Subject : Power plant	**موضوع هندسة بخارية**
Weekly Hours : Theoretical:2	**الساعات الأسبوعية : نظري : 2**
Tutorial : 1	**مناقشة : 1**
Experimental : 1	**عملي : 1**
UNITS: 5	**الوحدات : 5**

week	Contents	المحتويات	الأسبوع
1.	Boilers types'.	أنواع المراجل.	.1
2.	Boilers construction	تراكيب المراجل	.2
3.	Boilers accessories super heater.	ملحقات المراجل ، المحمصات ، الموفرات.	.3
4.	economizer	الموفرات	.4
5.	Boiler heat balance.	الموازنة الحرارية للمراجل.	.5
6.	Applications	تطبيقات	.6
7.	Fuel.	الوقود والاحتراق.	.7
8.	Combustion.	الاحتراق	.8
9.	Fuel system.	منظومات الوقود.	.9
10.	Burners	المحارق.	.10
11.	Chimney design.	المداخن ، تصميم وتركيب.	.11
12.	Chimney construction.	تركيب المداخن	.12
13.	Water treatment.	معالجة المياه.	.13
14.	Method of Water treatment.	طرق معالجة المياه.	.14
15.	Applications	تطبيقات	.15
16.	Condensers types	المكثفات، الأنواع ، الكفاءة ، الأداء.	.16
17.	Condensers efficiency, performance	المكثفات، الكفاءة ، الأداء.	.17
18.	Cooling towers.	أبراج التبريد	.18
19.	Types of Cooling towers.	أنواع أبراج التبريد	.19
20.	Cooling towers performance	كفاءة أبراج التبريد	.20
21.	Steam piping system and accessories.	منظومة أنابيب البخار وملحقاتها.	.21
22.	Steam piping system accessories.	ملحقات منظومة أنابيب البخار	.22
23.	Heat exchangers.	المبادلات الحرارية.	.23
24.	Types of Heat exchangers	أنواع المبادلات الحرارية	.24
25.	Applications	تطبيقات	.25
26.	Steam system inspection.	فحوصات الأداء لمنظومة البخار.	.26
27.	Steam system measurements.	القياسات لمنظومة البخار.	.27
28.	Applications	تطبيقات	.28
29.	Automatic control of steam systems.	أنظمة السيطرة في منظومات البخار	.29
30.	Applications	تطبيقات	.30

"Power Plants"

Syllabus :-

(1) Introduction
- classification of power plants
- Comparison between power plants

(2) steam cycles, Cogeneration plant (Combined power and heat plant)

(3) gas power plants

(4) Steam boilers

5) steam nozzles

6) steam turbines

7) economics of power plant.

References :-

- applied thermodynamics By Eastop & Mcconkey
- engineering thermodynamics work & heat transfer By Rogers & Mayhew
- power plant technology By M.M. EL-[redacted]kil.
- steam turbine theory and practice By W.J. Kearton
- a course in power plant engineering By Arora.

Power plant theory and design By Potter
Power plant system design By Kam W. Li

Chapter (2) Steam cycles
-1. Definitions
.2. Carnot cycle
-3. Rankine cycle
3-1. Simple Rankine cycle — superheat
.3.2 Modified Rankine ~~cycle~~ — Reheat — Regeneration.

.4 Cogeneration plant
4.1 The bottoming cycle — back pressure turbine
.4.2 The topping ~~cy~~cle — extraction turbine (Pas.

Chapter (3) Gas turbine power plants
-1. open cycle gas turbine
1.2. closed " " "
.3 analysis of closed cycle gas turbine
.4 analysis of open cycle gas turbine
.5 improvement the performance of gas turbin
.6 gas and steam cycle (combined cycle)

chapter (4) Steam boilers

4.1 feed water treatment
4.2 Classification of boilers
4.3 boiler mountings
4.4 boiler accessories
4.5 Combustion calculations
4.6 boiler performance
4.7 boiler heat balance

chapter (5) Steam nozzles

5.1. types of nozzles
5.2 off-design condition
5.3 basic equation for nozzle
5.4 supersaturation (metastable) expansion

chapter (6)

6.1 types of steam turbines
6.2 impulse turbine
6.2.1 Simple impulse
6.2.2. Compound impulse turbine
6.3. flow of steam through impulse turbine
6.3.1 simple impulse
a. velocity diagram b. blade efficiency
c. stage efficiency d. blade height
6.3.2 Compound impulse turbine
a. velocity diagram b. blade efficiency
c. blades height

6.4.1 . a. velocity diagram   b. degree of reaction
c. Parsons [illegible]   d. blade efficiency
e. Stage efficiency   f. blade height.

