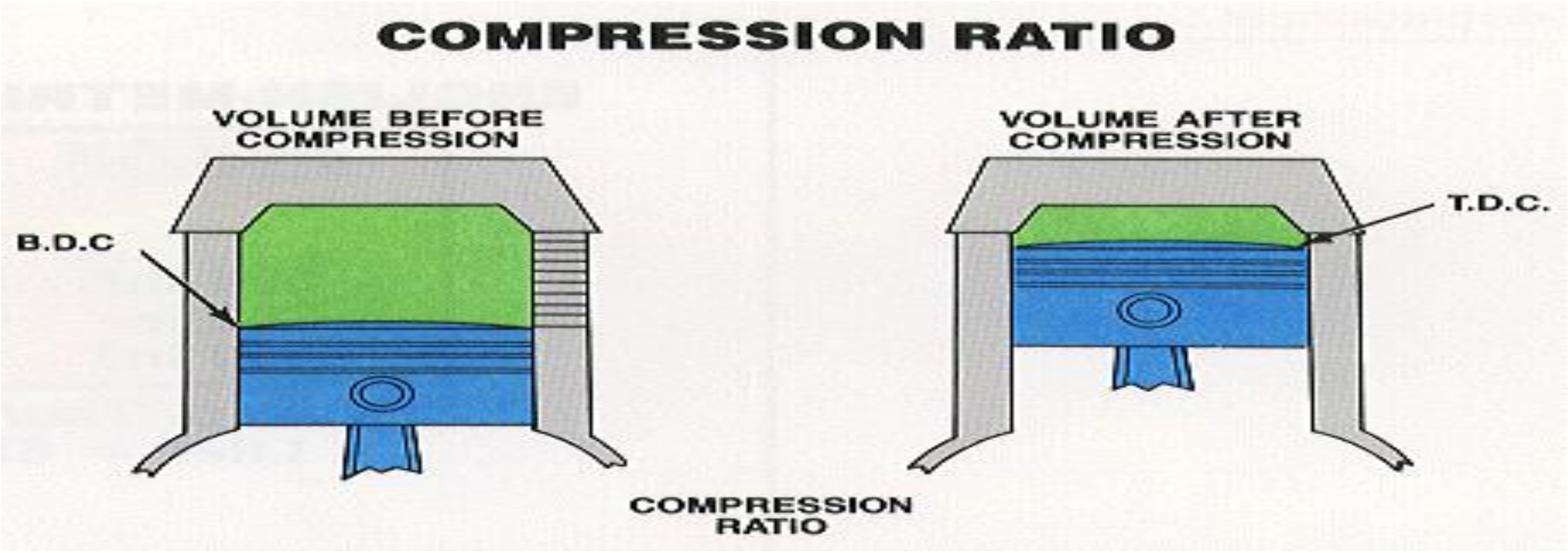
in case of an ideal gas:

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{k-1} = \left(\frac{V_4}{V_3}\right)^{k-1} = \frac{T_3}{T_4}$$

$$\frac{T_3}{T_2} = \frac{T_4}{T_1}$$

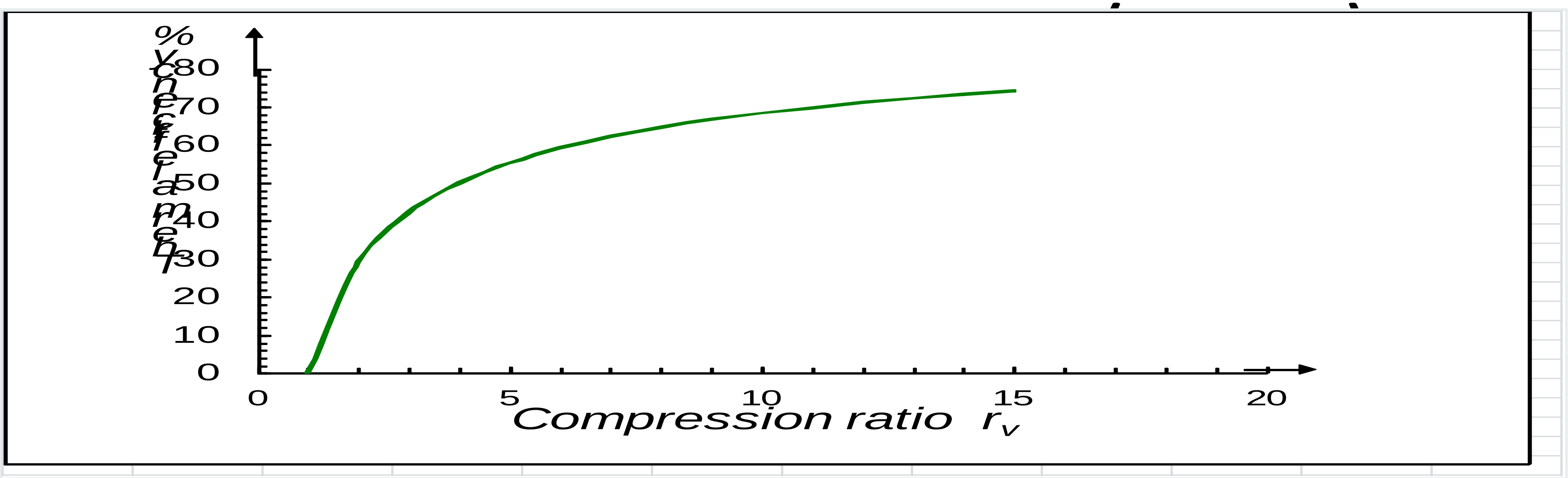
compression ratio

$$\eta = 1 - \frac{T_1}{T_2} = 1 - \left(\frac{V_1}{V_2}\right)^{1-k} = 1 - (r_v)^{1-k}$$


COMPRESSION RATIO
VOLUME BEFORE COMPRESSION
VOLUME AFTER COMPRESSION
B.D.C
T.D.C.
COMPRESSION RATIO

$$\eta = 1 - \frac{1}{(r_v)^{k-1}}$$

Ideal Otto Cycle

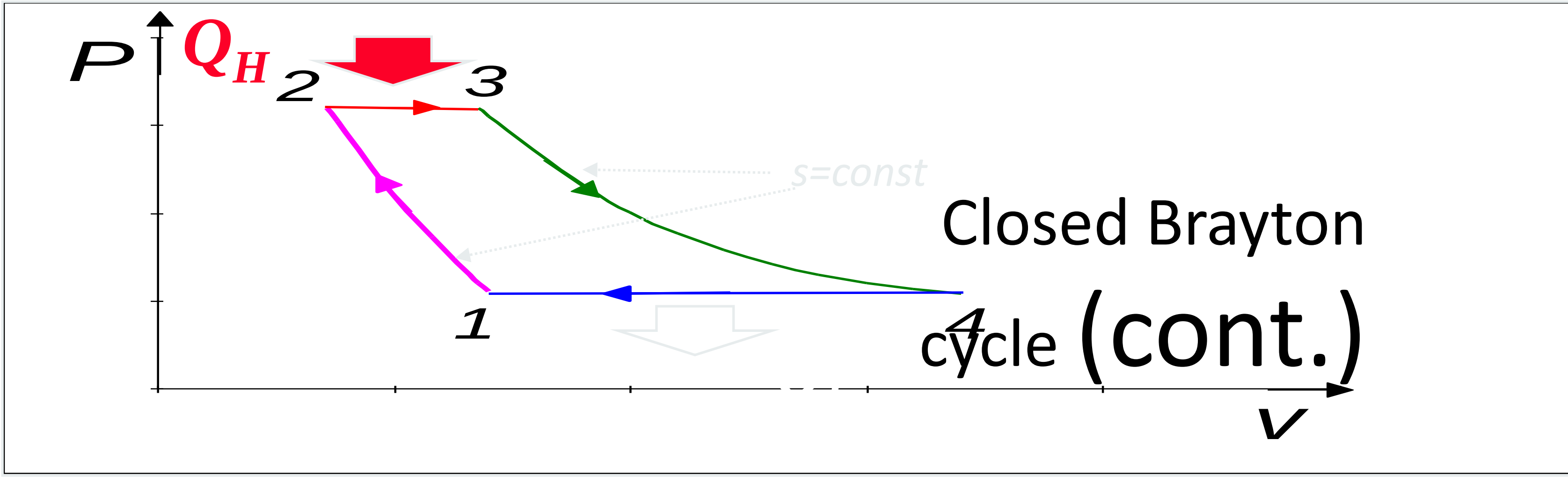


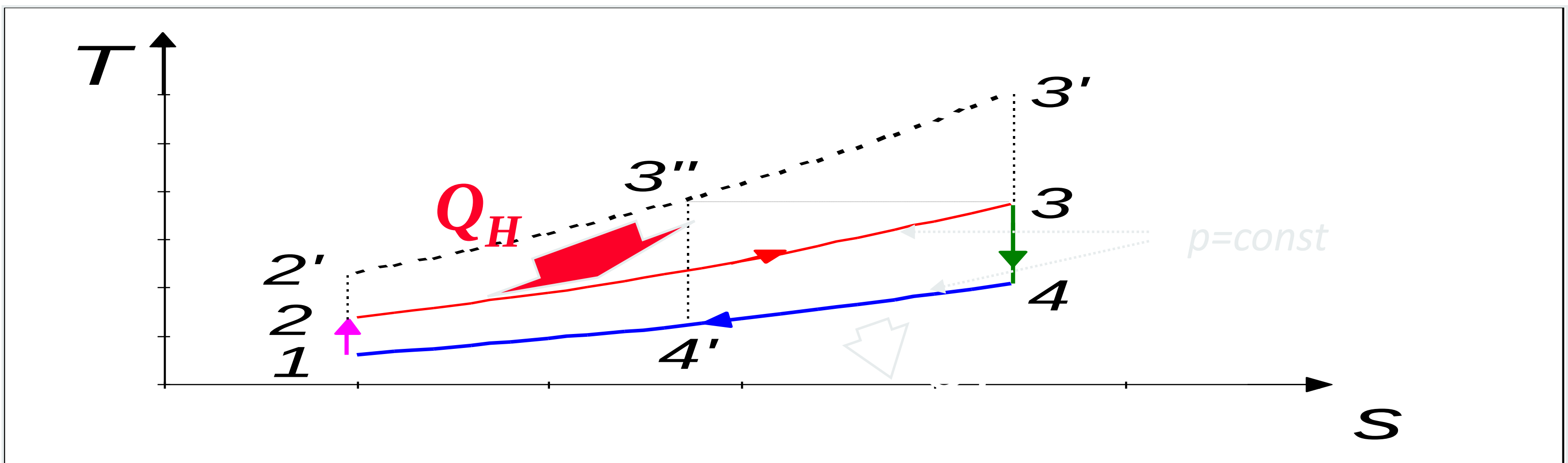
Otto Cycle (cont.)

Deviations of the Otto cycle from an open-cycle spark-ignition engine

- Cp, Cv increase with temperature
- combustion (incomplete) replaces the heat transfer process
- pressure drop across the exhaust valves
- heat transfer between the gas and the cylinder walls
- irreversibility associated with pressure and temperature gradients

Closed Brayton cycle (cont.)





Efficiency of a Brayton cycle

1st law for this cycle: $$W = Q_H - Q_L$$

energy conversion efficiency is:

$$\eta = \frac{\text{useful work}}{\text{heat input}} = \frac{W}{Q_H} = \frac{Q_H - Q_L}{Q_H}$$

$$\eta = 1 - \frac{Q_L}{Q_H} = 1 - \frac{mC_P(T_4 - T_1)}{mC_P(T_3 - T_2)}$$

$$\eta = 1 - \frac{T_1(T_4/T_1 - 1)}{T_2(T_3/T_2 - 1)}$$

Efficiency of a Brayton cycle (cont.)

for an isentropic process:

$$Pv^k = const$$

$$P_1 / P_2 = (V_2 / V_1)^k$$

in case of an ideal gas:

$$P_1 V_1 / P_2 V_2 = T_1 / T_2$$

$$\left(\frac{T_2}{T_1}\right)^{\frac{k}{k-1}} = \frac{P_2}{P_1} = \frac{P_3}{P_4} = \left(\frac{T_3}{T_4}\right)^{\frac{k}{k-1}}$$

$$\frac{T_3}{T_2} = \frac{T_4}{T_1}$$

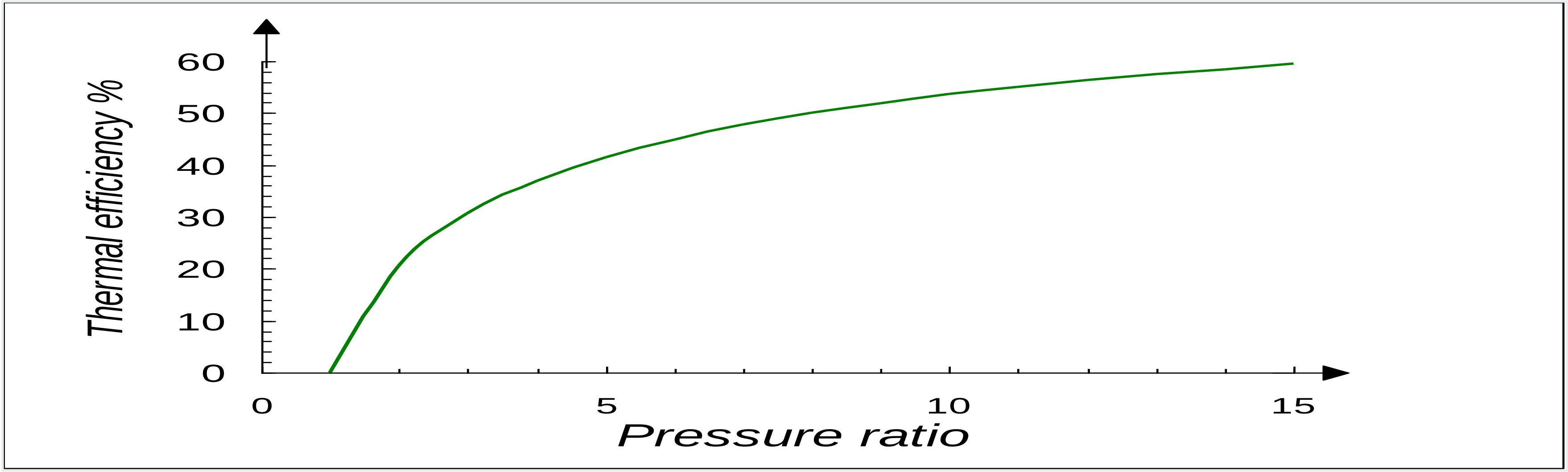
$$\eta = 1 - \frac{T_1}{T_2} = 1 - \left(\frac{P_1}{P_2}\right)^{\frac{k-1}{k}}$$

