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Middle Technical University
Engineering Technical College-Baghdad
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Power Plant

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Third Stage Year, 1st Course
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2024-2023

المادة:	محطات القدرة **Power Plants**	الرمز: **FS405**
البرنامج:	درجة البكالوريوس Bachelor Degree	**النظام:** سنوي (30 اسبوع)
المرحلة:	الرابعة	**نوع المادة:** تخصصية
لغة التدريس:	الانكليزية	**عدد الوحدات: 7**
الساعات الأسبوعية	النظرية: 2 العملية: 3	
أسلوب التعليم:	محاضرات نظرية تمارين وواجبات بيتية وزيارات ميدانية لمحطات انتاج الطاقة.	

CONVERSION FACTORS AND CONSTANTS FOR MECHANICAL ENGINEERING

NOMENCLATURE

Symbol	Meaning	SI units and/or value
A	Area	m^2
BTU	British Thermal Unit	1 BTU = 1055 J
C_D	Drag coefficient	---
C_L	Lift coefficient	---
C_P	Specific heat at constant pressure	J/kgK°
C_V	Specific heat at constant volume	J/kgK°
c	Sound speed	m/s
COP	Coefficient Of Performance	---
d	Diameter	m (meters)
E	Energy	J (Joules)
E	Elastic modulus	N/m^2
δ	Elongation	mm
F	Force	N (Newtons)
f	Friction factor (for pipe flow)	---
g	Acceleration of gravity	m/s^2 (earth gravity = 9.81)
g_c	USCS units conversion factor	32.174 lbm ft/ lbf sec^2 = 1
H	Enthalpy	J
h	Enthalpy per unit mass	J/kg
h	Convective heat transfer coefficient	W/m2 K
I	Area moment of inertia	m^4
I	Electric current	A (ampere)
k	Boltzmann's constant	1.380622 x 10^{-23} J/K
k	Thermal conductivity	W/mK
L	Length	m
$\mathcal{M}$	Molecular Mass	kg/mole
M	Moment of force	N m (Newtons x meters)
M	Mach number	---
m	Mass	kg
m	Mass flow rate	kg/s
n	Number of moles	---
N_A	Avogadro's number (6.0221415 x 10^{23})	---
P	Pressure	N/m^2
P	Point-load force	N
Q	Heat transfer	J

q	Heat transfer rate	W (Watts)
ℜ	Universal gas constant	8.314 J/mole °K
R	Mass-based gas constant = ℜ/M	J/kg K°
R	Electrical resistance	Ω (ohms)
Re	Reynolds number	---
r	Radius	m
S	Entropy	J/°K
T	Temperature	°K
T	Tension (in a rope or cable)	N
t	Time	s (seconds)
U	Internal energy	J
u	Internal energy per unit mass	J/kg
V	Volume	m^3
V	Voltage	Volts
V	Shear force	N
v	Velocity	m/s
W	Weight	N (Newtons)
W	Work	J
w	Loading (e.g. on a beam)	N/m
Z	Thermoelectric figure of merit	1/K
z	Elevation	m
α	Thermal diffusivity	m^2/s
γ	Gas specific heat ratio	---
η	Efficiency	---
ε	Strain	---
ε	Roughness factor (for pipe flow)	---
μ	Coefficient of friction	---
μ	Dynamic viscosity	Pa-s
θ	Angle	---
ν	Kinematic viscosity = μ/ρ	m^2/s
ν	Poisson's ratio	---
ρ	Density	kg/m^3
ρ	Electrical resistivity	ohm m
σ	Normal stress	N/m^2
σ	Stefan-Boltzmann constant	$5.67 \text{ x } 10^{-8}$ W/m^2 K^4
σ	Standard deviation	[Same units as sample set]
τ	Shear stress	N/m^2
τ	Thickness (e.g. of a pipe wall)	m

TEMPERATURE

$$°F = \frac{9}{5}°C + 32$$

$$°C = \frac{5}{9}(°F - 32)$$

$$\Delta°F = \frac{5}{9}\Delta°C$$

$$\Delta°C = \frac{9}{5}\Delta°F$$

$$\Delta°C = \Delta°K$$

$$\Delta°F = \Delta°R$$

PLANE ANGLE

1° (degree) = 60'
= 3600"
= $\pi rad/180°$
1 revolution = 360°
= 6.283 *rad*

LENGTH

1 in = 2.54 cm
1 ft = 12 in
3 ft = 1 yard
1 mile = 5280 ft
= 1760 yard
= 1.61 km
1 m = 3.28 ft
1 fathom = 6 ft
1 furlong = 660ft

VOLUME

1000 cm^3 = 1 L
1000 L = 1 m^3
1 gallon = 3.785 L
= 231 in^2
= 4 quarts
1 drum = 55 gal
1 ft^3 = 7.48 gal

MASS

1 kg = 2.205 lb
1 lb = 16 oz
1 slug = 32.2 lb
1 amu = 1.66x10^{-27} kg

VISCOSITY

***DYNAMIC VISCOSITY**

1 Pa-s = 10 poise
1 poise = $1\,\frac{dyne-sec}{cm^2}$

***KINEMATIC VISCOSITY**

1 Stoke = $1\,\frac{cm^2}{sec}$

FORCE

1 N = 10^5 dyne
1 lb = 4.448 N
= 32.17 poundal
1 kgf = 1lbf
1 kip = 1000 lbf

PRESSURE

1 atm = 101.325 kPa
= 14.7 psi
= 760 torr
= 760 mmHg
= 29.92 inHg
= 406.8 inch of water at 4°C
1 Bar = 100 kPa
1 ksi = 1000 psi

