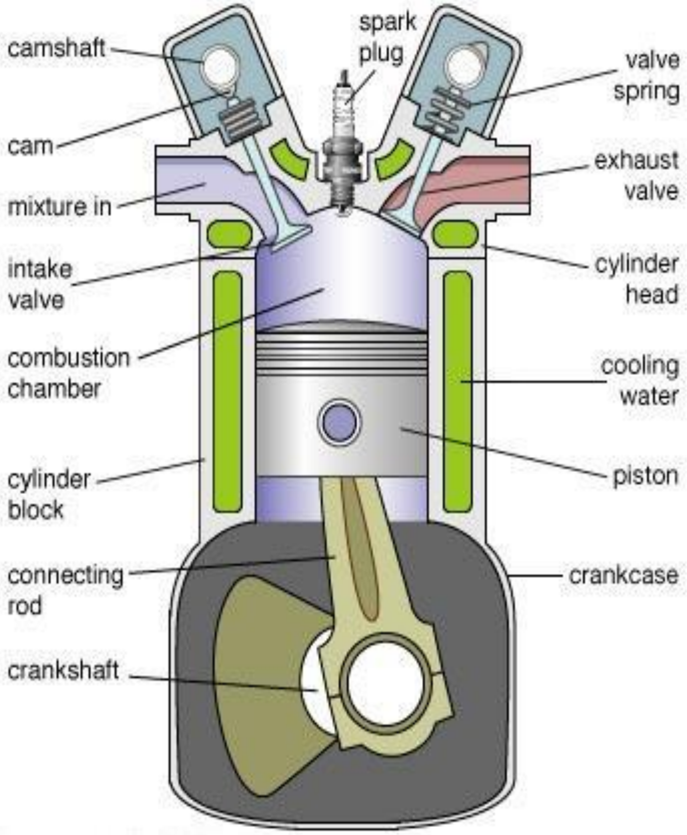
DIESEL ENGINE POWER PLANT

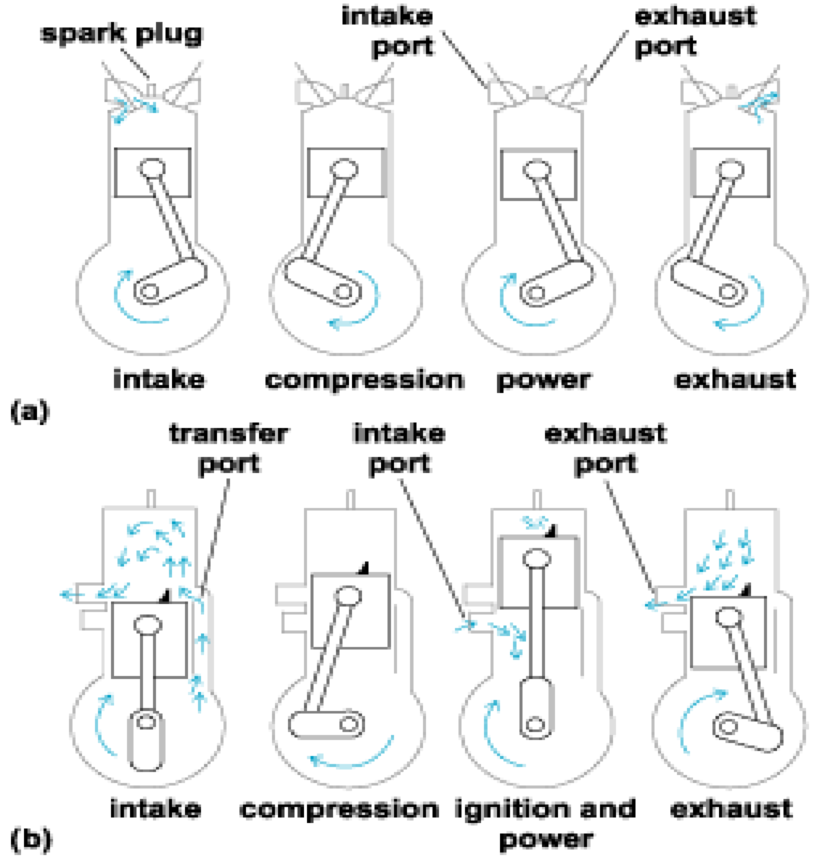
BASIC TYPE OF IC ENGINE



FUNCTION

(a) FOUR STROCK

(b)TWO STROCK



Diesel engine

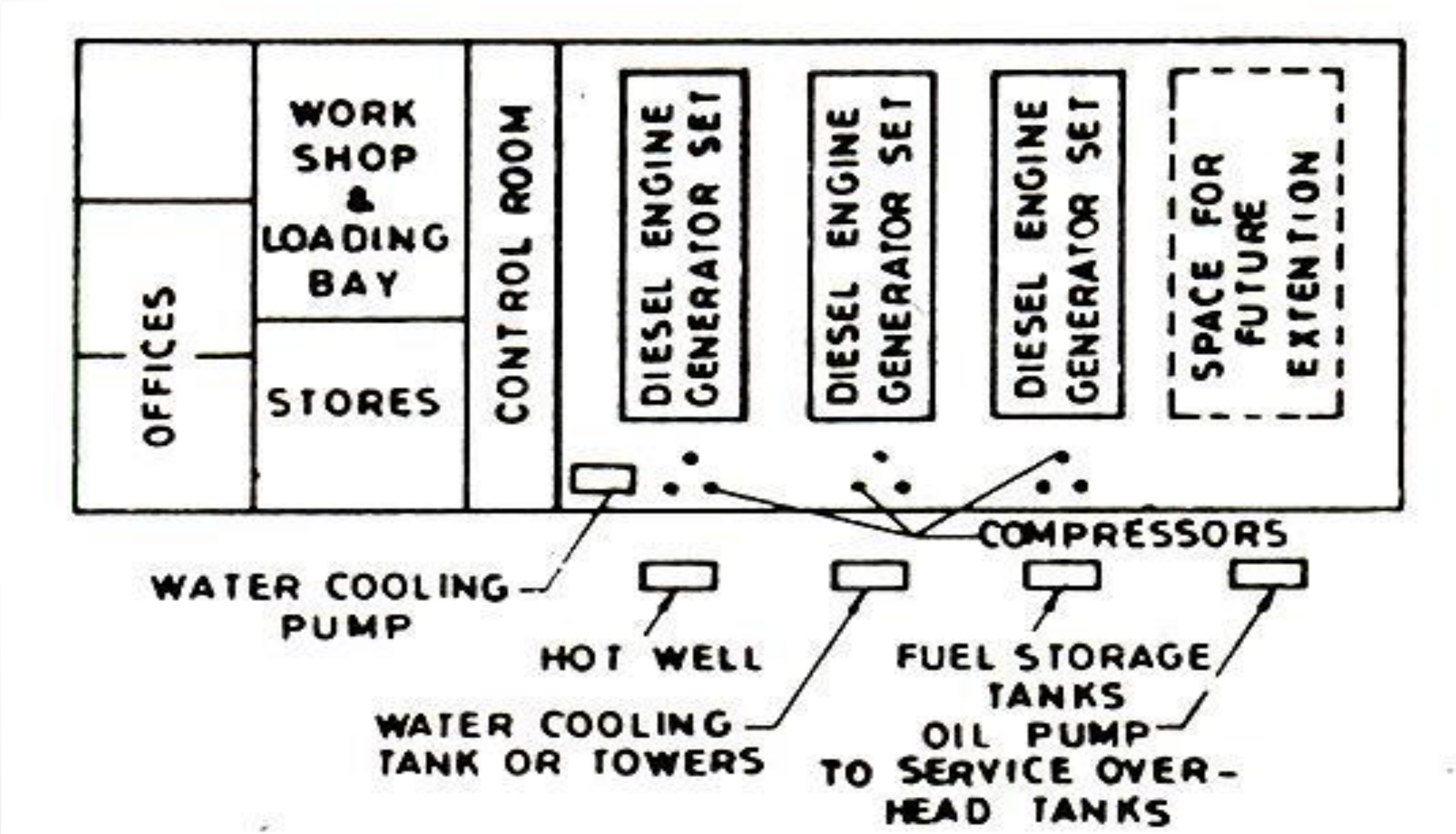
The two stroke cycle engine is more favored for diesel power plant.

- The air required for the diesel engine is drown through the air filter from the atmosphere and compressed inside the cylinder.
- The fuel from the diesel engine is drawn through a filter from the all day tank and injected into the cylinder through fuel injectors.
- Because of the high temperature and pressure of the compressed air,
- the fuel burns and the burnt gases expand to do work on the moving part inside the cylinder called piston.
- This movement of the piston rotates a flywheel and the engine is directly coupled to electric generator.
- The gases after expansion inside the cylinder is exhausted into the atmosphere and passes through a silencer in order to reduce the noise.

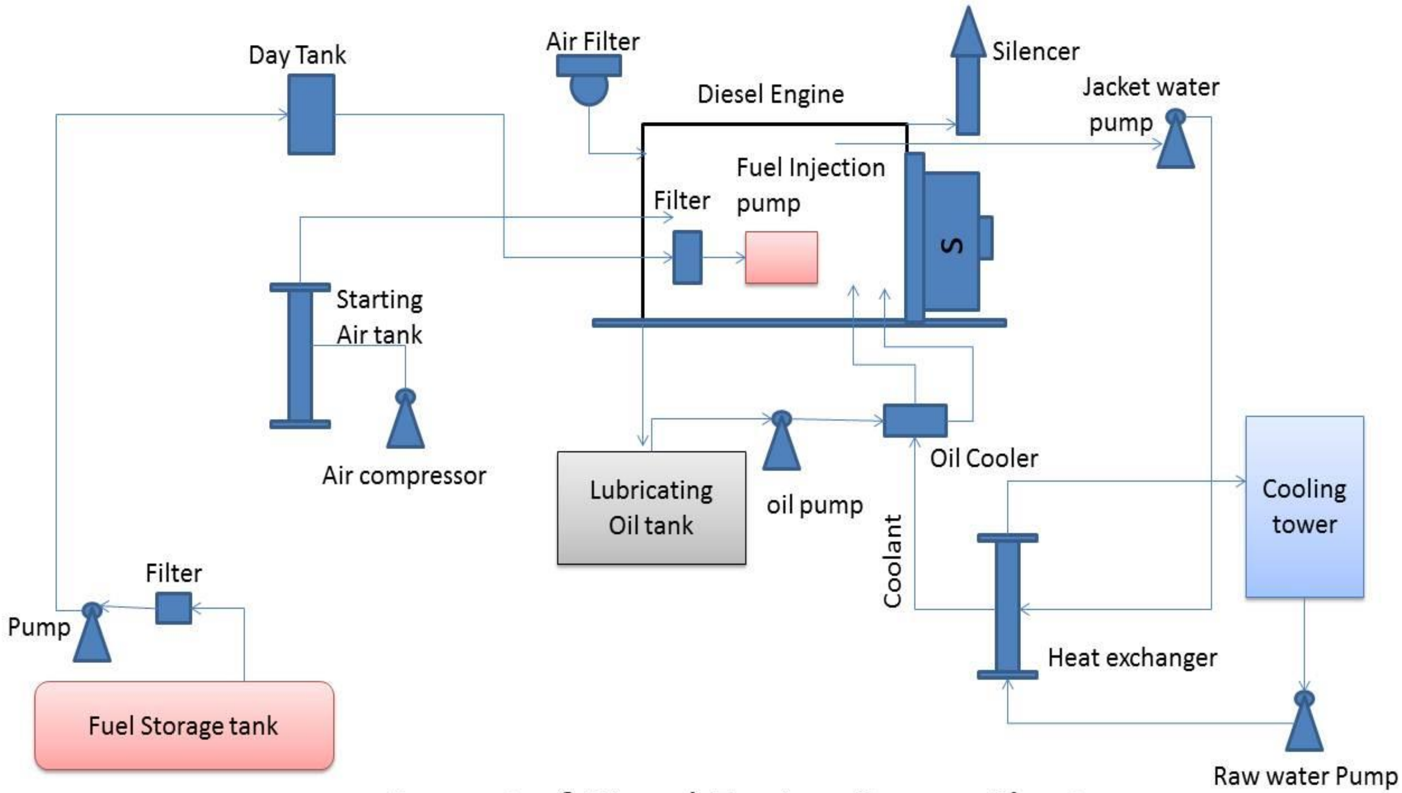
INTRODUCTION

- Diesel power plants produce power in the range of 2 to 50MW.
- They are used as standby sets for continuity of supply such as hospitals , telephone exchanges , radio station , cinema theatres and industries (peak load).
- They are suitable for mobile power generation and widely used in railways and ships.

GENERAL LAYOUT

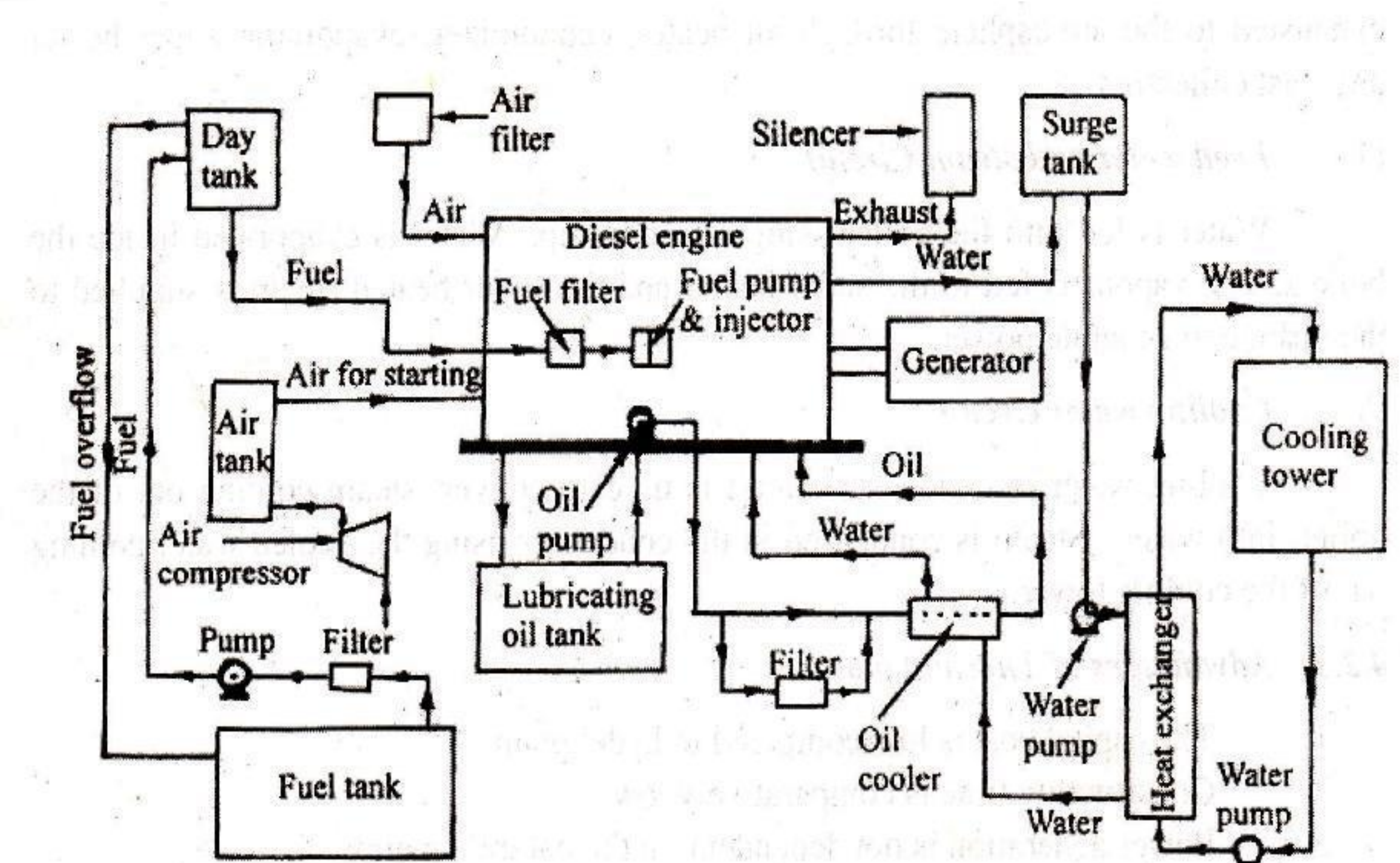


Simple layout



Layout of Diesel Engine Power Plant

LAYOUT

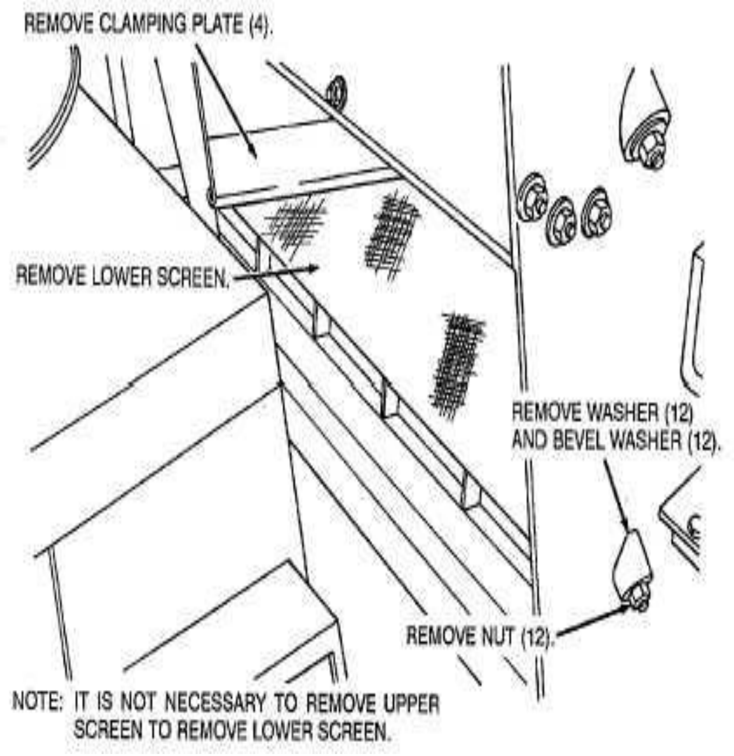

Day tank
Air filter
Silencer
Surge tank
Air
Exhaust
Diesel engine
Water
Fuel
Fuel filter
Fuel pump & injector
Water
Generator
Air for starting
Fuel overflow
Fuel
Air tank
Cooling tower
Oil
Oil pump
Air
Air compressor
Water
Lubricating oil tank
Pump
Filter
Filter
Heat exchanger
Water pump
Oil cooler
Fuel tank
Water
Water pump

Diesel plant equipment

- Air intake system
- Fuel supply system
- Exhaust system
- Cooling system
- Lubricating system
- Starting system

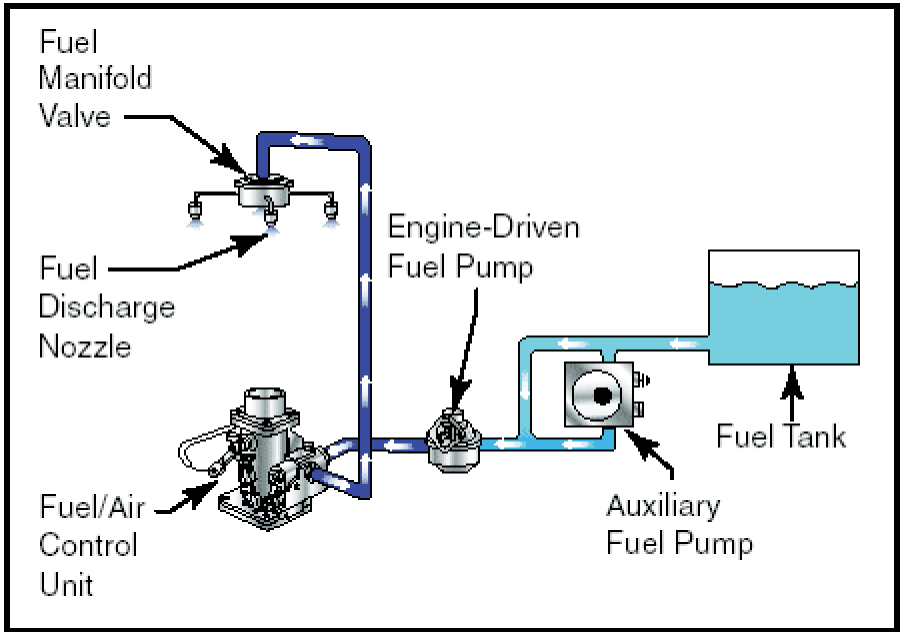
Air intake system

- The air required for the combustion of fuel inside the diesel engine cylinder is drawn through the air filter. The purpose of the filter is to remove dust from the incoming air.
- dry filter- may be made of felt , wood or cloth.
- wet filter- oil bath is used.



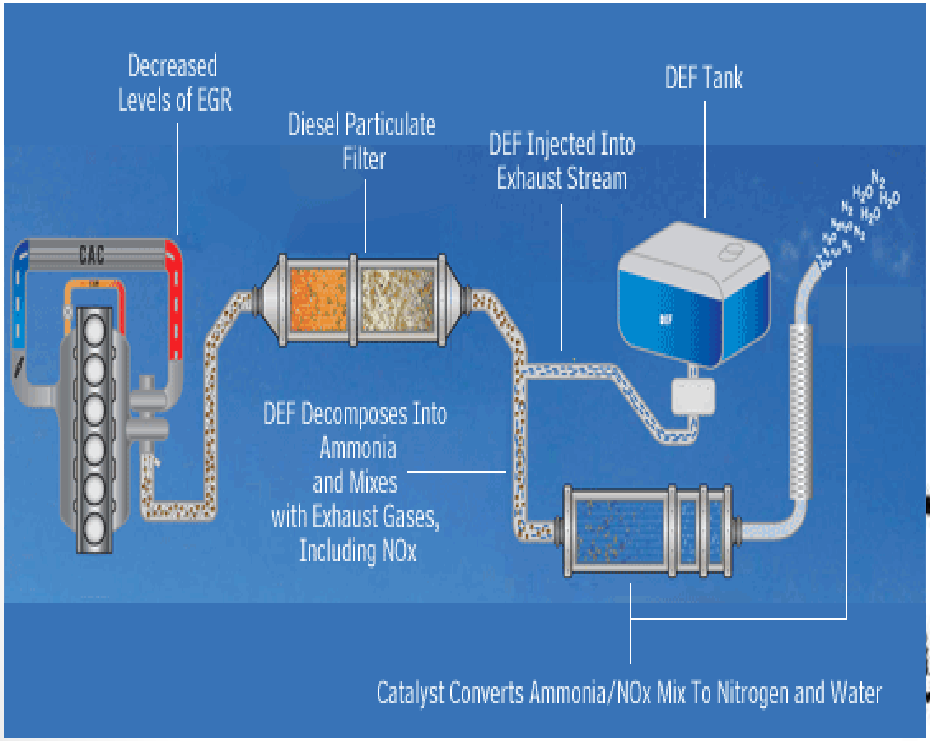
Fuel supply system

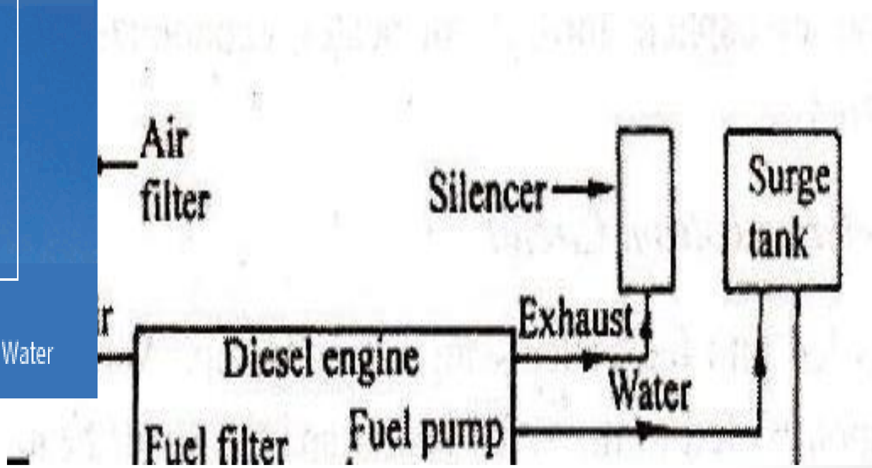
- Fuel from the storage tank is pumped through a filter into a smaller tank called all day tank . this tank supplies the daily requirements of the diesel engine.



