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BOILERS

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Abstract
Boilers are pivotal in numerous industrial and residential applications, providing the requisite thermal energy for a wide array of processes and heating applications. This study delves into the fundamental principles of boiler operation, highlighting the design considerations that influence efficiency and performance. We commence with an overview of boiler types, including fire-tube, water-tube, electric, and condensing boilers, each characterized by distinct advantages and suited for specific applications. The discussion extends to the thermodynamic principles underlying boiler operation, emphasizing the significance of heat transfer, combustion efficiency, and fuel types.
Moreover, the document addresses critical considerations in boiler maintenance and safety protocols, underscoring the importance of regular inspections, corrosion prevention, and the management of boiler feedwater. The exploration of technological advancements in boiler design reveals a trend towards energy efficiency and sustainability, including innovations in waste heat recovery, biomass boilers, and integration with renewable energy sources.The study also identifies the challenges and potential areas for improvement in boiler technology, such as emission reduction, scaling and fouling mitigation, and the adaptation of boilers for alternative fuels. The future of boiler technology is envisioned to align with global sustainability goals, focusing on enhancing efficiency, reducing environmental impact, and embracing smart technology for operation and maintenance.
This comprehensive review serves as a foundational resource for engineers, designers, and operators, offering insights into current practices and future directions in boiler technology. It aims to foster innovation and efficiency improvement in this essential field, contributing to the advancement of thermal systems and their sustainability.

Keywords: Energy efficiency, Smart technology, heat transfer, sustainability.

I. Introduction

A boiler is an enclosed vessel that provides a means for combustion heat to be transferred into water until it becomes heated water or steam. The hot water or steam under pressure is then usable for transferring the heat to a process. Water is a useful and cheap medium for transferring heat to a process. When water is boiled into steam its volume increases about 1,600 times, producing a force that is almost as explosive as gunpowder. This causes the boiler to be extremely dangerous equipment that must be treated with utmost care.
The process of heating a liquid until it reaches its gaseous state is called evaporation. Heat is transferred from one body to another by means of (1) radiation, which is the transfer of heat from a hot body to a cold body without a conveying medium, (2) convection, the transfer of heat by a conveying medium, such as air or water and (3) conduction, transfer of heat by actual physical contact, molecule to molecule.

1.1 Boiler Specification

The heating surface is any part of the boiler metal that has hot gases of combustion on one side and water on the other. Any part of the boiler metal that actually contributes to making steam is heating surface. The amount of heating surface of a boiler is expressed in square meters. The larger the heating surface a boiler has, the more efficient it becomes. The quantity of the steam produced is indicated in tons of water evaporated to steam per hour. Maximum continuous rating is the hourly evaporation that

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can be maintained for 24 hours. F & A means the amount of steam generated from water at 100 °C to saturated steam at 100 °C.

Typical Boiler Specification		
Boiler Make & Year	:	XYZ & 2003
MCR(Maximum Continuous Rating)	:	10TPH (F & A 100°C)
Rated Working Pressure	:	10.54 kg/cm^2(g)
Type of Boiler	:	3 Pass Fire tube
Fuel Fired	:	Fuel Oil

1.2 Indian Boiler Regulation

The Indian Boilers Act was enacted to consolidate and amend the law relating to steam boilers. Indian Boilers Regulation (IBR) was created in exercise of the powers conferred by section 28 & 29 of the Indian Boilers Act.

IBR Steam Boilers means any closed vessel exceeding 22.75 liters in capacity and which is used expressively for generating steam under pressure and includes any mounting or other fitting attached to such vessel, which is wholly, or partly under pressure when the steam is shut off.

IBR Steam Pipe means any pipe through which steam passes from a boiler to a prime mover or other user or both, if pressure at which steam passes through such pipes exceeds 3.5 kg/cm2 above atmospheric pressure or such pipe exceeds 254 mm in internal diameter and includes in either case any connected fitting of a steam pipe.

II. Literature

The boiler system comprises of: feed water system, steam system and fuel system. The **feed water system** provides water to the boiler and regulates it automatically to meet the steam demand. Various valves provide access for maintenance and repair. The **steam system** collects and controls the steam produced in the boiler. Steam is directed through a piping system to the point of use. Throughout the system, steam pressure is regulated using valves and checked with steam pressure gauges. The **fuel system** includes all equipment used to provide fuel to generate the necessary heat. The equipment required in the fuel system depends on the type of fuel used in the system. A typical boiler room schematic is shown in Figure 2.1.