6.5. losses in steam turbines
6.6. steam turbine governing (steam distribution)
6.7. stage efficiency, overall efficiency and reheat factor

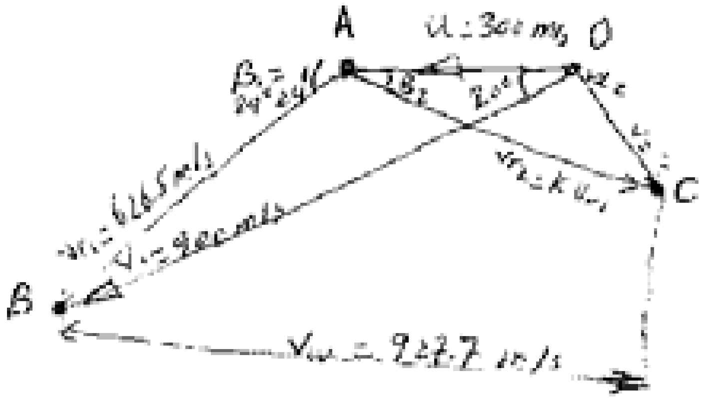
chapter (7) economics of Power plant

7.1. cost of electrical energy
7.2 selection generation type
7.3 load curve and load duration curve
7.4 different terms & definitions
7.5 Peak load plants
7.5.1. Pump storage plant
7.5.2 Air storage Plant

Ex. The velocity of steam leaving the nozzles of an impulse turb[ine] is 900 m/s and the nozzle angle is 20°. The blade velocity is 300 m[/s] and the blade velocity coefficient is 0.7. Calculate for a mass flow [of] 1 kg/s, and symmetrical blading:-

(a) the blade inlet angle (b) the driving force on the wheel
(c) the axial thrust (d) the diagram horse power (e) the diagram e[fficiency]

Solution Let 1cm = 100 m/s



or from analytical method:-
Applying the cosine rule to Δ OAB

$V_{r1}^2 = V_1^2 + u^2 - 2uV_1 \cos\alpha_1$
$V_{r1} = \sqrt{900^2 + 300^2 - 2 \cdot 300 \cdot 900 \cos 20} = \underline{626.5 \text{ m/s}}$

Then using the sine rule in Δ OAB

$\frac{V_1}{\sin OAB} = \frac{V_{r1}}{\sin\alpha_1}$ but $\sin OAB = \sin(180 - \beta_1) = \sin\beta_1$

$\therefore \sin\beta_1 = \frac{900 \cdot \sin\alpha_1}{626.5} = 0.491$ $\therefore \underline{\beta_1 = 29°24'}$

$K = \frac{V_{r2}}{V_{r1}} = 0.7$ $\therefore V_{r2} = 0.7 \times 626.5 = 438.5$ m/s

$V_w = V_{r1}\cos\beta_1 + V_{r2}\cos\beta_2$
$= 626.5 \cos 29°24' + 438.5 \cos 29°24'$
$= 927.7$ m/s

$\therefore$ driving force $= \dot{m} V_w = 1 \cdot 927.7 = \underline{927.7}$ N

Axial thrust $= \dot{m}(V_{f1} - V_{f2})$
$= \dot{m}(V_{r1}\sin\beta_1 - V_{r2}\sin\beta_2) = \underline{92.3}$ N

diagram power $= \dot{m} V_w u = 1 \cdot 927.7 \cdot \frac{300}{10^3} = \underline{278.3}$ kW

diagram efficiency $= \frac{2uV_w}{V_1^2} = \frac{2 \times 300 \times 927.7}{900^2} = \underline{68.7\%}$

Chapter (5)

Steam turbines

5-1- General principle

A steam turbine is a machine which converts part of heat energy in the steam into mechanical work. Steam turbine essentially consists of the following two parts:-

1- The nozzles:- in which the steam expands from high pressure and a state of comparative rest to a lower pressure and state of comparatively rapid motion.
2- The moving blades:- In which the momentum of the stream of steam particles change.