Exhaust system

- The exhaust gases coming out of the engine is very noisy. In order to reduce the noise a silencer is used.

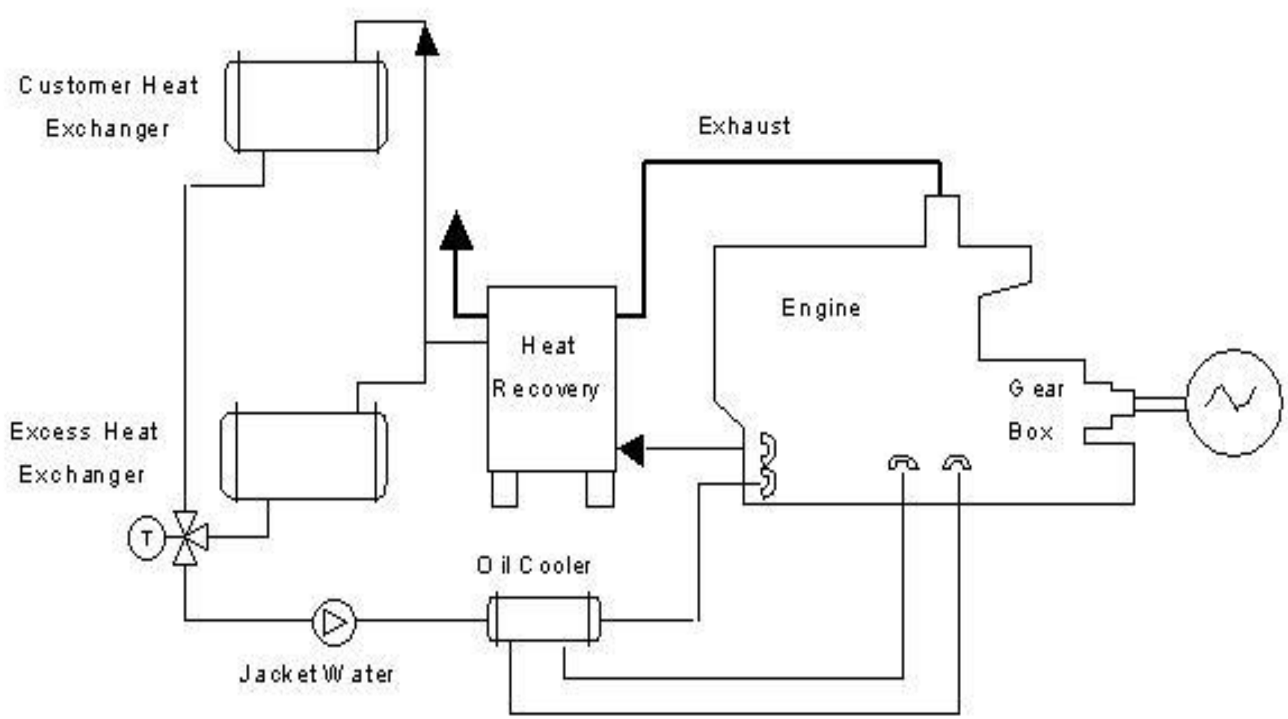




Cooling system

- The temperature of the burning fuel inside the engine cylinder -1500 degree Centigrade to 2000 degree centigrade. In order to lower this temperature water is circulated around the engine.
- The hot water leaving the jacket is passed through the heat exchanger.
- The heat from the heat exchanger is carried away by the raw water circulated through the heat exchanger and is cooled in the cooling tower

Cooling system



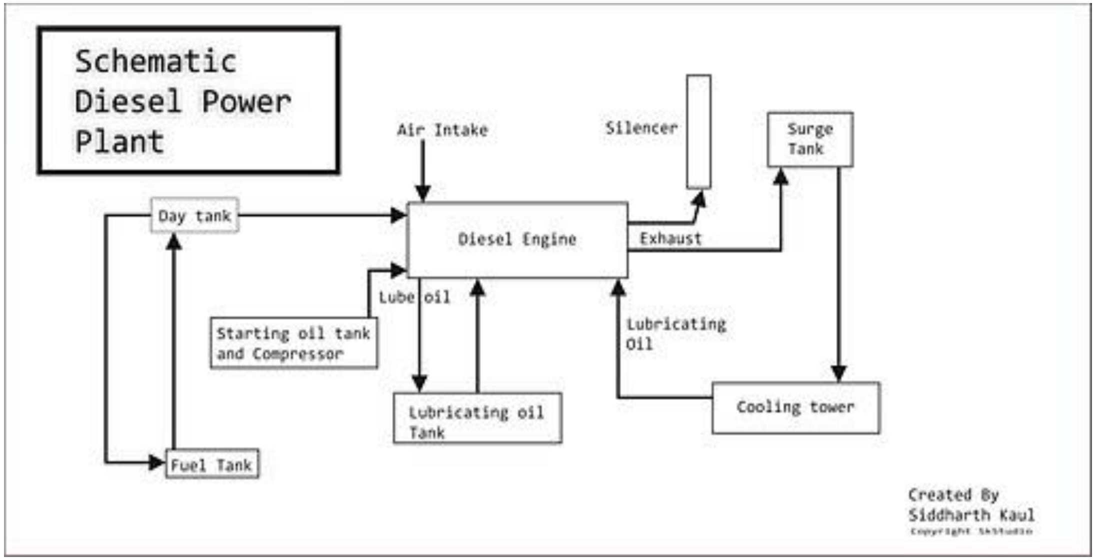
Lubricating system

- This circuit includes lubricating oil tank , oil pump and oil cooler.
- The purpose of the lubrication system is to reduce the wear of the engine moving parts .part of the cylinder such as piston , shafts , valves must be lubricated.
- Lubrication also helps to cool the engine.

Starting system

- Diesel engine used in diesel power plant is not self starting . The engine is started from cold condition whit the help of an air compressor.

Schematic diesel engine power

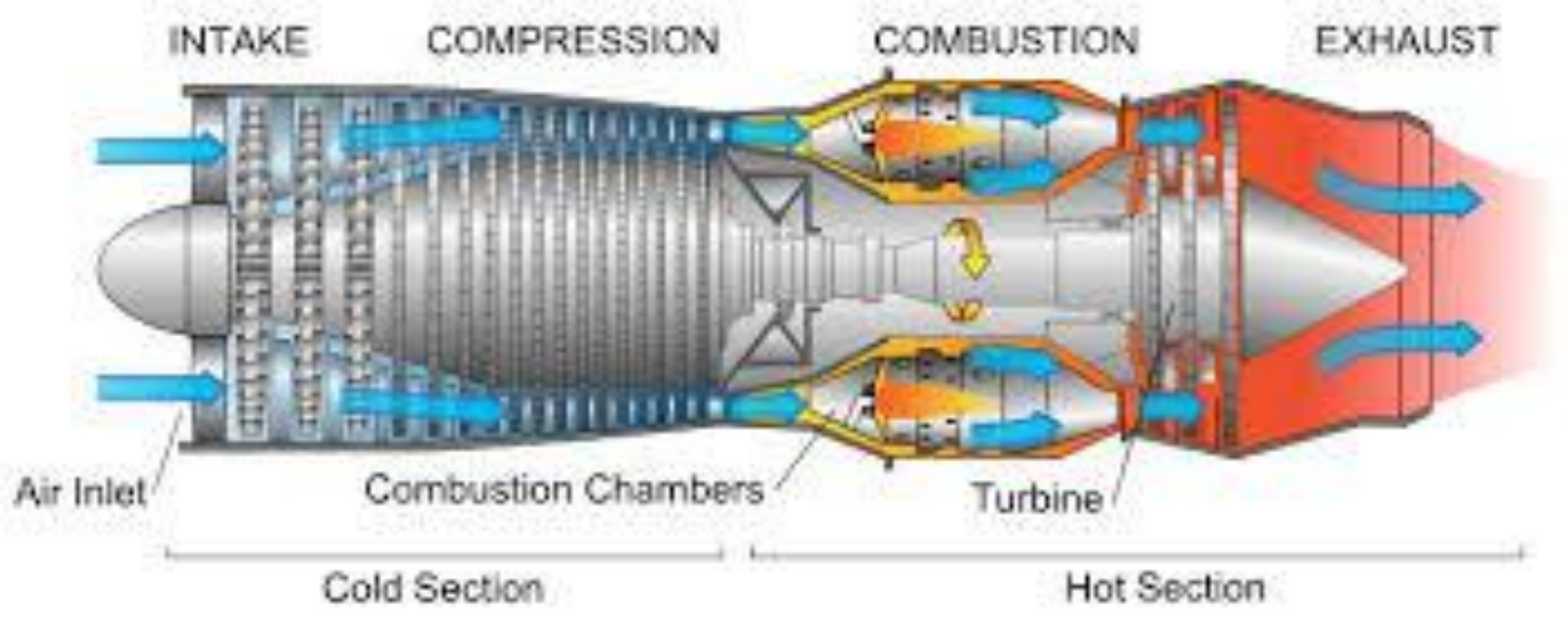


ADVANTAGE OF DIESEL POWER PLANT

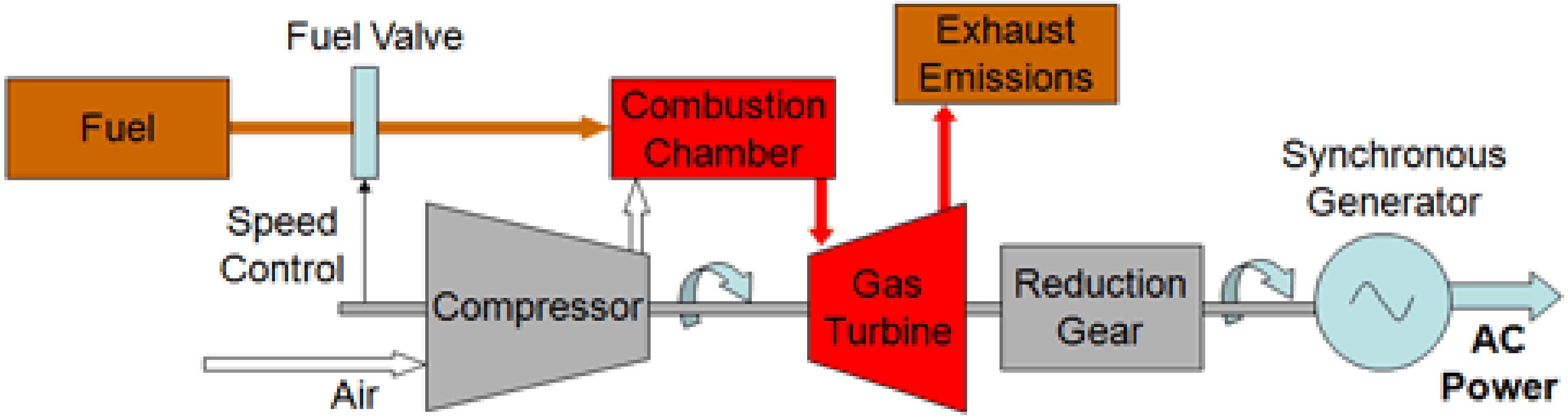
1. Very simple design also simple installation and occupies less space.
2. Limited cooling water requirement.
3. Diesel power plant are more efficient than steam power in the range of 150MW capacity.
4. Quickly started and put on load.
5. It can respond to varying loads without any difficulty.
6. Smaller storage is needed for the fuel.
7. Layout of power plant is quite simple.
8. There is no problem of ash handling.
9. Less supervision required.

DISADVANTAGE OF DIESEL POWER PLANT

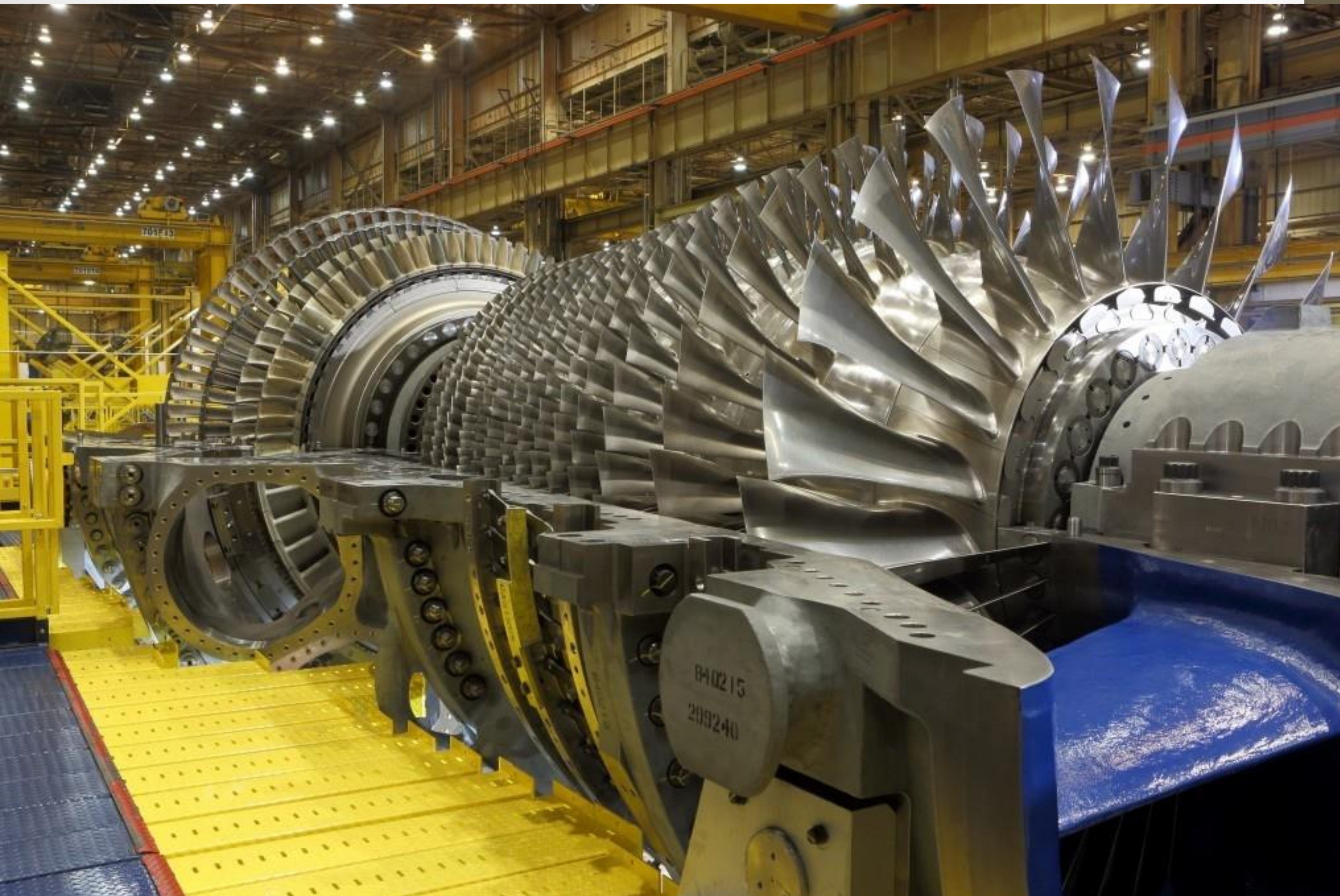
1. High Maintenance ,lubrication cost and operating cost.
2. Fuel cost is more, since in India diesel is costly.
3. The plant cost per kW is comparatively more.
4. The life of diesel power plant is small due to high maintenance.
5. Noise is a serious problem in diesel power plant.
6. Diesel power plant cannot be constructed for large scale.



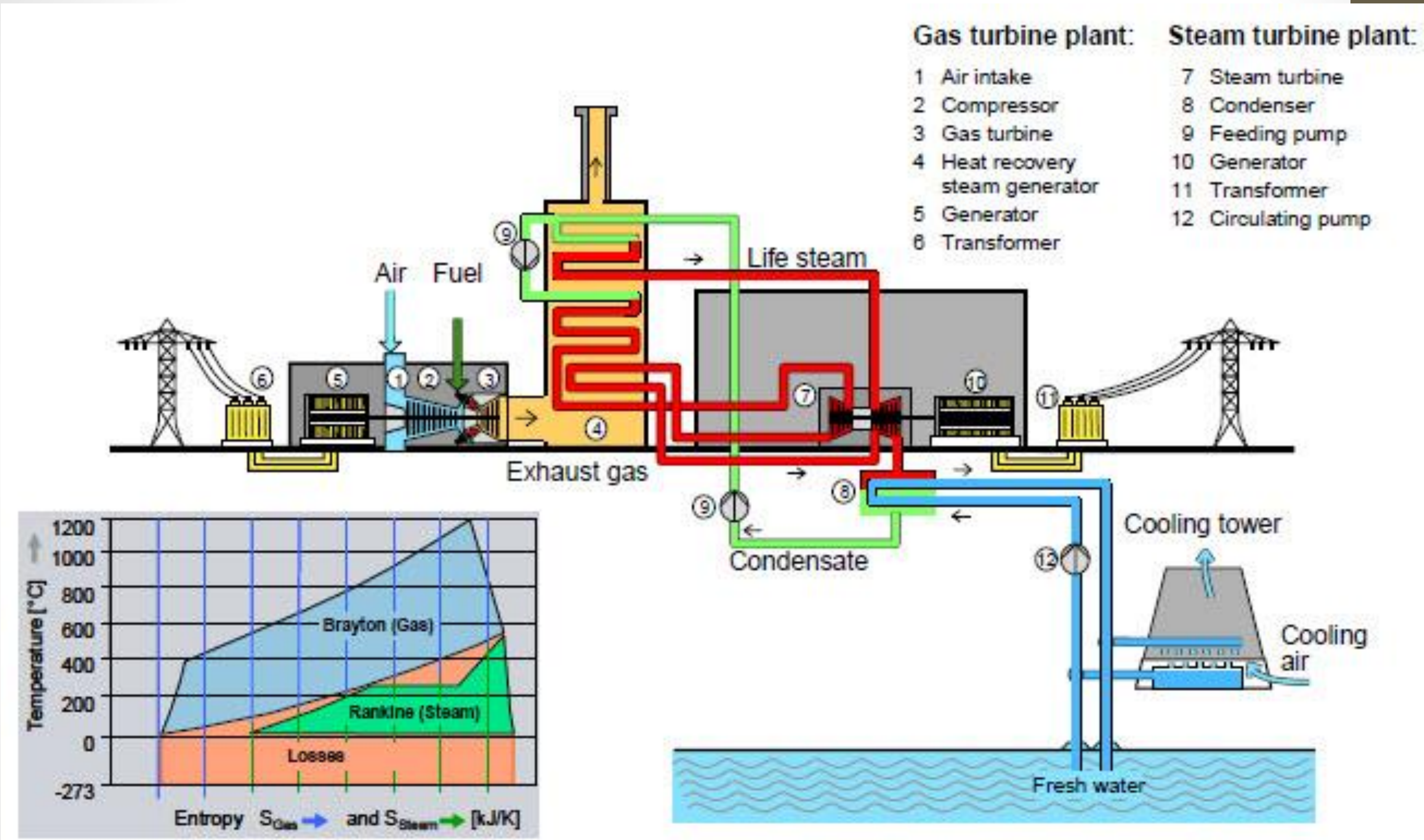
GAS power plant

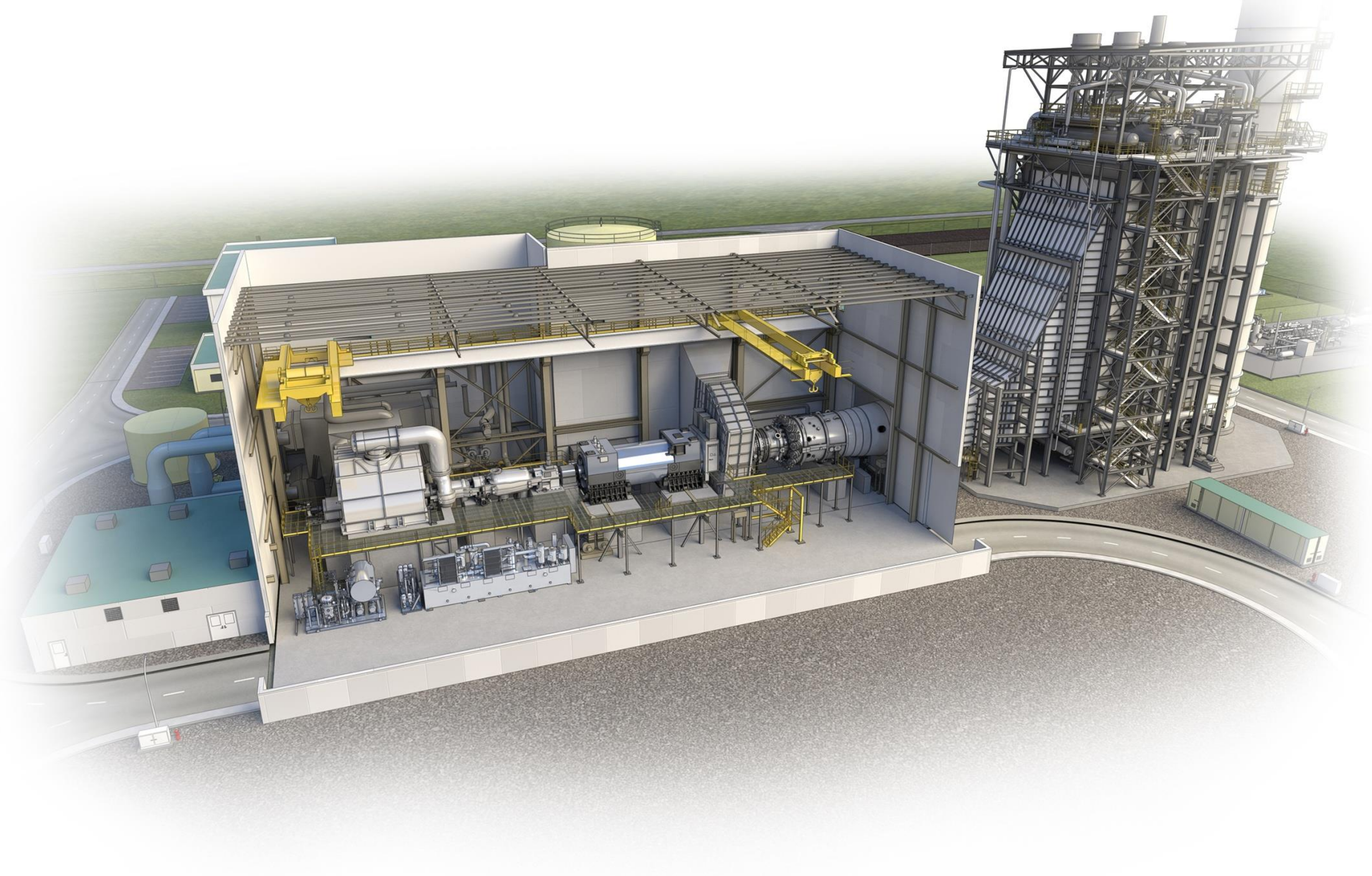


Gas Turbine Electric Power Generation




GTG


Gas turbine plant:
1 Air intake
2 Compressor
3 Gas turbine
4 Heat recovery steam generator
5 Generator
6 Transformer
Steam turbine plant:
7 Steam turbine
8 Condenser
9 Feeding pump
10 Generator
11 Transformer
12 Circulating pump
Air
Fuel
Life steam
Exhaust gas
Condensate
Cooling tower
Cooling air
Fresh water
Temperature [°C]
1200
1000
800
600
400
200
0
-273
Brayton (Gas)
Rankine (Steam)
Losses
Entropy S_{Gas} and S_{Steam} [kJ/K]