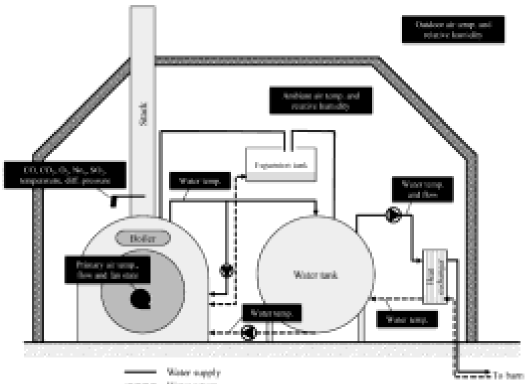

Figure 2.1 Boiler Room Schematic

The water supplied to the boiler that is converted into steam is called **feed water**. The two sources of feed water are: (1) **Condensate** or condensed steam returned from the processes and (2) **Makeup**

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water (treated raw water) which must come from outside the boiler room and plant processes. For higher boiler efficiencies, the feed water is preheated by economizer, using the waste heat in the flue gas.

2.1 Boiler Types and Classifications

There are virtually infinite numbers of boiler designs but generally they fit into one of two categories: **Fire tube** or "fire in tube" boilers; contain long steel tubes through which the hot gasses from a furnace pass and around which the water to be converted to steam circulates. (Refer Figure 2.2). Fire tube boilers, typically have a lower initial cost, are more fuel efficient and easier to operate, but they are limited generally to capacities of 25 tons/hr and pressures of 17.5 kg/cm2.

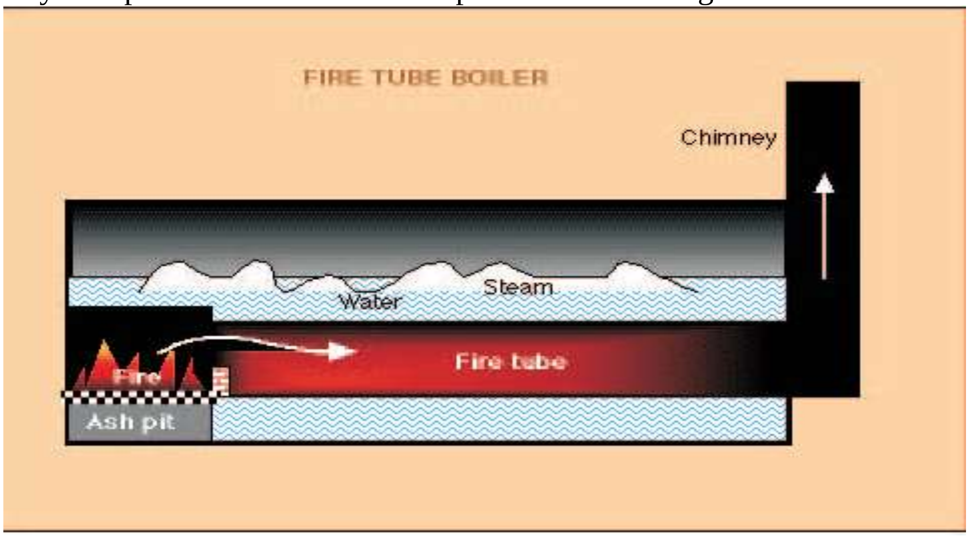

Figure 2.2 Fire Tube Boiler

Water tube or "water in tube" boilers in which the conditions are reversed with the water passing through the tubes and the hot gasses passing outside the tubes (see figure 2.3). These boilers can be of single- or multiple-drum type. These boilers can be built to any steam capacities and pressures, and have higher efficiencies than fire tube boilers.

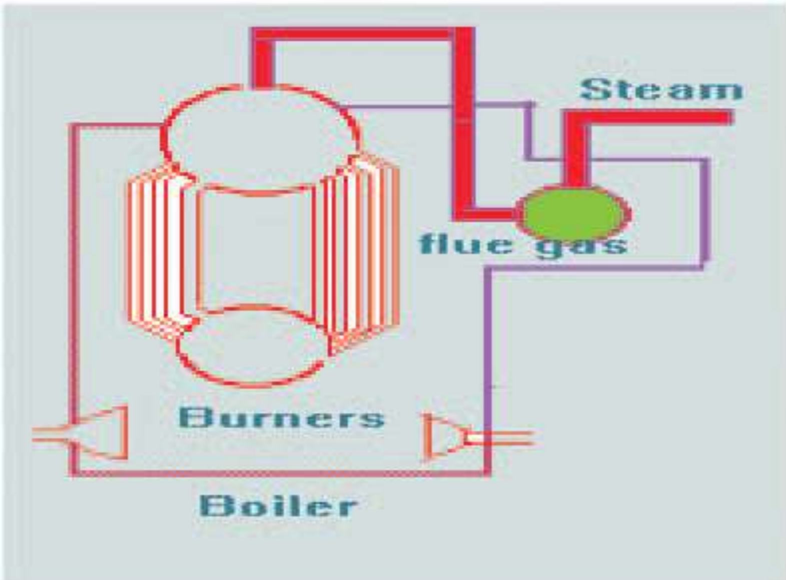

Figure 2.3 Water Tube Boiler

Packaged Boiler: The packaged boiler is so called because it comes as a complete package.Once delivered to site, it requires only the steam, water pipe work, fuel supply and electrical connections to be made for it to become operational. Package boilers are generally of shell type with fire tube design so as to achieve high heat transfer rates by both radiation and convection (Refer Figure 2.4).