Efficiency of a Brayton cycle (cont.)

$$\eta = 1 - \frac{1}{(P_2/P_1)^{\frac{k-1}{k}}}$$

isentropic pressure ratio

Example 9.6

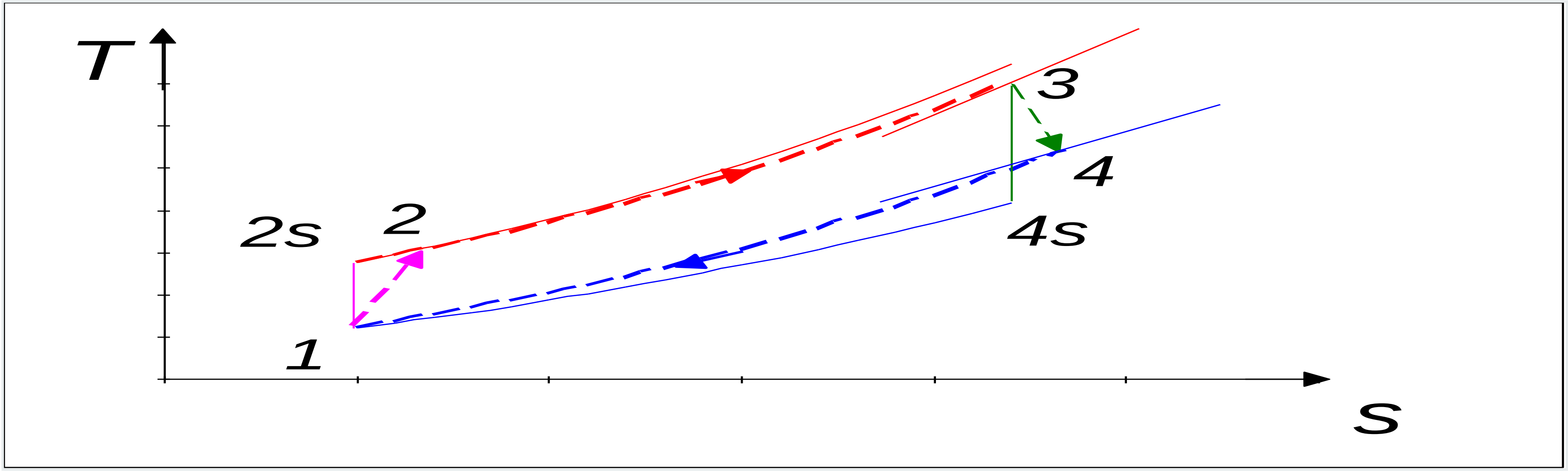


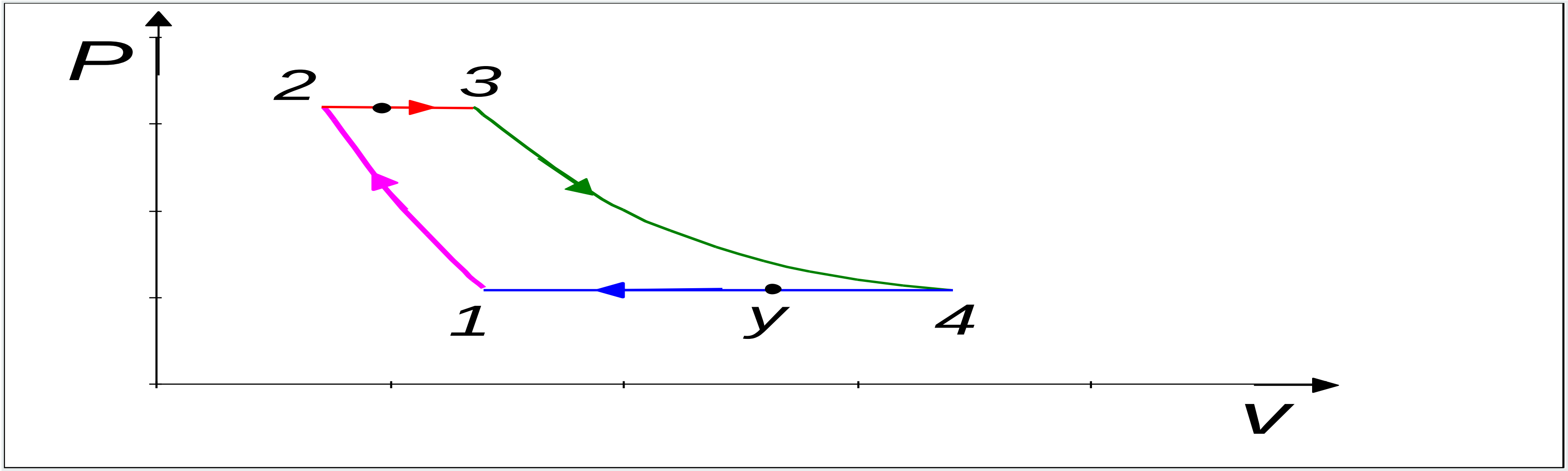
$$\eta_{comp} = \frac{h_{2s} - h_1}{h_2 - h_1}$$

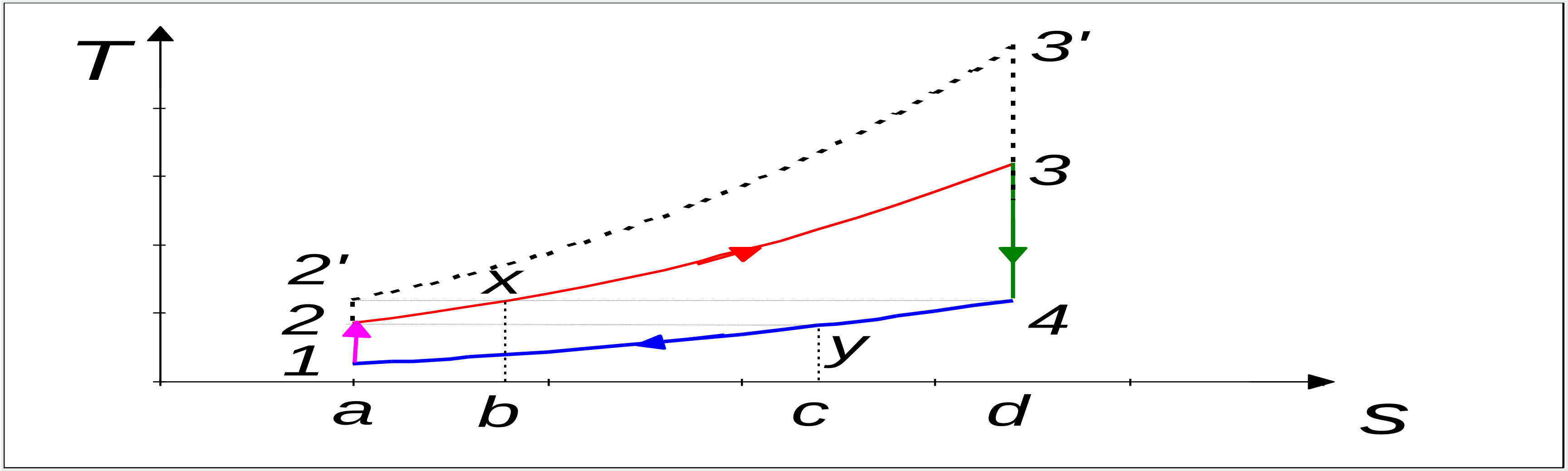
$$\eta_{turb} = \frac{h_3 - h_4}{h_3 - h_{4s}}$$

The actual gas turbine process

Example 9.7




P
2
3
1
y
4
V


T
3'
3
2'
x
2
4
1
y
a
b
c
d
S

Efficiency of a regenerative cycle

$$\eta = \frac{\text{net work}}{\text{heat input}} = \frac{w}{q_H} = \frac{w_t - w_c}{q_H}$$

$$q_H = h_3 - h_x = C_P(T_3 - T_x)$$

$$w_t = h_3 - h_4 = C_P(T_3 - T_4)$$

for an ideal regenerator:

$$T_4 = T_x$$

so:

$$w_t = q_H$$

$$\eta = 1 - \frac{w_c}{w_t} = 1 - \frac{C_P(T_2 - T_1)}{C_P(T_3 - T_4)}$$

$$\eta = 1 - \frac{T_1(T_2/T_1 - 1)}{T_4(T_3/T_4 - 1)}$$

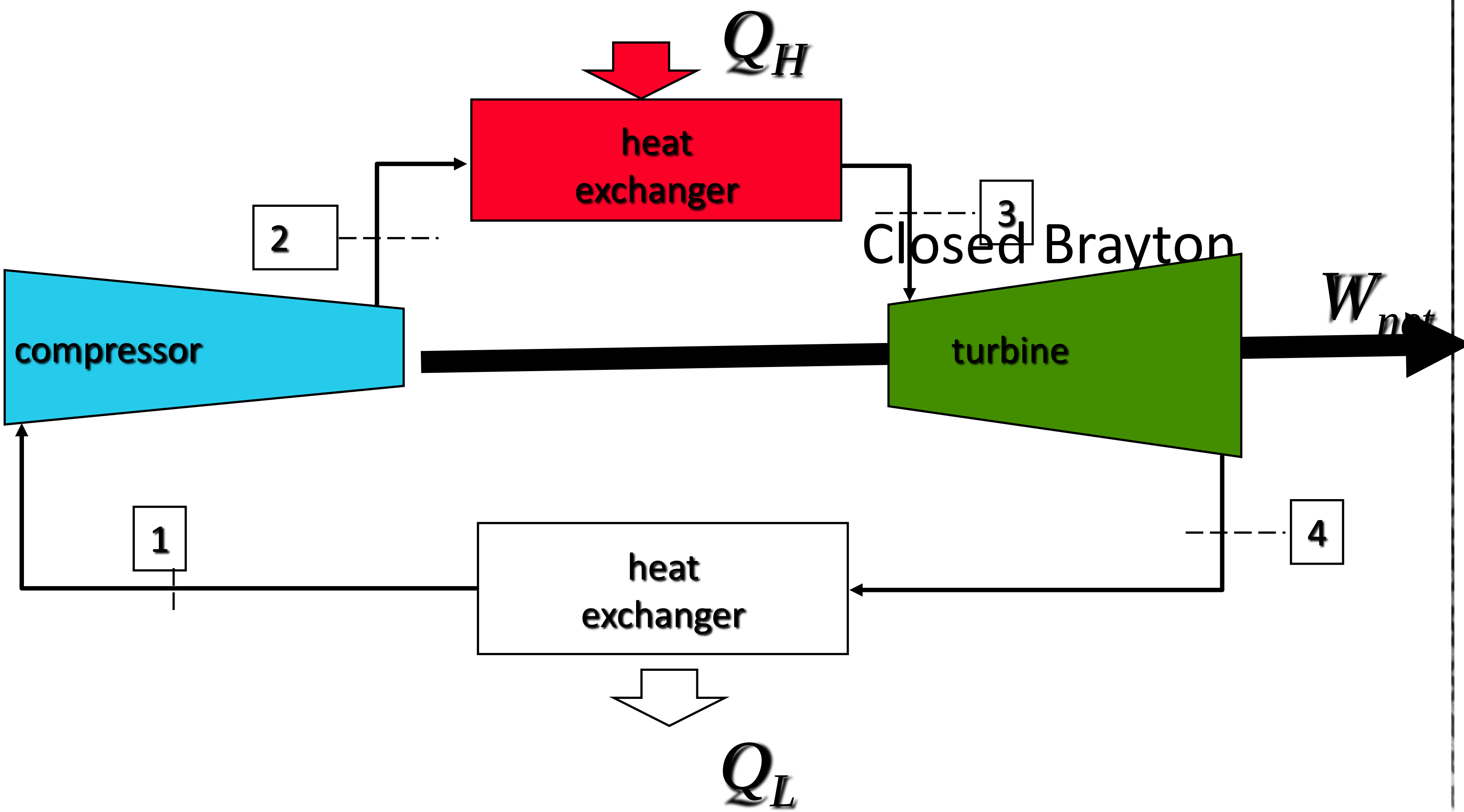
Efficiency of a regenerative cycle

for an isentropic process:

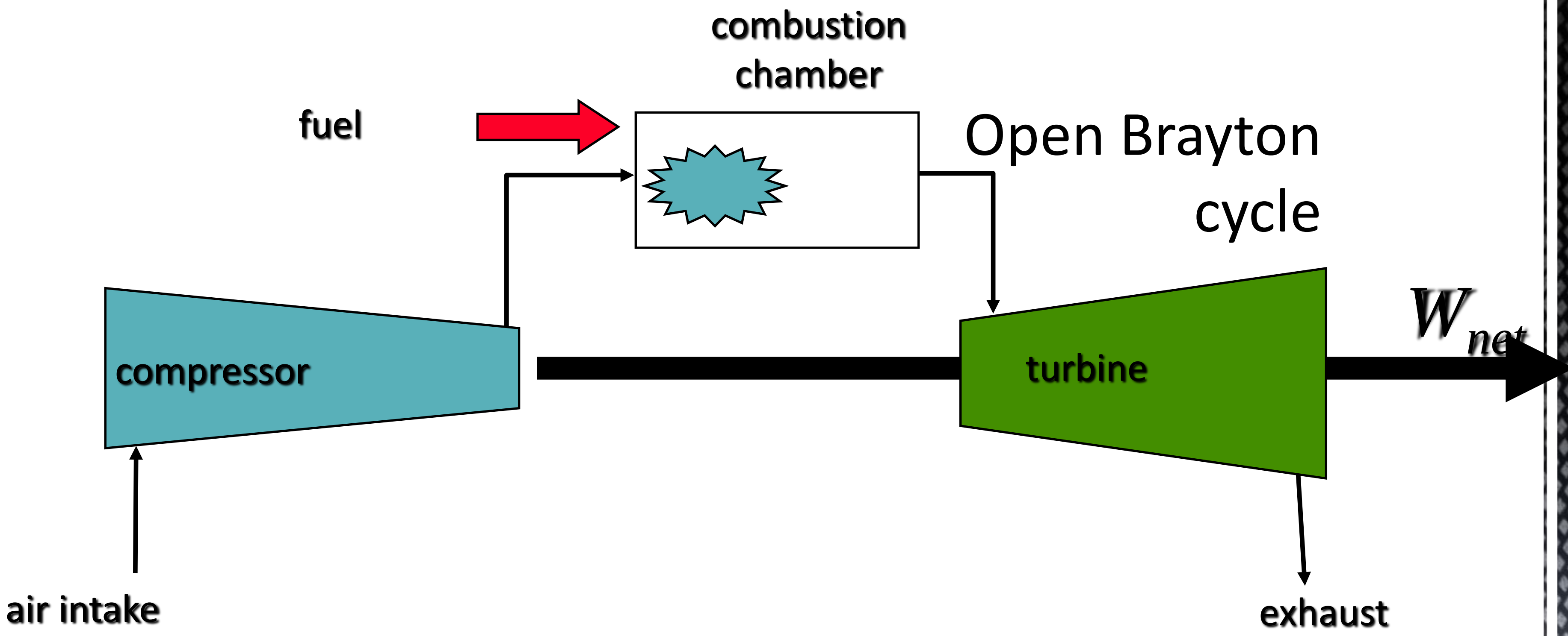
$$\left(\frac{T_2}{T_1}\right)^{\frac{k}{k-1}} = \frac{P_2}{P_1} = \frac{P_3}{P_4} = \left(\frac{T_3}{T_4}\right)^{\frac{k}{k-1}}$$

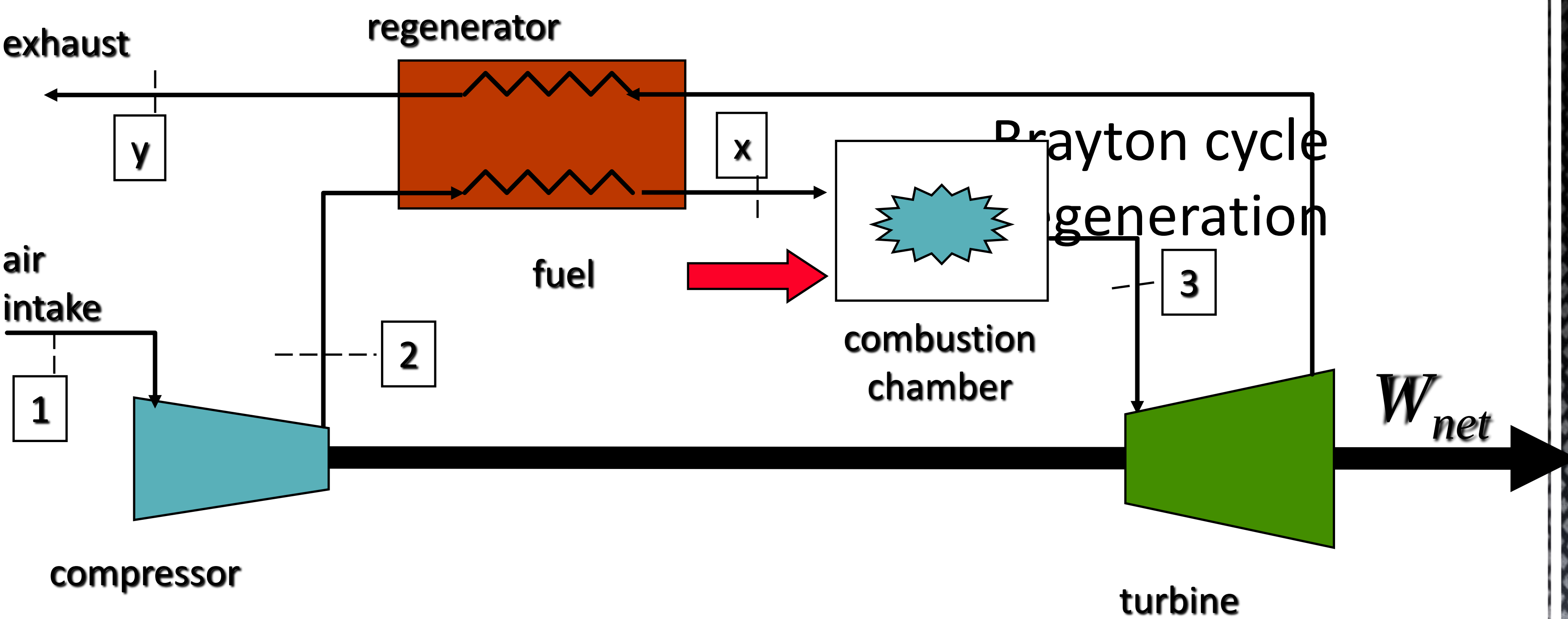
$$\eta = 1 - \frac{T_1}{T_4}$$

Closed Brayton

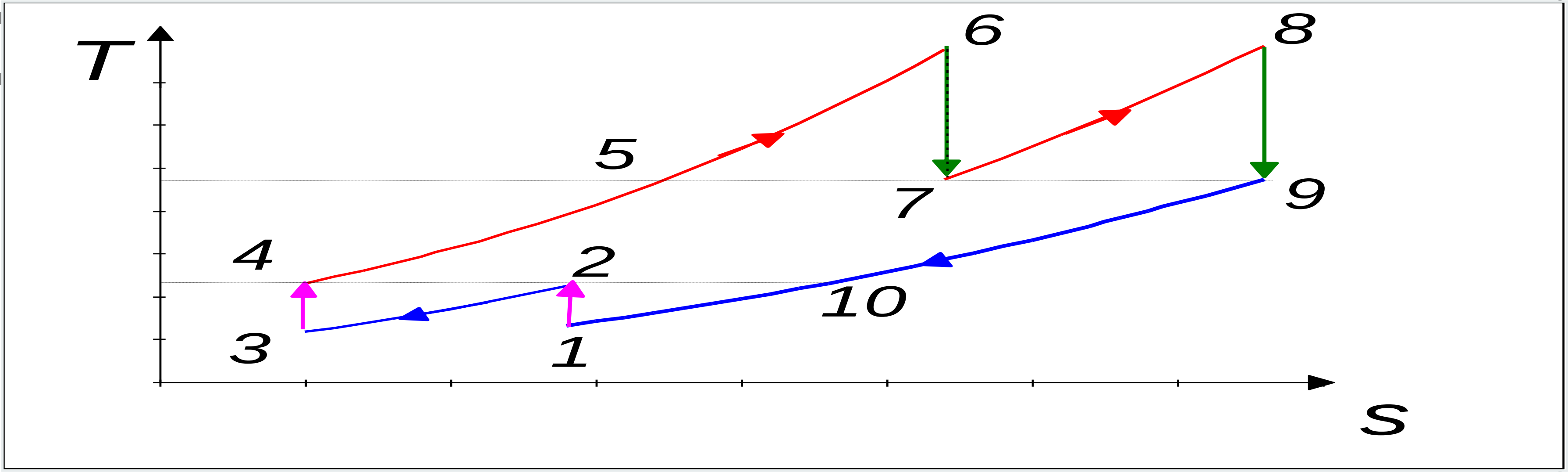


Gas turbine cycle

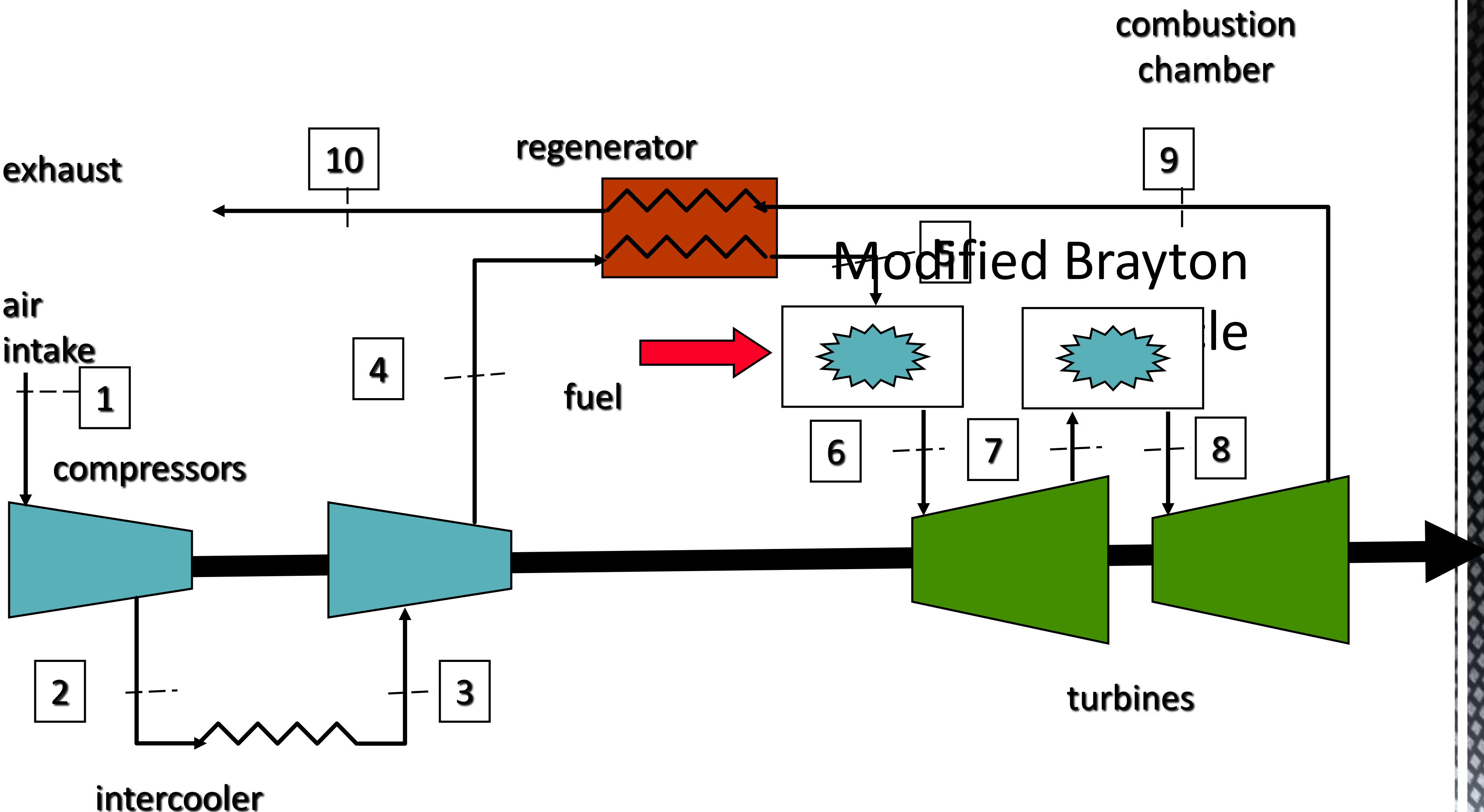



Brayton cycle
egeneration
regenerator
exhaust
y
x
air
intake
fuel
1
2
3
combustion
chamber
W_{net}
compressor
turbine