Power produced in india by Gas power plant

Sector	Gas
Central	7,237.91
State	7,048.95
Private	10,580.60
All India	24,867.46
Percentage	**7.21**

Total capacity 344,719 MW

GAS POWER PLANTS IN INDIA

Largest Gas Power Plants

Power Plant	Owner	Location	Total Capacity (MW)
Uran	Maharashtra SEB	Ransai Dam, Maharashtra	912
Dahbol	Ratnagiri Gas and Power Pvt Ltd	Ratanagiri District Maharashtra	826
Dadri (gas-fired section)	NTPC	Dadri Uttar Pradesh Natural Gas	817
Kawas	NTPC	Surat, Gujarat	656
Paguthan	Gujarat Pagathuan Energy Corp	Paguthan, Gujurat	655

- Advantages of Gas turbine power plants.
  - Storage of fuel requires less area and handling is easy.
  - The cost of maintenance is less.
  - It is simple in construction. There is no need for boiler, condenser and other accessories as in the case of steam power plants.
  - Cheaper fuel such as kerosene , paraffin, benzene and powdered coal can be used which are cheaper than petrol and diesel.
  - Gas turbine plants can be used in water scarcity areas.
  - Less pollution and less water is required.

- Disadvantages of gas turbine power plant

1. 66% of the power developed is used to drive the compressor. Therefore the gas turbine unit has a low thermal efficiency.
2. The running speed of gas turbine is in the range of (40,000 to 100,000 rpm) and the operating temperature is as high as 1100 – 1260^{0}C. For this reason special metals and alloys have to be used for the various parts of the turbine.
3. High frequency noise from the compressor is objectionable.

Brayton Cycle

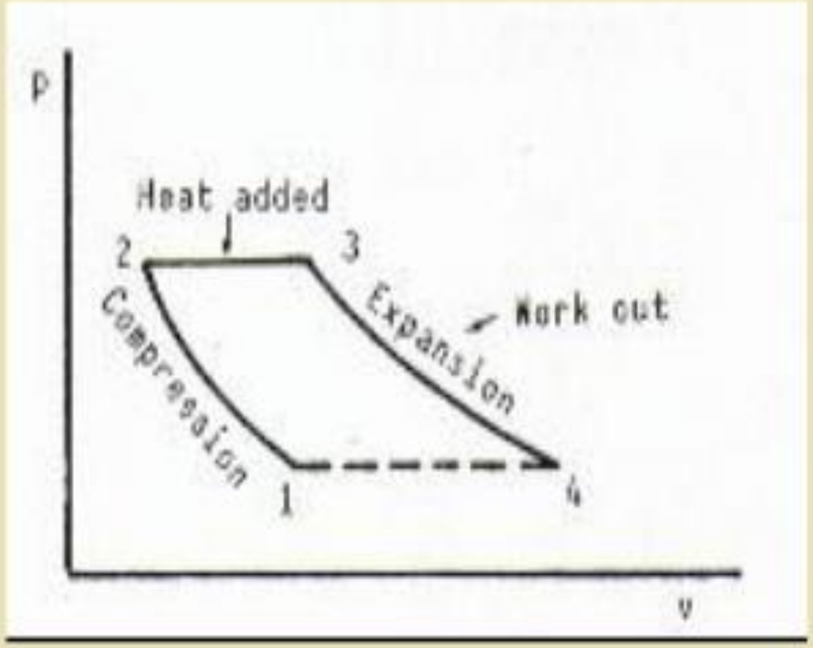
- Unlike diesels, operate on STEADY-FLOW cycle
- Open cycle, unheated engine

1-2: Compression

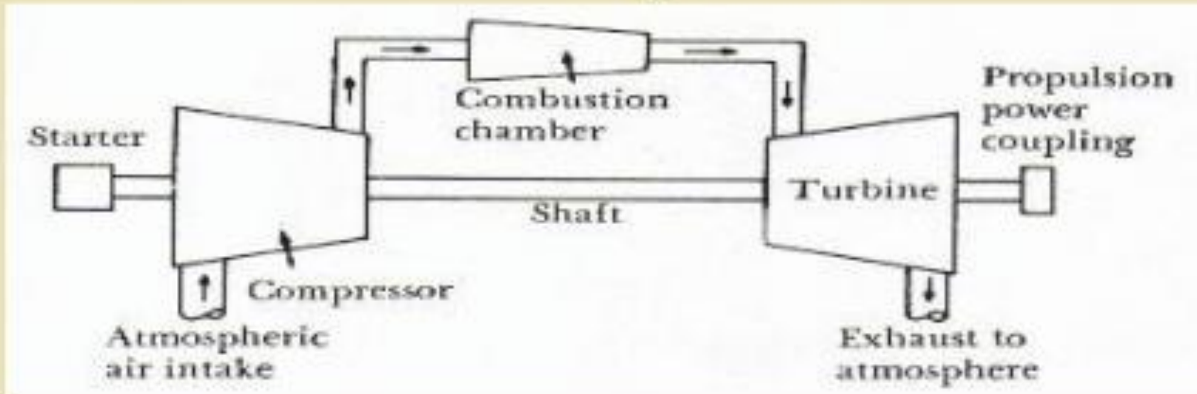
2-3: Combustion

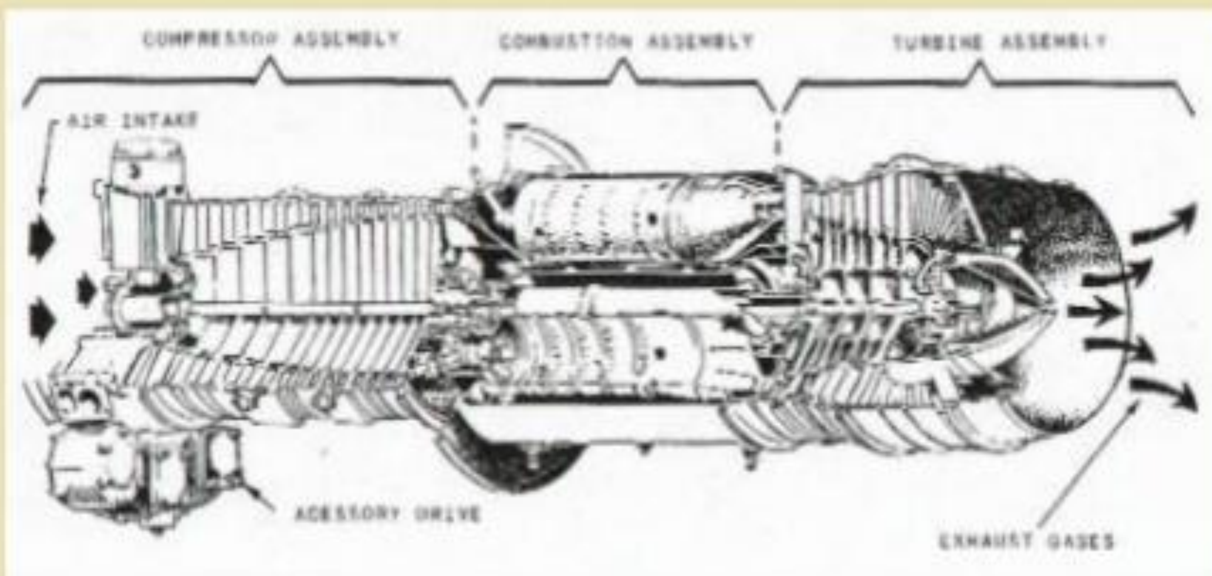
3-4: Expansion through Turbine and Exhaust Nozzle

(4-1: Atmospheric Pressure)

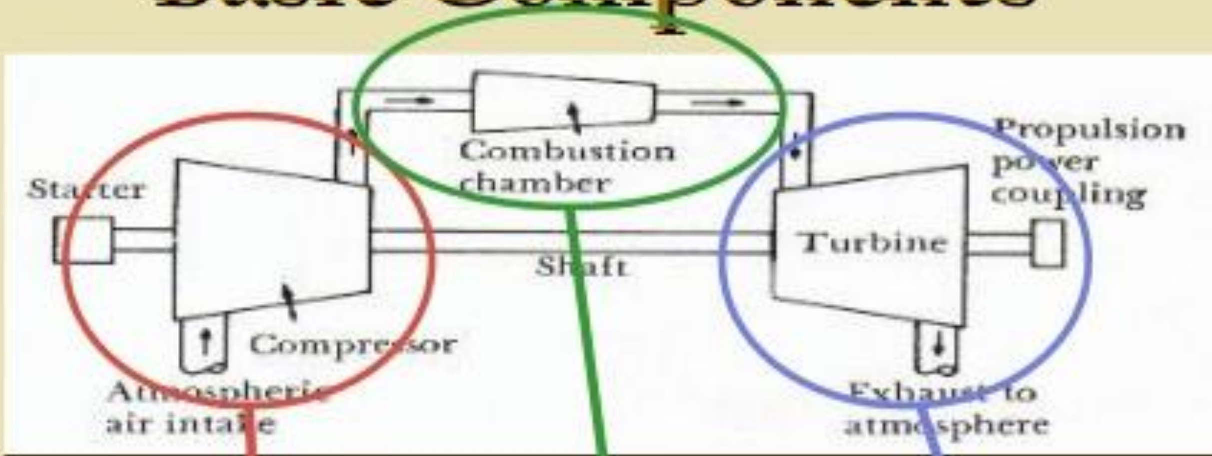


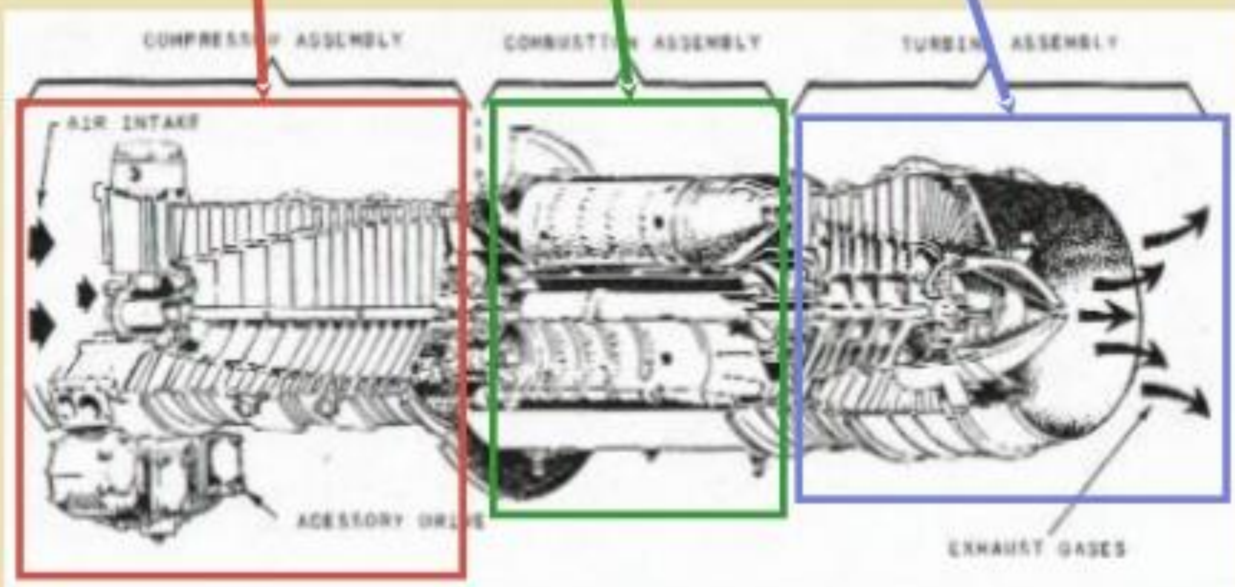
Basic Components





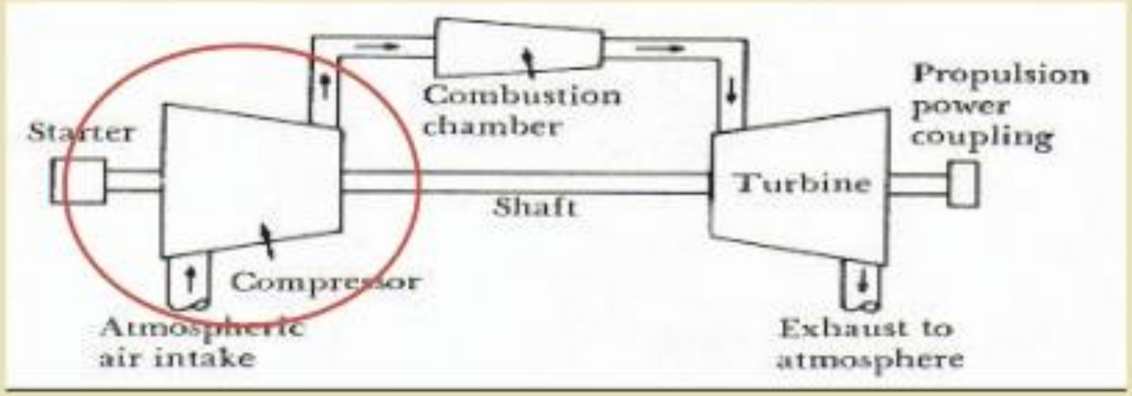
Basic Components





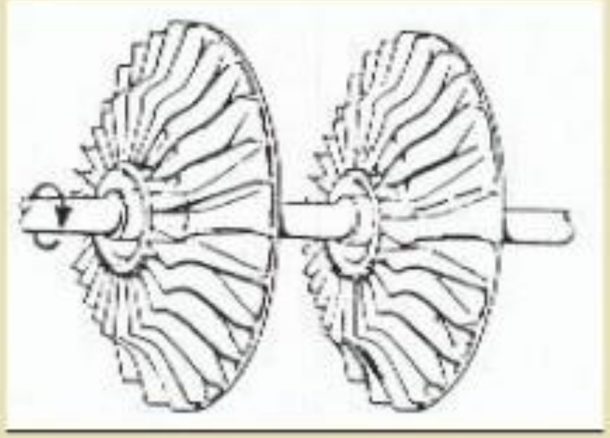
Basic Components

- Compressor
  - Draws in air & compresses it
- Combustion Chamber
  - Fuel pumped in and ignited to burn with compressed air
- Turbine
  - Hot gases converted to work
  - Can drive compressor & external load

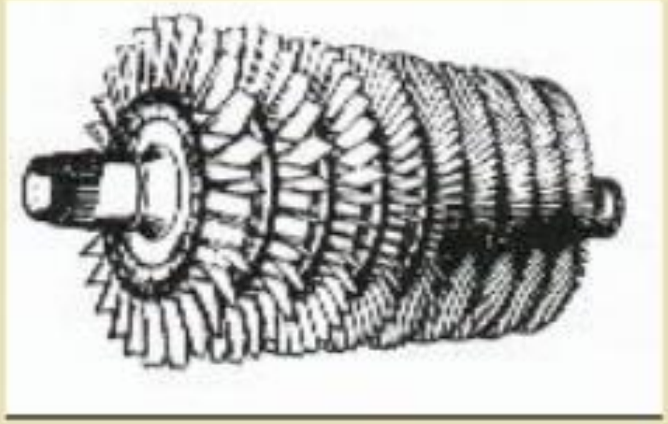


Compressor

- Radial/centrifugal flow
  - Adv: simple design, good for low compression ratios (5:1)
  - Disadvantage: Difficult to stage, less efficient



- Axial flow
  - Good for high compression ratios (20:1) - Most commonly used



Compressor

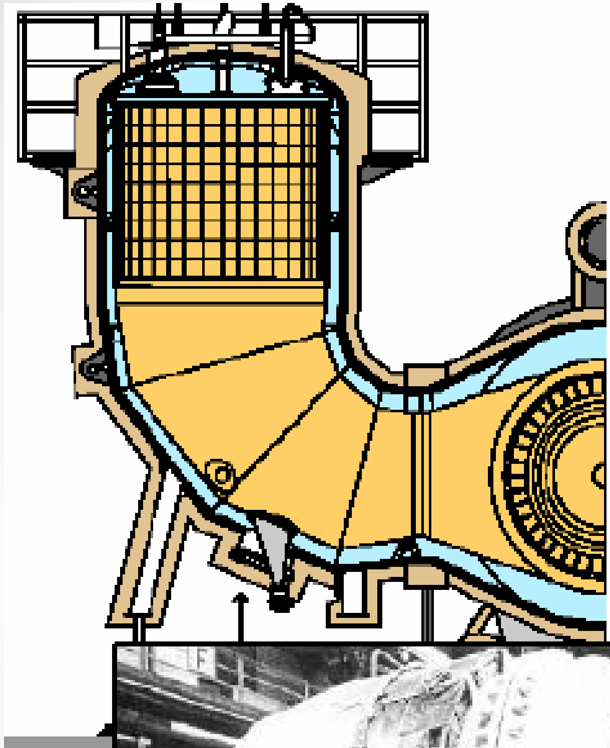
- Controlling Load on Compressor
  - To ensure maximum efficiency and allow for flexibility, compressor can be split into HP & LP sections
  - Vane control: inlet vanes/nozzle angles can be varied to control air flow
- Compressor Stall
  - Interruption of air flow due to turbulence

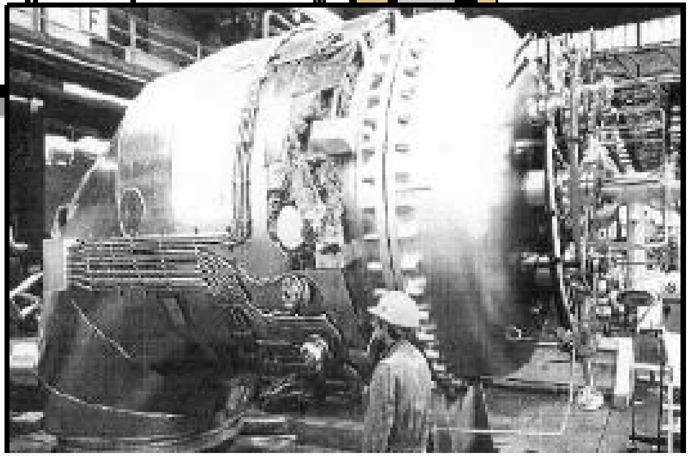
Use of Compressed Air

- Primary Air (30%)
  - Passes directly to combustor for combustion process
- Secondary Air (65%)
  - Passes through holes in perforated inner shell & mixes with combustion gases
- Film Cooling Air (5%)
  - Insulates/cools turbine blades

Combustion Chambers

- Where air & fuel are mixed, ignited, and burned
- Spark plugs used to ignite fuel
- Types
  - Can: for small, centrifugal compressors
  - Annular: for larger, axial compressors (LM 2500)
  - Can-annular: for really large turbines





- Flame tube lined with easily replaceable ceramic tiles
- Walk-in combustion chamber design enables minor inspection without cover lift
- Hybrid burners in premix mode for Dry Low NOx and Low CO Emissions (natural gas & fuel oil)
- Diffusion burners for special fuels (ash forming fuel oil, low btu gas) with water or steam injection
- Turbine Blading benefits from highly uniform hot-gas temperature distribution and no direct flame radiation