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Figure 2.4 Packaged Boiler

The features of package boilers are:
_ Small combustion space and high heat release rate resulting in faster evaporation.
_ Large number of small diameter tubes leading to good convective heat transfer.
_ Forced or induced draft systems resulting in good combustion efficiency.
_ Number of passes resulting in better overall heat transfer.
_ Higher thermal efficiency levels compared with other boilers.

These boilers are classified based on the number of passes – the number of times the hot combustion gases pass through the boiler. The combustion chamber is taken, as the first pass after which there may be one, two or three sets of fire-tubes. The most common boiler of this class is a three-pass unit with two sets of fire-tubes and with the exhaust gases exiting through the rear of the boiler.

Stoker Fired Boiler:
Stokers are classified according to the method of feeding fuel to the furnace and by the type of grate. The main classifications are:
1. Chain-grate or traveling-grate stoker
2. Spreader stoker

Chain-Grate or Traveling-Grate Stoker Boiler
Coal is fed onto one end of a moving steel chain grate. As grate moves along the length of the furnace, the coal burns before dropping off at the end as ash. Some degree of skill is required, particularly when setting up the grate, air dampers and baffles, to ensure clean combustion leaving minimum of unburnt carbon in the ash.

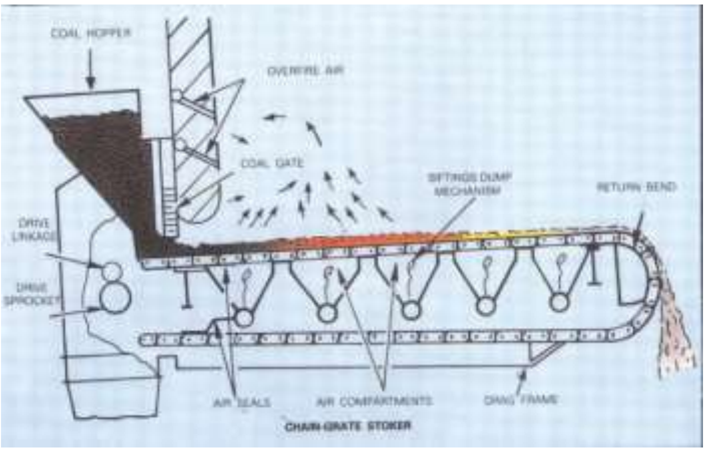

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Figure 2.5 Chain Grate Stoker

The coal-feed hopper runs along the entire coal-feed end of the furnace. Acoal grate is used to control the rate at which coal is fed into the furnace, and to control the thickness of the coal bed and speed of the grate. Coal must be uniform in size, as large lumps will not burn out completely by the time they reach the end of the grate. As the bed thickness decreases from coalfeed end to rear end, different amounts of air are required- more quantity at coal-feed end and less at rear end (see Figure 2.5).

Spreader Stoker Boiler

Spreader stokers (see figure 2.6) utilize a combination of suspension burning and grate burning. The coal is continually fed into the furnace above a burning bed of coal. The coal fines are burned in suspension; the larger particles fall to the grate, where they are burned in a thin, fastburning coal bed. This method of firing provides good flexibility to meet load fluctuations, since ignition is almost instantaneous when firing rate is increased. Hence, the spreader stoker is favored over other types of stokers in many industrial applications.