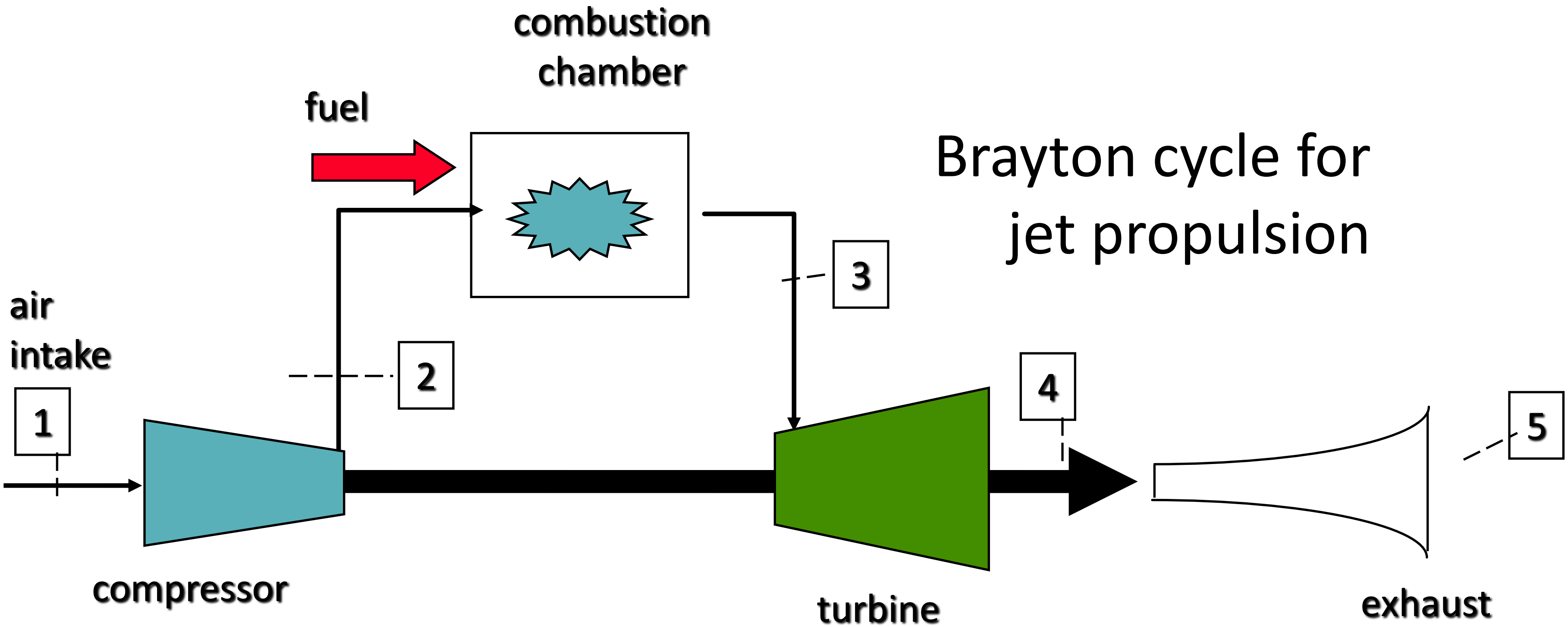
Modified Brayton cycle



Modified Brayton Cycle

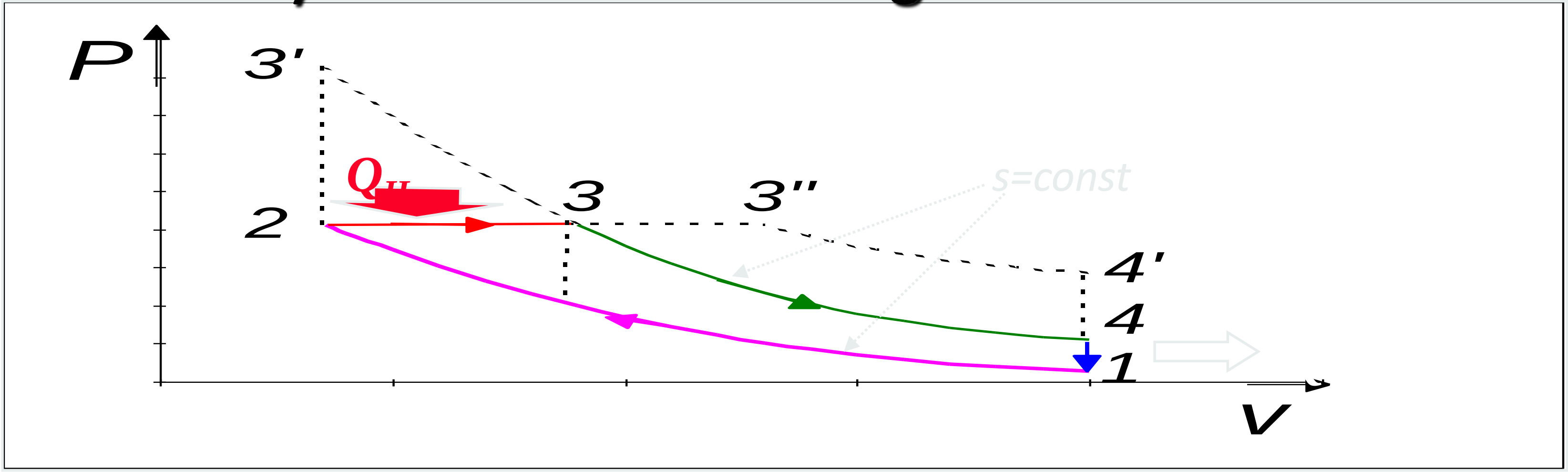


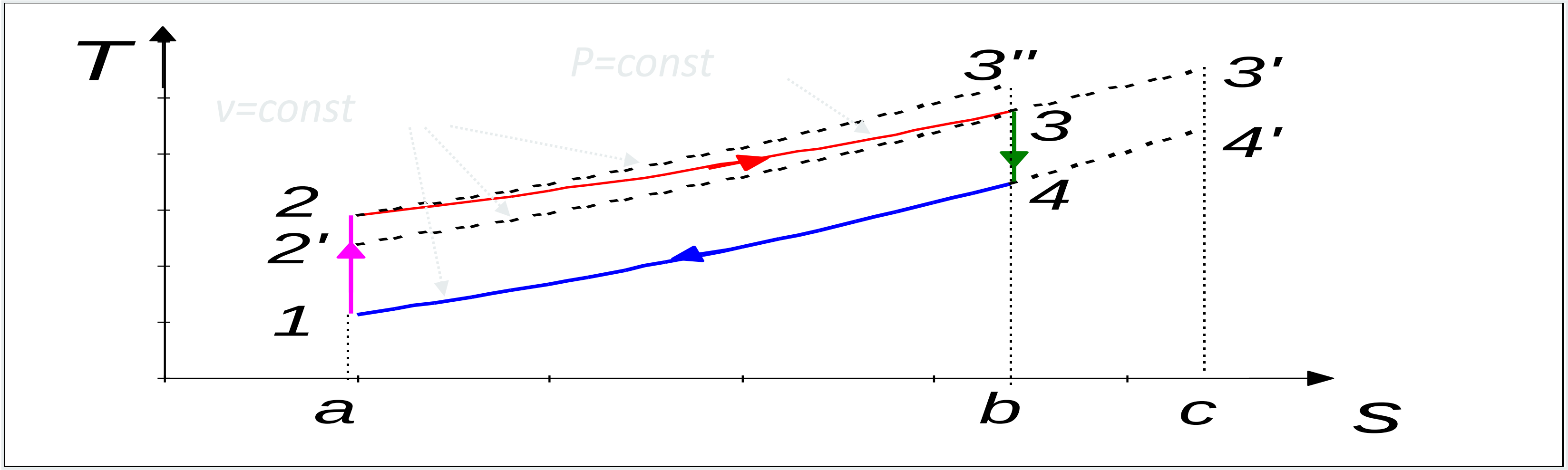
Brayton cycle for jet propulsion



Example 9.10

Ideal cycle for the Diesel engine





The Diesel Cycle (cont.)

1st law for this cycle: $W = Q_H - Q_L$

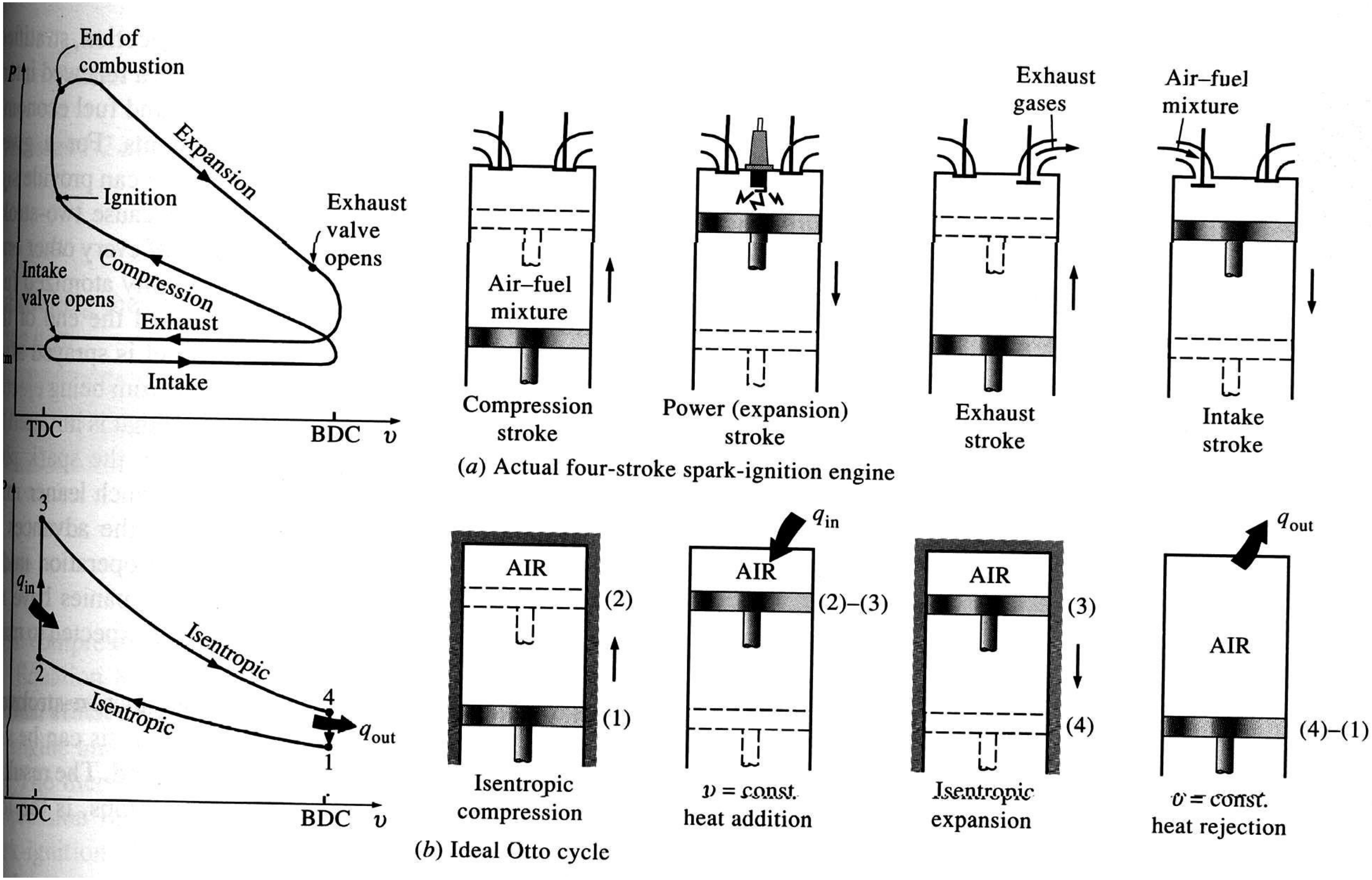
energy conversion efficiency is:

$$\eta = \frac{\text{useful work}}{\text{heat input}} = \frac{W}{Q_H} = \frac{Q_H - Q_L}{Q_H}$$

$$\eta = 1 - \frac{Q_L}{Q_H} = 1 - \frac{mC_v(T_4 - T_1)}{mC_P(T_3 - T_2)}$$

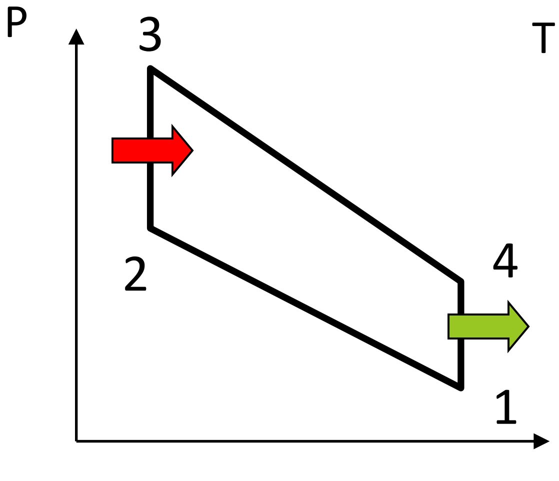
$$\eta = 1 - \frac{T_1(T_4/T_1 - 1)}{kT_2(T_3/T_2 - 1)}$$

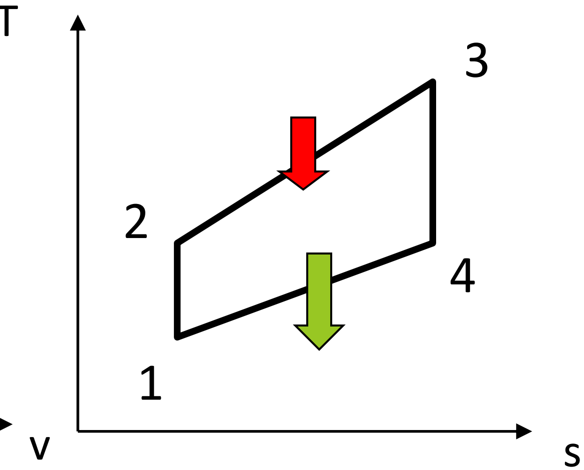
Gas Power Cycle - Internal Combustion Engine



[Otto Cycle]

Otto Cycle





- 1-2 isentropic compression
- 2-3 constant volume heat transfer
- 3-4 isentropic expansion
- 4-1 constant volume heat rejection

Thermal efficiency of the system:

$$\eta = \frac{\mathrm{W_{cycle}}}{\mathrm{Q_{in}}} = \frac{W_{34} + W_{12}}{Q_{23}} = \frac{m[(u_3 - u_4) + (u_1 - u_2)]}{m(u_3 - u_2)} = 1 - \frac{(u_4 - u_1)}{(u_3 - u_2)}$$