ENERGY

1 BTU = 1055 J
= 778.169 ft-lb
= 252 cal
= 1.055x10^{10} erg

POWER

1 HP = 746 watts

= $550 \frac{ft-lb}{sec}$

= 2545 BTU/hr

= 178.2 cal/sec

TON OF REFRIGERATION

1 TR = 211 KJ/min

= 12000 BTU/hr

= 3.516 kW

= 4.714 HP

➢ CONSTANTS

GRAVITY

g = $9.81\ m/s^2$

= $32.2\ ft/s^2$

DENSITY

ρH_2O = $1000\ kg/m^3$

= $62.4\ lbm/ft^3$

ρ air = $1.2\ kg/m^3$

= $0.075\ lbm/ft^3$

SPECIFIC WEIGHT

γH_2O = $9.81\ KN/m^3$

= $62.4\ lbf/ft^3$

AIR CONSTANTS

C_P = 0.24 BTU/lb•R°

= 1.0062 KJ/kg•K°

C_V = 0.1714 BTU/lb•R°

= 0.7186 KJ/kg•K°

k = 1.4

R = 53.342 ft-lbf/lbm•R°

= 287.08 J/kg•K°

Chapter 1

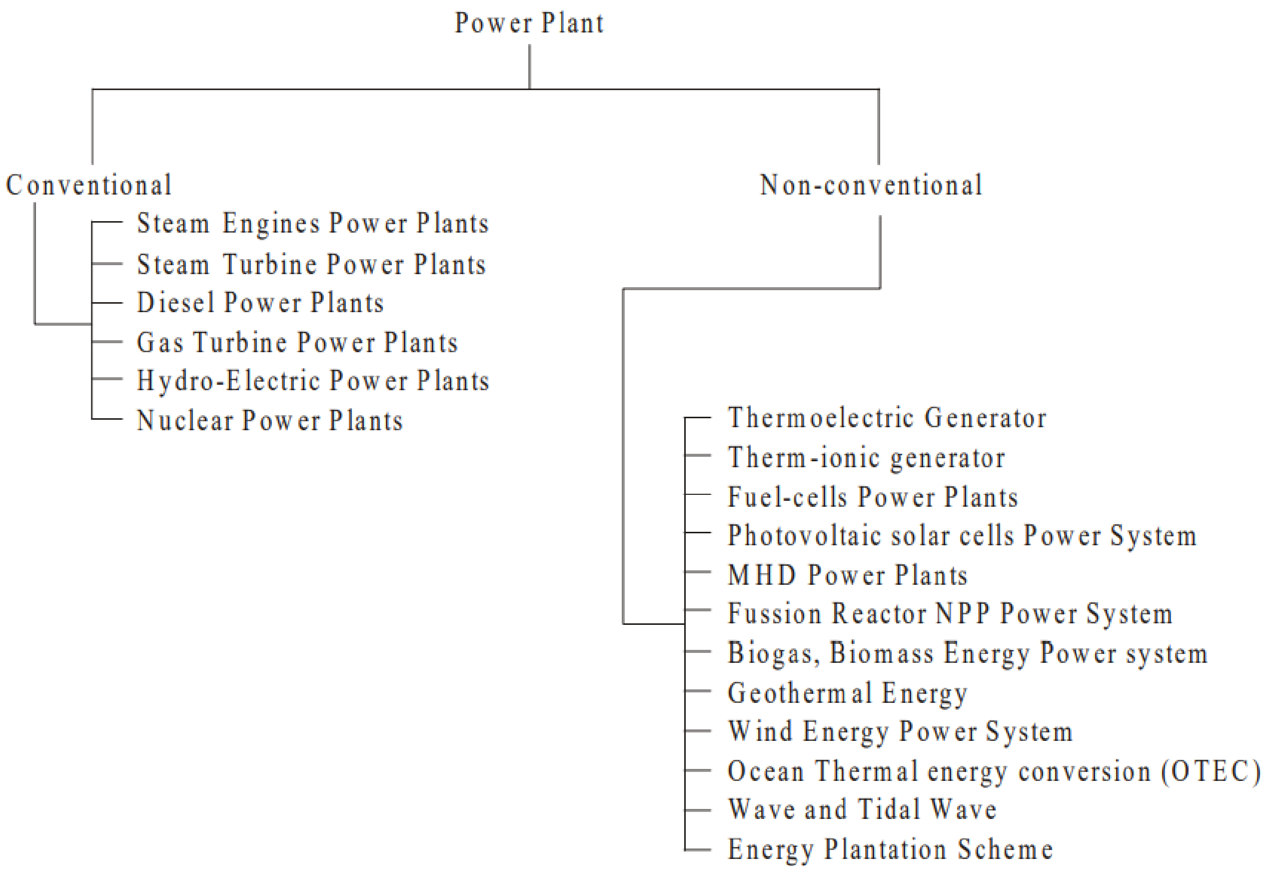
Basic of Power Plant

1.1 INTRODUCTION

A power plant is an industrial facility that generates electricity from primary energy. Most power plants use one or more generators that convert mechanical energy into electrical energy in order to supply power to the electrical grid for society's electrical needs. The exception is solar power plants, which use photovoltaic cells (instead of a turbine) to generate this electricity. A power plant is a powerhouse generating electricity from the primary source of energy. There are different types of power plants. The most common type of power plant uses fossil fuels such as coal, natural gas, or oil to turn turbines. These turbines generate mechanical energy, which then turns into generators to produce electricity. There are also other types of power plants that use renewable energy sources such as hydroelectricity, wind power, or solar power.

1.3 CLASSIFICATION OF POWER PLANTS

A power plant may be defined as a machine or assembly of equipment that generates and delivers a flow of mechanical or electrical energy. The main equipment for the generation of electric power is generator. When coupling it to a prime mover runs the generator, the electricity is generated. The type of prime move determines, the type of power plants.



The major power plants, which are discussed in this class, are:

1. Steam power plant
2. Diesel power plant
3. Gas turbine power plant
4. Nuclear power plant
5. Hydroelectric power plant

The Steam Power Plant, Diesel Power Plant, Gas Turbine Power Plant and Nuclear Power Plants are called THERMAL POWER PLANT, because these convert heat into electric energy.

1.4 ENERGY

Energy is the capacity for doing work, generating heat, and emitting light. The equation for work is the force, which is the mass time the gravity times the distance. Heat is the ability to change the temperature of an object or phase of a substance. For example, heat changes a solid into a liquid or a liquid into a vapor. Heat is part of the definition of energy.