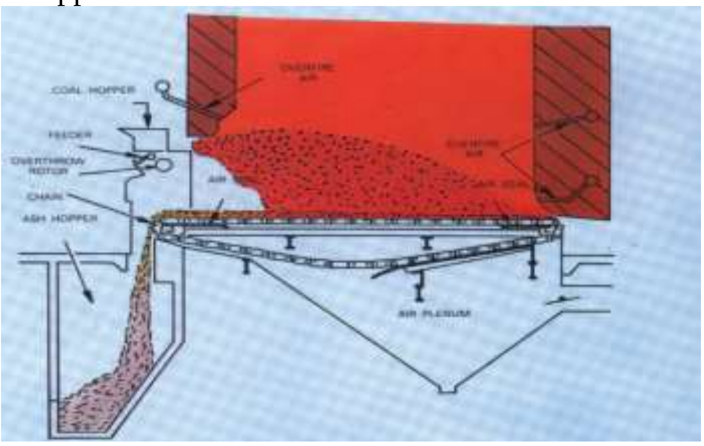

Figure 2.6 Spreader Stoker

Pulverized Fuel Boiler

Most coal-fired power station boilers use pulverized coal, and many of the larger industrial water-tube boilers also use this pulverized fuel. This technology is well developed, and there are thousands of units around the world, accounting for well over 90% of coal-fired capacity. The coal is ground (pulverised) to a fine powder, so that less than 2% is +300 micro metre (μm) and 70-75% is below 75 microns, for a bituminous coal. It should be noted that too fine a powder is wasteful of grinding mill power. On the other hand, too coarse a powder does not burn completely in the combustion chamber and results in higher unburnt losses. The pulverised coal is blown with part of the combustion air into the boiler plant through a series of burner nozzles. Secondary and tertiary air may also be added. Combustion takes place at temperatures from 1300-1700°C, depending largely on coal grade. Particle residence time in the boiler is typically 2 to 5 seconds, and the particles must be small enough for complete combustion to have taken place during this time. This system has many advantages such as ability to fire varying quality of coal, quick responses to changes in load, use of high pre-heat air temperatures etc. One of the most popular systems for firing pulverized coal is the tangential firing using four burners corner to corner to create a fireball at the center of the furnace (see Figure 2.7).

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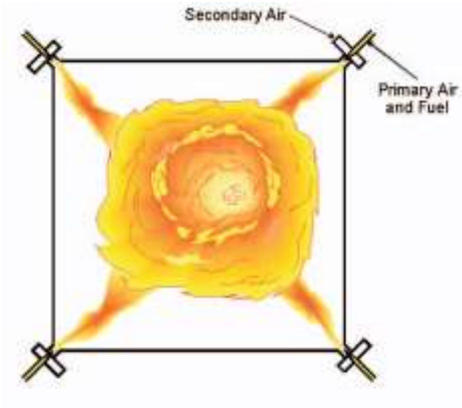

Figure 2.7 Tangential Firing

FBC Boiler

When an evenly distributed air or gas is passed upward through a finely divided bed of solid particles such as sand supported on a fine mesh, the particles are undisturbed at low velocity. As air velocity is gradually increased, a stage is reached when the individual particles are suspended in the air stream. Further, increase in velocity gives rise to bubble formation, vigorous turbulence and rapid mixing and the bed is said to be fluidized. If the sand in a fluidized state is heated to the ignition temperature of the coal and the coal is injected continuously in to the bed, the coal will burn rapidly, and the bed attains a uniform temperature due to effective mixing. Proper air distribution is vital for maintaining uniform fluidisation across the bed.). Ash is disposed by dry and wet ash disposal systems.

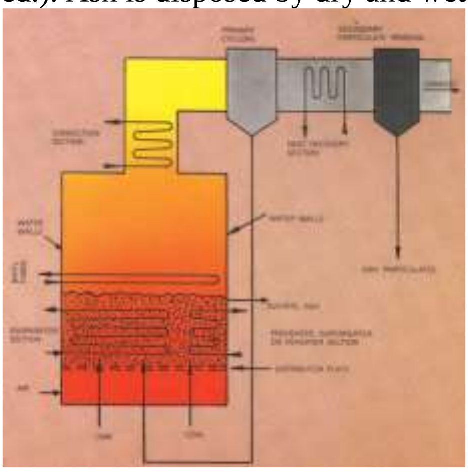

Figure 2.8 Fluidised Bed Combustion

Fluidised bed combustion has significant advantages over conventional firing systems and offers multiple benefits namely fuel flexibility, reduced emission of noxious pollutants such as SOx and NOx, compact boiler design and higher combustion efficiency. More details about FBC boilers are given in Chapter 6 on Fluidized Bed Boiler.

2.2 Performance Evaluation of Boilers

The performance parameters of boiler, like efficiency and evaporation ratio reduces with time due to poor combustion, heat transfer surface fouling and poor operation and maintenance.
Even for a new boiler, reasons such as deteriorating fuel quality, water quality etc. can result in poor boiler performance. Boiler efficiency tests help us to find out the deviation of boiler efficiency from the best efficiency and target problem area for corrective action.

Boiler Efficiency

Thermal efficiency of boiler is defined as the percentage of heat input that is effectively utilised

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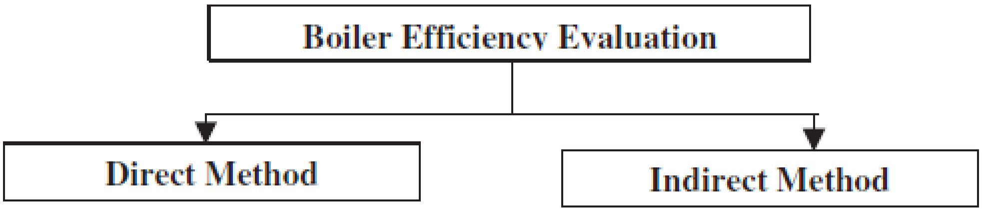
to generate steam. There are two methods of assessing boiler efficiency.