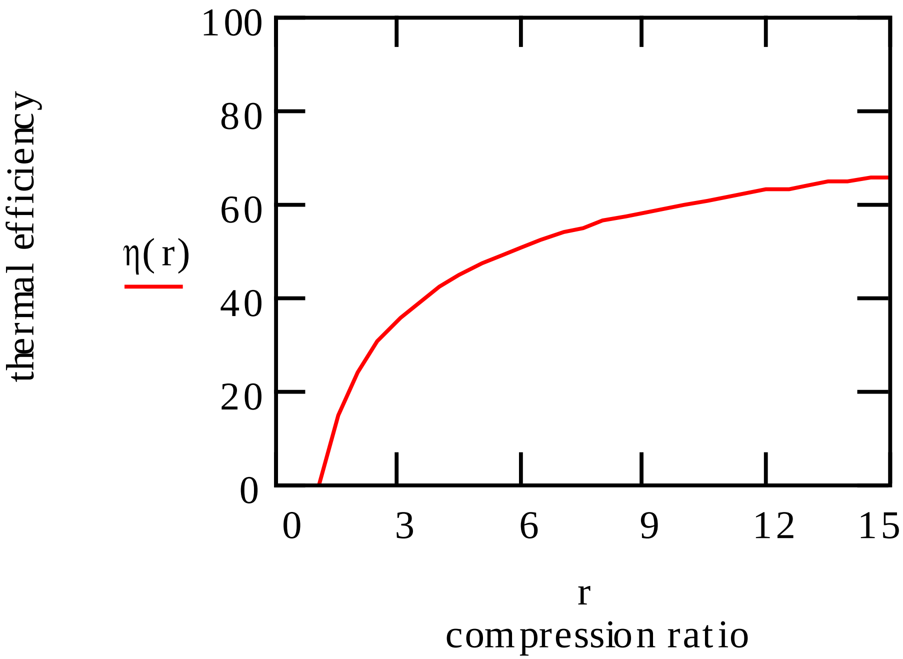
For an ideal gas, u=$C_v T$, $\eta = 1 - \dfrac{(u_4 - u_1)}{(u_3 - u_2)} = 1 - \dfrac{C_v (T_4 - T_1)}{C_v (T_3 - T_2)} = 1 - \dfrac{T_1}{T_2}\left(\dfrac{T_4 / T_1 - 1}{T_3 / T_2 - 1}\right)$

Since $T_4 / T_1 = T_3 / T_2$ (why?)

$\eta = 1 - \dfrac{T_1}{T_2}$. From isentropic compression relation for an ideal gas

$\dfrac{T_1}{T_2} = \left(\dfrac{V_2}{V_1}\right)^{k-1} = \dfrac{1}{r^{k-1}}$, where r=$\left(\dfrac{V_1}{V_2}\right)$ is the volume compression ratio

Otto Cycle-2



Thermal efficiency of an Otto cycle,

$$\eta = 1 - \frac{1}{r^{k-1}}$$

Typical value of r for a real engine: between 7 and 10

- The higher the compression ratio, the higher the thermal efficiency.
- Higher r will led to engine knock (spontaneous ignition) problem.

Improvement of Performance

- Increase the compression ratio

- Increase the engine displacement: more power

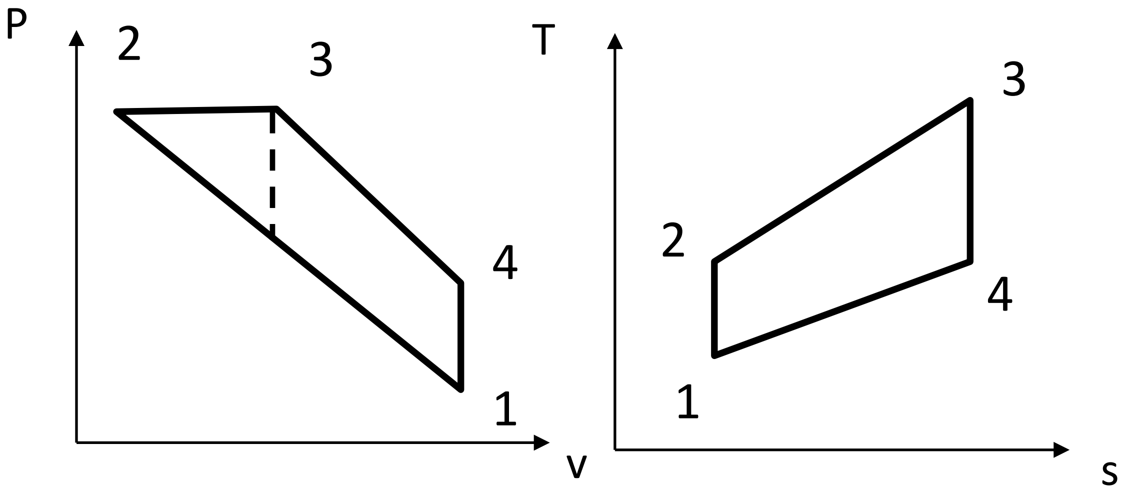
- Compress more air into the cylinder during intake: using supercharger and turbocharger.

- Cool the air before allowing it to enter the cylinder: cooler air can expand more, thus, increase the work output.

- Reduce resistance during intake and exhaust stages: multiple valve configuration: 4 cylinders/16 valves engine

- Fuel injection: do away with the carburetor and provide precise metering of fuel into the cylinders.

Diesel Cycle



2-3: a constant pressure process (instead of a constant volume process) and is the only difference between an idealized Diesel cycle and an idealized Otto cycle.

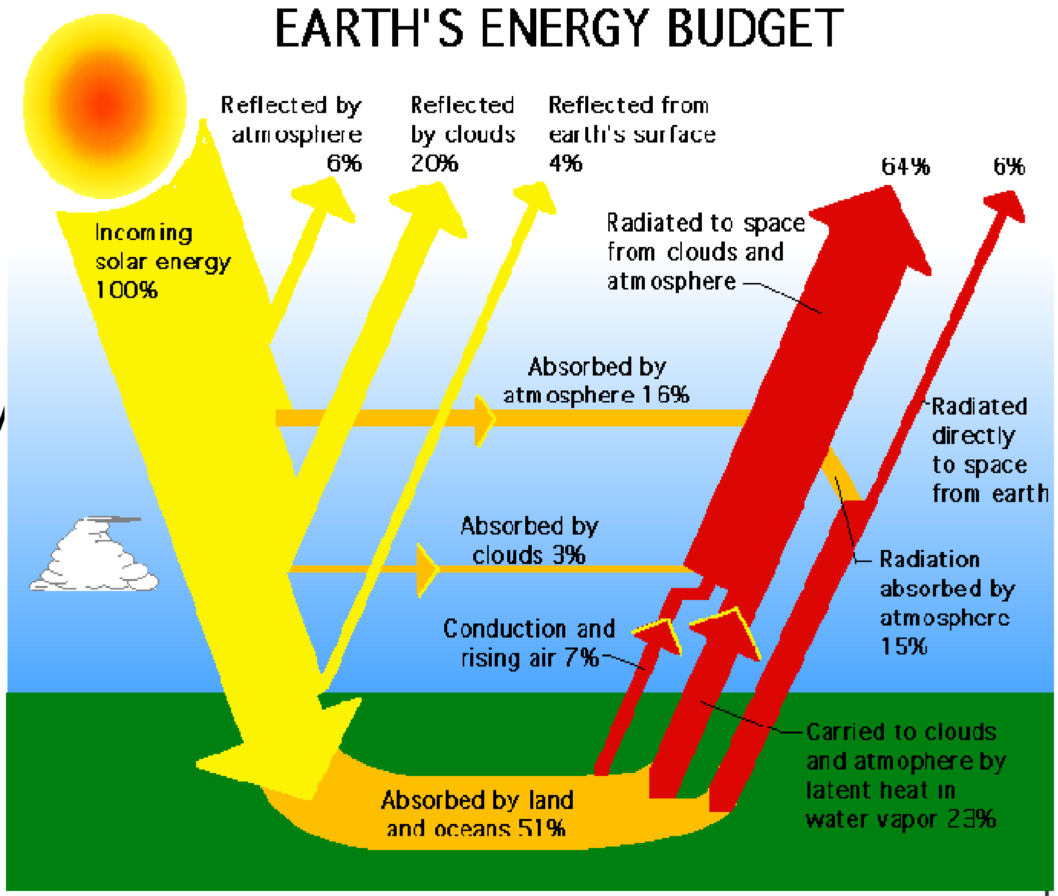
- Fuel injection for an extended period during the power stroke and therefore maintaining a relatively constant pressure.
- Diesel cycle has a lower thermal efficiency as compared to an Otto cycle under the same compression ratio.
- In general, Diesel engine has a higher thermal efficiency than spark-ignition engine because the Diesel engine has a much higher compression ratio.
- Compression-ignition: very high compression ratio 10 to 20 or even higher.

[Diesel Cycle](#) [Internal Combustion Engine](#)

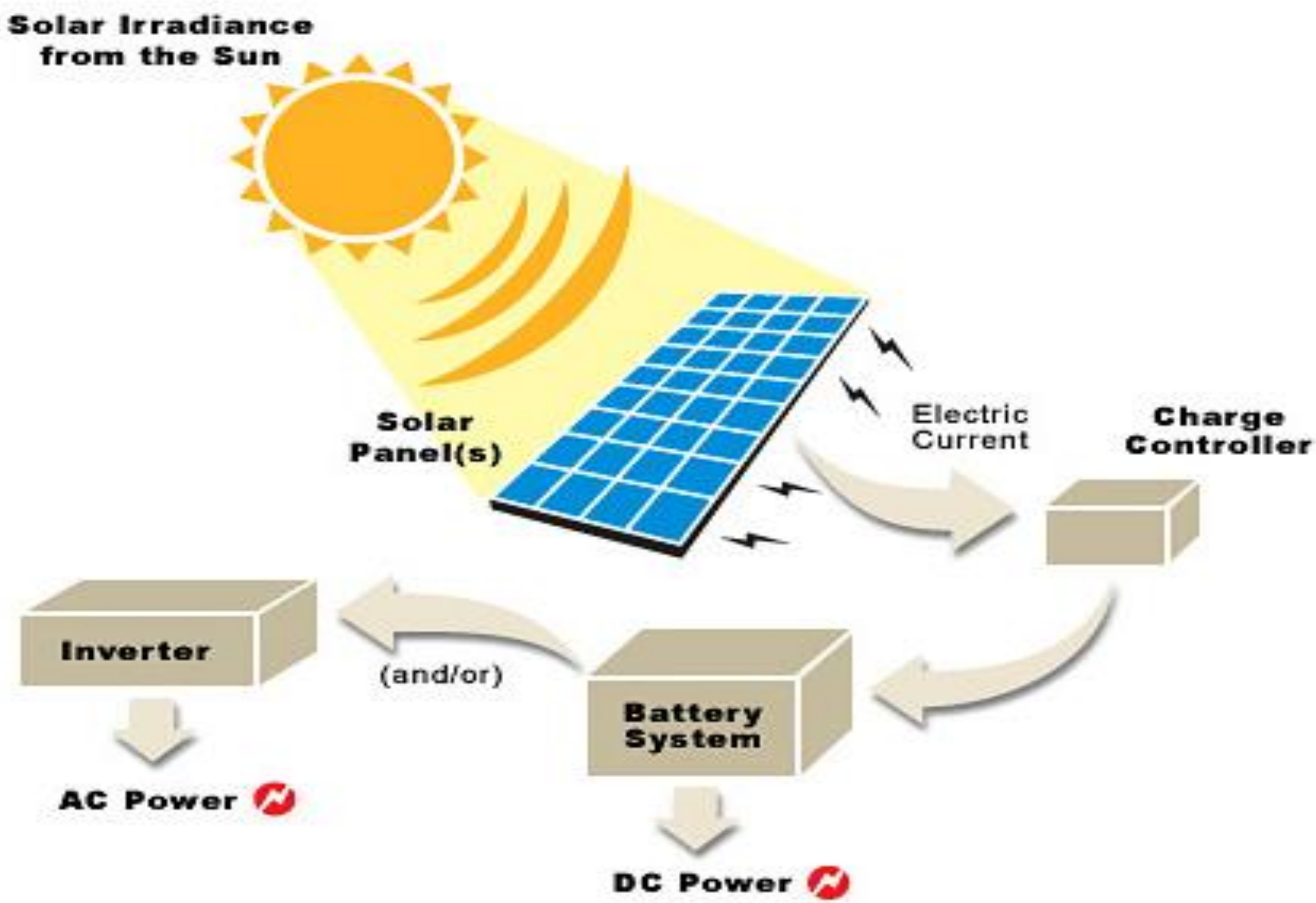
Solar Power Cycles

Trai Nguyen
ME3322

- Renewable resource
- Create electricity by means of heat engines or photovoltaic
    - Active – increase supply
    - Passive – reduce alternative resources



http://www.solar-benefits.com



Solar Power Cycle: Trai Nguyen: ME3322: Georgia Institute of Technology

Applications

Solar power plant in Portugal
http://en.wikipedia.org/wiki/File:SolarPowerPlantSerpa.jpg

http://i.treehugger.com/images/2007/10/24/solar%20energy-jj-001.jpg

Solar pond: http://www.daviddarling.info/images/solar_pond.jpg

Other Applications

http://en.wikipedia.org/wiki/File:Helios_in_flight.jpg

http://i.treehugger.com/files/TH_bikermain_031905.jpg

http://www.blogcdn.com/www.engadget.com/media/2007/06/sunred-solar-bike.jpg

& A

References

- www.treehugger.com
- www.solar-benefits.com
- www.daviddarling.info
- www.wikipedia.com