The nozzles are attached to the stationary part of the turbine, which is usually termed the stator (casing), whereas the moving blades are attached to the rotating element of the machine (rotor).

5-2- Types of steam turbines

Steam turbines are classified according to the method of expansion into:

1- Impulse turbine

2- Impulse-reaction turbine (reaction turbine)

1- Impulse turbine:- The steam is caused to fall in pressure in nozzles, due to this fall in pressure a certain amount of heat energy is converted into mechanical kinetic energy and the steam is set moving with a greater velocity. The rapid moving particles of steam enter the moving part of the turbine (moving blades) and hence suffer change in direction of motion occurs which gives rise to change of momentum and therefore to force known as impulse force, which causes the rotation of turbine shaft. In this type of turbine all pressure drops occurs in nozzle and no pressure drop occurs in moving blades.

2- Impulse-reaction (reaction):- In such turbine expansion of steam (pressure drops) takes place while it passes through the moving blades as well as through the nozzles. The pressure drops suffered by steam during its flow through the moving blades causes a further generation of K.E. within the blade and adds to the propelling force, which is applied to the turbine shaft. In this type part of pressure drops occurs in nozzles and [illegible] in moving blades.

Impulse turbine:-

a- Simple impulse turbine (De-laval)

Such a turbine has one set of nozzles which is followed by one set of moving blades. Nozzles are set at suitable angle to the side of blades. The high pressure steam is first passed through the set of nozzles, where it expands from high pressure to a low pressure and thereby acquires a high velocity. This steam of high velocity is next directed to the blades and hence due to the change of direction there is a change in momentum, then a force is applied to the blades, which causes the turbine wheel and the shaft to rotate. Simple impulse turbine is show diagrammatically in figure (1). The top portion of the figure shows a longitudinal section through the upper half of turbine, the middle portion shows a development of the nozzles and blades while the lower part of the diagram shows approximately how the absolute pressure and the absolute velocity vary from point to point during the passage of the steam through the turbine. The simple impulse turbine, which is described above is called De-laval and it is also known as a single-stage impulse turbine. This turbine is not in common use due to the following disadvantages:-

1- Since all pressure drops occurs in one set of nozzles and all K.E. absorbs in only one ring of moving blades turbine rotation is to high about 30000 rpm.

2- Steam velocity at exit is quite high which means that there is a considerable losses of K.E.