A) The Direct Method: Where the energy gain of the working fluid (water and steam) is compared with the energy content of the boiler fuel.

B) The Indirect Method: Where the efficiency is the difference between the losses and the energy input.



A. Direct Method

This is also known as 'input-output method' due to the fact that it needs only the useful output (steam) and the heat input (i.e. fuel) for evaluating the efficiency. This efficiency can be evaluated using the formula

$$Boiler\ Efficiency = \frac{Heat\ Output}{Heat\ Input} \times 100$$

Advantages of direct method:

_ Plant people can evaluate quickly the efficiency of boilers
_ Requires few parameters for computation
_ Needs few instruments for monitoring

Disadvantages of direct method:

_ Does not give clues to the operator as to why efficiency of system is lower
_ Does not calculate various losses accountable for various efficiency levels

B. Indirect Method

There are reference standards for Boiler Testing at Site using indirect method namely British Standard, BS 845: 1987 and USA Standard is ASME PTC-4-1 Power Test Code Steam Generating Units'.
Indirect method is also called as heat loss method. The efficiency can be arrived at, by subtracting the heat loss fractions from 100. The standards do not include blow down loss in the efficiency determination process.

2.3 Boiler Blowdown

When water is boiled and steam is generated, any dissolved solids contained in the water remain in the boiler. If more solids are put in with the feed water, they will concentrate and may eventually reach a level where their solubility in the water is exceeded and they deposit from the solution. Above a certain level of concentration, these solids encourage foaming and cause carryover of water into the steam. The deposits also lead to scale formation inside the boiler, resulting in localized overheating and finally causing boiler tube failure.
It is, therefore, necessary to control the level of concentration of the solids and this is achieved by the process of 'blowing down', where a certain volume of water is blown off and is automatically replaced by feed water – thus maintaining the optimum level of total dissolved solids (TDS) in the boiler water. Blow down is necessary to protect the surfaces of the heat exchanger in the boiler. However, blow down can be a significant source of heat loss, if improperly carried out. The maximum amount of total dissolved solids (TDS) concentration permissible in various types of boilers is given in Table 2.

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TABLE 2.1 RECOMMENDED TDS LEVELS FOR VARIOUS BOILERS		
	Boiler Type	Maximum TDS (ppm)*
1.	Lancashire	10,000 ppm
2.	Smoke and water tube boilers (12 kg/cm^2)	5,000 ppm
3.	Low pressure Water tube boiler	2000–3000
4.	High Pressure Water tube boiler with superheater etc.	3,000–3,500 ppm
5.	Package and economic boilers	3,000 ppm
6.	Coil boilers and steam generators	2000 (in the feed water

Note: Refer guidelines specified by manufacturer for more details
*parts per million

1.

Conductivity as Indicator of BoilerWater Quality

Since it is tedious and time consuming to measure total dissolved solids (TDS) in boiler water system, conductivity measurement is used for monitoring the overall TDS present in the boiler. A rise in conductivity indicates a rise in the “contamination” of the boiler water. Conventional methods for blowing down the boiler depend on two kinds of blowdown –intermittent and continuous

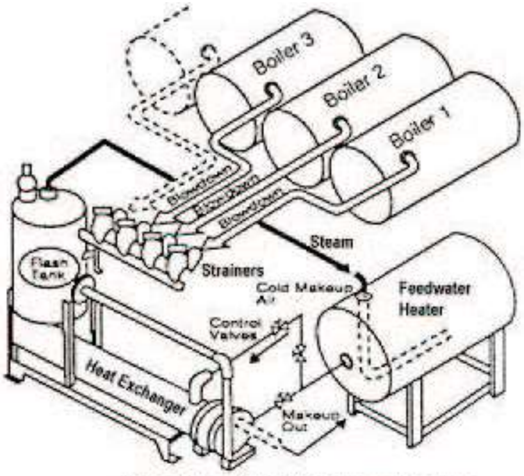
Intermittent Blowdown

The intermittent blown down is given by manually operating a valve fitted to discharge pipe at the lowest point of boiler shell to reduce parameters (TDS or conductivity, pH, Silica and Phosphates concentration) within prescribed limits so that steam quality is not likely to be affected. In intermittent blowdown, a large diameter line is opened for a short period of time, the time being based on a thumb rule such as “once in a shift for 2 minutes”.