Vapor Power Cycles

Thermodynamics

Professor Lee Carkner

Lecture 19

PAL # 18 Turbines

- Power of Brayton Turbine
- If the specific heats are constant (k = 1.4) can find T from $(T_2/T_1) = (P_2/P_1)^{(k-1)/k}$
  - $T_2 = T_1(P_2/P_1)^{(k-1)/k} = (290)(8)^{0.4/1.4} =$
  - $T_4 = T_3(P_4/P_3)^{(k-1)/k} = (1100)(1/8)^{0.4/1.4} =$
- $\eta_{th} = 1 - (T_4-T_1)/(T_3-T_2) = (607.2-290)/(1100-525.3) =$
- $W' = \eta_{th}Q'_{in} = (0.448)(35000) =$

- For variable specific heats we use $(P_{r2}/P_{r1}) = (P_2/P_1)$ for the isentropic processes
  - $T_1 = 290$ K which give us (Table A-17), $h_1 = 290.16$, $P_r = 1.2311$
  - $P_{r2} = (P_2/P_1)P_{r1} = (8)(1.12311) =$

PAL # 18 Turbines

  - $T_3 = 1000$, which gives $h_3 = 1161.07$, $P_{r3} = 167.1$
  - $P_{r4} = (P_4/P_3)P_{r3} = (1/8)(167.1) =$

- $\eta_{th} = 1 – (h_4\text{-}h_1)/(h_3\text{-}h_2) = 1 – (651.37\text{-}290.16)/(1161.07\text{-}526.11) =$
- $W' = h_{th}Q'_{in} = (0.431)(35000) =$

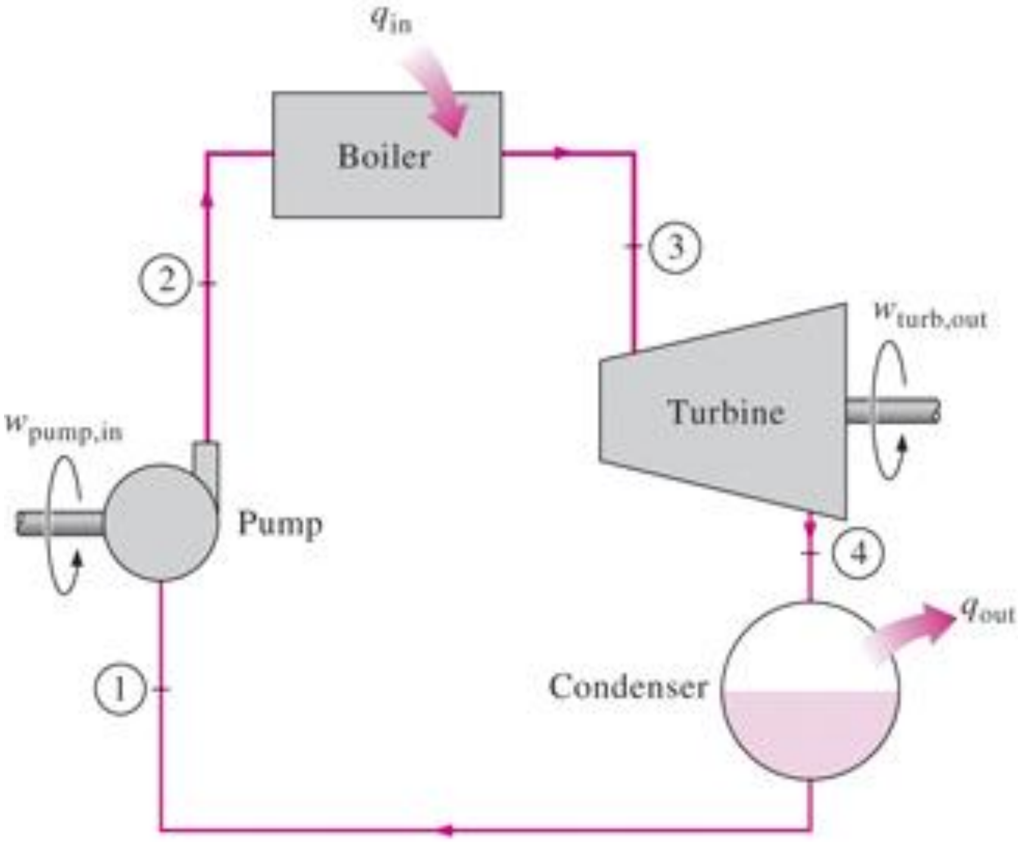
Vapor Cycles

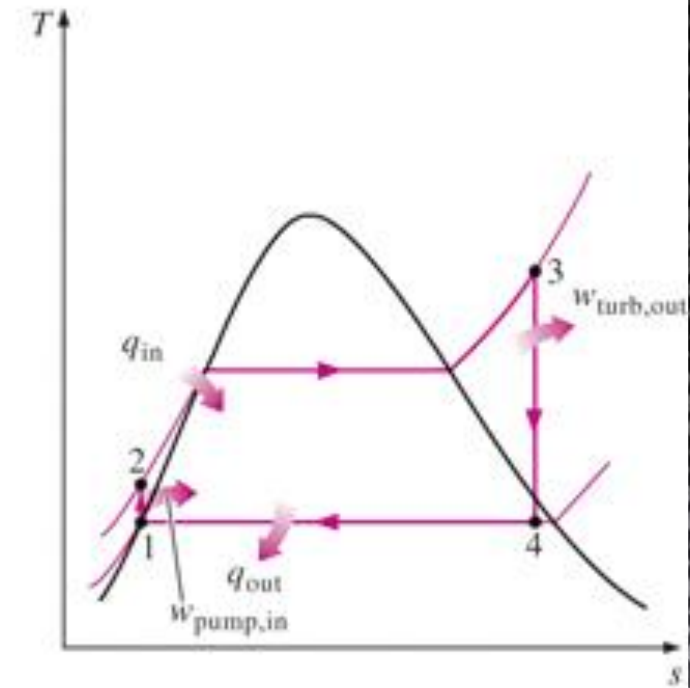
- For vapor cycles we use a working substance that changes phase between liquid and gas
- Rather than a compressor we need a boiler, pump and condenser
- Steam engines were the first engines to be developed since you don't need precisely controlled combustion

Rankine Cycle

- The ideal steam cycle is called the Rankine cycle and is similar to the Brayton cycle
    -
    - Isobaric heat addition in a boiler
    -
    - Isobaric heat rejection in a condenser
-

Basic Rankine Diagram





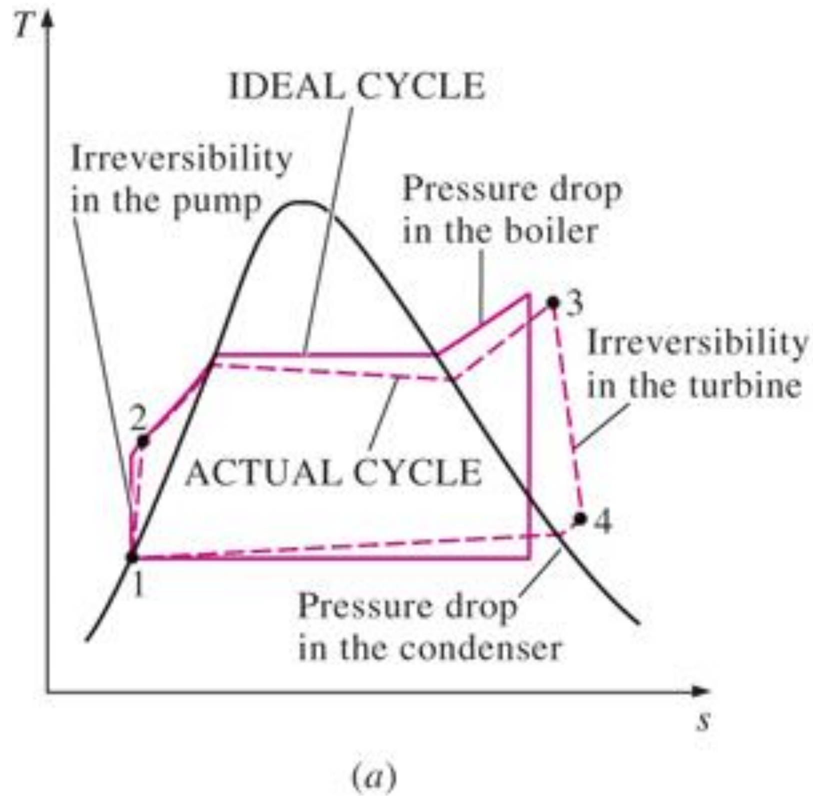
Rankine Efficiency

- For each process the heat or work is just Δh
- The work and efficiency are $\eta_{th} = w_{net}/q_{in} = 1 - q_{out}/q_{in}$
  -
- For the pump we can also use the incompressible isenthalpic relationship
  -
  -
-
- We may also need to find x to find h from
  -

Real Cycles

- The real vapor cycles have to take irreversibilities into account
  -
  - The steam being much hotter than the surroundings loses heat and requires an increase in heat transfer to the boiler
- For the pump and turbine we can adjust for these deviations by using the isentropic efficiencies
  -
  - $\eta_{turbine} = w_a/w_s = (h_3-h_{4a})/(h_3-h_{4s})$

Deviations from Ideal



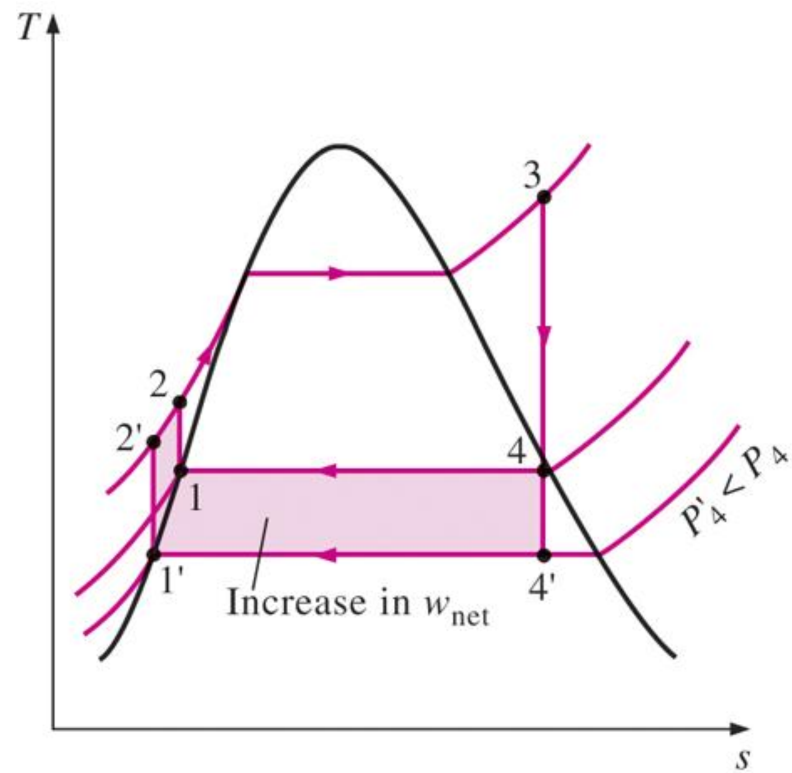
Increasing Efficiency

- How do we make a power cycle more efficient?
  -
- We can do this for the Rankine cycle by changing the temperature and pressure we operate at
  -

Lowering Condenser Pressure

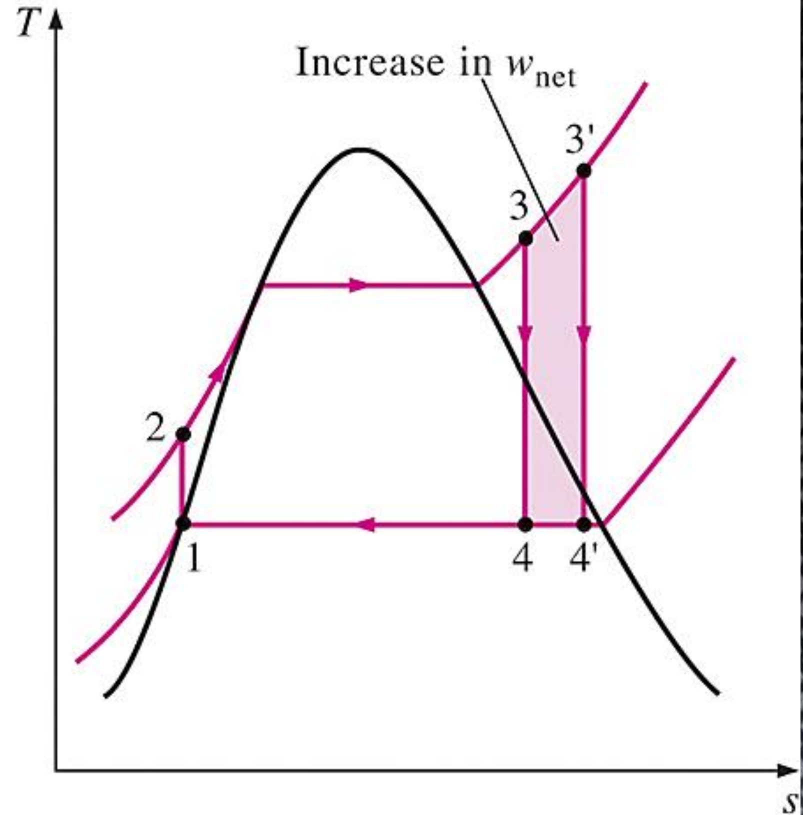
-

- Problems:
  - Can’t lower temperature below that of the cooling medium (e.g. local river)
  -
  - Increases amount of moisture in the output
    - Bad for turbines