Energy is measured in units of Calorie and Joule. A kilocalorie is the amount of energy or heat required to raise the temperature of 1 kilogram of water from 14.5°C to 15.5°C.

The Government has formulated an energy policy with objectives of ensuring adequate energy supply at minimum cost, achieving self-sufficiency in energy supplies and protecting environment from adverse impact of utilising energy resources in an injudicious manner. Main elements of the policy are:

1. Accelerated the energy resources-oil, coal, hydro and nuclear power.
2. Increase production of oil and gas.
3. Management of demand for oil and other forms of energy.
4. Energy conservation and management.
5. Optimization of existing capacity in the country.
6. Development of renewable sources of energy.
7. Research and development activities in new and renewable energy sources.

1.5 TYPES OF ENERGY

1. Nuclear Energy: Nuclear energy produces heat by fission on nuclei, which is generated by heat engines.
2. Electrical Energy: Electricity is the conduction or transfer of energy from one place to another. The electricity is the flow of energy.
3. Thermal Energy: Thermal energy is kinetic and potential energy, but it is associated with the random motion of atoms in an object.
4. Chemical Energy: Chemical energy is a form of energy that comes from chemical reactions, in which the chemical reaction is a process of oxidation.
5. Radiant Energy: Radiant energy is converted to chemical energy by the process of photosynthesis.
6. Potential energy and kinetic energy that combines to produce mechanical energy.

The potential energy of an object in this case is given by the relation:

$PE = mgh$,
PE = energy in joules,
m = mass of the object
g = gravitational acceleration
h = height of the object goes.
The equation for kinetic energy is:
$KE=\frac{1}{2} mv^2$
m = mass
v = velocity.

1.6 POWER

Power is the rate doing work, which equals energy per time. Energy is thus required to produce power. We need energy to run power plants to generate electricity. We need power to run our appliances, and heat our homes. Without energy we would not have electricity. The units of power are Watts, Joules per second, and Horsepower, where;

1 Watt = 1 joule per second

1 Kilowatt = 1,000 Watts

1 Megawatt = 1,000 kilowatts = 1 horsepower Electricity is the most convenient and versatile form of energy.

1.7 POWER DEVELOPMENT IN IRAQ

Iraq generates electrical energy in several ways, through 109 gas, thermal, and hydroelectric stations, with a production of 22,680 megawatts during 2022, despite Iraq's need for 40,000 megawatts and another 20,000 megawatts in the event of supporting local industries.

1) Thermal stations

Iraq has 7 thermal stations to generate energy by heating water and converting it into steam, which is used to rotate steam turbine turbines (with high speeds), which in turn rotate machines to generate electricity with different capacities. Thermal power stations are 6,895 megawatts.

The stations are distributed across 6 Iraqi governorates.

In Baghdad

Al-Doura, with a capacity of 640 megawatts and Southern Baghdad, with a capacity of 355 megawatts.

In Nineveh

North station, which is the largest thermal station in Iraq, with a capacity of 2,000 and 100 megawatts.

In Salah al-Din

Baiji thermal station with a capacity of 1,320 megawatts,

In Babil

Musayyib station, which has a capacity of 1,280 megawatts,

In Dhi Qar

Nasiriyah station with a capacity of 800 megawatts

In Basra

Hartha station with a capacity of 400 megawatt

2) Hydroelectric stations

Iraq produces electrical energy through 8 hydroelectric stations that use the energy contained in water complexes such as dams and waterfalls to rotate water turbine turbines at low speeds, which in turn rotate machines to generate electricity with different capacities.

In Sulaymaniyah

Darbandikhan Dam station with a capacity of 248 MW

In Dokan

Dokan Dam station with a capacity of 400 MW.

In Salah al-Din

Al-Azim Dam stations with a capacity of 27 MW

Samarra Dam station with a capacity of 84 MW.

In Mosul

Mosul Dam station, which is the largest in Iraq with a production capacity of 152 megawatts

the second Mosul Dam station with a capacity of 62 megawatts.

In Diyala

Hamrin Dam station has a capacity of 50 megawatts,

In Anbar

there is a modern dam station with a capacity of 660 megawatts.

Thus, the total production of hydroelectric stations reaches 2,583 megawatts.

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3) Gas stations

Iraq relies heavily on gas stations to generate electricity. Iraq has 26 gas stations that work by converting chemical fuel energy into thermal energy to heat gases that are fed into gas turbines, which convert that energy into kinetic energy first, which works to manage the gas turbine, and then into mechanical energy, which works to rotate the rotor in the generator that works with Magnetic field converts mechanical energy into electrical energy.

In Baghdad

a) South Baghdad stations 1 and 2, with capacities of 246 and 400 megawatts,
b) Al-Dora stations 1 and 2, with capacities of 146 and 700 megawatts.
c) Al-Taji stations 1 and 2, with capacities of 156 and 160 megawatts,
d) Al-Quds 1 stations. And 2 and 3, with capacities of 450 for each of 1 and 2, and a capacity of 500 for station 3.
e) Al-Sadr station with a capacity of 160 megawatts
f) Al-Rasheed station 1 with a capacity of 94 megawatts

so the total production of Baghdad gas stations of electrical energy is 3 thousand and 462 megawatts.

In Basra, there are 4 gas stations:

a) the Rumaila station with a capacity of 1,460 megawatts,
b) the Shatt al-Basra station with a capacity of 1,250 megawatts,
c) the Zubair station 750 megawatts
d) the Najibiyah station with a production capacity of 500 megawatts each.

In Kirkuk

a) Mulla Abdullah stations with a production capacity of 222 megawatts
b) Taza with a capacity of 292 megawatts,

In Dohuk

Dohuk station with a capacity of 500 megawatts, and in

In Erbil

the Erbil station with a production capacity of 1,500 megawatts.