Intermittent blowdown requires large short-term increases in the amount of feed water put into the boiler, and hence may necessitate larger feed water pumps than if continuous blow down is used. Also, TDS level will be varying, thereby causing fluctuations of the water level in the boiler due to changes in steam bubble size and distribution which accompany changes in concentration of solids. Also substantial amount of heat energy is lost with intermittent blowdown.

Continuous Blowdown

There is a steady and constant dispatch of small stream of concentrated boiler water, and replacement by steady and constant inflow of feed water. This ensures constant TDS and steam purity at given steam load. Once blow down valve is set for a given conditions, there is no need for regular operator intervention.



Blowdown Heat Recovery System

Even though large quantities of heat are wasted, opportunity exists for recovering this heat by blowing into a flash tank and generating flash steam. This flash steam can be used for preheating boiler feed water or for any other purpose (see Figure 2.9 for blow down heat recovery system). This type of blow down is common in high-pressure boilers.

Benefits of Blowdown

Good boiler blow down control can significantly reduce treatment and operational costs that include:

– Lower pretreatment costs
– Less make-up water consumption
– Reduced maintenance downtime
– Increased boiler life
– Lower consumption of treatment chemicals

2.4 BoilerWater Treatment

Producing quality steam on demand depends on properly managed water treatment to control steam purity, deposits and corrosion. A boiler is the sump of the boiler system. It ultimately receives all of the pre-boiler contaminants. Boiler performance, efficiency, and service life are direct products of selecting and controlling feed water used in the boiler.

When feed water enters the boiler, the elevated temperatures and pressures cause the components of water to behave differently. Most of the components in the feed water are soluble. However, under heat and pressure most of the soluble components come out of solution as particulate solids, sometimes in crystallized forms and other times as amorphous particles. When solubility of a specific component in water is exceeded, scale or deposits develop. The boiler water must be sufficiently free of deposit forming solids to allow rapid and efficient heat transfer and it must not be corrosive to the boiler metal.

Deposit Control

Deposits in boilers may result from hardness contamination of feed water and corrosion products from the condensate and feed water system. Hardness contamination of the feed water may arise due to deficient softener system.

Deposits and corrosion result in efficiency losses and may result in boiler tube failures and inability to produce steam. Deposits act as insulators and slows heat transfer. Large amounts of deposits throughout the boiler could reduce the heat transfer enough to reduce the boiler efficiency significantly. Different type of deposits affects the boiler efficiency differently. Thus it may be useful to analyse the deposits for its characteristics. The insulating effect of deposits causes the boiler metal temperature to rise and may lead to tube-failure by overheating.

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Impurities Causing Deposits

The most important chemicals contained in water that influences the formation of deposits in the boilers are the salts of calcium and magnesium, which are known as hardness salts. Calcium and magnesium bicarbonate dissolve in water to form an alkaline solution and these salts are known as alkaline hardness. They decompose upon heating, releasing carbon dioxide and forming a soft sludge, which settles out. These are called temporary hardness-hardness that can be removed by boiling.

Calcium and magnesium sulphates, chlorides and nitrates, etc. when dissolved in water are chemically neutral and are known as non-alkaline hardness. These are called permanent hardness and form hard scales on boiler surfaces, which are difficult to remove. Non-alkalinity hardness chemicals fall out the solution due to reduction in solubility as the temperature rises, by concentration due to evaporation which takes place within the boiler, or by chemical change to a less soluble compound.

Silica

The presence of silica in boiler water can rise to formation of hard silicate scales. It can also associate with calcium and magnesium salts, forming calcium and magnesium silicates of very low thermal conductivity. Silica can give rise to deposits on steam turbine blades, after been carried over either in droplets of water in steam, or in volatile form in steam at higher pressures. Two major types of boiler water treatment are: Internal water treatment and External water treatment.

Internal Water Treatment

Internal treatment is carried out by adding chemicals to boiler to prevent the formation of scale by converting the scale-forming compounds to free-flowing sludges, which can be removed by blowdown. This method is limited to boilers, where feed water is low in hardness salts, to low pressures- high TDS content in boiler water is tolerated, and when only small quantity of water is required to be treated. If these conditions are not applied, then high rates of blowdown are required to dispose off the sludge. They become uneconomical from heat and water loss consideration. Different waters require different chemicals. Sodium carbonate, sodium aluminate, sodium phosphate, sodium sulphite and compounds of vegetable or inorganic origin are all used for this purpose. Proprietary chemicals are available to suit various water conditions. The specialist must be consulted to determine the most suitable chemicals to use in each case. Internal treatment alone is not recommended.

External Water Treatment

External treatment is used to remove suspended solids, dissolved solids (particularly the calcium and magnesium ions which are a major cause of scale formation) and dissolved gases (oxygen and carbon dioxide).