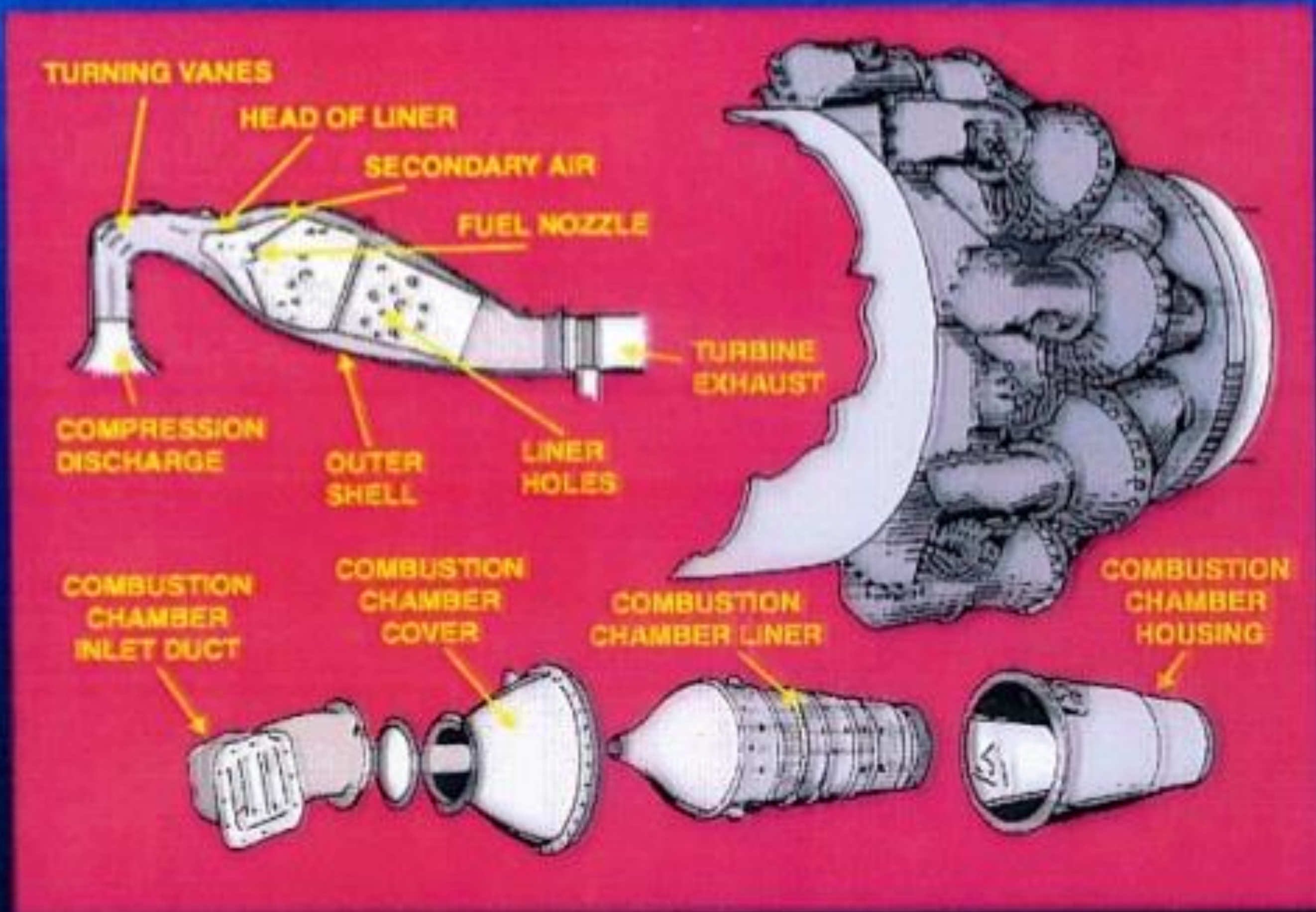


Figure 16-10

CAN-TYPE COMBUSTION CHAMBER

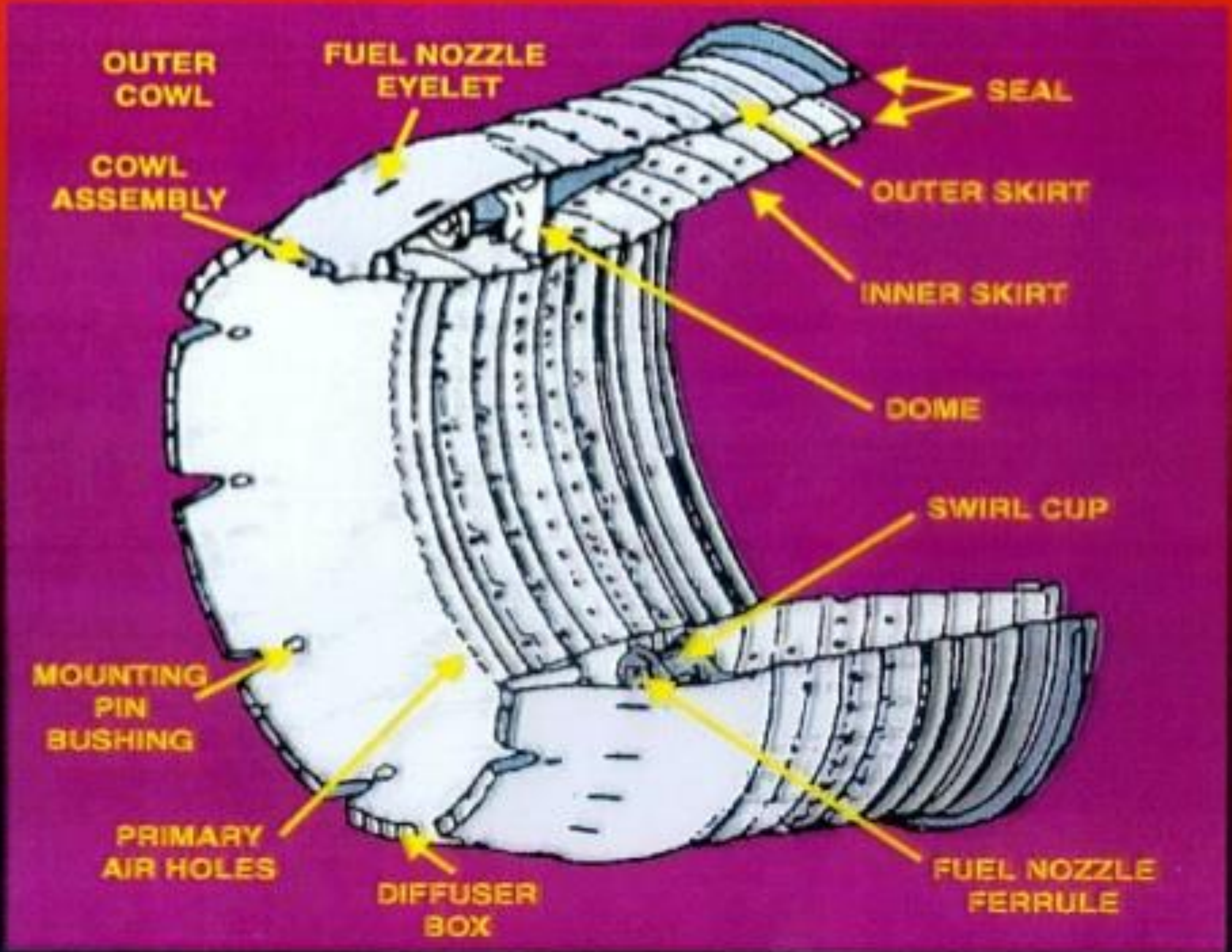


Figure 16-11

ANNULAR-TYPE COMBUSTION CHAMBER

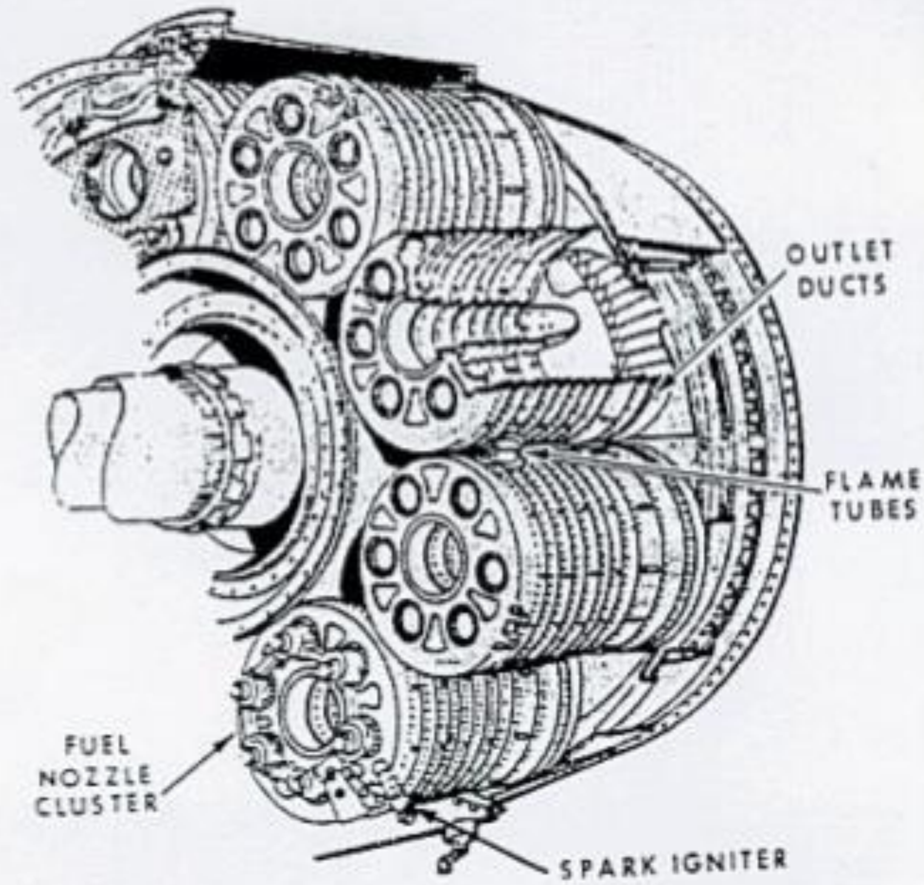
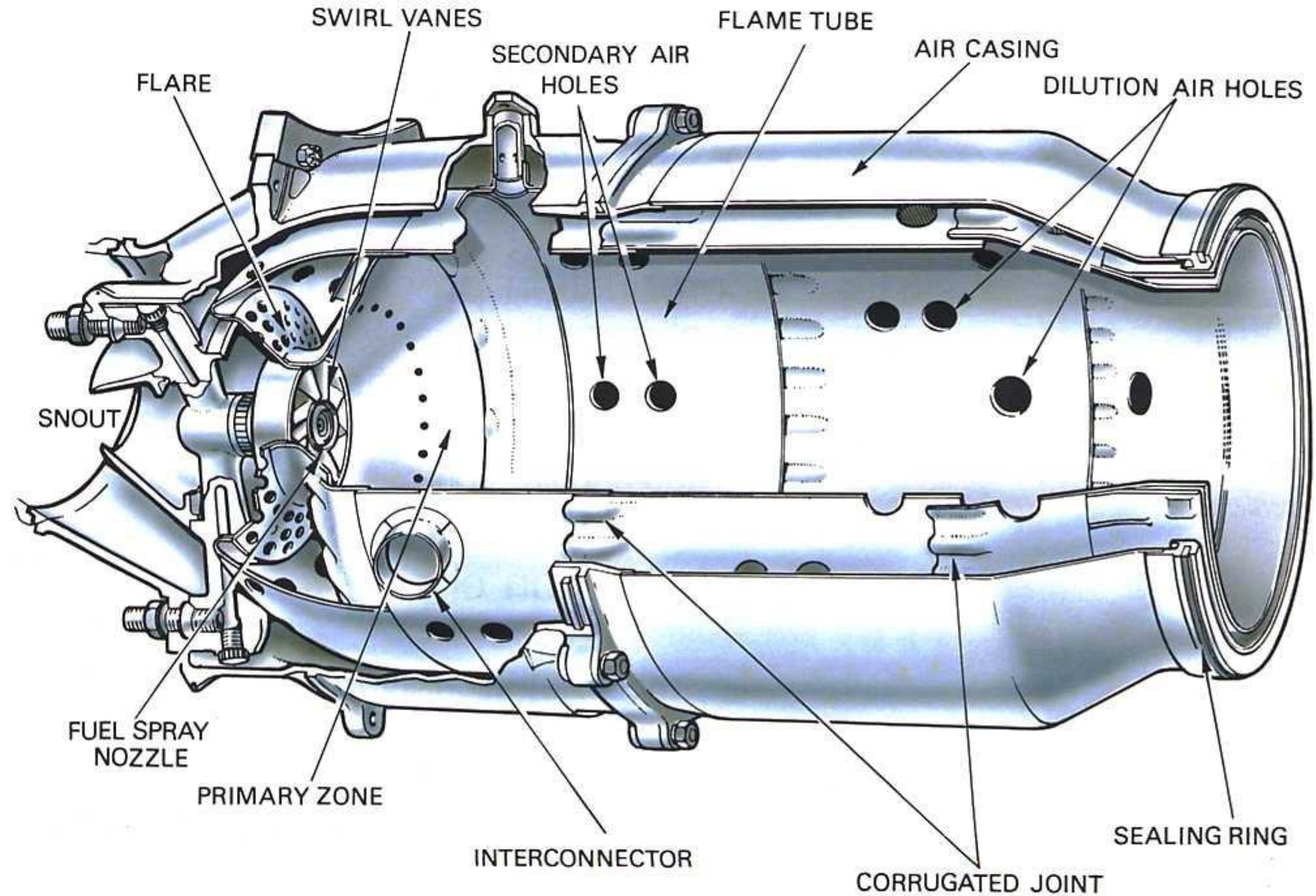


Figure 16-12.—Can-annual-type combustion chamber.


SWIRL VANES
FLAME TUBE
SECONDARY AIR HOLES
AIR CASING
FLARE
DILUTION AIR HOLES
SNOUT
FUEL SPRAY NOZZLE
PRIMARY ZONE
INTERCONNECTOR
SEALING RING
CORRUGATED JOINT

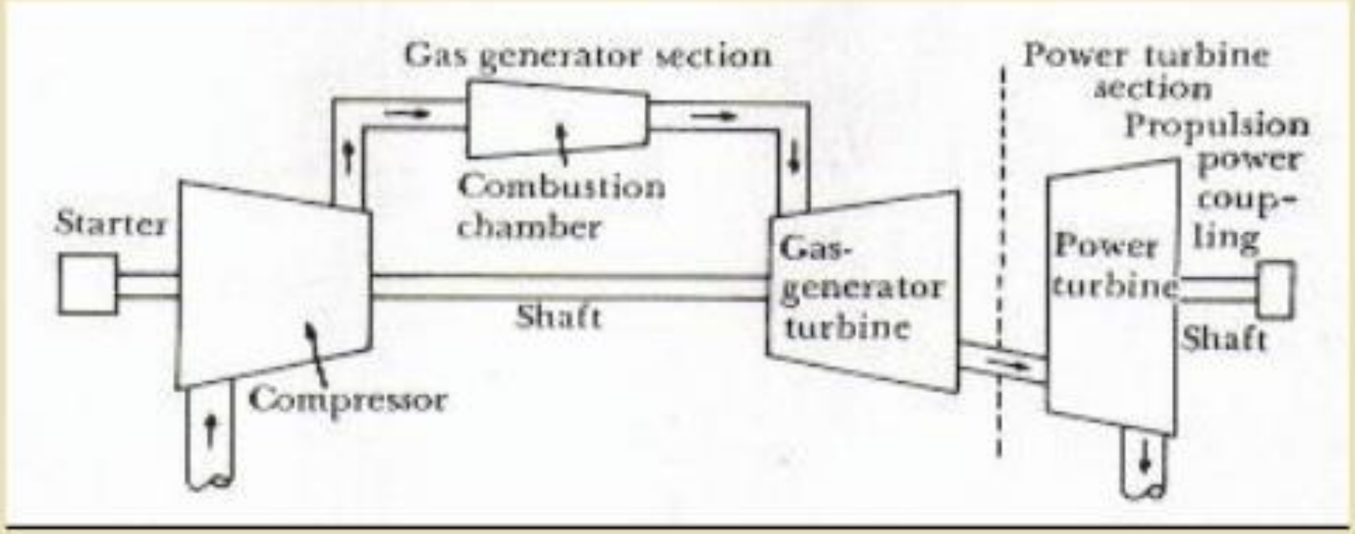
Turbines

- Consists of one or more stages designed to develop rotational energy
- Uses sets of nozzles & blades

Turbine blade nickel base
VIM (Vacuum induction melting)
(1953)
VAR Vacuum arc metling) (1958)
1970 HIP (**Hot isostatic pressing**)

Turbines

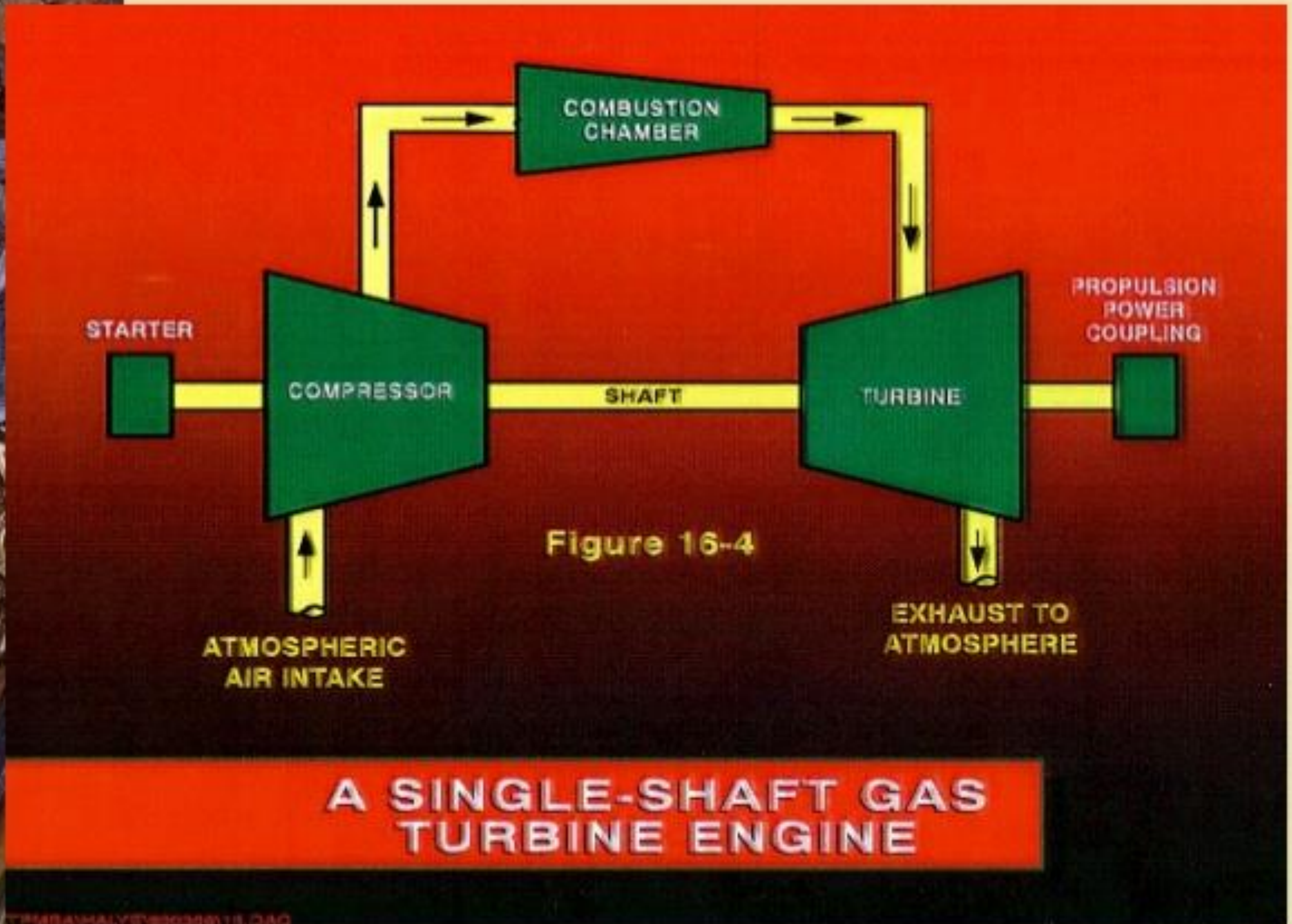
- Split Shaft
  - Gas generator turbine drives compressor
  - Power turbine separate from gas generator turbine
  - Power turbine driven by exhaust from gas generator turbine
  - Power turbine drives power coupling



Single Shaft

- Efficiently operates at constant speeds
- Used in GTGS (gas turbine generator systems)
- Single shaft
  - Power coupling on same shaft as turbine
  - Same shaft drives rotor of compressor and power components

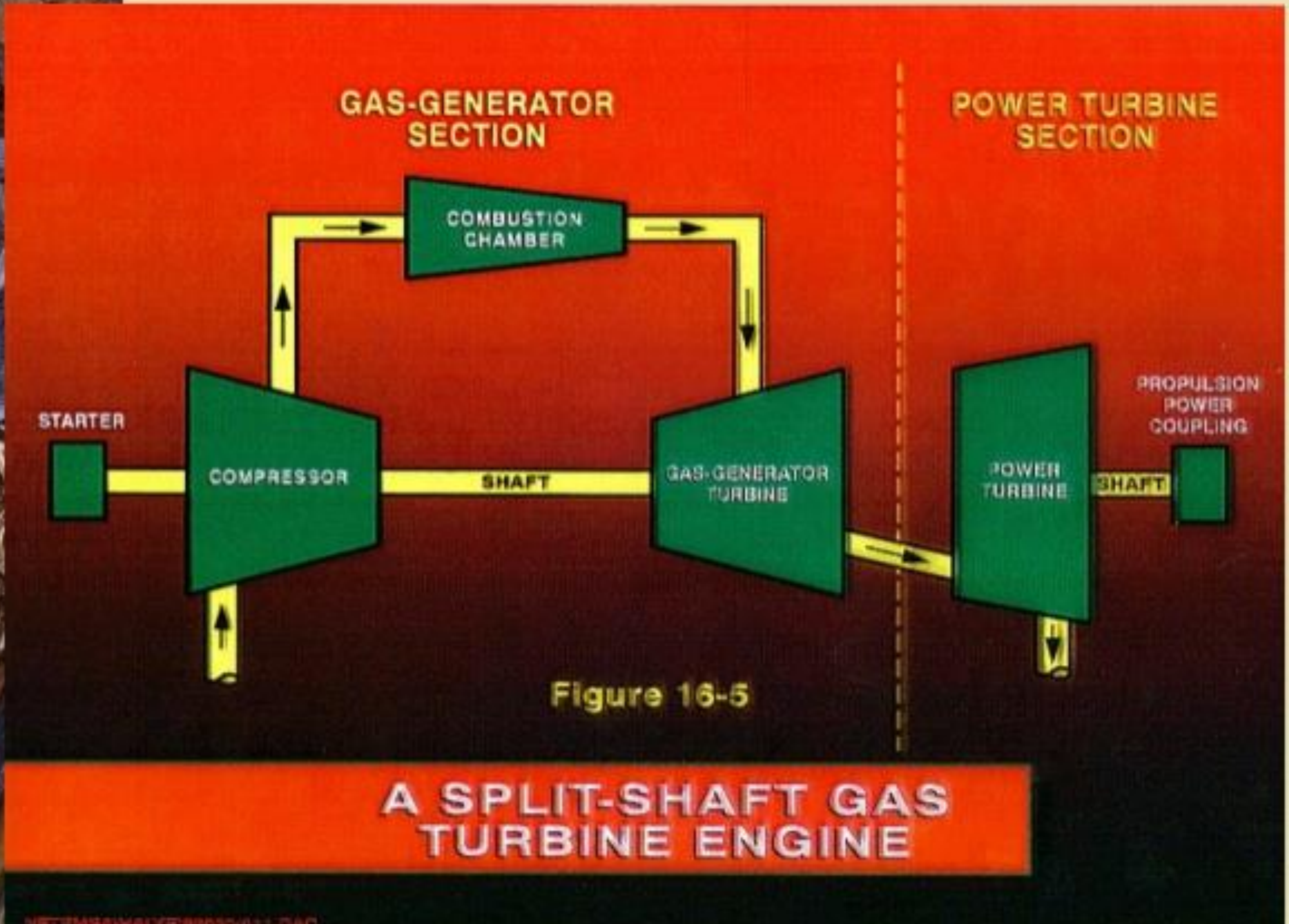
*Primarily used for electric power because of constant speed, regardless of load.