In Anbar

Anbar gas station with a production capacity of 1,646 megawatts,

In Sulaymaniyah

the Sulaymaniyah station with a capacity of 1,500 megawatts,

In Najaf

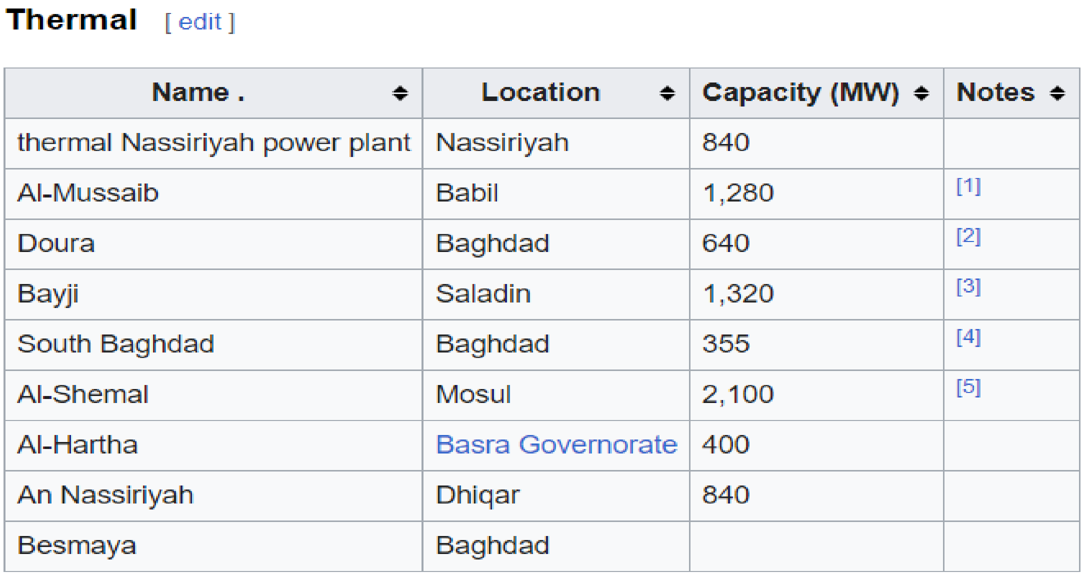
the Najaf station with a capacity of 430 megawatts.

In Diyala,

the Mansouriya station has a production capacity of 728 megawatts

in Karbala station,

with a production capacity of 250 megawatts, bringing the total production of gas power stations to 14,550 megawatts.

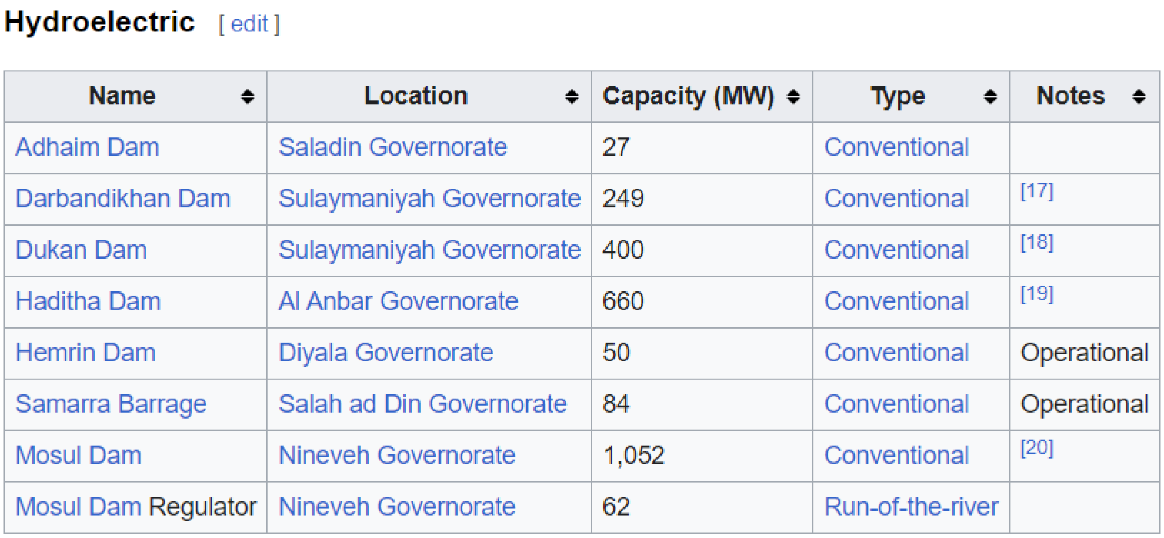


Thermal [edit]

Name . ⬍	Location ⬍	Capacity (MW) ⬍	Notes ⬍
thermal Nassiriyah power plant	Nassiriyah	840	
Al-Mussaib	Babil	1,280	[1]
Doura	Baghdad	640	[2]
Bayji	Saladin	1,320	[3]
South Baghdad	Baghdad	355	[4]
Al-Shemal	Mosul	2,100	[5]
Al-Hartha	Basra Governorate	400	
An Nassiriyah	Dhiqar	840	
Besmaya	Baghdad		

Natural gas [edit]