The external treatment processes available are: ion exchange; demineralization; reverse osmosis and de-aeration. Before any of these are used, it is necessary to remove suspended solids and colour from the raw water, because these may foul the resins used in the subsequent treatment sections.

Methods of pre-treatment include simple sedimentation in settling tanks or settling in clarifiers with aid of coagulants and flocculants. Pressure sand filters, with spray aeration to remove carbon dioxide and iron, may be used to remove metal salts from bore well water.

The first stage of treatment is to remove hardness salt and possibly non-hardness salts. Removal of only hardness salts is called softening, while total removal of salts from solution is called demineralization.

The processes are:

Ion-exchange process (Softener Plant)

In ion-exchange process, the hardness is removed as the water passes through bed of natural zeolite or synthetic resin and without the formation of any precipitate. The simplest type is 'base exchange' in

which calcium and magnesium ions are exchanged for sodium ions. After saturation regeneration is done with sodium chloride. The sodium salts being soluble, do not form scales in boilers. Since base exchanger only replaces the calcium and magnesium with sodium, it does not reduce the TDS content, and blowdown quantity. It also does not reduce the alkalinity.
Softening reaction:
Na2R + Ca(HCO3)2 « CaR + 2 Na(HCO3)
Regeneration reaction
CaR + 2 NaCl « Na2R + CaCl2
Demineralization is the complete removal of all salts. This is achieved by using a "cation" resin, which exchanges the cations in the raw water with hydrogen ions, producing hydrochloric, sulphuric and carbonic acid. Carbonic acid is removed in degassing tower in which air is blown through the acid water. Following this, the water passes through an "anion" resin which exchanges anions with the mineral acid (e.g. sulphuric acid) and forms water.
Regeneration of cations and anions is necessary at intervals using, typically, mineral acid and caustic soda respectively. The complete removal of silica can be achieved by correct choice of anion resin. Ion exchange processes can be used for almost total demineralization if required, as is the case in large electric power plant boilers

De-aeration
In de-aeration, dissolved gases, such as oxygen and carbon dioxide, are expelled by preheating the feed water before it enters the boiler. All natural waters contain dissolved gases in solution. Certain gases, such as carbon dioxide and oxygen, greatly increase corrosion. When heated in boiler systems, carbon dioxide (CO2) and oxygen (O2) are released as gases and combine with water (H2O) to form carbonic acid, (H2CO3). Removal of oxygen, carbon dioxide and other non-condensable gases from boiler feedwater is vital to boiler equipment longevity as well as safety of operation. Carbonic acid corrodes metal reducing the life of equipment and piping. It also dissolves iron (Fe) which when returned to the boiler precipitates and causes scaling on the boiler and tubes. This scale not only contributes to reducing the life of the equipment but also increases the amount of energy needed to achieve heat transfer. De-aeration can be done by mechanical de-aeration, by chemical de-deration or by both together.

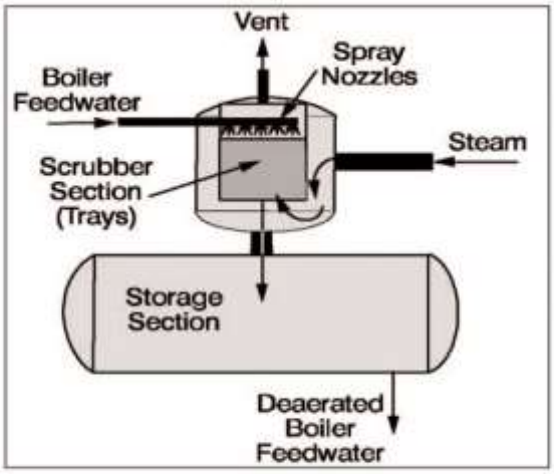

Figure 2.10 Deaerator

Mechanical de-aeration
Mechanical de-aeration for the removal of these dissolved gases is typically utilized prior to the addition of chemical oxygen scavengers. Mechanical de-aeration is based on Charles' and Henry's laws of physics. Simplified, these laws state that removal of oxygen and carbon dioxide can be

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accomplished by heating the boiler feed water, which reduces the concentration of oxygen and carbon dioxide in the atmosphere surrounding the feed water. Mechanical de-aeration can be the most economical. They operate at the boiling point of water at the pressure in the deaerator.

They can be of vacuum or pressure type.
The vacuum type of de-aerator operates below atmospheric pressure, at about 82 °C, can reduce the oxygen content in water to less than 0.02 mg/litre. Vacuum pumps or steam ejectors are required to maintain the vacuum.
The pressure-type de-aerators operates by allowing steam into the feed water through a pressure control valve to maintain the desired operating pressure, and hence temperature at a minimum of 105 °C. The steam raises the water temperature causing the release of O2 and CO2 gases that are then vented from the system. This type can reduce the oxygen content to 0.005 mg/litre.
Where excess low-pressure steam is available, the operating pressure can be selected to make use of this steam and hence improve fuel economy. In boiler systems, steam is preferred for de-aeration because:
– Steam is essentially free from O2 and CO2,
– Steam is readily available
– Steam adds the heat required to complete the reaction.