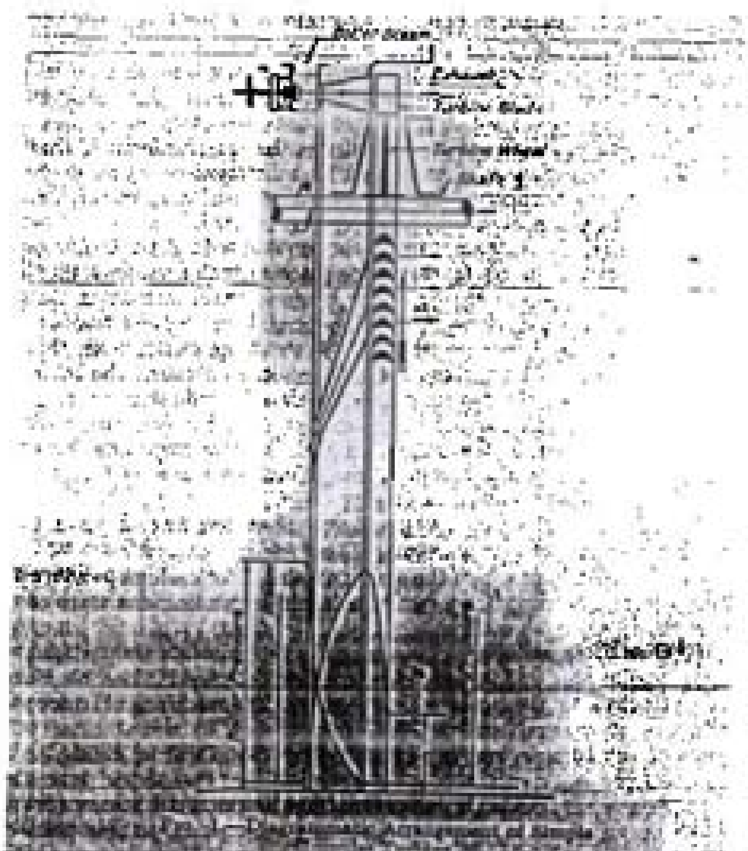


Figure (1)

b- Compounding of impulse turbines

Disadvantages of simple impulse turbine can be overcome by arrangement the expansion of steam or utilization of its K.E. or both in several rings of blades (rather than one ring only). This process is known as (compounding). Methods of compounding impulse turbine are:-

1- Pressure- compounding 2- velocity- compounding 3- pressure-velocity compounding.

1- <u>Pressure-compound impulse turbine</u>

In this turbine the compounding is done by arranging the expansion of steam in number of steps, each step is a simple impulse turbine, which consists of one set of nozzles and one row of blades and is known as stage of the turbine. The exhaust steam from each row of moving blades enters the succeeding set of nozzles. The expansion of steam takes place only in the nozzles. The moving blades in rotor change the direction of the entering steam and cause force to be applied and torque to be developed. Since the pressure drops per stage is reduced (compare with simple impulse turbine) the steam velocity leaving the nozzle is reduced. Thus the speed of the shaft is reduced. The leaving (carry over) loss... in this type of turbine is also reduced. This type of turbine is also known as Rateau turbine. This turbine has disadvantage of long number of stages, hence it is most expensive.

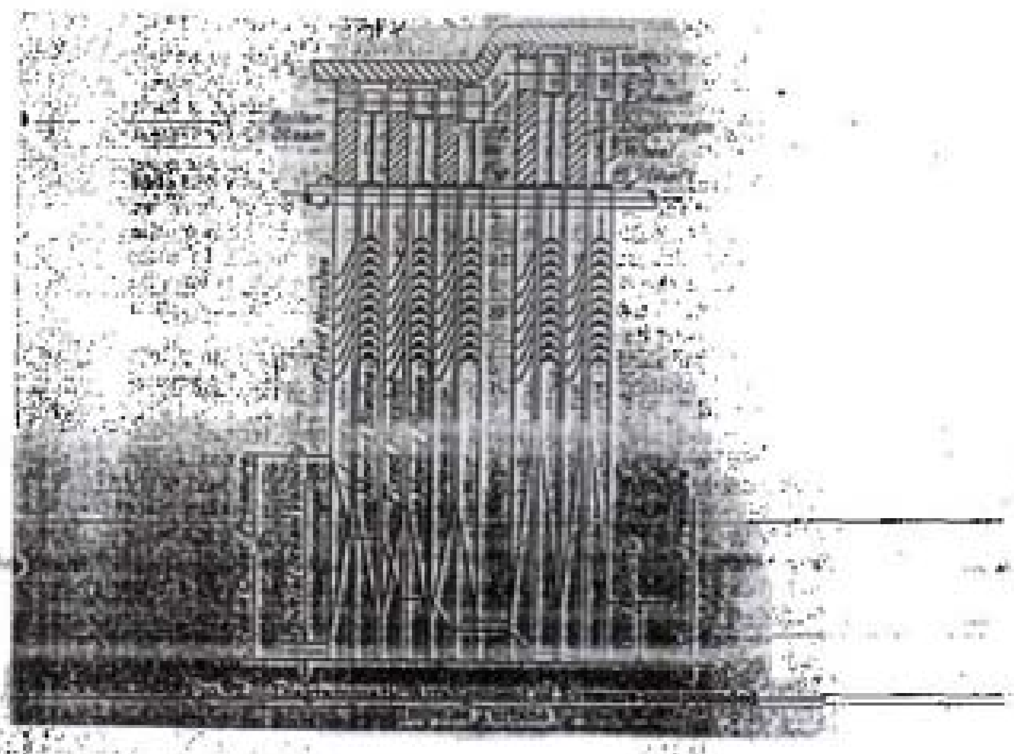


Figure (2)