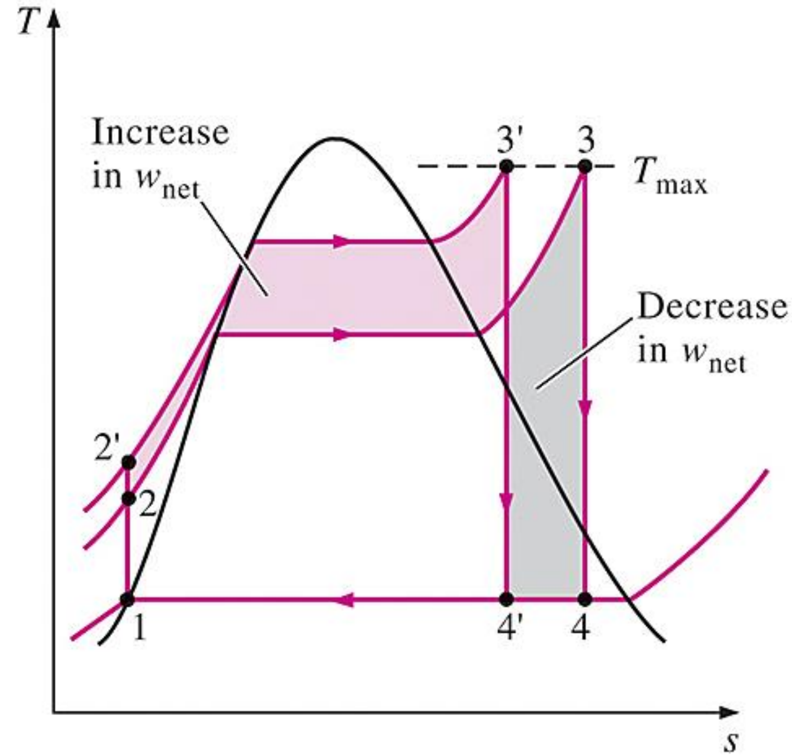
Superheating Steam

-
- Increases output work and input heat but increases efficiency
  -
- Don’t want to melt the turbine
  -



Increasing Boiler Pressure

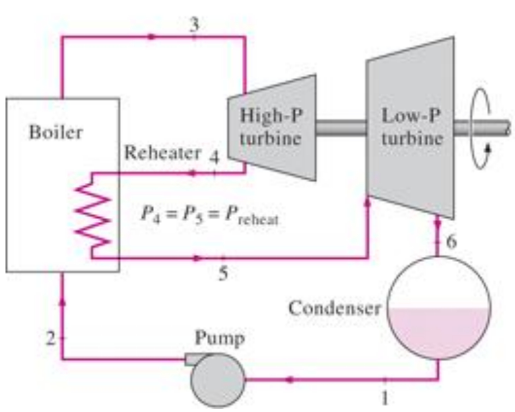
-
    - Also increases moisture
-
    - 22.6 MPa for steam
- Need to build strong boilers
    -

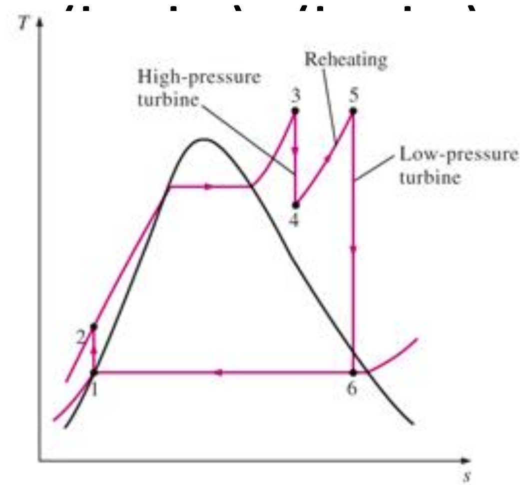


Reheating

- We now have two heat inputs and two work outputs

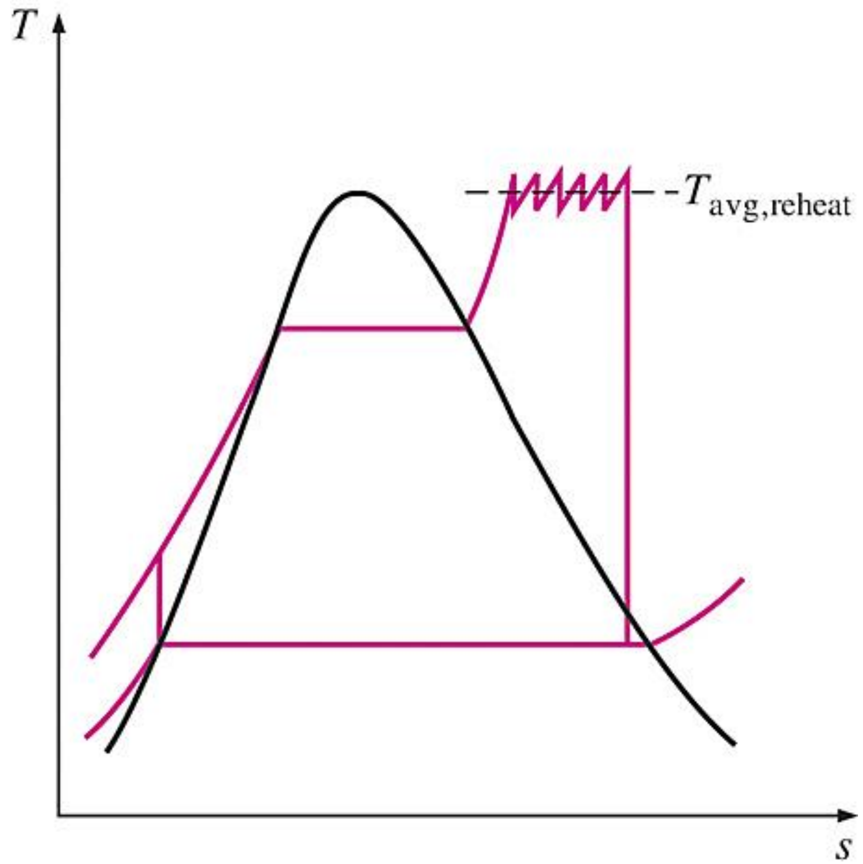
$$q_{in} = q_{primary} + q_{reheat} = (h_3\text{-}h_2) + (h_5\text{-}h_4)$$





Extra Reheating

-
- With a large number of processes, reheating approaches isothermal case
-



Next Time

- Read: 10.6-10.9
- Homework: Ch 10, P: 22, 32, 44,

Fuels. The main sources of energy are fuels *viz*., solid fuel as coal, liquid fuel as oil and gas fuel as natural gas. The heat energy of these fuels is converted into mechanical energy by suitable prime movers such as steam engines, steam turbines, internal combustion engines etc.

The prime mover drives the alternator which converts mechanical energy into electrical energy. Although fuels continue to enjoy the place of chief source for the generation of electrical energy, yet their reserves are diminishing day by day.

Therefore, the present trend is to harness water power which is more or less a permanent source of power.

1.8 Calorific Value of Fuels

The amount of heat produced by the complete combustion of a unit weight of fuel is known as its **calorific value**.

Calorific value indicates the amount of heat available from a fuel. The greater the calorific value of fuel, the larger is its ability to produce heat. In case of solid and liquid fuels, the calorific value is expressed in *cal/gm* or *kcal/kg*. However, in case of gaseous fuels, it is generally stated in *cal/litre* or *kcal/litre*. Below is given a table of various types of fuels and their calorific values along with composition.

S.No.	Particular	Calorific value	Composition
1.	**Solid fuels**		
	(*i*) Lignite	5,000 kcal/kg	C = 67%, H = 5%, O = 20%, ash = 8%
	(*ii*) Bituminous coal	7,600 kcal/kg	C = 83%, H = 5·5%, O = 5%, ash = 6·5%
	(*iii*) Anthracite coal	8,500 kcal/kg	C = 90%, H = 3%, O = 2%, ash = 5%
2.	**Liquid fuels**		
	(*i*) Heavy oil	11,000 kcal/kg	C = 86%, H = 12%, S = 2%
	(*ii*) Diesel oil	11,000 kcal/kg	C = 86·3%, H = 12·8%, S = 0·9%
	(*iii*) Petrol	11,110 kcal/kg	C = 86%, H = 14%
3.	**Gaseous fuels**		
	(*i*) Natural gas	520 kcal/m^3	CH_4 = 84%, C_2H_6 = 10% Other hydrocarbons = 5%
	(*ii*) Coal gas	7,600 kcal/m^3	CH_4 = 35%, H = 45%, CO= 8%, N = 6% CO_2 = 2%, Other hydrocarbons = 4%

1.9 Advantages of Liquid Fuels over Solid Fuels

3.	**Gaseous fuels**		
	(*i*) Natural gas	520 kcal/m^3	$CH_4 = 84\%$, $C_2H_6 = 10\%$ Other hydrocarbons = 5%
	(*ii*) Coal gas	7,600 kcal/m^3	$CH_4 = 35\%$, $H = 45\%$, $CO = 8\%$, $N = 6\%$ $CO_2 = 2\%$, Other hydrocarbons = 4%

1.9 Advantages of Liquid Fuels over Solid Fuels

The following are the advantages of liquid fuels over the solid fuels :

(*i*) The handling of liquid fuels is easier and they require less storage space.

(*ii*) The combustion of liquid fuels is uniform.

(*iii*) The solid fuels have higher percentage of moisture and consequently they burn with great difficulty. However, liquid fuels can be burnt with a fair degree of ease and attain high temperature very quickly compared to solid fuels.

(*iv*) The waste product of solid fuels is a large quantity of ash and its disposal becomes a problem. However, liquid fuels leave no or very little ash after burning.

(*v*) The firing of liquid fuels can be easily controlled. This permits to meet the variation in load demand easily.

1.10 Advantages of Solid Fuels over Liquid Fuels

The following are the advantages of solid fuels over the liquid fuels :

2.11 Diesel Power Station

A generating station in which diesel engine is used as the prime mover for the generation of electrical energy is known as **diesel power station.**

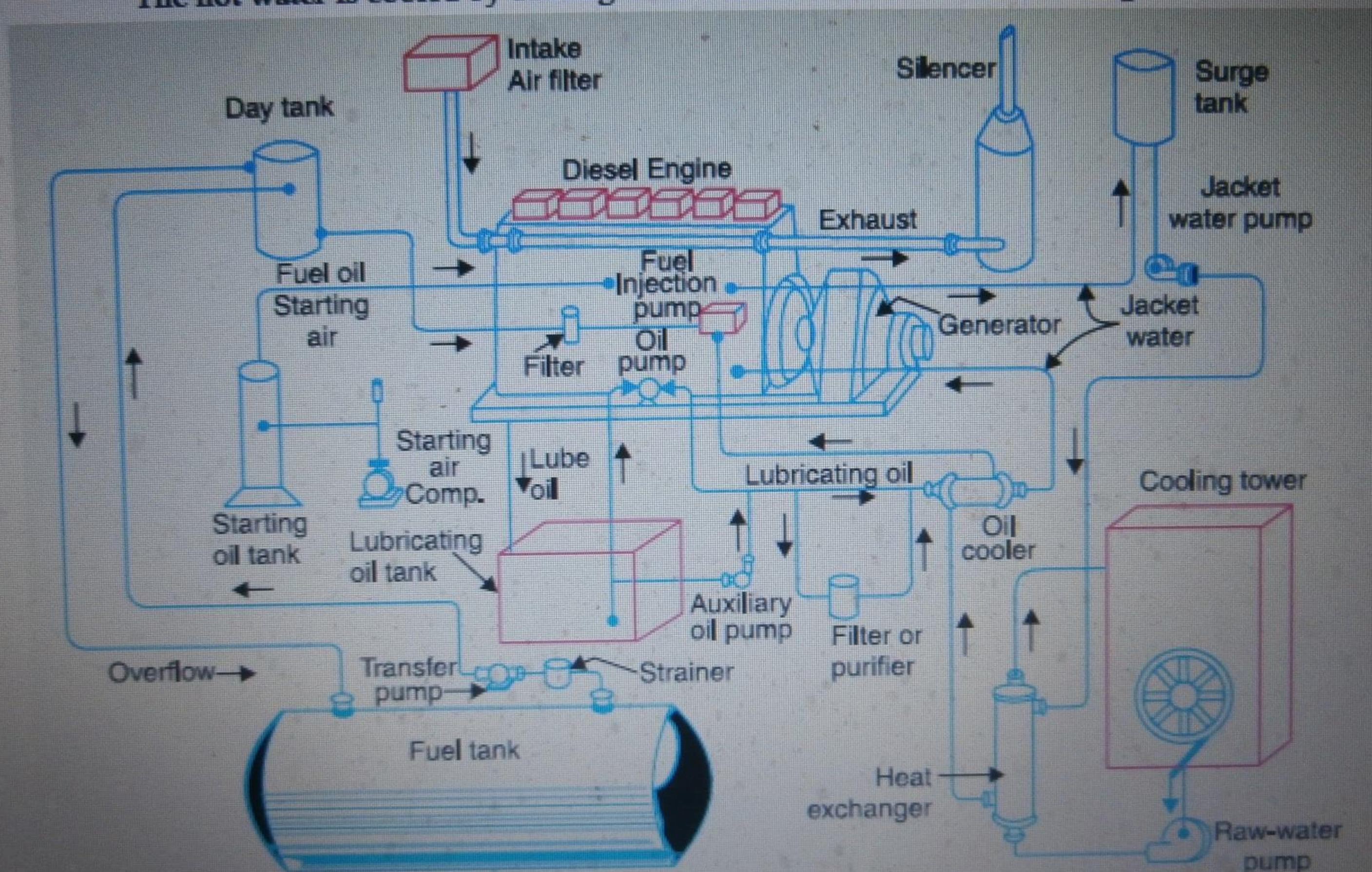
In a diesel power station, diesel engine is used as the prime mover. The diesel burns inside the engine and the products of this combustion act as the "working fluid" to produce mechanical energy. The diesel engine drives the alternator which converts mechanical energy into electrical energy. As the generation cost is considerable due to high price of diesel, therefore, such power stations are only used to produce small power.