Chemical de-Aeration
While the most efficient mechanical deaerators reduce oxygen to very low levels (0.005 mg/litre), even trace amounts of oxygen may cause corrosion damage to a system.
Consequently, good operating practice requires removal of that trace oxygen with a chemical oxygen scavenger such as sodium sulfite or hydrazine. Sodium sulphite reacts with oxygen to form sodium sulphate, which increases the TDS in the boiler water and hence increases the blowdown requirements and make-up water quality. Hydrazine reacts with oxygen to form nitrogen and water. It is invariably used in high pressures boilers when low boiler water solids are necessary, as it does not increase the TDS of the boiler water.

Reverse Osmosis
Reverse osmosis uses the fact that when solutions of differing concentrations are separated by a semi-permeable membrane, water from less concentrated solution passes through the membrane to dilute the liquid of high concentration. If the solution of high concentration is pressurized, the process is reversed and the water from the solution of high concentration flows to the weaker solution.
This is known as reverse osmosis. The quality of water produced depends upon the concentration of the solution on the high-pressure side and pressure differential ascross the membrane.
This process is suitable for waters with very high TDS, such as sea water.

Recommended boiler and feed water quality
The impurities found in boiler water depend on the untreated feed water quality, the treatment process used and the boiler operating procedures. As a general rule, the higher the boiler operating pressure, the greater will be the sensitivity to impurities. Recommended feed water and boiler water limits are shown in Table 2.2 and Table 2.3.

TABLE 2.2 RECOMMENDED FEED WATER LIMITS			
Factor	Upto 20 kg/cm²	21 – 39 kg/cm²	41 – 59 kg/cm²
Total iron (max) ppm	0.05	0.02	0.01
Total copper (max) ppm	0.01	0.01	0.01
Total silica (max) ppm	1.0	0.3	0.1
Oxygen (max) ppm	0.02	0.02	0.01
Hydrazine residual ppm	–	–	-0.02-0.04
pH at 25°C	8.8-9.2	8.8-9.2	8.2-9.2
Hardness, ppm	1.0	0.5	–

TABLE 2.3 RECOMMENDED BOILER WATER LIMITS (IS 10392, YEAR 1982)			
Factor	Upto 20 kg/cm²	21 – 39 kg/cm²	40 – 59 kg/cm²
TDS, ppm	3000–3500	1500–2500	500–1500
Total iron dissolved solids ppm	500	200	150
Specific electrical conductivity at 25°C (mho)	1000	400	300
Phosphate residual ppm	20-40	20-40	15-25
pH at 25°C	10–10.5	10–10.5	9.8–10.2
Silica (max) ppm	25	15	10

III. Conclusion

Throughout this investigation into boiler technology, we have traversed the expansive landscape of boiler design, operation, efficiency, and the pivotal role boilers play in industrial, commercial, and residential settings. From the fundamental principles governing their functionality to the intricate details of their types and applications, it is clear that boilers constitute an indispensable component of modern thermal systems, facilitating essential processes and comfort.

Our examination revealed that, despite their long-standing presence in our industries and homes, boilers continue to evolve, driven by an unyielding pursuit of efficiency, reliability, and environmental sustainability. Innovations in boiler design, such as the development of ultra-efficient condensing boilers and the integration of renewable energy sources, exemplify the sector's commitment to reducing carbon footprints and operational costs. Moreover, the exploration of alternative fuels and advanced combustion techniques presents a promising avenue for future developments, potentially revolutionizing how boilers contribute to energy systems worldwide.

However, challenges remain, particularly in areas such as emissions control, scaling, and efficiency losses. Addressing these issues requires a multidisciplinary approach, combining advancements in materials science, chemistry, and engineering, with an emphasis on sustainability and environmental protection. The adoption of smart technologies and IoT integration into boiler systems also emerges as a key strategy for enhancing operational efficiency, predictive maintenance, and user interface, setting a course towards more autonomous and user-friendly thermal systems.

In conclusion, as we stand on the cusp of a new era in boiler technology, it is imperative that continued research, innovation, and collaboration drive our efforts. By embracing the challenges and opportunities that lie ahead, we can ensure that boilers will remain a cornerstone of energy systems, evolving to meet the demands of the 21st century and beyond. The future of boiler technology, while rooted in its rich history, is poised for a revolution, promising enhanced performance, sustainability, and adaptability in an ever-changing world.

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