COMBUSTION CHAMBER
STARTER
COMPRESSOR
SHAFT
TURBINE
PROPULSION POWER COUPLING
Figure 16-4
ATMOSPHERIC AIR INTAKE
EXHAUST TO ATMOSPHERE
A SINGLE-SHAFT GAS TURBINE ENGINE

Split Shaft

- Best where speeds and loads vary
- Used in LM-2500
- Power shaft is decoupled from compressor
- Allows both to operate at efficient speeds (not the same)

*More suitable for main propulsion applications due to the fact that the gas generator turbine and power turbine operate near their most efficient speeds throughout a RANGE of load demands.


GAS-GENERATOR SECTION
POWER TURBINE SECTION
COMBUSTION CHAMBER
STARTER
COMPRESSOR
SHAFT
GAS-GENERATOR TURBINE
POWER TURBINE
SHAFT
PROPULSION POWER COUPLING
Figure 16-5
A SPLIT-SHAFT GAS TURBINE ENGINE

Accessory Drive Assembly

- Purpose - Provides motive force for driving the accessories required for operation and control of engine
- Attached Accessory Equipment
  - Fuel oil pump
  - Lube oil pump
  - Starter (pneumatic, electric, hydraulic)

Gas Turbine Systems

- Air System
  - Air intakes are located high up & multiple filters
  - Exhaust discharged out stacks
- Fuel System
  - Uses either DFM or JP-5
- Lubrication System
  - Supply bearings and gears with oil

Gas Turbine Systems

- Starting System
  - To get compressor initially rotated, HP air used (can use electrical also)
  - Once at certain RPM, fuel injected and spark ignited
- Power Transmission System
  - Reduction gears used to transfer torque
  - With split shaft, turbines can run @ different speeds

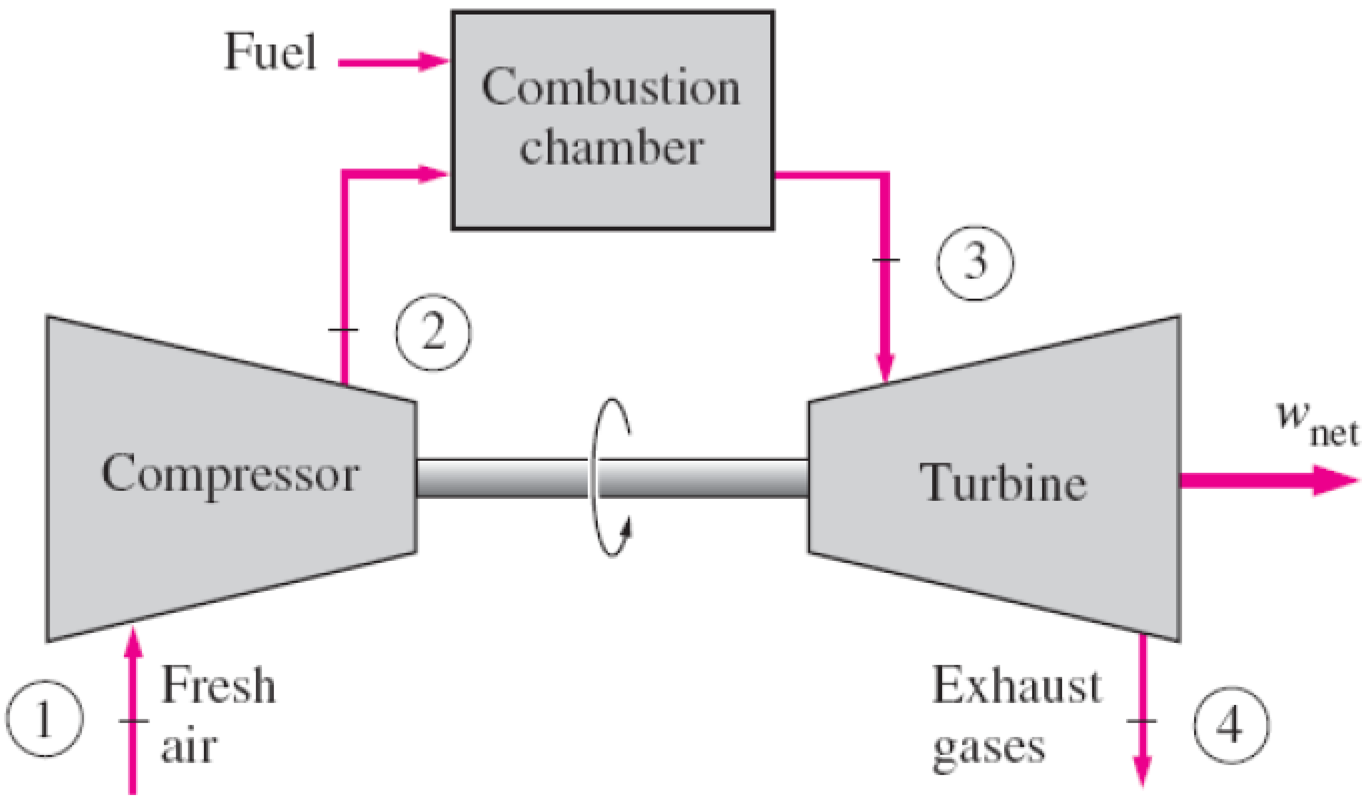
Performance Terms

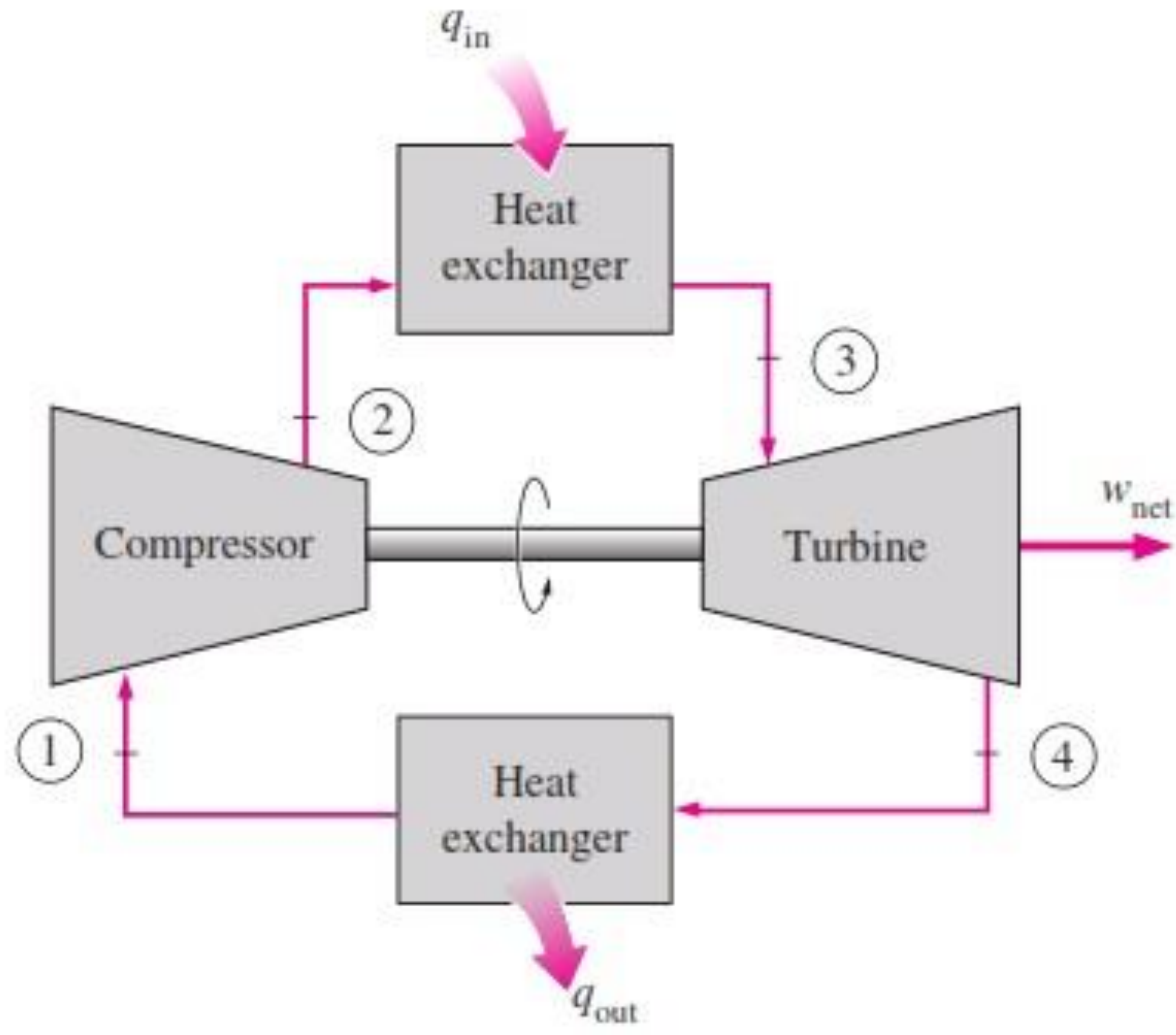
- **Pressure Ratio-** Ratio of the cycle's highest pressure to its lowest pressure.
- **Work Ratio**: Ratio of network output to the total work developed in the turbine.
- **Air Ratio**: kg of air entering the compressor inlet per unit of cycle net output, Kg/kWh
- **Compression efficiency**: Ratio of work needed for ideal air compressor through a given pressure range to work actually used by the compressor.
- **Engine Efficiency**: It is the ratio of the work actually developed by the turbine expanding hot power gas through a given pressure range to that would be yeilded for ideal expansion conditions
- **Machine Efficiency**: Collective term of engine efficiency and compressor efficiency of turbine and compressor.
- **Combustion Efficiency**: It is the ratio of heat actually released by 1 g of the fuel to heat that would be released by complete perfect combustion.
- **Thermal Efficiency**: It is the percentage of total energy input appearing as net work output of the cycle.

Classification of gas turbine cycles

a) Open cycle 2) closed cycle

A) Open cycle





q_{in}
Heat exchanger
3
2
Compressor
Turbine
w_{net}
1
4
Heat exchanger
q_{out}

Merits and Demerits of Closed Loop Cycle Turbine over Open Loop Cycle turbine

- Merits:
- Higher thermal efficiency
- Reduced size
- No contamination
- Improved heat transmission
- Lesser Fluid friction
- No loss in working medium
- Greater output
- Inexpensive fuel.

- Demerits:
- Complexity
- Large amount of cooling water is required.
- Dependent System
- Not economical for moving vehicles as weight /kW developed is high.
- Requires the use of very large air heater.

Ideal Brayton Cycle

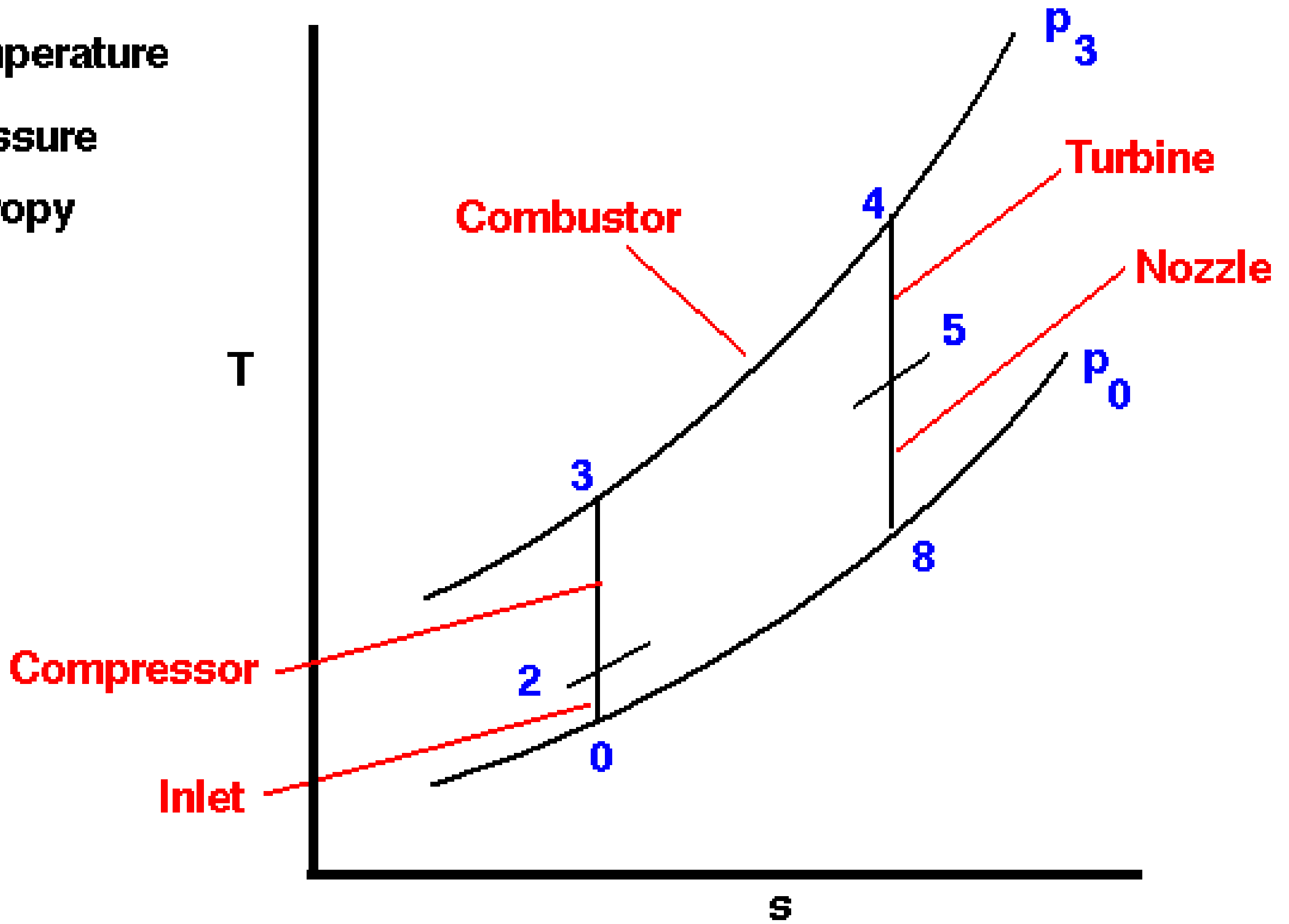
T-s diagram

Glenn Research Center

T = Temperature

p = pressure

s = entropy



Brayton Cycle

- A gas turbine is a rotary power unit used for producing large quantities of power in a self contained and compact unit.
- The gas turbine power plant are suitable for aircraft, marine, military and transport application due to its smaller size and low weight power ratio.
- These plants are free from vibration, perfect in balance, simple in installation, operation and maintenance. These are highly reliable
- The brayton cycle is the air-standard ideal cycle approximation for the gas-turbine engine.
- This cycle differs from the otto and diesel cycles in that the processes making the cycle occur in open systems or control volumes.
- We assume the working fluid is air and the specific heats are constant and will consider the cold-air-standard cycle.

Process involved in a cycle :

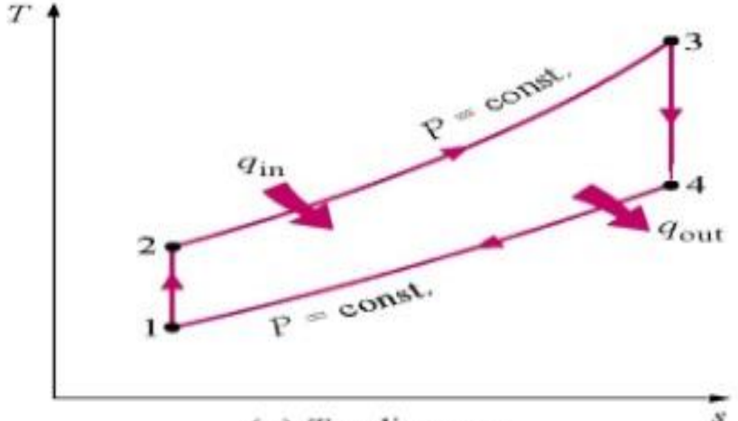
1.Isentropic compression (1-2) :- surrounding air is compressed isentropically $pv^\gamma = c$ in the compressor from pressure p1 to p2 work of compression Wc

2.Constant pressure heat addition (2-3:)- heat is added in combustor at constant pressure and constant temp is raised from T2 to T3 there fore pressure P3= p2

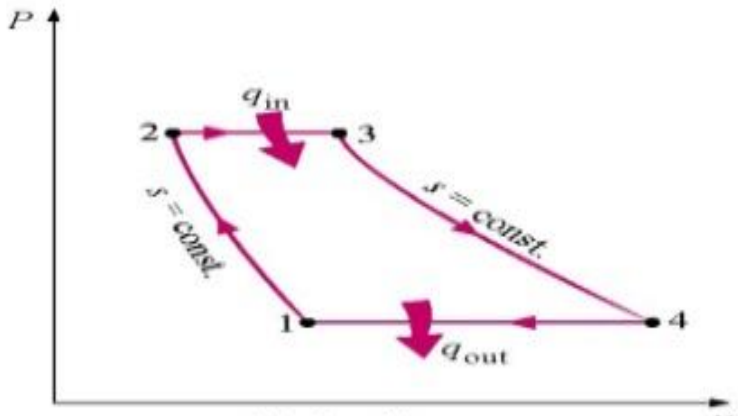
3.Isentropic expansion (3-4):-hot gases at p2, T3 expand in gas turbine isentropically up to atmospheric pressure P1 , work developed by turbine wt

4.Constant pressure heat rejection (4-1) :- heat is rejected by exaust gases at constant pressure to the atmosphere.

The *T-s* and *P-v* diagrams are



(a) T-s diagram



(b) P-v diagram

Thermal efficiency of the brayton cycle

$$\eta_{th,\ Brayton} = 1 - \frac{\dot{Q}_{out}}{\dot{Q}_{in}} = 1 - \frac{q_{out}}{q_{in}}$$

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

$$\eta_{th,\ Brayton} = 1 - \frac{(T_4 - T_1)}{(T_3 - T_2)}$$

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

- The steady flow energy equation can be used for cycle analysis with changes in K.E and P.E negligible

S.F.E.E can be written as

$Q\text{-}W_{sf} = m\,(\Delta h + \Delta K.E + \Delta P.E)$

But $\Delta K.E = 0$ $\Delta P.E = 0$ and $h = Cp.T$

S.F.E.E. reduce to $Q\text{-}W_{sf} = m\,\Delta h$

1.compresser work

- Process (1-2) is irreversible adiabatic process Q1-2 = 0 and work is nagative.

$$0-(-Wc) = m\,(h2-h1) = m\,Cp\,(T2-T1)$$

$$Wc = m\,Cp\,(T2-T1)$$

Heat addition process:-

$W_{sf} = 0$ therefore $Q_{2\text{-}3} = m\,(h_3 - h_2) = m\,C_p\,(T_3 - T_2)$

Turbine work:- process (3-4) is reversible adiabatic , hence Q=0

$$0 - W_t = m\,(h_4 - h_3)$$

$$W_t = m\,(h_3 - h_4) = m\,C_p\,(T_3 - T_4)$$

Shaft work W_s = turbine work (W_t) – compressor work (W_c)

$$= m\,C_p\,(T_3 - T_4) - m\,C_p\,(T_2 - T_1)$$

Air standard efficiency of cycle

Air standard efficiency of cycle:-

$$\eta = \frac{m\,Cp\,(T3-T4) - m\,Cp\,(T2-T1)}{m\,Cp\,(T3-T2)}$$

$$\eta = 1 - \frac{(T4-T1)}{(T3-T2)}$$

$$\eta_{th,\,Brayton} = 1 - \frac{(T_4 - T_1)}{(T_3 - T_2)}$$

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

(d) Efficiency in terms of pressure ratio

Let, pressure ratio $Rp = \frac{P2}{P1} = \frac{P3}{P4}$

$$\frac{T2}{T1} = \left(\frac{P2}{P1}\right)^{(\gamma - 1)/\gamma} \quad \text{And} \quad \frac{T3}{T4} = \left(\frac{P3}{P4}\right)^{(\gamma - 1)/\gamma}$$

$$= (Rp)^{(\gamma - 1)/\gamma}$$

$$T2 = T1\,(Rp)^{(\gamma - 1)/\gamma} \text{ and}$$

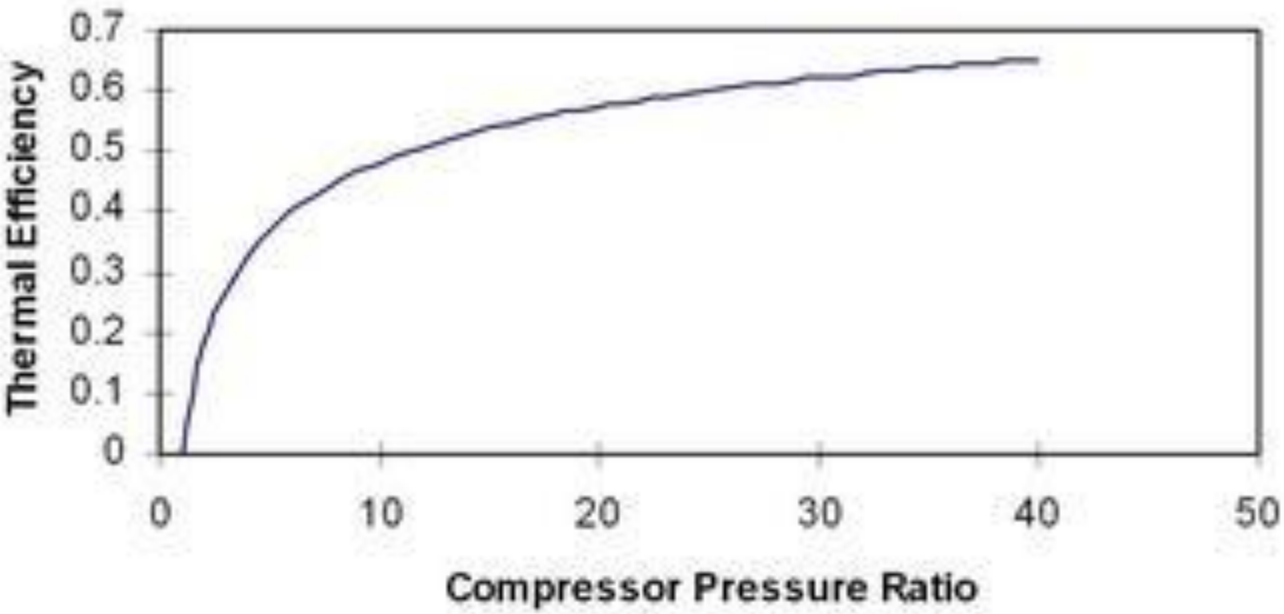
$$T3 = T4\,(Rp)^{(\gamma - 1)/\gamma}$$

so we get ,

$$\eta = 1 - \frac{(T4-T1)}{T4\,(Rp)^{(\gamma - 1)/\gamma} - T1\,(Rp)^{(\gamma - 1)/\gamma}}$$

$$\eta = 1 - 1/(R_p)^{(\gamma - 1)/\gamma}$$

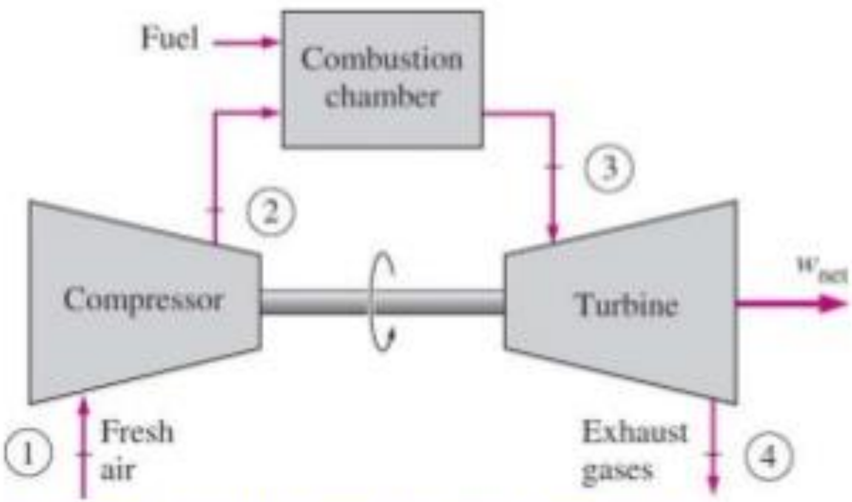
Which is the efficiency of brayton cycle in term of pressure ratio