2- Velocity-compound impulse turbine

In this turbine complete drops of steam pressure (from boiler to condenser pressure) takes place in one set of nozzles, but drop in the velocity of steam is carried out in more than one ring of moving blades. The high velocity steam from nozzles first passes on the first row of moving blades where it's K.E. is only partially reduced. From there steam passes into row of fixed blades which are mounted in turbine casing. These fixed blades are so arranged as to direct steam along direct correct direction into a second row of moving blades, which are mounted on the same turbine wheel. In the second row, as the first row of moving blades K.E. of steam is again partially reduced. Since there is a gradual decreasing in the steam velocity, it results in a slower turbine speed (compare with simple impulse). The advantage of velocity compound turbine is relatively less number of stages and hence less initial cost. The disadvantage is low efficiency. The velocity compounded stage is called as Curtis stage.

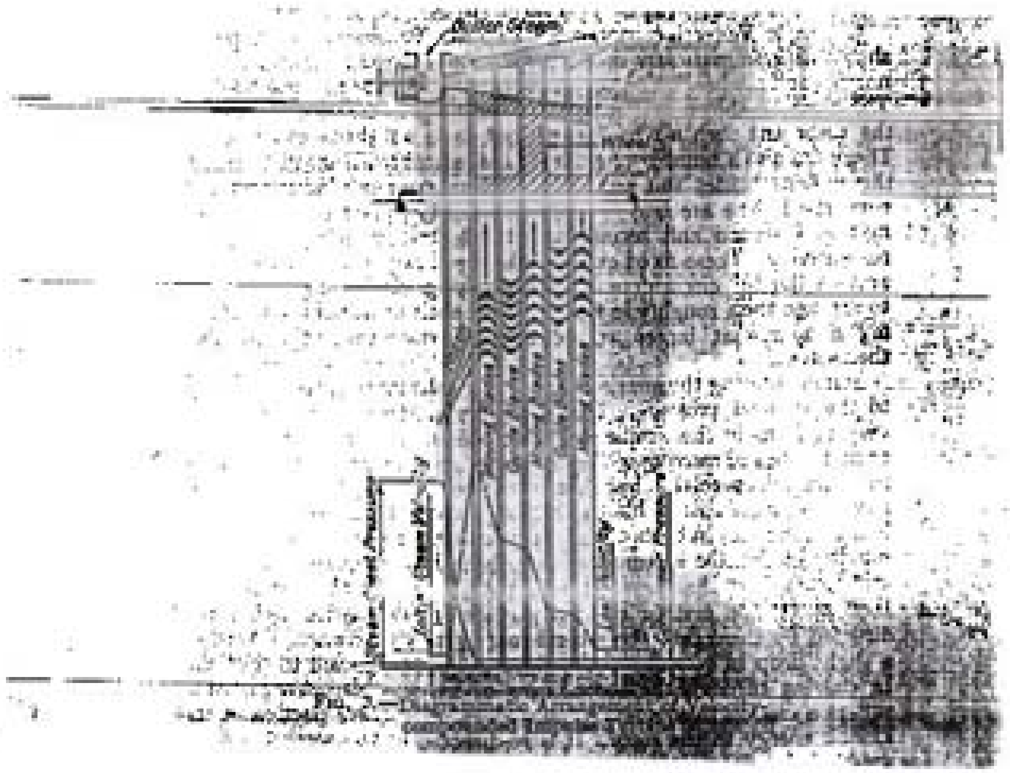


Figure (3)

3- Pressure-velocity c[redacted]

This type of turbine is a combination of pressure and velocity compounding. The total pressure drop of steam from boiler to condenser pressure is divided into a number of stages as is done in pressure compounded method. Each stage may be having a number of rows of fixed and moving blades. Thus, the velocity obtained in each stage is utilized in a number of moving blades as is done in the velocity compounded method. Hence each stage of this turbine will consists of a set of nozzles followed by a set of moving blades. Steam is partially expanded in a row of nozzles where its velocity is increased; the steam then enters a few rows of velocity compounding. From this stage the steam then enters a second row of nozzles where its velocity is again increased. This is followed by another few rows of velocity compounding and so on. This type of turbine is simple in construction but its efficiency is low comparing with pressure-compounded.