Name	Location	Capacity (MW)	Type	Notes
Mulla Abdulla (New)	Kirkuk Governorate	222	Open-cycle	
Khor Al Zubayr	Basra Governorate	252	Open-cycle	[6]
Al-Mansurya	Diyala Governorate	728	Open-cycle	[7]
Al-Anbar	Al-Anbar Governorate	1,642.6	Combined-cycle	[8]
Shatt Al-Basra	Basra Governorate	1,900	Combined-cycle	[9]
Erbil	Erbil Governorate	1,500	Combined-cycle	[10]
South Baghdad 1	Baghdad Governorate	246	Open-cycle	
South Baghdad 2	Baghdad Governorate	400	Open-cycle	
Daura 1	Baghdad Governorate	146	Open-cycle	
Daura 2	Baghdad Governorate	750	Open-cycle	[11]
Al-Rasheed 1	Baghdad Governorate	94	Open-cycle	
Taji 1	Baghdad Governorate	156	Open-cycle	
Taji 2	Baghdad Governorate	160	Open-cycle	
Sadr	Baghdad Governorate	160	Open-cycle	
Al-Quds 1	Baghdad Governorate	450	Open-cycle	
Al-Quds 2	Baghdad Governorate	450	Open-cycle	
Al-Quds 3	Baghdad Governorate	500	Open-cycle	[12]
Al-Najybia	Basra Governorate	500	Open-cycle	
Sulaymaniyah	Sulaymaniyah Governorate	1,500	Combined-cycle	[13]
Dohuk	Dohuk Governorate	500	Open-cycle	[14]
Rumaila	Basra Governorate	1,460	Open-cycle	[15]
Taza	Kirkuk Governorate	292	Open-cycle	[16]
Hilla	Babil Governorate	250	Open-cycle	
Karbala	Karbala Governorate	250	Open-cycle	
Al-Najaf	Najaf Governorate	250	Open-cycle	



Hydroelectric [edit]

Name	Location	Capacity (MW)	Type	Notes
Adhaim Dam	Saladin Governorate	27	Conventional	
Darbandikhan Dam	Sulaymaniyah Governorate	249	Conventional	[17]
Dukan Dam	Sulaymaniyah Governorate	400	Conventional	[18]
Haditha Dam	Al Anbar Governorate	660	Conventional	[19]
Hemrin Dam	Diyala Governorate	50	Conventional	Operational
Samarra Barrage	Salah ad Din Governorate	84	Conventional	Operational
Mosul Dam	Nineveh Governorate	1,052	Conventional	[20]
Mosul Dam Regulator	Nineveh Governorate	62	Run-of-the-river	

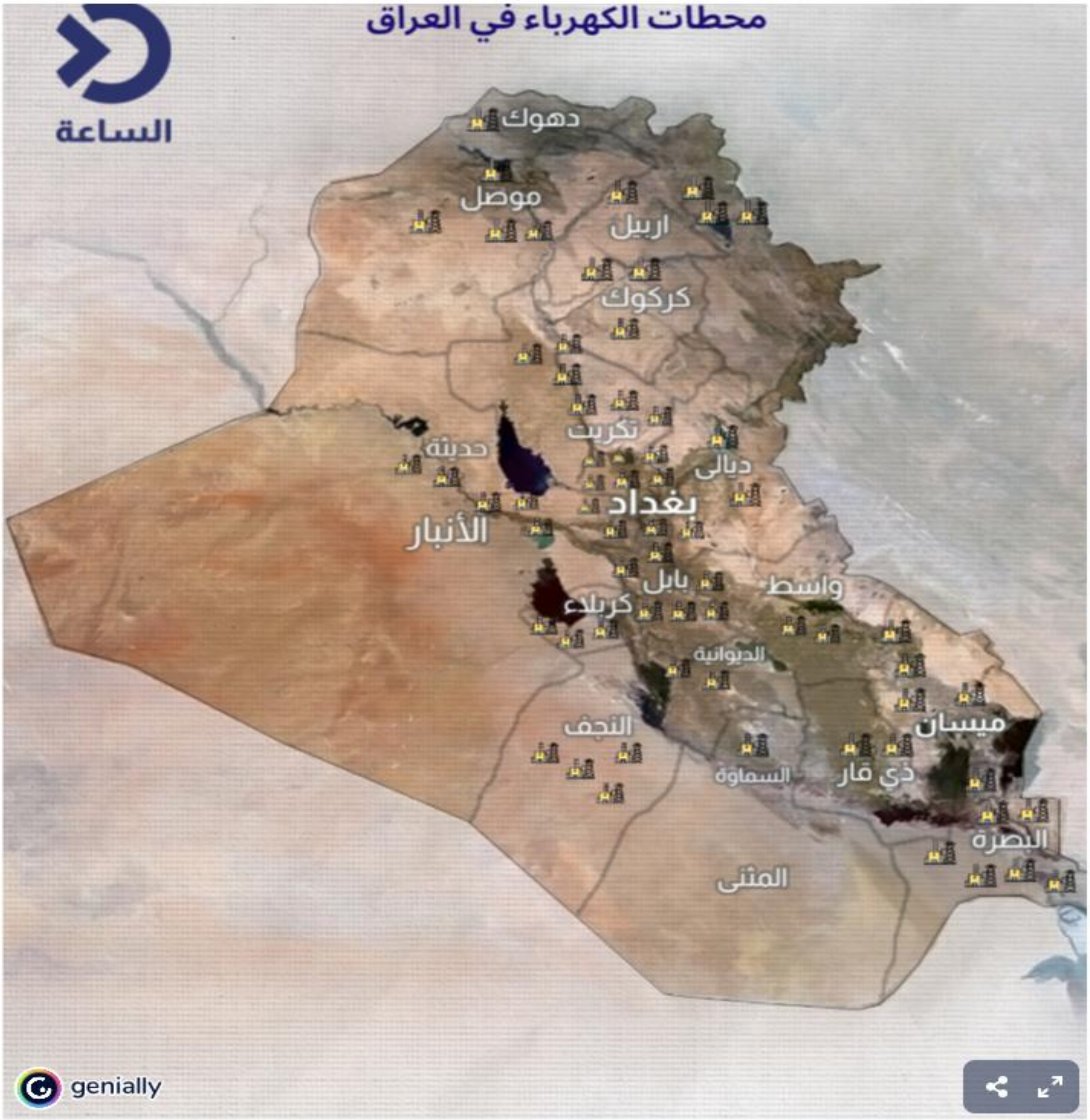
4) Imports electricity

Jordan, tariff is 1 US cent per kWh

Turkey, tariff 5.58 US cent per kWh

Iran: As of January 2011 Iraq imports 650 MW of electricity from Iran.