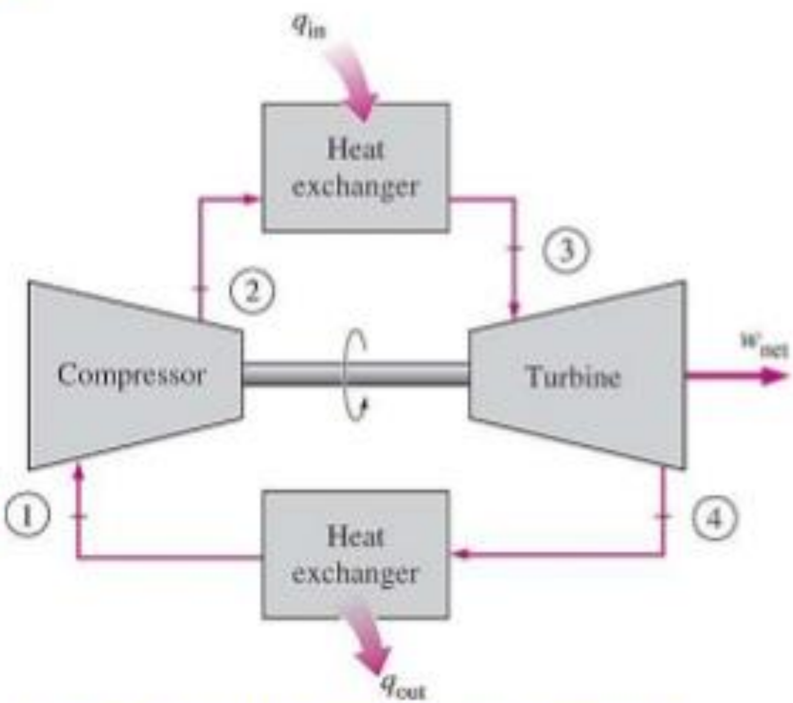
BRAYTON CYCLE: THE IDEAL CYCLE FOR GAS-TURBINE ENGINES

The combustion process is replaced by a constant-pressure heat-addition process from an external source, and the exhaust process is replaced by a constant-pressure heat-rejection process to the ambient air.

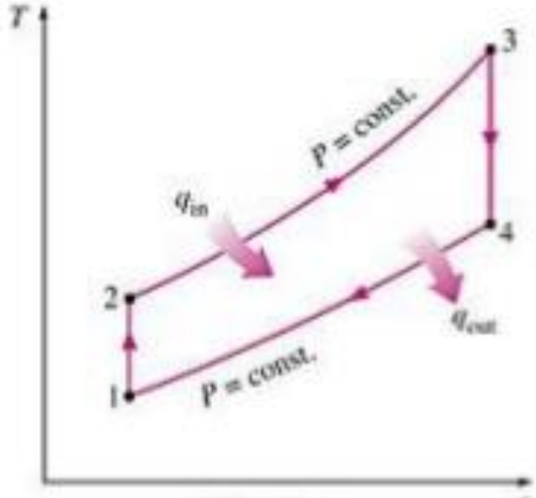
1-2 Isentropic compression (in a compressor)
2-3 Constant-pressure heat addition
3-4 Isentropic expansion (in a turbine)
4-1 Constant-pressure heat rejection



An open-cycle gas-turbine engine.



A closed-cycle gas-turbine engine.



(a) T-s diagram

$$(q_{in} - q_{out}) + (w_{in} - w_{out}) = h_{exit} - h_{inlet}$$

$$q_{in} = h_3 - h_2 = c_p(T_3 - T_2)$$

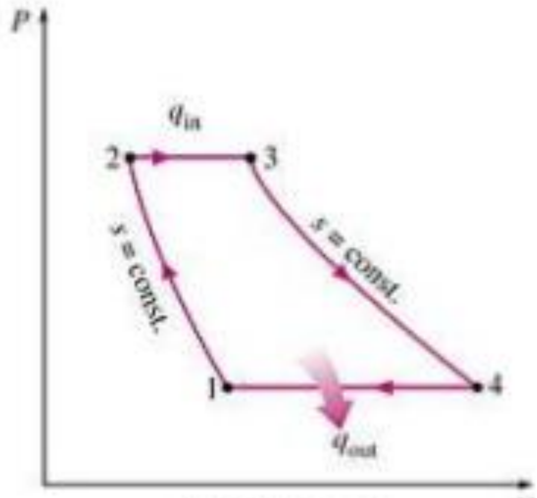
$$q_{out} = h_4 - h_1 = c_p(T_4 - T_1)$$

$$\eta_{th,Brayton} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{c_p(T_4 - T_1)}{c_p(T_3 - T_2)} = 1 - \frac{T_1(T_4/T_1 - 1)}{T_2(T_3/T_2 - 1)}$$

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

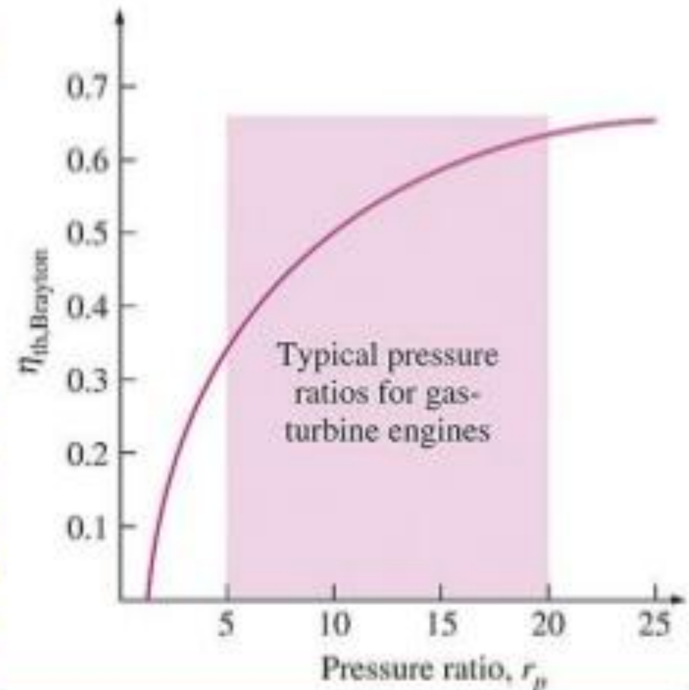
Pressure ratio

$$\eta_{th,Brayton} = 1 - \frac{1}{r_p^{(k-1)/k}}$$



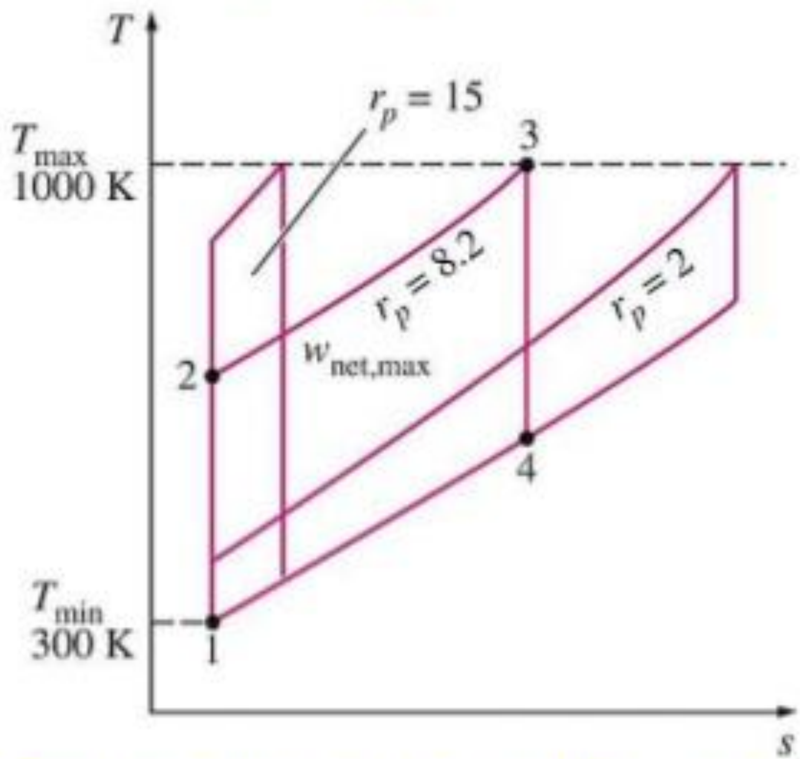
(b) P-v diagram

T-s and *P-v* diagrams for the ideal Brayton cycle.



Thermal efficiency of the ideal Brayton cycle as a function of the pressure ratio.

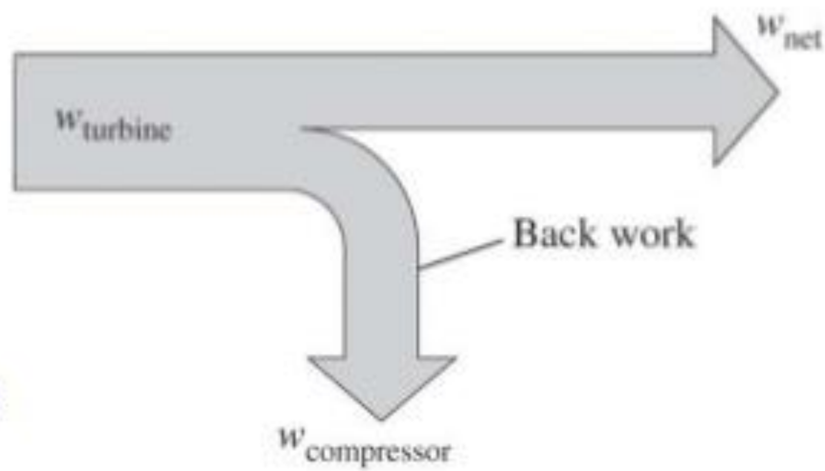
The two major application areas of gas-turbine engines are *aircraft propulsion* and *electric power generation*.



For fixed values of T_{min} and T_{max}, the net work of the Brayton cycle first increases with the pressure ratio, then reaches a maximum at $r_p = (T_{max}/T_{min})^{k/[2(k-1)]}$, and finally decreases.

The highest temperature in the cycle is limited by the maximum temperature that the turbine blades can withstand. This also limits the pressure ratios that can be used in the cycle.

The air in gas turbines supplies the necessary oxidant for the combustion of the fuel, and it serves as a coolant to keep the temperature of various components within safe limits. An air–fuel ratio of 50 or above is not uncommon.



The fraction of the turbine work used to drive the compressor is called the back work ratio.

Example 1

A gas-turbine power plant operating on an ideal Brayton cycle has a pressure ratio of 8. The gas temperature is 300 K at the compressor inlet and 1300 K at the turbine inlet. Utilizing the air-standard assumptions, determine

(*a*) *the* gas temperature at the exits of the compressor and the turbine

(*b*) *the back* work ratio

(c) *the thermal efficiency.*

Development of Gas Turbines

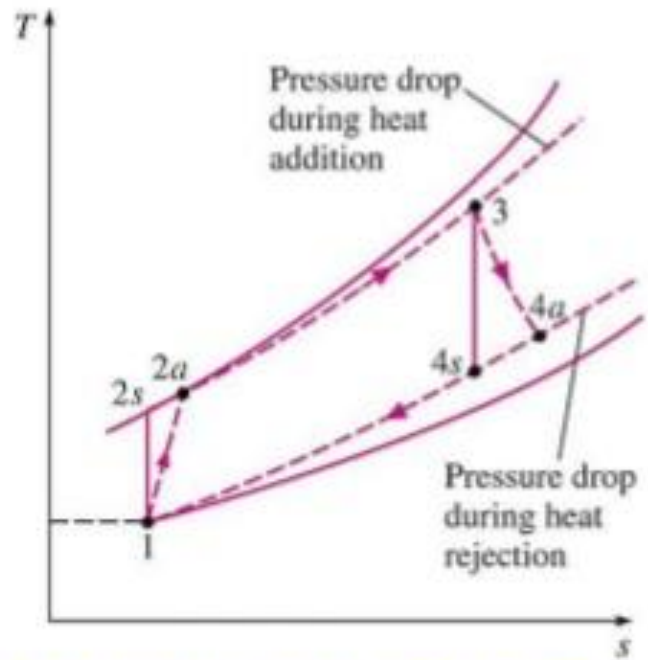
1. Increasing the turbine inlet (or firing) temperatures
2. Increasing the efficiencies of turbomachinery components (turbines, compressors):
3. Adding modifications to the basic cycle (intercooling, regeneration or recuperation, and reheating).

Deviation of Actual Gas-Turbine Cycles from Idealized Ones

Reasons: Irreversibilities in turbine and compressors, pressure drops, heat losses

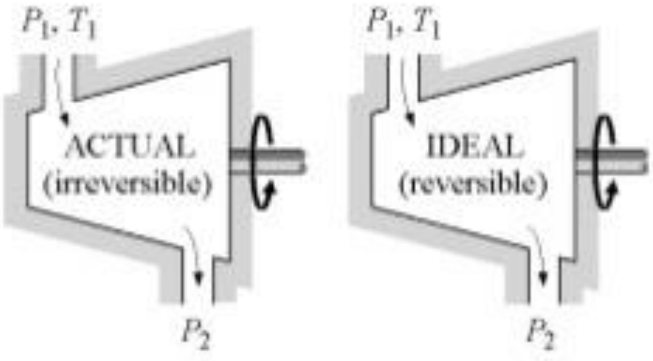
Isentropic efficiencies of the compressor and turbine

$$\eta_C = \frac{w_s}{w_a} \cong \frac{h_{2s} - h_1}{h_{2a} - h_1} \quad \eta_T = \frac{w_a}{w_s} \cong \frac{h_3 - h_{4a}}{h_3 - h_{4s}}$$



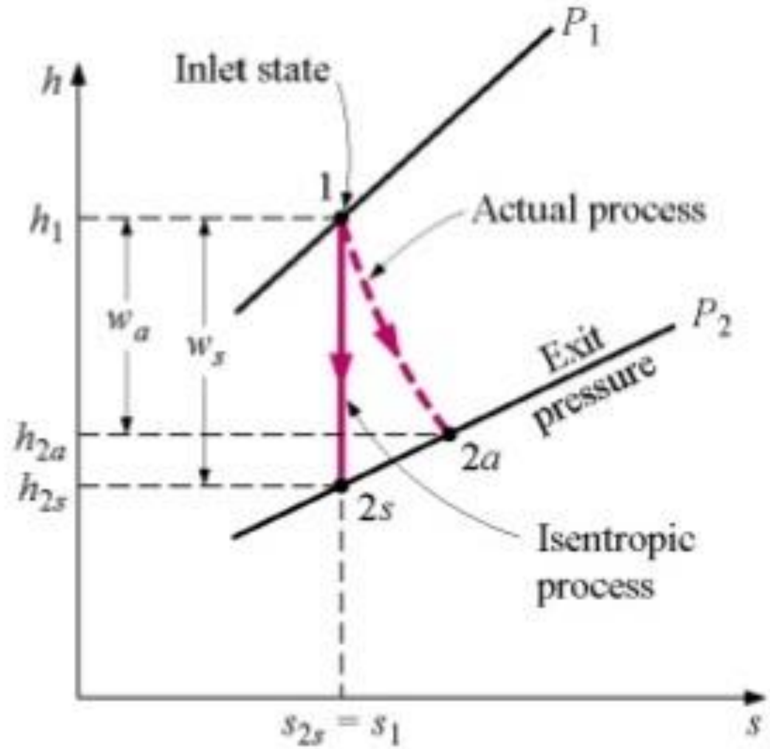
The deviation of an actual gas-turbine cycle from the ideal Brayton cycle as a result of irreversibilities.

Isentropic efficiency for turbine:



$$\eta_T = \frac{\text{Actual turbine work}}{\text{Isentropic turbine work}} = \frac{w_a}{w_s}$$

$$\eta_T \cong \frac{h_1 - h_{2a}}{h_1 - h_{2s}}$$

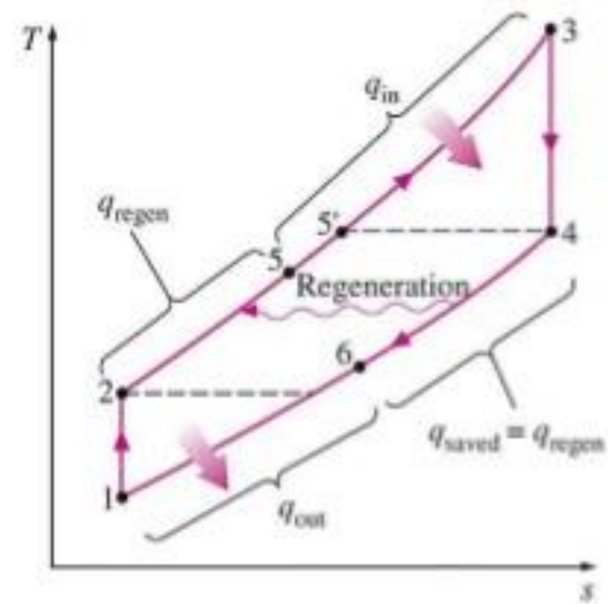


THE BRAYTON CYCLE WITH REGENERATION

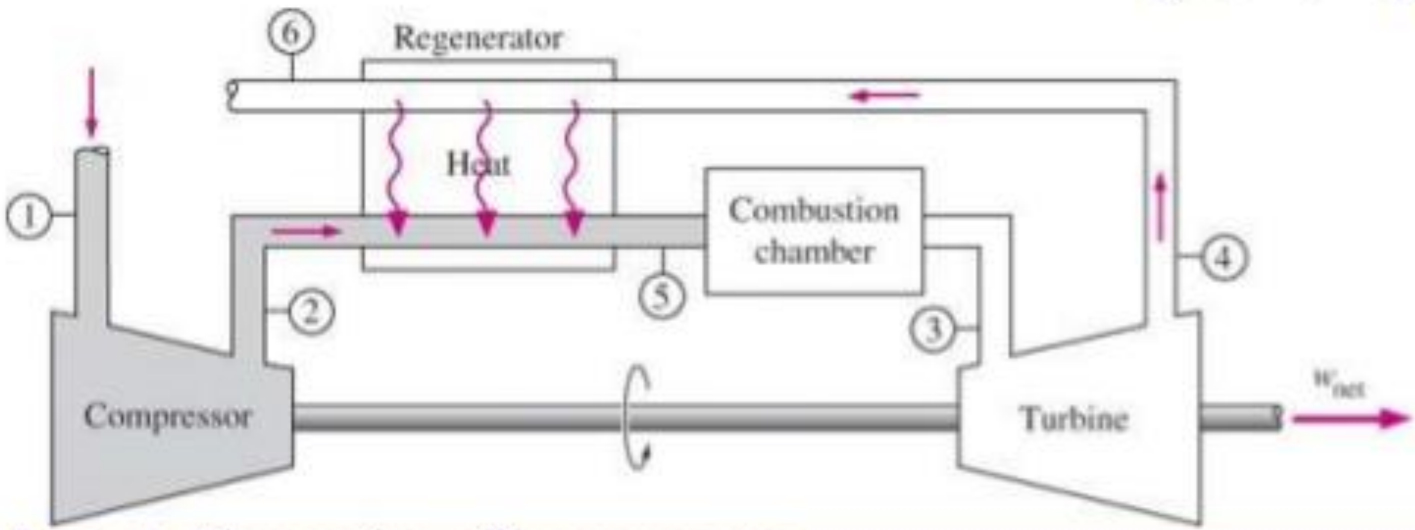
In gas-turbine engines, the temperature of the exhaust gas leaving the turbine is often considerably higher than the temperature of the air leaving the compressor.

Therefore, the high-pressure air leaving the compressor can be heated by the hot exhaust gases in a counter-flow heat exchanger (a *regenerator* or a *recuperator*).

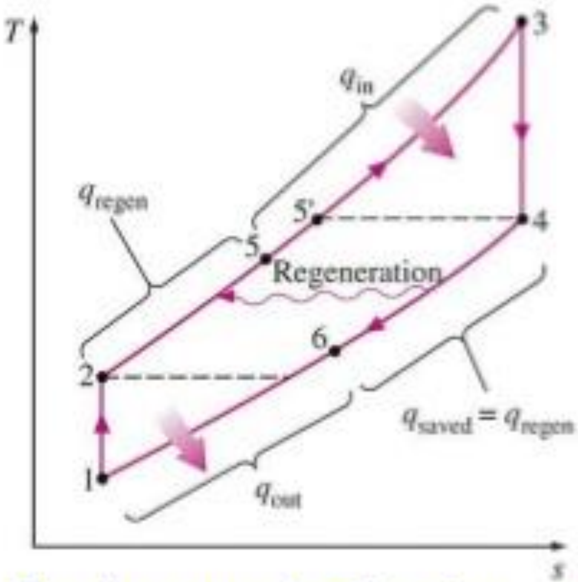
The thermal efficiency of the Brayton cycle increases as a result of regeneration since less fuel is used for the same work output.