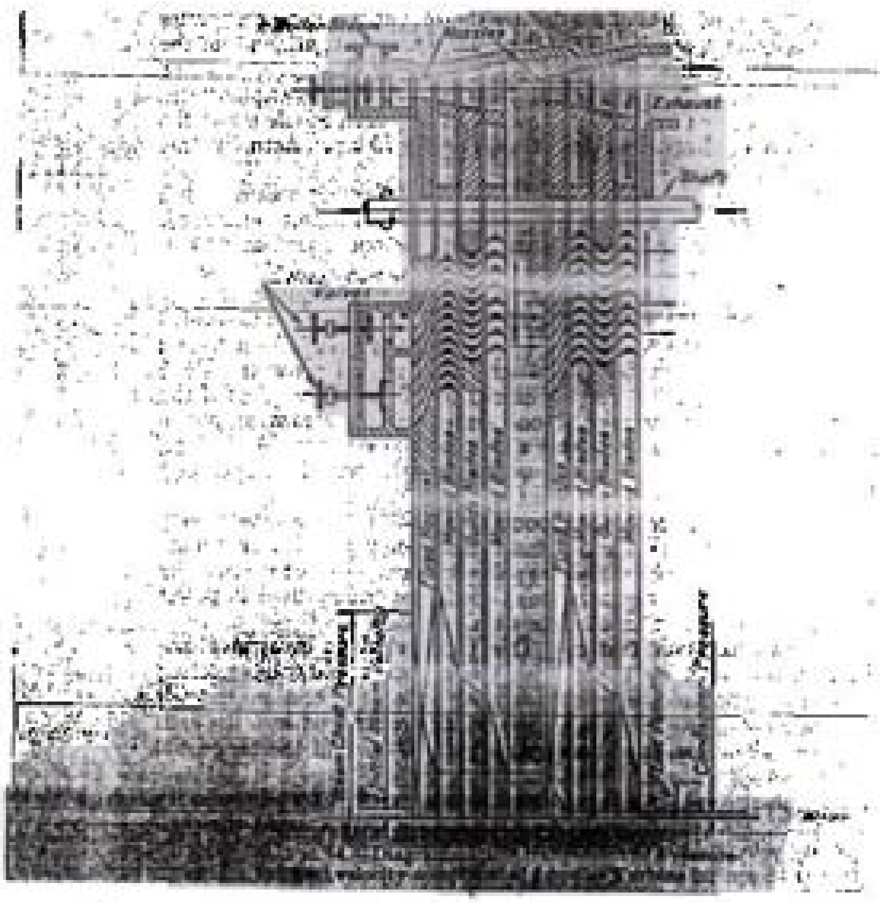


Figure (4)

Chapter 2: Steam boilers

1- Feed water treatment

1.1. introduction

The sources of the earth's water supply its rainfall. This initially pure water which is neutral in reaction (pH=7) passes through the atmosphere and absorbs Co_2 and O_2, the presence of Co_2 and other impurities cause it to become slightly acid. This slightly acidity causes it to dissolved certain rock and mineral deposits on the ground, as a result the water tends to lose its soft character and become hard. Therefore water available for supply to boiler contains many dissolved and dissolved impurities.

2.1. Impurities in water

The impurities present in the feed water are classified as given below:-

1- un dissolved and suspended materials (oil, mud, sand).
2- dissolved salts (calcium, magnesium, sodium).
3- dissolved gases (O_2, CO_2).