Kuwait 500 megawatts (MW)



1.13 CLASSIFICATION OF POWER PLANT CYCLE

Power plants cycle generally divided in to the following groups,

(1) Vapour Power Cycle (Carnot cycle, Rankine cycle, Regenerative cycle, Reheat cycle, Binary vapour cycle)

(2) Gas Power Cycles (Otto cycle, Diesel cycle, Dual combustion cycle, Gas turbine cycle.)

1 CARNOT CYCLE

This cycle is of great value to heat power theory although it has not been possible to construct a practical plant on this cycle. It has high thermodynamics efficiency. It is a standard of comparison for all other cycles. The thermal efficiency (η) of Carnot cycle is as follows:

$\eta = (T1 - T2)/T1$

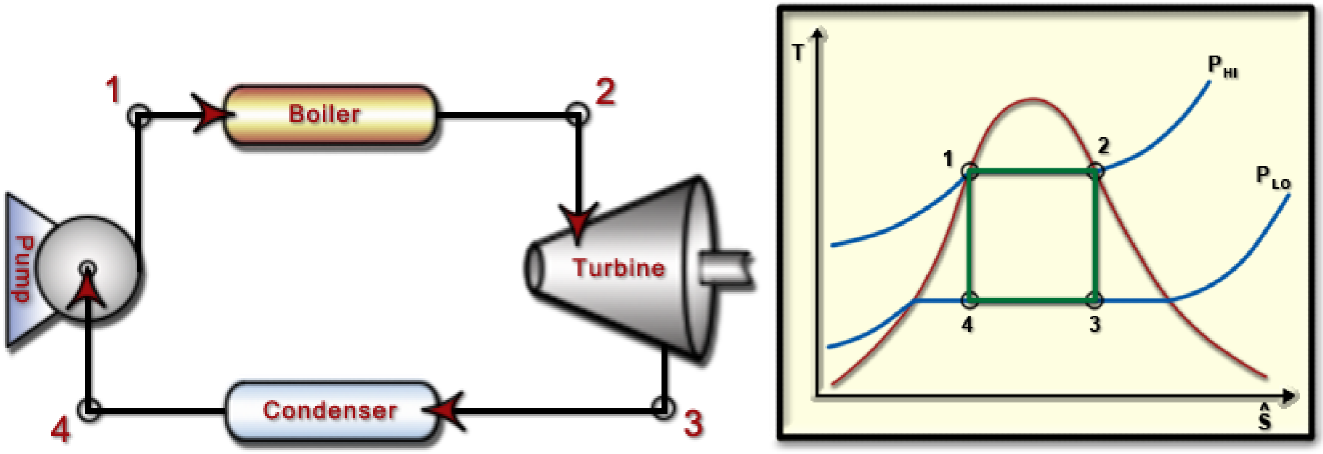
T1 = Temperature of heat source

T2 = Temperature of receiver

We have always used the Carnot Cycle as our model for thermodynamic cycles.

1) Boiler: Isothermal heat transfer eliminates the possibility of using subcooled liquid boiler feed or producing superheated vapor in the boiler effluent.
2) Turbine: Adiabatic expansion yields low steam quality in the turbine feed. This can result in damage to the turbine rotor.

3) Condenser: Isothermal heat transfer eliminates the possibility of using superheated vapor in the condenser feed.
4) Pump: Quality > 0 in the pump feed. This can result in damage to the pump rotor.



2 RANKINE CYCLE

Steam engine and steam turbines in which steam is used as working medium follow Rankine cycle. This cycle can be carried out in four pieces of equipment joint by pipes for conveying working medium as shown in Fig. 1.1. The cycle is represented on Pressure Volume P-V and S-T diagram as shown in Figs. 1.2 and 1.3 respectively

Efficiency of Rankine cycle = (H1 – H2)/ (H1 – Hw2)

Hl = Total heat of steam at entry pressure

H2 = Total heat of steam at condenser pressure (exhaust pressure)

Hw2= Total heat of water at exhaust pressure

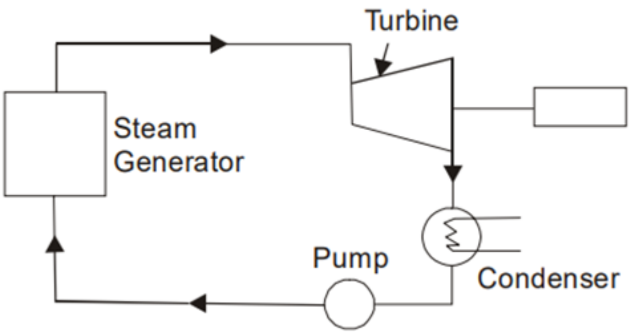


Fig. 1.1

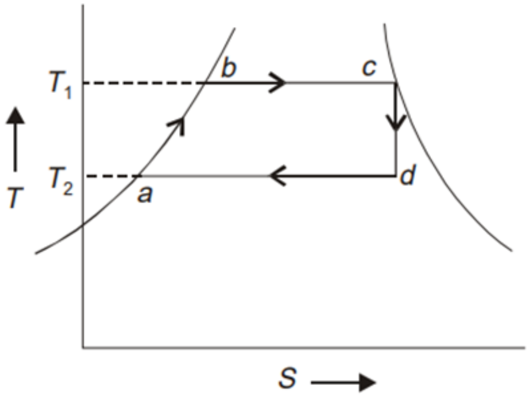


Fig. 1.3

3 REHEAT CYCLE

In this cycle steam is extracted from a suitable point in the turbine and reheated generally to the original temperature by flue gases. Reheating is generally used when the pressure is high say above 100 kg/cm2.

The various **advantages** of reheating are as follows:

(i) It increases dryness fraction of steam at exhaust so that blade erosion due to impact of water particles is reduced.

(ii) It increases thermal efficiency.

(iii) It increases the work done per kg of steam and this results in reduced size of boiler.

The **disadvantages** of reheating are as follows:

(i) Cost of plant is increased due to the reheater and its long connections.

(ii) It increases condenser capacity due to increased dryness fraction. Fig. 1.4 shows flow diagram of reheat cycle. First turbine is high-pressure turbine and second turbine is low pressure (L.P.) turbine. This cycle is shown on T-S (Temperature entropy) diagram (Fig. 1.5).