T-s diagram of a Brayton cycle with regeneration.



A gas-turbine engine with regenerator.



T-s diagram of a Brayton cycle with regeneration.

$$q_{regen,act} = h_5 - h_2$$
$$q_{regen,max} = h_{5'} - h_2 = h_4 - h_2$$

$$\epsilon = \frac{q_{regen,act}}{q_{regen,max}} = \frac{h_5 - h_2}{h_4 - h_2}$$ Effectiveness of regenerator

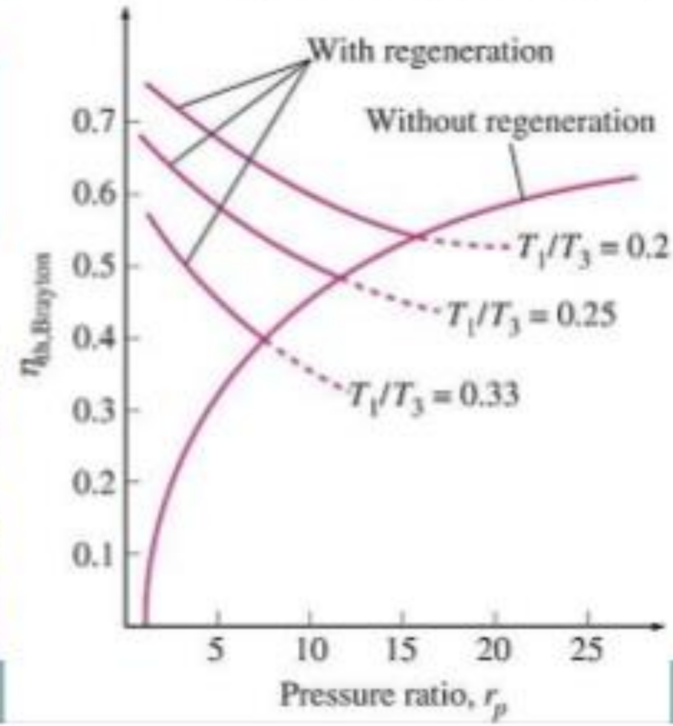
$$\epsilon \cong \frac{T_5 - T_2}{T_4 - T_2}$$ Effectiveness under cold-air standard assumptions

$$\eta_{th,regen} = 1 - \left(\frac{T_1}{T_3}\right)(r_p)^{(k-1)/k}$$ Under cold-air standard assumptions

Can regeneration be used at high pressure ratios?

The thermal efficiency depends on the ratio of the minimum to maximum temperatures as well as the pressure ratio.

Regeneration is most effective at lower pressure ratios and low minimum-to-maximum temperature ratios.



Thermal efficiency of the ideal Brayton cycle with and without regeneration.

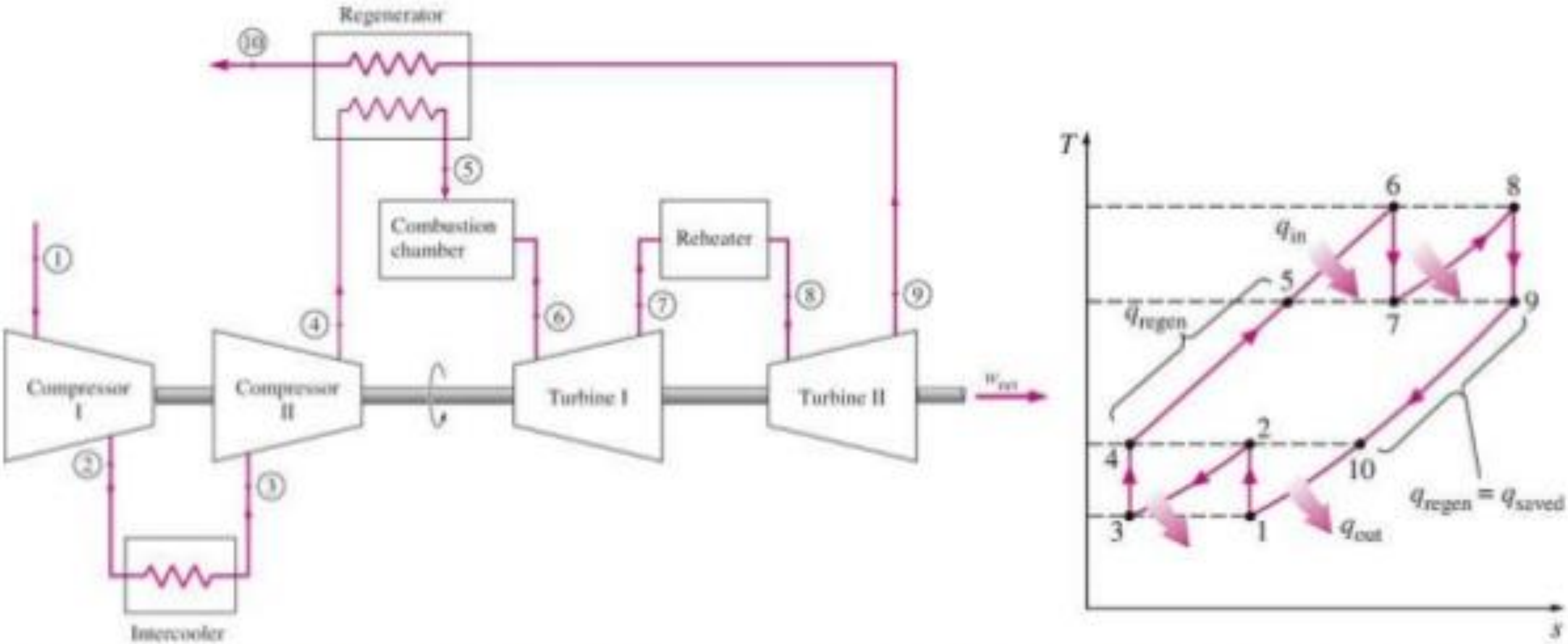
Example 2

- A Brayton cycle with regeneration using air as the working fluid has a pressure ratio of 7. The minimum and maximum temperatures in the cycle are 310 and 1150 K. Assuming an isentropic efficiency of 75 percent for the compressor and 82 percent for the turbine and an effectiveness of 65 percent for the regenerator, determine
- (*a*) *the air temperature at the turbine* exit
- (*b*) *the net work output*
- *(c) the thermal efficiency.*
- *Answers: (a) 783 K, (b) 108.1 kJ/kg, (c) 22.5 percent*

THE BRAYTON CYCLE WITH INTERCOOLING, REHEATING, AND REGENERATION

For minimizing work input to compressor and maximizing work output from turbine:

$$\frac{P_2}{P_1} = \frac{P_4}{P_3} \quad \text{and} \quad \frac{P_6}{P_7} = \frac{P_8}{P_9}$$

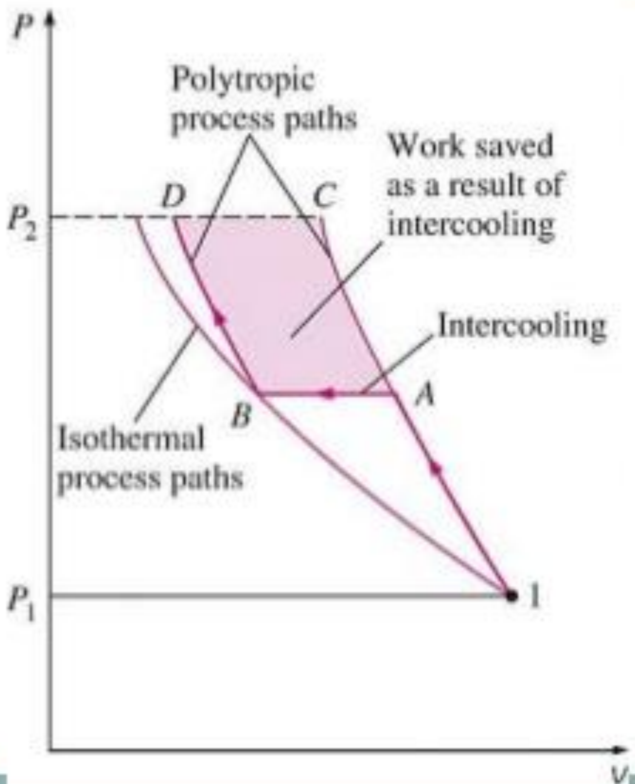


A gas-turbine engine with two-stage compression with intercooling, two-stage expansion with reheating, and regeneration and its *T-s* diagram.

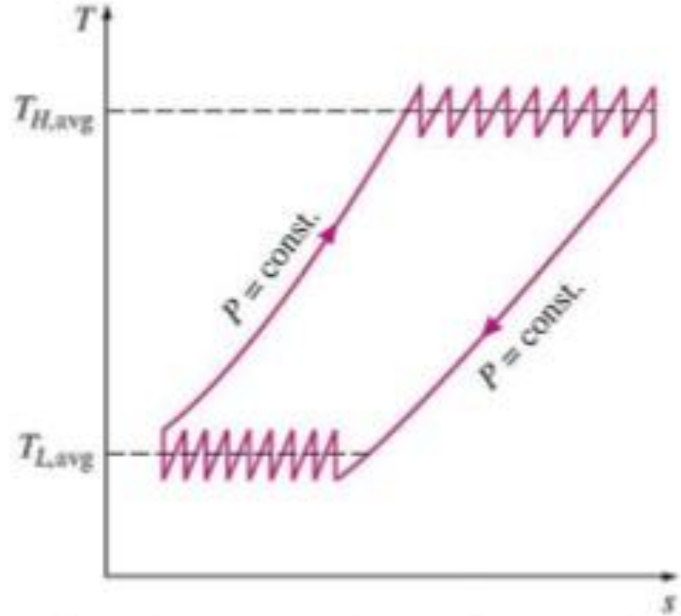
Multistage compression with intercooling: The work required to compress a gas between two specified pressures can be decreased by carrying out the compression process in stages and cooling the gas in between. This keeps the specific volume as low as possible.

Multistage expansion with reheating keeps the specific volume of the working fluid as high as possible during an expansion process, thus maximizing work output.

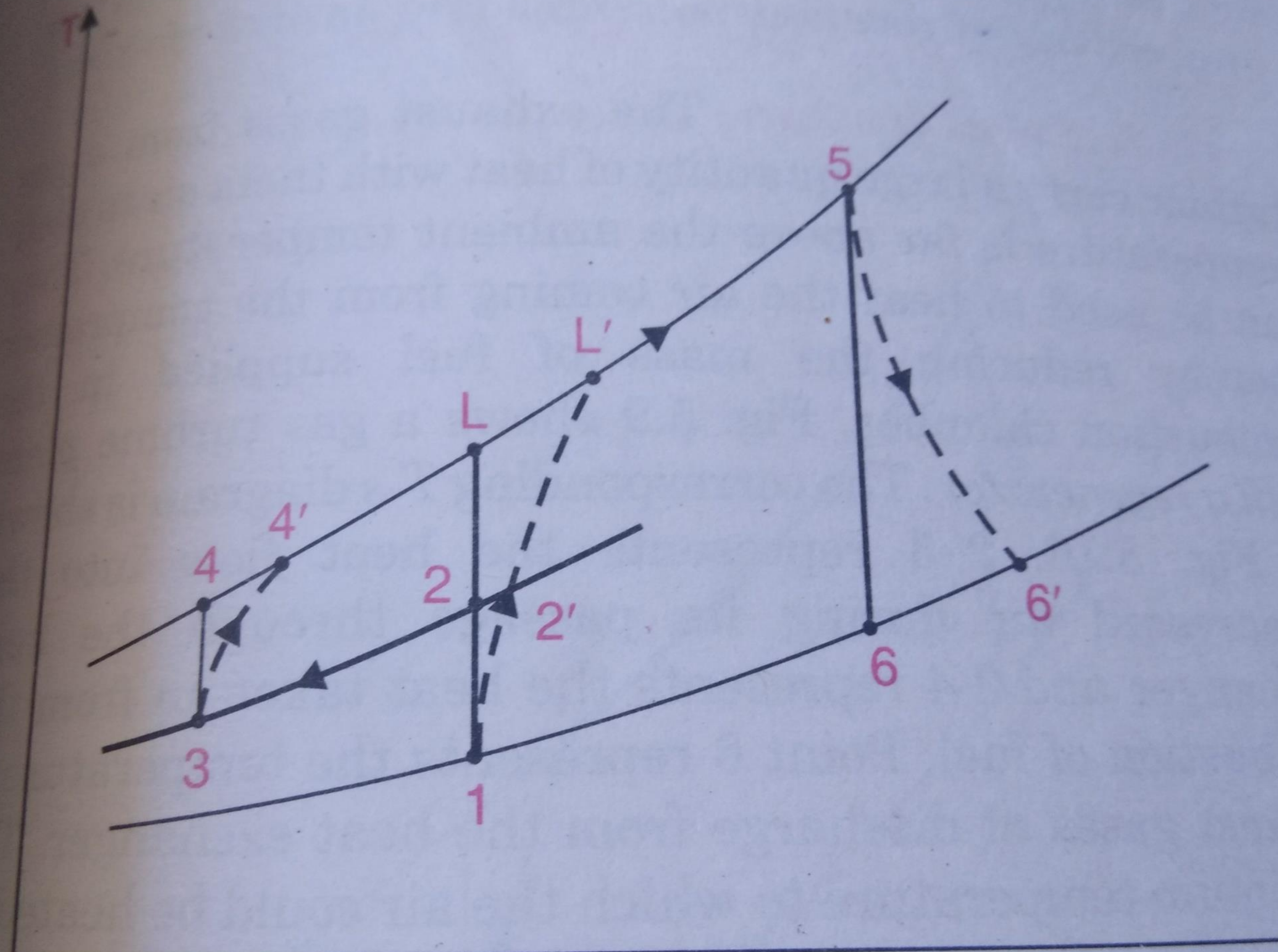
Intercooling and reheating always decreases the thermal efficiency unless they are accompanied by regeneration. **Why?**

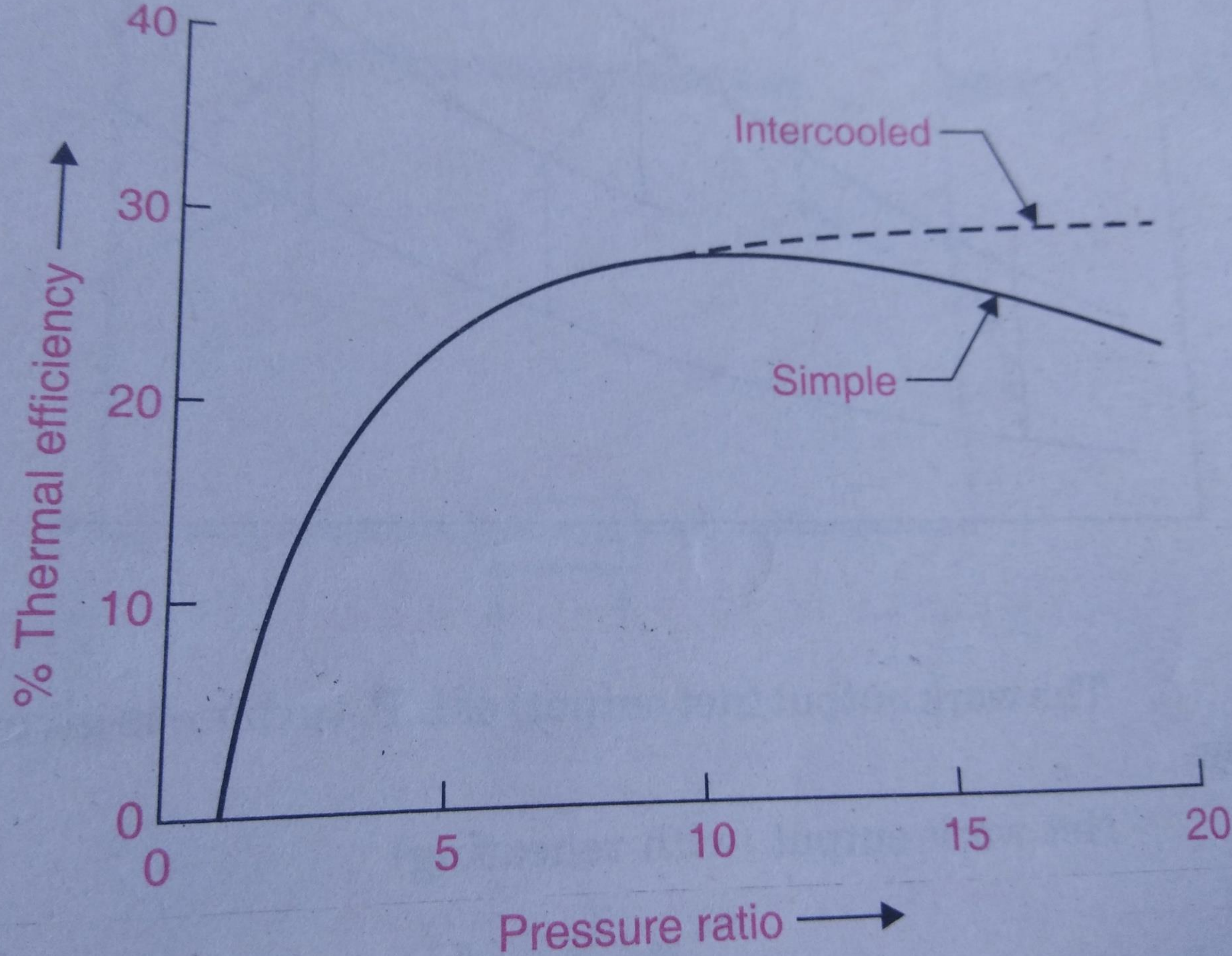


Comparison of work inputs to a single-stage compressor (1*AC*) and a two-stage compressor with intercooling (1*ABD*).



As the number of compression and expansion stages increases, the gas-turbine cycle with intercooling, reheating, and regeneration approaches the Ericsson cycle.


T
5
L′
L
4′
4
2
2′
3
1
6
6′



40
30
20
10
0
% Thermal efficiency
Intercooled
Simple
0
5
10
15
20
Pressure ratio