Although steam power stations and hydro-electric plants are invariably used to generate bulk power at cheaper cost, yet diesel power stations are finding favour at places where demand of power is less, sufficient quantity of coal and water is not available and the transportation facilities are inadequate. These plants are also used as standby sets for continuity of supply to important points such as hospitals, radio stations, cinema houses and telephone exchanges.

Advantages

(*i*) The design and layout of the plant are quite simple.
(*ii*) It occupies less space as the number and size of the auxiliaries is small.
(*iii*) It can be located at any place.
(*iv*) It can be started quickly and can pick up load in a short time.
(*v*) There are no standby losses.
(*vi*) It requires less quantity of water for cooling.
(*vii*) The overall cost is much less than that of steam power station of the same capacity.
(*viii*) The thermal efficiency of the plant is higher than that of a steam power station.
(*ix*) It requires less operating staff.

(iv) *Cooling system*. The heat released by the burning of fuel in the engine cylinder is partially converted into work. The remainder part of the heat passes through the cylinder walls, piston, rings etc. and may cause damage to the system. In order to keep the temperature of the engine parts within the safe operating limits, cooling is provided. The cooling system consists of a water source, pump and cooling towers. The pump circulates water through cylinder and head jacket. The water takes away heat form the engine and itself becomes hot. The hot water is cooled by cooling towers and is recirculated for cooling.



Schematic arrangement of Diesel Power Plant

Fig. 2.6

(v) *Lubricating system*. This system minimises the wear of rubbing surfaces of the engine. It comprises of lubricating oil tank, pump, filter and oil cooler. The lubricating oil is drawn turbine contain sufficient heat.

(iv) The temperature of combustion chamber is quite high (3000°F) so that its life is comparatively reduced.

2.17 Schematic Arrangement of Gas Turbine Power Plant

The schematic arrangement of a gas turbine power plant is shown in Fig. 2.9. The main components of the plant are :

(i) Compressor (ii) Regenerator
(iii) Combustion chamber (iv) Gas turbine
(v) Alternator (vi) Starting motor

(i) **Compressor.** The compressor used in the plant is generally of rotatory type. The air at atmospheric pressure is drawn by the compressor *via* the filter which removes the dust from air. The rotatory blades of the compressor push the air between stationary blades to raise its pressure. Thus air at high pressure is available at the output of the compressor.

(ii) **Regenerator.** A regenerator is a device which recovers heat from the exhaust gases of the turbine. The exhaust is passed through the regenerator before wasting to atmosphere. A regenerator consists of a nest of tubes contained in a shell. The compressed air from the compressor passes through the tubes on its way to the combustion chamber. In this way, compressed air is heated by the hot exhaust gases.

(iii) **Combustion chamber.** The air at high pressure from the compressor is led to the combustion chamber *via* the regenerator. In the combustion chamber, heat* is added to the air by burning oil. The oil is injected through the burner into the chamber at high pressure to ensure atomisation of oil and its thorough mixing with air. The result is that the chamber attains a very high temperature (about 3000°F). The combustion gases are suitably cooled to 1300°F to 1500°F and then delivered to the gas turbine.

(iv) **Gas turbine.** The products of combustion consisting of a mixture of gases at high temperature and pressure are passed to the gas turbine. These gases in passing over the turbine blades expand and thus do the mechanical work. The temperature of the exhaust gases from the turbine is about 900°F.

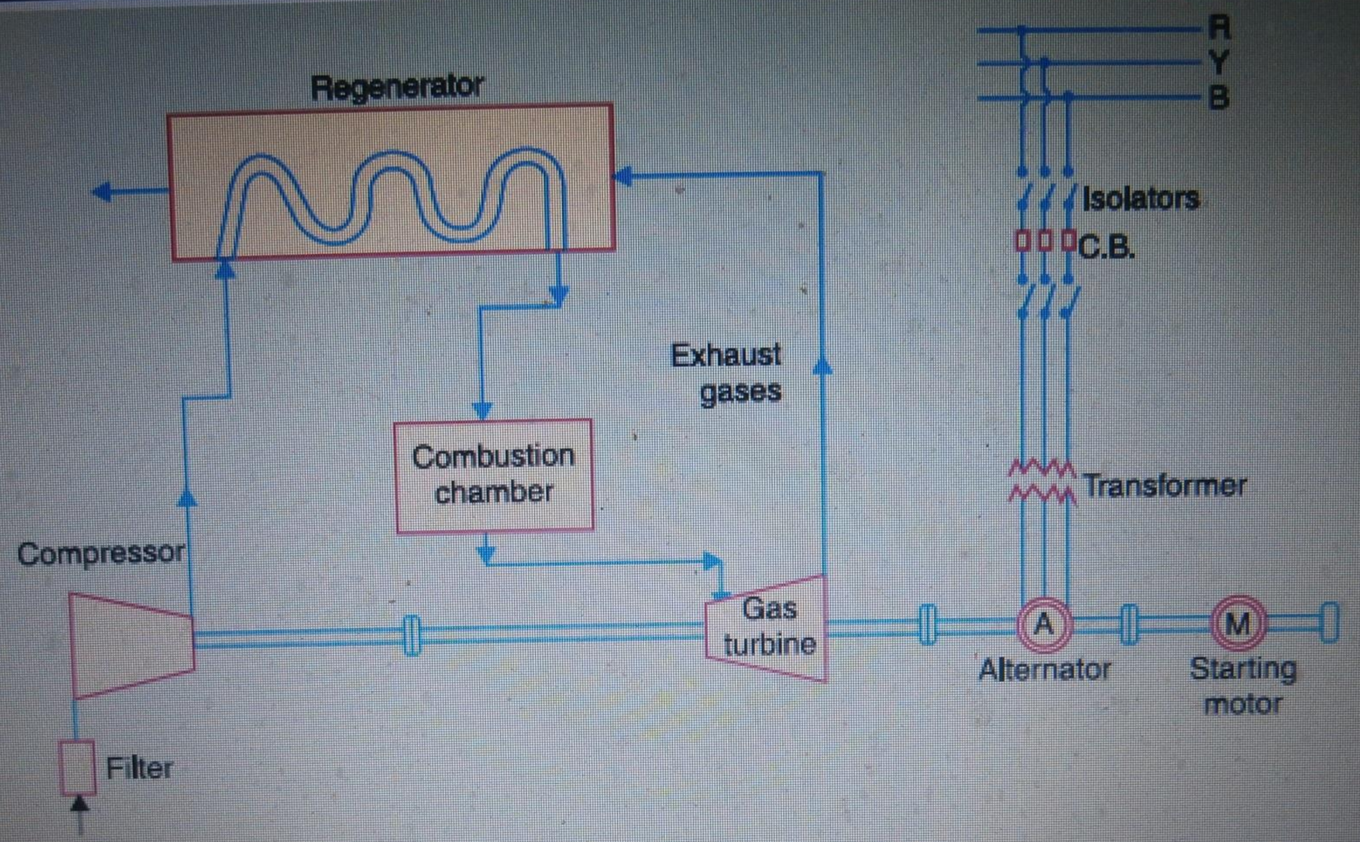
---

* Only hot pressurised air makes it possible to convert heat into mechanical work. Heating air at atmospheric pressure generally does not make it permissible to convert heat into mehanical work.

2.18 Comparison of the Various Power Plants

The comparison of steam power plant, hydro-electric plant, diesel power plant and nuclear power plant is given below in the tabular form :

S.No.	Item	Steam Power Station	Hydro-electric Power Plant	Diesel Power Plant	Nuclear power Plant
1.	*Site*	Such plants are located at a place where ample supply of water and coal is available, transportation facilities are adequate	Such plants are located where large reservoirs can be obtained by constructing a dam *e.g.* in hilly areas.	Such plants can be located at any place because they require less space and small quantity of water.	These plants are located away from thickly populated areas to avoid radioactive pollution.
2.	*Initial cost*	Initial cost is lower than those of hydroelectric and nuclear power plants.	Initial cost is very high because of dam construction and excavation work.	Initial cost is less as compared to other plants.	Initial cost is highest because of huge investement on building a nuclear reactor.
3.	*Running cost*	Higher than hydroelectric and nuclear plant because of the requirement of huge amount of coal.	Practically nil because no fuel is required.	Highest among all plants because of high price of diesel.	Except the hydroelectric plant, it has the minimum running cost because small amount of fuel can produce relatively large amount of power.
4.	*Limit of source of power*	Coal is the source of power which has limited reserves all over the world.	Water is the source of power which is not dependable becuase of wide variations in the rainfall every year.	Diesel is the source of power which is not available in huge quantities due to limited reserves.	The source of power is the nuclear fuel which is available in sufficient quantity. It is because small amount of fuel can produce huge power.
5.	*Cost of fuel transportation*	Maximum because huge amount of coal is transported to the plant site.	Practically nil.	Higher than hydro and nuclear power plants	Minimum because small quantity of fuel is required.
6.	*Cleanliness and simplicity*	Least clean as atmosphere is polluted due to smoke.	Most simple and clean.	More clean than steam power and nuclear power plants.	Less cleaner than hydroelectric and diesel power plants.

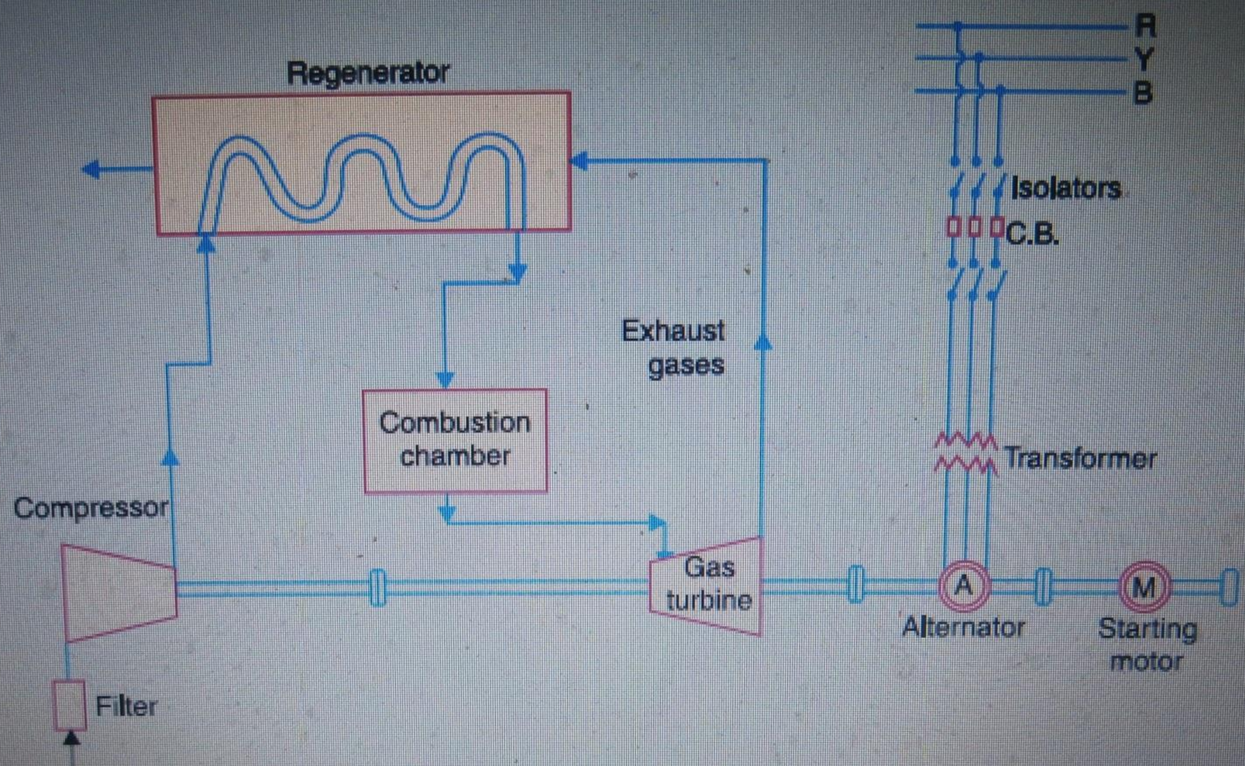


Schematic arrangement of gas turbine power plant.

Fig. 2.9

(v) **Alternator.** The gas turbine is coupled to the alternator. The alternator converts mechanical energy of the turbine into electrical energy. The output from the alternator is given to the bus-bars through transformer, circuit breakers and isolators.

(vi) **Starting motor.** Before starting the turbine, compressor has to be started. For this purpose, an electric motor is mounted on the same shaft as that of the turbine. The motor is energised by the batteries. Once the unit starts, a part of mechanical power of the turbine drives the compressor and there is no need of motor now.



Schematic arrangement of gas turbine power plant.

Fig. 2.9

(v) **Alternator.** The gas turbine is coupled to the alternator. The alternator converts mechanical energy of the turbine into electrical energy. The output from the alternator is given to the bus-bars through transformer, circuit breakers and isolators.

(vi) **Starting motor.** Before starting the turbine, compressor has to be started. For this purpose, an electric motor is mounted on the same shaft as that of the turbine. The motor is energised by the batteries. Once the unit starts, a part of mechanical power of the turbine drives the compressor and there is no need of motor now.

SELF-TEST