Efficiency = {(H1 – H2) + (H3 – H4)}/{H1 + (H3 – H2) – Hw4}

H1 = Total heat of steam at 1

H2 = Total heat of steam at 2

H3 = Total heat of steam at 3

H4 = Total heat of steam at 4

Hw4 = Total heat of water at 4

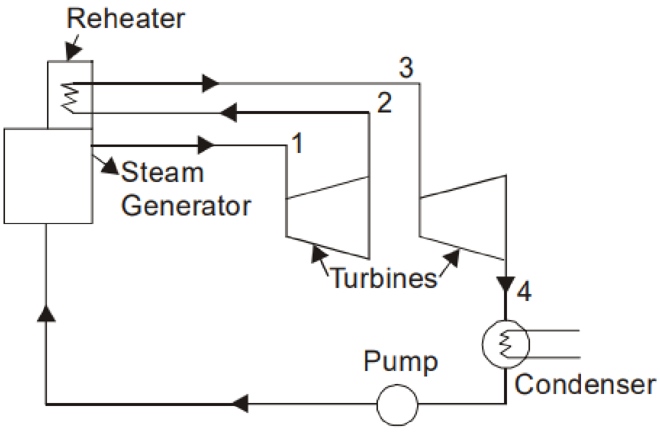


Fig. 1.4

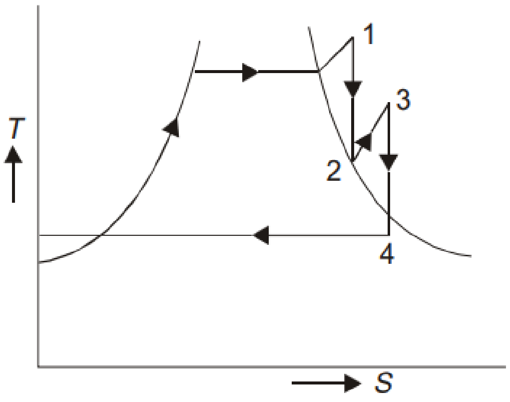
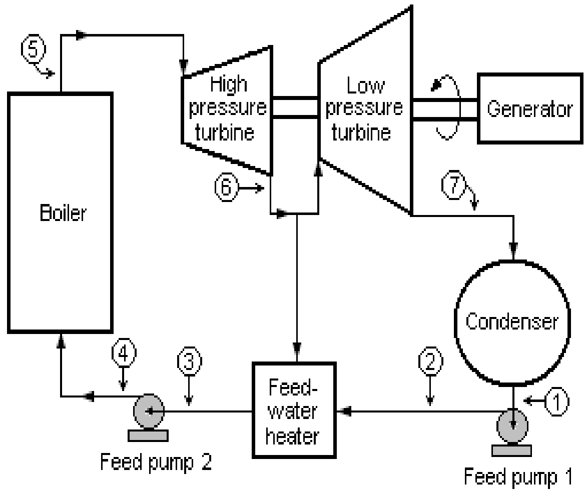
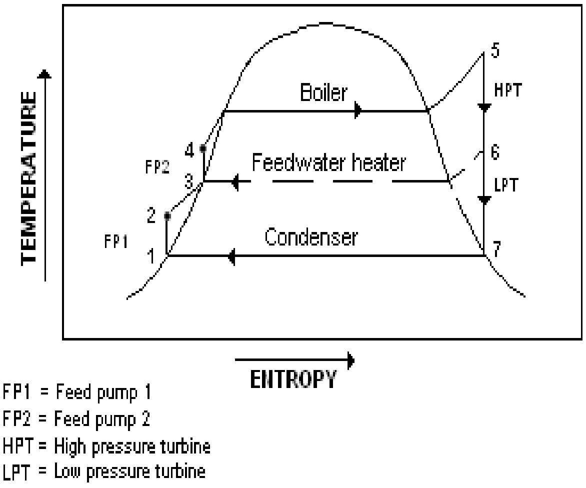


Fig. 1.5

4 REGENERATIVE CYCLE (FEED WATER HEATING)

The process of extracting steam from the turbine at certain points during its expansion and using this steam for heating for feed water is known as Regeneration or Bleeding of steam. The arrangement of bleeding the steam at two stages is shown in Fig. 1.6.





Efficiency (η) = Total work done/Total heat supplied = {(H1 – H2) + (1 – m2)(H2 – H3) + (1 – m2 – m3)(H3 – H4)}/(H1 – Hw2)

m2 = Weight of bled steam at a per kg of feed water heated

H1 = Enthalpies of steam and water in boiler

Hw1 = Enthalpies of steam and water in boiler

H2, H3 = Enthalpies of steam at points a and b

t2, t3 = Temperatures of steam at points a and b

H4, Hw4 = Enthalpy of steam and water exhausted to hot well.