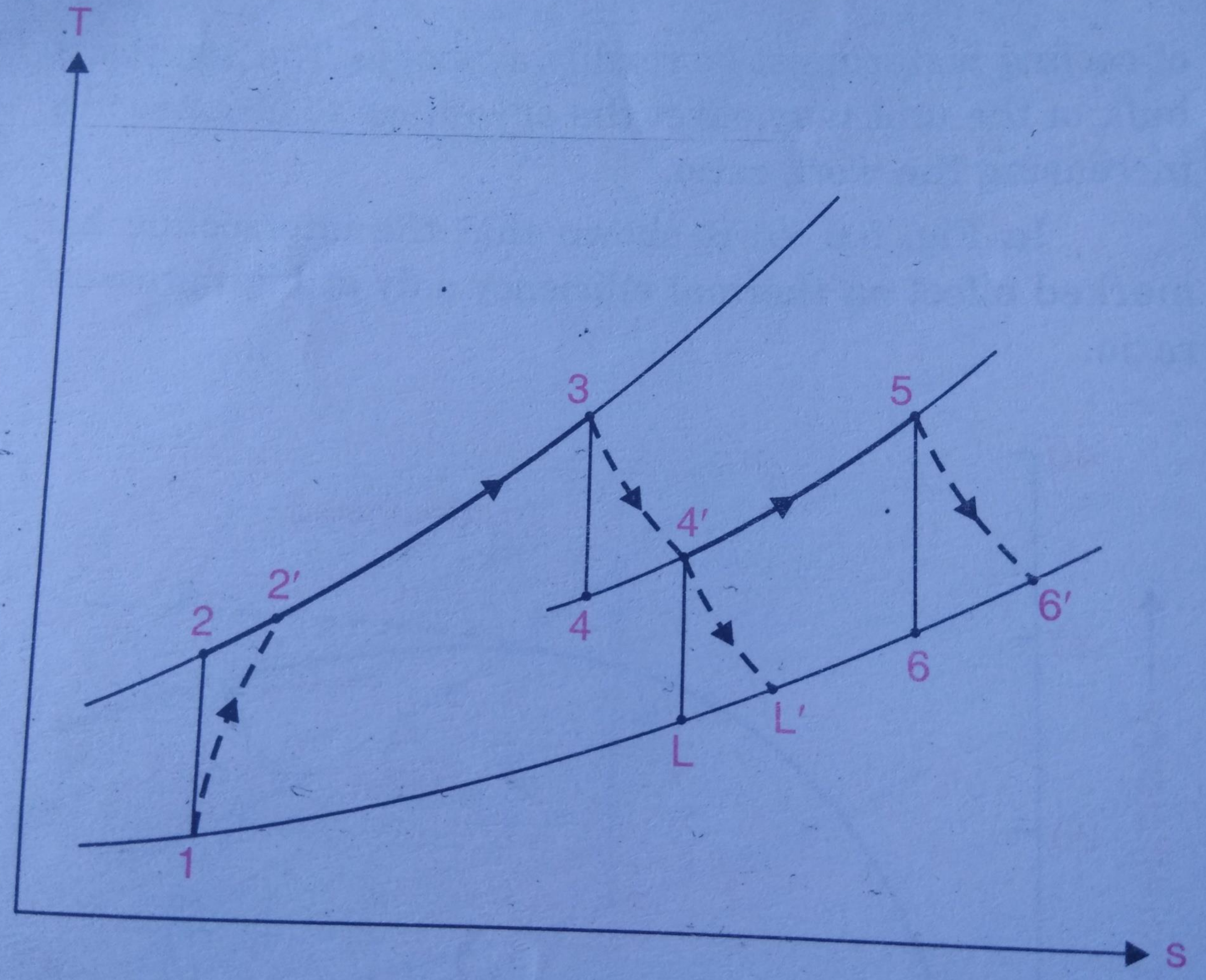
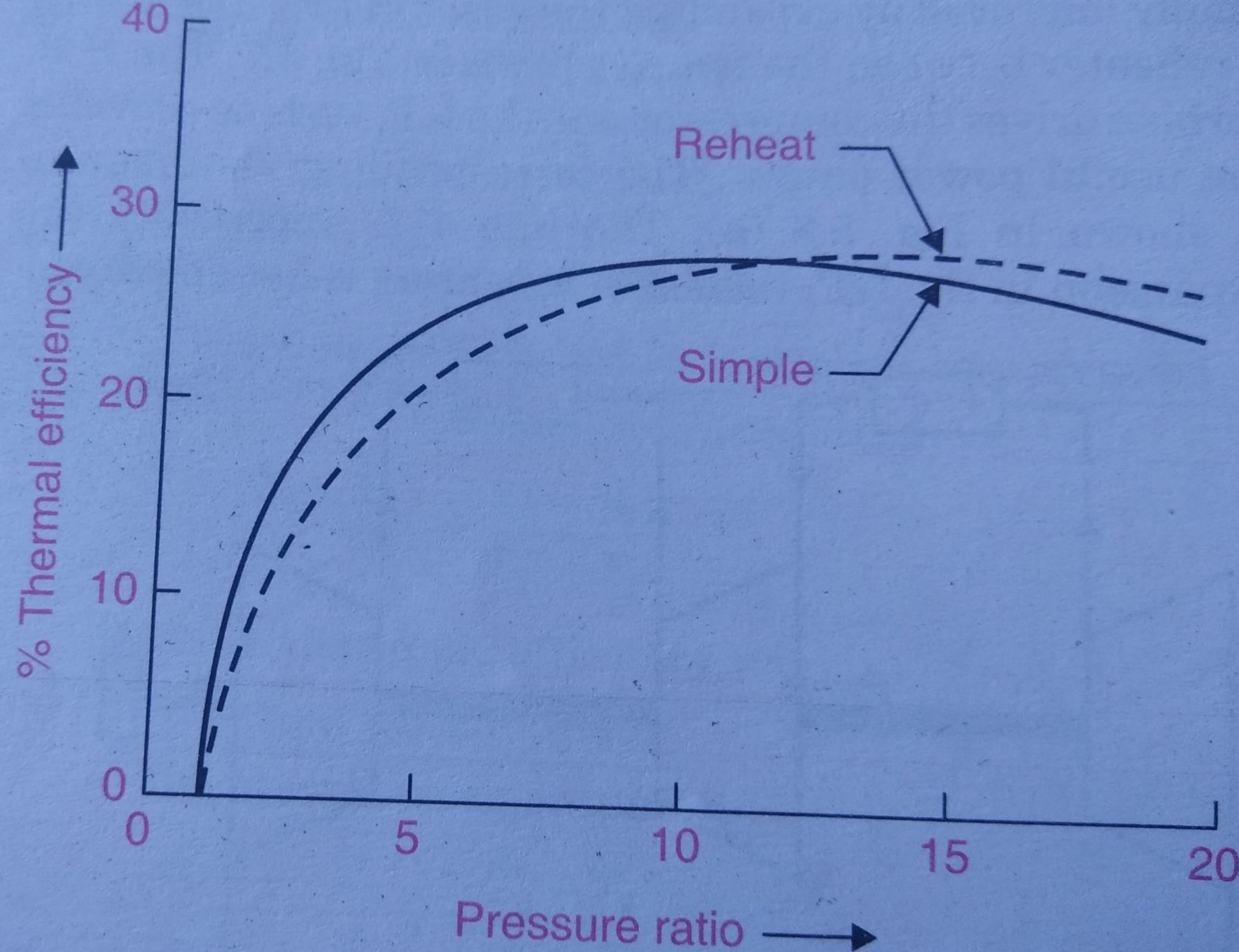
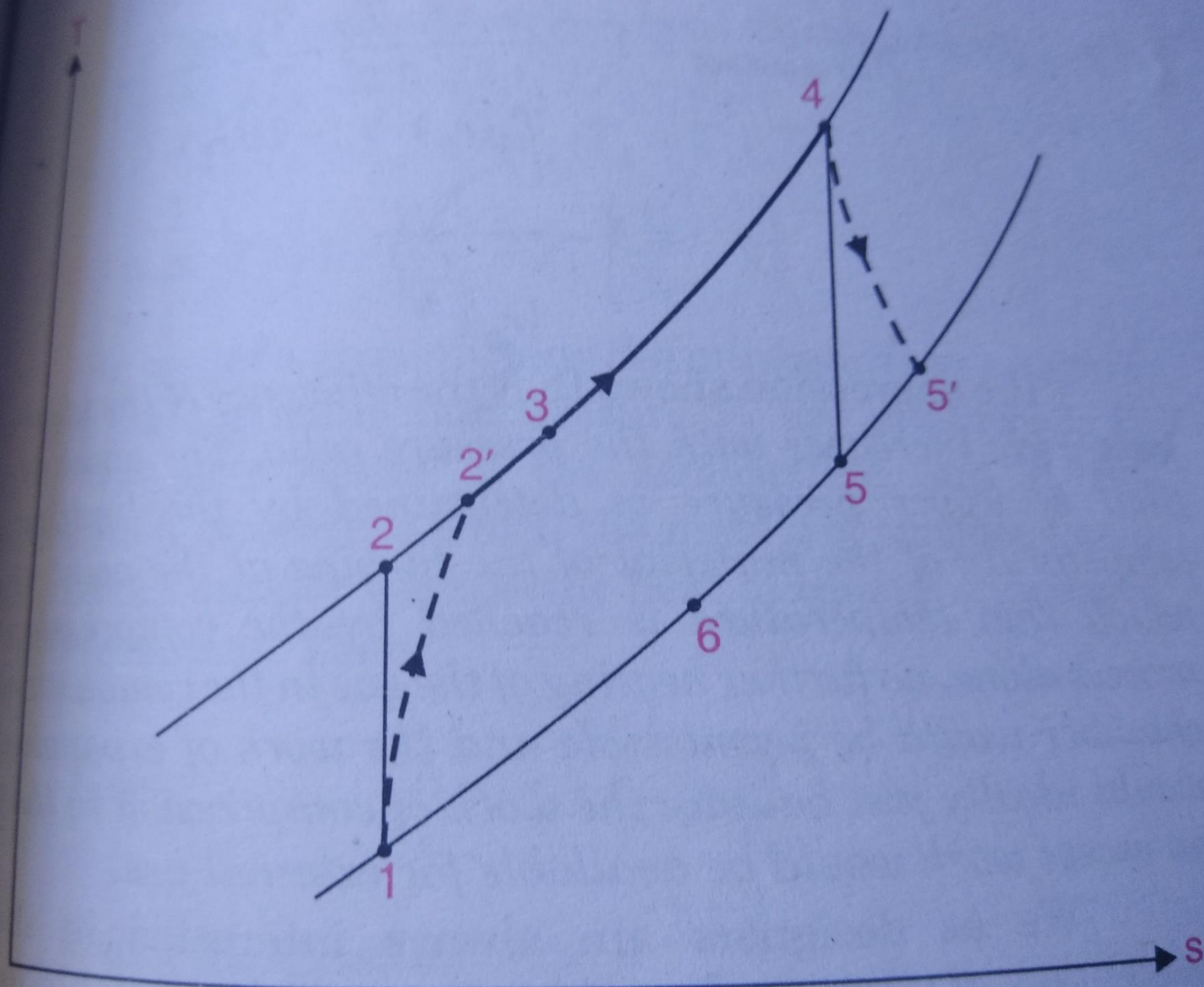


Fig. 5.8 (a) T

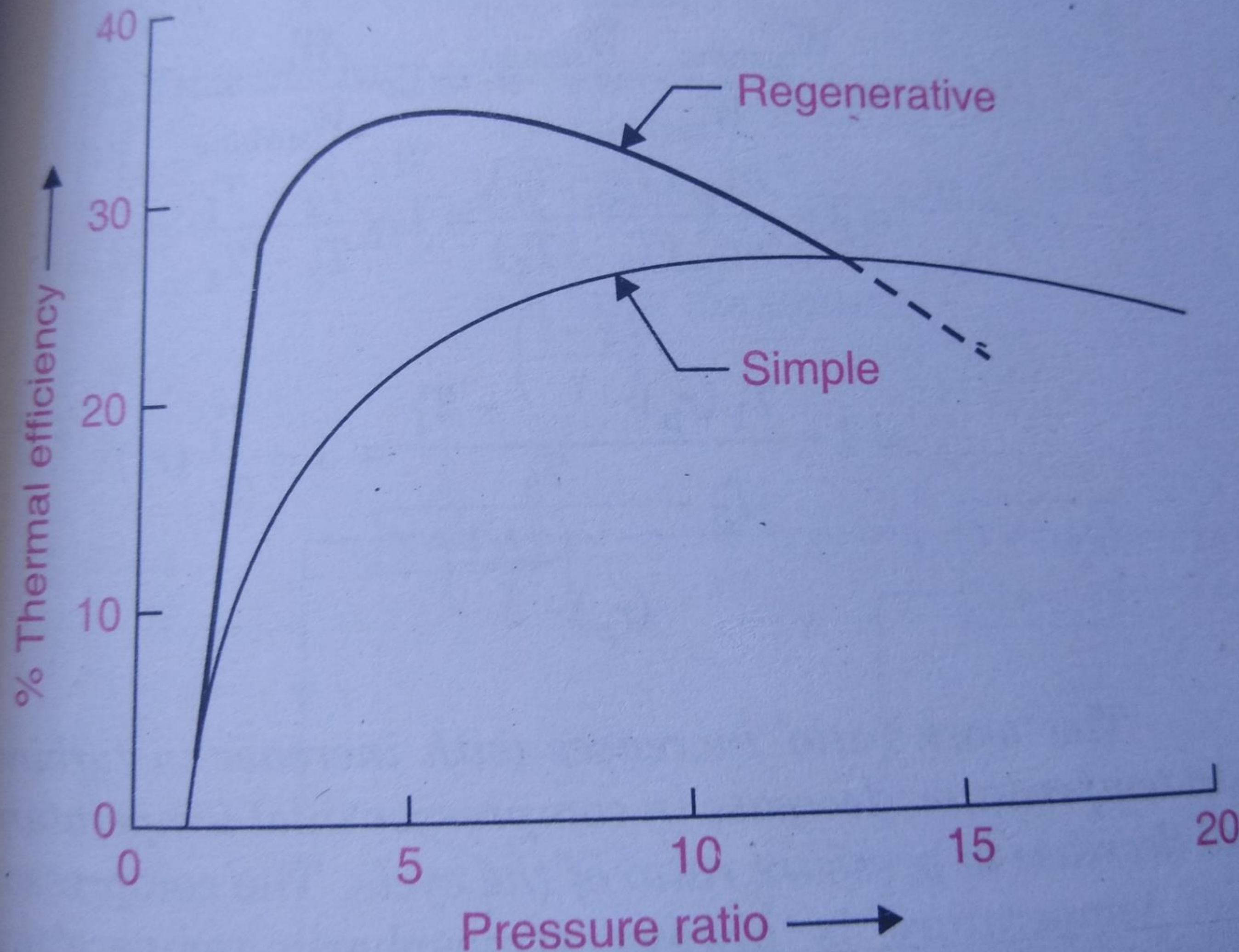


40
30
20
10
0
% Thermal efficiency
Reheat
Simple
0
5
10
15
20
Pressure ratio



T
4
3
2′
2
5′
5
6
1
s

Fig. 5.10. (*a*) *T-s* diagram for the unit.



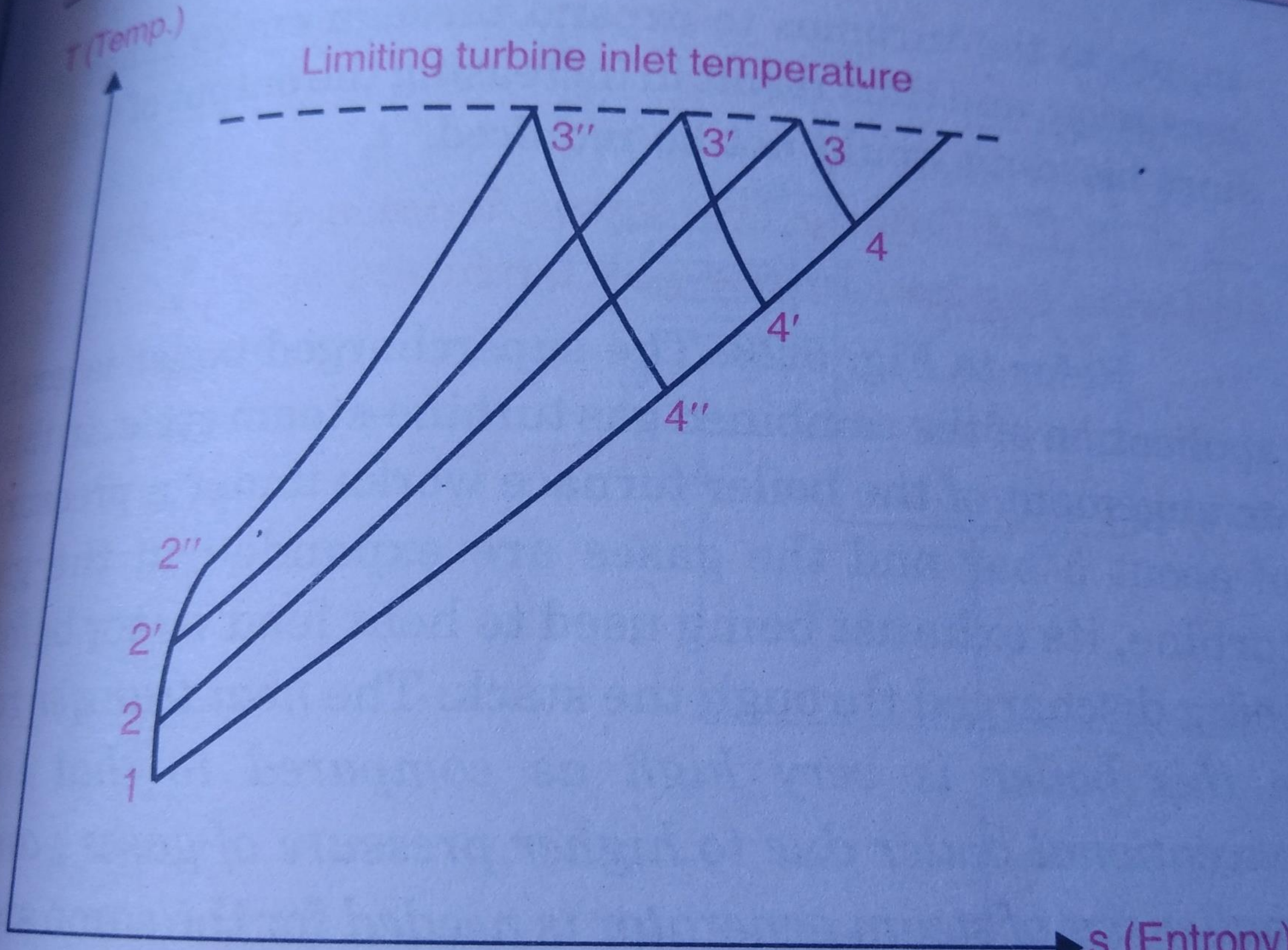

T (Temp.)
Limiting turbine inlet temperature
3''
3'
3
4
4'
4''
2''
2'
2
1
s (Entropy)

Fig. 5.18

...5.19). Further,

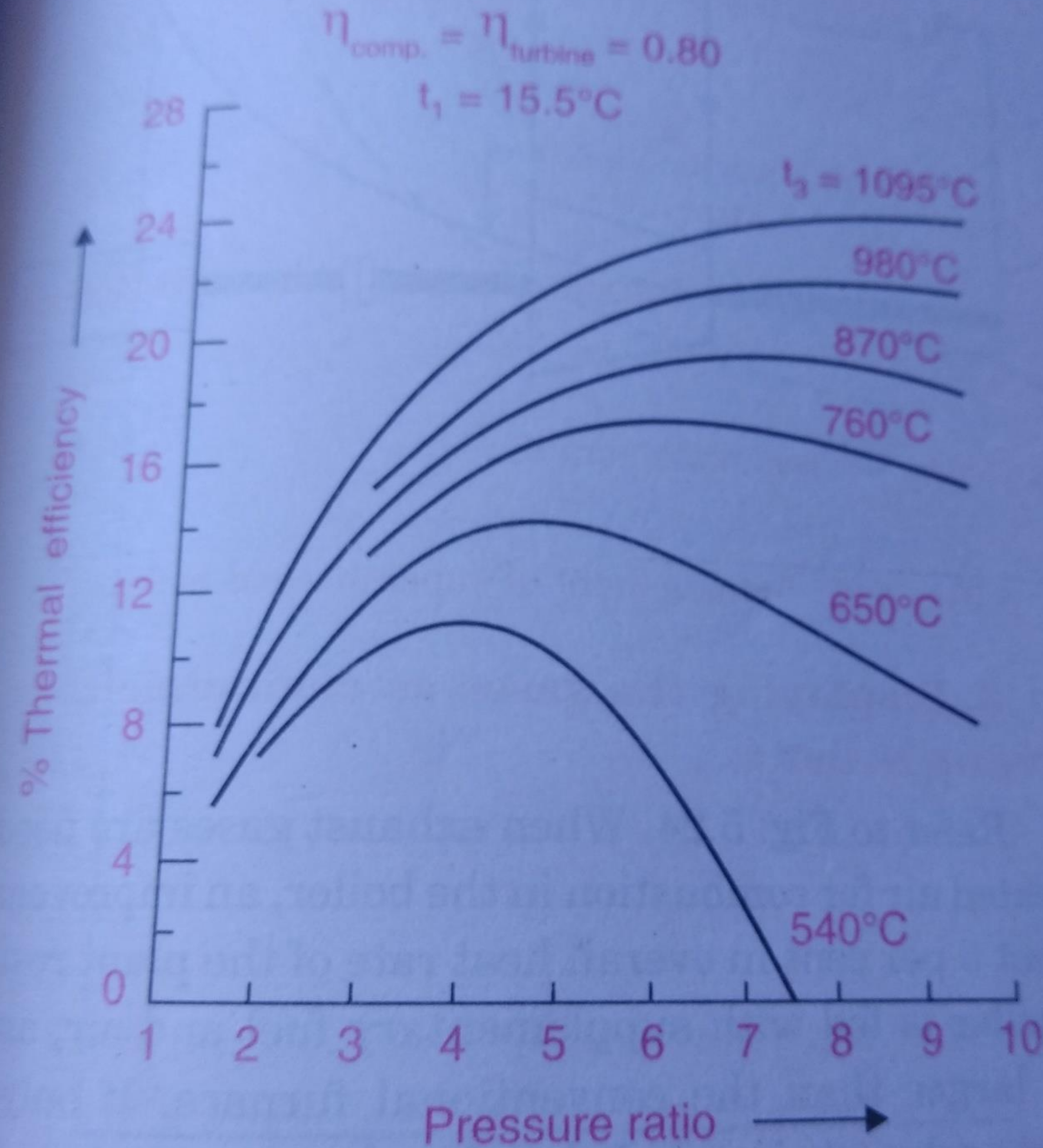


Fig. 5.19. Effect of pressure ratio and turbine inlet temperature.

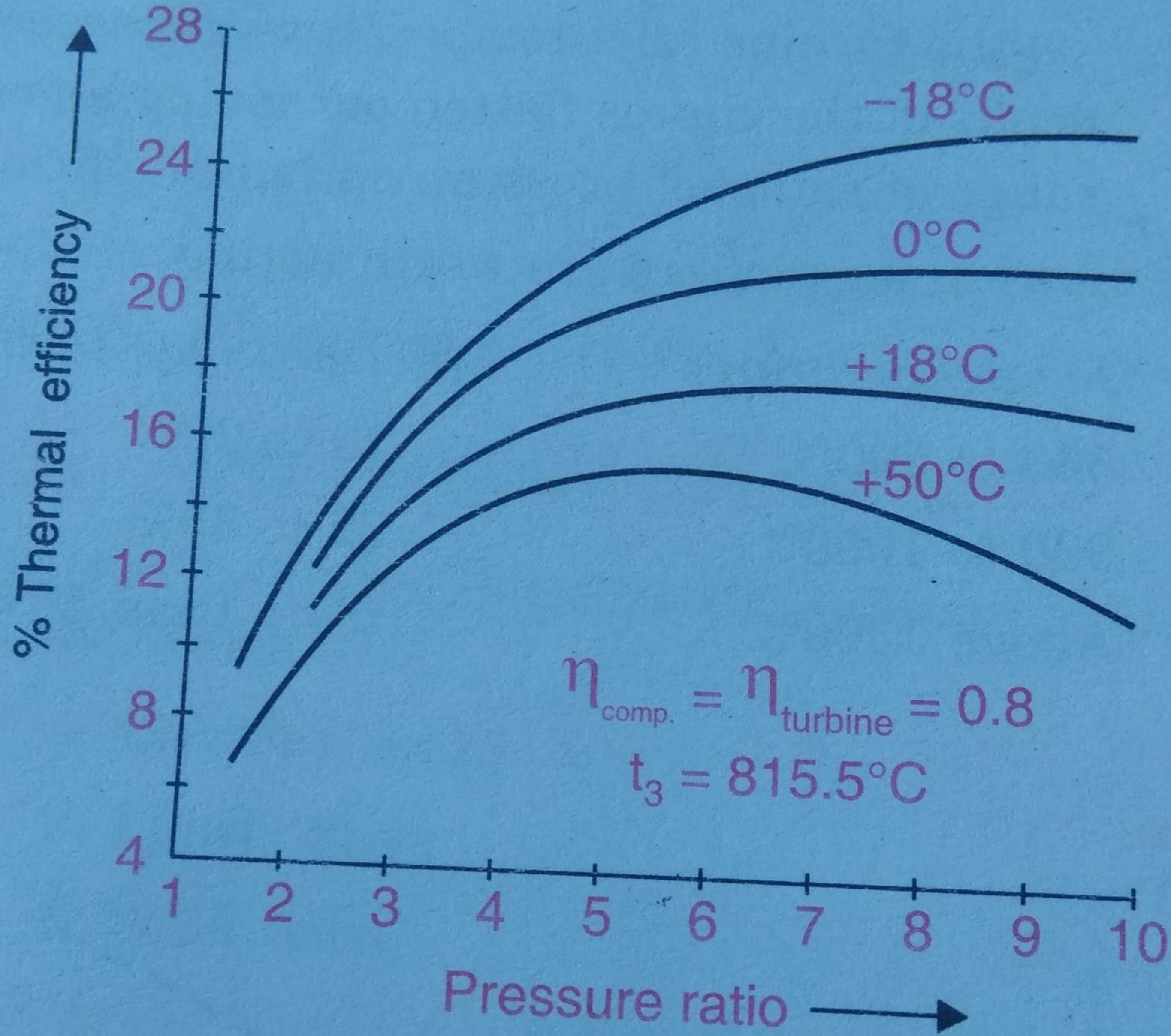


Fig. 5.21. Effect of compressor inlet temperature.

Example 3

- An ideal gas-turbine cycle with two stages of compression and two stages of expansion has an overall pressure ratio of 8. Air enters each stage of the compressor at 300 K and each stage of the turbine at 1300 K. Determine the back work ratio and the thermal efficiency of this gas-turbine cycle, assuming
- *(a) no regenerators*
- *(b) an ideal regenerator with 100 percent* effectiveness.

Compare the results with those obtained in Example 1.

THANK YOU