3.1. Effects of impurities;

1- Scale formation:- feed water is containing a group of impurities in dissolved and suspended form which flow into the boiler for continuous generation of steam. During the conversion of water into steam in boiler the solubility of dissolved salts (Ca, Mg) decreases with increase in temperature then salts and suspended impurities stay in boiler and form scale. Scale in boiler creates a problem because:
- the low degree of thermal conductivity (reduce rate of heat transfer).
- reduce the flow area and increase the pressure required to maintain the flow.
- cause over heating of tube material.

Note. Sodium salts are highly soluble in water and is non scale forming.

2- Corrosion: - the corrosion is the eating away pieces of piping and boiler metal and requires major repairs or expensive shut-down for replacement. The corrosion is caused due to acid present (low PH) in the water in the presence of CO_2 and O_2. The O_2 is carried with air which generally escapes into the condenser, the CO_2 is formed due to decomposition of bicarbonates in boiler and CO_2 combines with water to form weak acid known as carbonic acid. This slowly reacts with iron and other metals to form their bicarbonates which again decomposing and new CO_2 release and the cycle is repeated. The corrosion causes pitting and grooving on metal surface and reduces the strength of metal.

3- Foaming and priming (carry over) :- foaming is the formation of small stable bubbles in the boiler. The foam is caused in the boiler due to:

- dissolved and suspended impurities
- excess in alkalinity (high PH)
- excess in total dissolved solid (TDS)

Foaming prevents the free escape of steam from boiler and prevents its formation (decrease boiler efficiency). Priming is carry over small water particles with steam as it leaves the boiler and also some solid dissolved, this is undesirable as the contaminated steam is unsuitable for steam turbines. The priming (carry over) is appeared due to, foaming, (TDS), improper boiler design and improper firing method.

4- Caustic embrittlement:- the caustic embrittlement is the weak of boiler metal due to inner crack. This is caused by long exposure of boiler metal to alkaline water under high pressure, the presence of (NaoH) is most responsible for embrittlement.

The object of water treatment is to prevent scale forming on heating surfaces, prevent corrosion, caustic cracking and to enable clean steam to be produced.

1.4. <u>Methods of feed water treatment</u>

There are different methods for feed water treatment and the choice of method depends on many factors, as the composition of the water supply, the quantity of make-up water required, boiler

operating conditions and cost. These methods are classified as below:

1- External treatment
- mechanical for suspended impurities.
- chemical for dissolved salts.
- thermal for dissolved gases.

2- Internal treatment: chemical treatment for dissolved salts.
3- Conditioning treatment; chemical addition after external treatment.

1. External treatment:- if impurities remove from the water before supplying it to the boiler, then this method is known as external treatment which is classified as below:

a. Mechanical treatment

The suspended solid impurities are removed by this method which includes:

- sedimentation - coagulation - filtration.

Sedimentation involves allowing water to remain stand in big tanks, the solid matter settles down due to gravity and it is removed periodically. In coagulation system, some coagulant like aluminum soleplate adds to this to form colloidal which settles down quickly. The suspended solids which cannot remove by sedimentation and coagulation are removing by filtration.

b. Chemical treatment

The dissolved solids (salts) are removed by this method which is divided into:-

- lime-soda - ion exchange – demineralization

1- Lime-soda: - The object of this method is to add correct amount of lime and sodium carbonate (soda) to row water so that the calcium and magnesium salts are precipitated out of solution.

$$Ca\,(HCo_3) + Ca\,(oH)_2 \longrightarrow 2\,CaCo_3\downarrow + 2\,H_2o$$

$$Mg\,(HCo_3)_2 + Ca\,(oH)_2 \longrightarrow 2\,CaCo_3\downarrow + Mg\,(oH)_2\downarrow + 2\,H_2o$$

$$Mg\,So_4 + Ca\,(oH)_2 \longrightarrow Mg\,(oH)_2\downarrow + CaSo_4$$

$$CaSo_4 + Na_2\,Co_3 \longrightarrow Na_2So_4 + CaCo_3\downarrow$$

This method is usually considered unsuitable for water with a low initial hardness (up to 100 ppm).