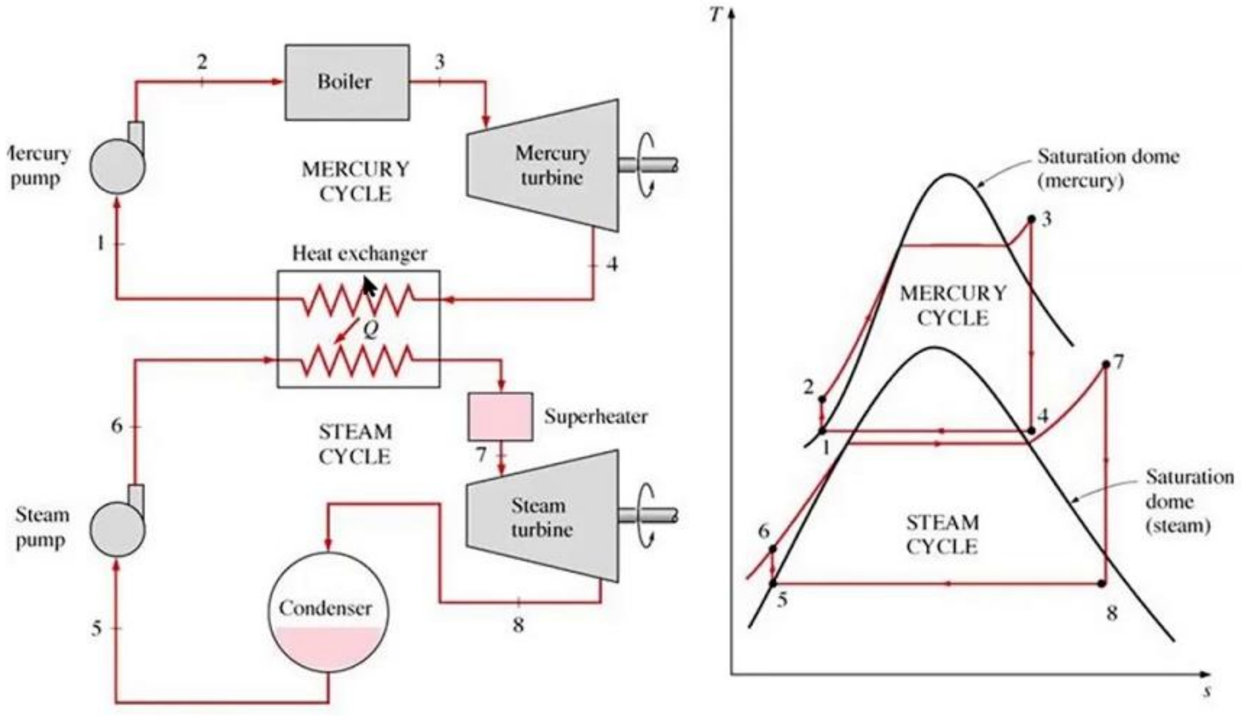
a = H1 – H2 is Work done in turbine per kg of feed water between entrance and b = (1 – m2)(H2 – H3) is Work done between

Work done between b and exhaust = (1 – m2 – m3)(H3 – H4)

Total heat supplied per kg of feed water = H1 – Hw2

5 BINARY VAPOUR CYCLE

In this cycle two working fluids are used. Fig. 1.7 shows Elements of Binary vapour power plant. The mercury boiler heats the mercury into mercury vapours in a dry and saturated state. These mercury vapours expand in the mercury turbine and then flow through heat exchanger where they transfer the heat to the feed water, convert it into steam. The steam is passed through the steam super heater where the steam is super-heated by the hot flue gases. The steam then expands in the steam turbine.



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6 REHEAT-REGENERATIVE CYCLE

In steam power plants using high steam pressure reheat regenerative cycle is used. The thermal efficiency of this cycle is higher than only reheat or regenerative cycle. Fig. 1.8 shows the flow diagram of reheat regenerative cycle. This cycle is commonly used to produce high pressure steam (90 kg/cm2) to increase the cycle efficiency.

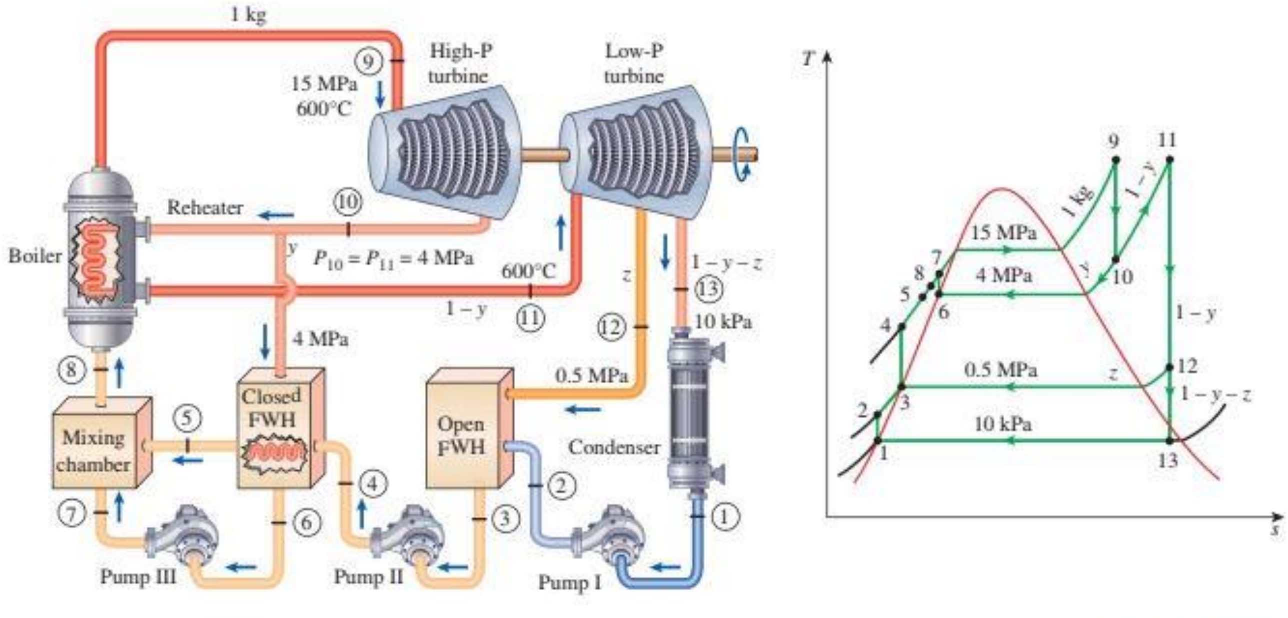

FIGURE 10–19
Schematic and T-s diagram for Example 10–6.

7 FORMULA SUMMARY

1. Rankine efficiency = (H1 – H2)/(H1 – Hw2)

2. Efficiency ratio or Relative efficiency = Indicated or Brake thermal efficiency/Rankine efficiency

3. Thermal efficiency = 3600/m(H1 – Hw2), m = steam flow/kw hr 4. Carnot efficiency = (T1 – T2)/T1