2. Ion exchange (typical Na_2Z):- In this method the removed of hardness salts is achieved by interchanging them for other non-scale forming salts (sodium salts). The raw water passes through a bed of zeolite which has the property of exchanging its sodium ion for calcium and magnesium ions within the water,

$$Na_2Z + Ca\,(HCo_3)_2 \longrightarrow CaZ + 2\,NaHCo_3$$
$$Na_2Z + Ca\,So_4 \longrightarrow CaZ + 2\,Na_2So_4$$

The zeolite, in taking up the calcium and magnesium salts from the water, becomes saturated and needs to be regenerated and this is accomplished by stopping the flow of raw water and passing a strong solution of brine through the bed,

$$CaZ + 2\,NaCl \longrightarrow Na_2Z + CaCl_2$$

This method is more suitable for a raw water of law hardness, but because calcium and magnesium salts change to sodium salts in this process it is not recommended for treating water having high bicarbonate salts.

3. Demineralization: - This process results water having a high purity required for high pressure boiler. First the raw water is passed through a bed of hydrogen exchange (cat-ion) which has a property of converting all salts present in the water into the corresponding acids.

$$
\begin{array}{lcl}
RH^{+} + CaSo_4 & \longrightarrow & R\,Ca + HSo_4 \\
\quad MgCl_2 & & \quad Mg \quad Cl \\
\quad Ca(HCo_3) & & \qquad\quad Co_3
\end{array}
$$

The second phase is to pass the acidic water through a bed of acid-absorbing resin (an-ion) where acids are removed resulting in a softened water of negligible hardness,

$$
\begin{array}{lcl}
ROH^{-} + HSo_4 & \longrightarrow & R\,So_4 + H_2o \\
\qquad\quad Cl & & \; Cl
\end{array}
$$

For regenerate cat-ion,

$$
\begin{array}{lcl}
RNa + HCl & \longrightarrow & RH + CaCl \\
\; Ca & & \qquad Na \\
\; Mg & & \qquad Mg
\end{array}
$$

And for anion,

$$
\begin{array}{lcl}
RSo_4 + NaOH & \longrightarrow & ROH + NaSo_4 \\
\; Cl & & \qquad\qquad Cl
\end{array}
$$

c. Thermal treatment

The dissolved gases like O_2 and CO_2 in the water are removed by thermal treatment. The heating removes the dissolved gasses from the water as the gas absorption capacity of water decreases with increasing temperature. The device used for thermal treatment is the thermal or heat deaerator in which the temperature raises to saturated (boiling) temperature at a certain pressure.

2. Internal treatment

If the dissolved solids in the water are removed in the boiler itself by a chemical treatment, then this method is known as internal treatment. Internal treatment is generally confined to low pressure boiler operation and it is not recommended for water tube boiler. Internal treatment is accomplished by adding chemicals to the boiler water either to precipitate the impurities so that can be remove in the form of sludge or to convert them into salts which will stay in water and do not harm.

The common internal treatment used is:

a. Sodium carbonate treatment, the main disadvantage of this process it is lead to increase alkalinity very rapidly with an increase in pressure and temperature and also with increasing temperature and pressure the rate of generation of CO_2 increasing. For this reason the use of sodium carbonate is limited to boiler pressure of (10 bar).

b. sodium phosphate, for higher pressure boiler phosphate compounds are used instead of carbonate.

c. colloidal treatment, to remove the sludge formed effectively from the boiler.

d. blow down, the sludge formed from internal chemical treatment increases because there is continued addition of make-up water. Sludge become undesirable so it increases alkalinity and causes foaming and carry over, also (TDS) increase as chemical add which produce undesirable foaming and carry over, therefore some water having a high concentration of salts remove from the boiler by blow down system which is a valve connected to the lowest water space and replace by feed water of much lower solids.

3. Conditioning treatment

These terms imply treatment supplementary to that carried out on the water before feeding it into the boiler. This treatment is necessary since no external treatment regardless of efficiency can remove all harmful salts and gases. The injection of additional chemicals either into the feed water prior to its entering the boiler or into the boiler itself nullifies the effect of any residual hardness and corrosive elements present in the externally feed water. The chemicals are,

- sodium phosphate: to treat salts
- sodium sulfate, caustic soda: to treat corrosive element
- colloidal element: to condition sludge.

The blow down process is needed from time to time when these chemical add.