

CHAPTER ONE

INTRODUCTION

1.1 Introduction:

The boiler tube failure is occurring frequently in fertilizer plants, power plants, sugar manufacturing plants, paper manufacturing plants and all industries using boilers. The function of the boiler is to convert water into superheated steam, which is then delivered to turbine to generate electricity [1]. Pulverized coal is the common fuel used in boiler along with preheated air. The boiler consists of different critical components like economizer, water wall, and super heater and re heater tubes.

Failure of tubes in boiler of the power plants may occur due to various reasons. These include failures due to creep, corrosion, erosion, overheating and a host of other reasons. This project deals with the probable cause(s) of failure and also suggests remedial action to prevent similar repetitive failure in future. Visual examination, dimensional measurement, chemical analysis (Chemical Composition examination), oxide scale thickness measurement and micro structural examination, and Mechanical Properties measurement (Tensile Test, Torsion Test), also use Bore scopes Examination. Were carried to ascertain the probable cause(s) of failure of inner leg of platen super heater tube, and economizer, and water wall of boiler. It was observed that the inner surface of the failed portion of the tube was covered with a white deposit. The elemental composition of inner surface containing adherent deposits reveals Fe, Si, Mg, Al etc. This is possibly due to the presence of aluminum silicate, magnesium silicate, and calcium Silicate in inner surface of the tube, which results in poor conductivity. Insulating effect of this poor conductive deposit on the inner surface caused localized overheating of tube metal leading to accelerated creep damage and premature failure of the Tube. Inferior quality of de-superheated spray water used to control the steam temperature was identified as the source of white deposit [2].

1.2 Problem statement:

As the life of the boiler tube reaches its limit, failure such as rupture will occur. Since the boiler is operated at elevated temperature and pressure, any tube rupture will definitely cause major physical damages to the nearby tubes and the boiler's water wall, these lead to: A higher repair cost, an increase in the water consumption, and so increased operating costs of the power station (KNPPS). In some extreme cases, it may also threaten human's life due to the high pressure explosion Therefore, it is important to carry out a proper study in order to minimize such problems.

1.3 Objective of study:

The objective of this study is to analysis and determines:

- To determine the effect & causes of boiler tube failures on efficiency of plant (KNPPS).
- To determine the mechanical properties of the tubes use in boiler.
- How to detect& protection boiler tubes, and control of boiler tube leakage.

1.4 Scope:

The study Scope investigates the causes of the leakages in the boiler tubes. The main concern is to minimize the leakages and if possible find alternative materials that can be used as substitute materials for boiler and super-heater tubes.

1.5 Significance of Research:

The significance of this study as follows:

1. This study will assist thermal power plants using boilers, how detect boilers tubes from difference problems, for avoid losses availability and

generation due to forced outage of plant, and also minimize the cost of the repair.

2. Boiler tube failure to be the leading cause of forced outage in fossil fired boilers. This study to get your boiler back online and reduce or eliminate future forced outages due to tube failure, it is extremely important to determine and correct the root cause. Experience shows that a comprehensive assessment is the most effective method of determining the root cause of a failure.

1.6 Thesis outline:

The general outline of the thesis is as follows:

- General background, problem statement, objective of study, scope and significance of study (chapter one).
- Literature review consist from general historical background for boilers of thermal power plant types, classification, steam generation and review of Causes and Boilers Typical Failure mechanisms also review Current Studies on Boiler tube failure(chapter two).
- This chapter Explain methodology and Experimental methods used up in this study, In order to compare the difference in the material properties, and behavior of boiler tube, for reveal causes and types of tube failures occurs in (KNPPS), (chapter three).
- Results and discussions, Effect of boiler tubes failure on efficiency of plant (chapter four).
- General conclusions drawn from the study and Recommendations including how the study results could be used, possible improvements in the present work, and potential areas of future work (chapter five).

CHAPTER TWO
LITERATURE REVIEW

2.1 preface:

Thermal power plant plays a vital role in our daily life. The power demand is increasing day by day due to increasing the population and consumption. The power is required for Industrialization and development of nation. Our country mainly depends on thermal power plant for electrical supply. In thermal power plants boiler is considered to be HEART of the plant. Maintained required condenser parameters to improve the performance of boiler and these parameters direct impact the economical growth of power plant. Thermal power plant boiler is one of the critical equipment for the power generation industries. In the present situation of power generation, pulverized coal fired power stations are the backbones of industrial development in the country, thus necessitating their maximum availability in terms of plant load factor (PLF). At the same time reliability and safety aspect is also to be considered. The major percentage of the forced shutdown of the power stations is from boiler side. So it is necessary to predict the probable root cause/causes of the forced outages and also the remedial action to prevent the recurrence of similar failure in future. A drum type utility Boiler for thermal power generation typically consists of different pressure parts tubes like water wall, economizer, super heater and re heater [1]. Different damage mechanism like creep, fatigue, erosion and corrosion are responsible of the different pressure parts tube failure.

Successful, reliable operation of steam generation equipment requires the application of the best available methods to prevent scale and corrosion. When equipment failures do occur, it is important that the cause of the problem be correctly identified so that proper corrective steps can be taken to prevent a recurrence. An incorrect diagnosis of a failure can lead to improper corrective measures; thus, problems continue.

2.2 Plant Location:

The Khartoum North power plant station is located in industrial area district in Khartoum, Sudan it started to produce power in year 1985. The power plant has a total installed power capacity of 380MW; (six units steam turbine), the plant composed of three stages, first stage (phase 1) has been two units 30MW for each one, beginning of start operation in year 1985, while second stage (Phase 2) also has two units 60MW for each unit start operation in year 1994, and third stage nominates (Phase 3) has two units 100MW for each unit installing in year 2005. The power plant uses two type fuel, Furness, Heavy Fuel Oil (**HFO**) and Heavy-Cock gas oil (**HCGO**) which is obtained from refinery of Alobied and Aljaily refinery by tow way, Road Tankers and Railway Tankers, The total fuel consumption in the day about more than (2000tons/24hr).



Figure 2.1: Khartoum North Power Plant Station.

Table2.1:ph1&ph2&ph3 Boiler Data of (KNPPS)

Item	Phase1(ph1)	Phase2(ph2)	Phase3(ph3)
Boilers Manufacture	NEI, International combustion LTD.	WAAGNER BIRO	WUHAN BOILER
Boilers Type	VU 60	ETS	WGZ420/9.8-1
Boilers MCR	136ton/hr.	243ton/hr.	420t/h.
Steam Pressure out	64.9Bar	90Bar	98Bar
Steam Temperature out	488C	515C	540C
Number of Oil Burner	4	6	8
Number of Safety valve	3	4	6
Type of Fuel Oil	HFO,HCGO	HFO,HCGO	HFO,HCGO
Economizer	Not available	YES	YES
Super heater	Primary& secondary super heater.	Primary& Secondary super heater.	6(Roof, Back pass, Primary, Platen, Third and Final Super heater).

*(KNPS manual)

2.3Layout of Thermal Power Plant:

A thermal power plant is a system that produces electrical energy by utilizing the fossil fuels as a major raw Material a basic layout of the power plant is depicted below:

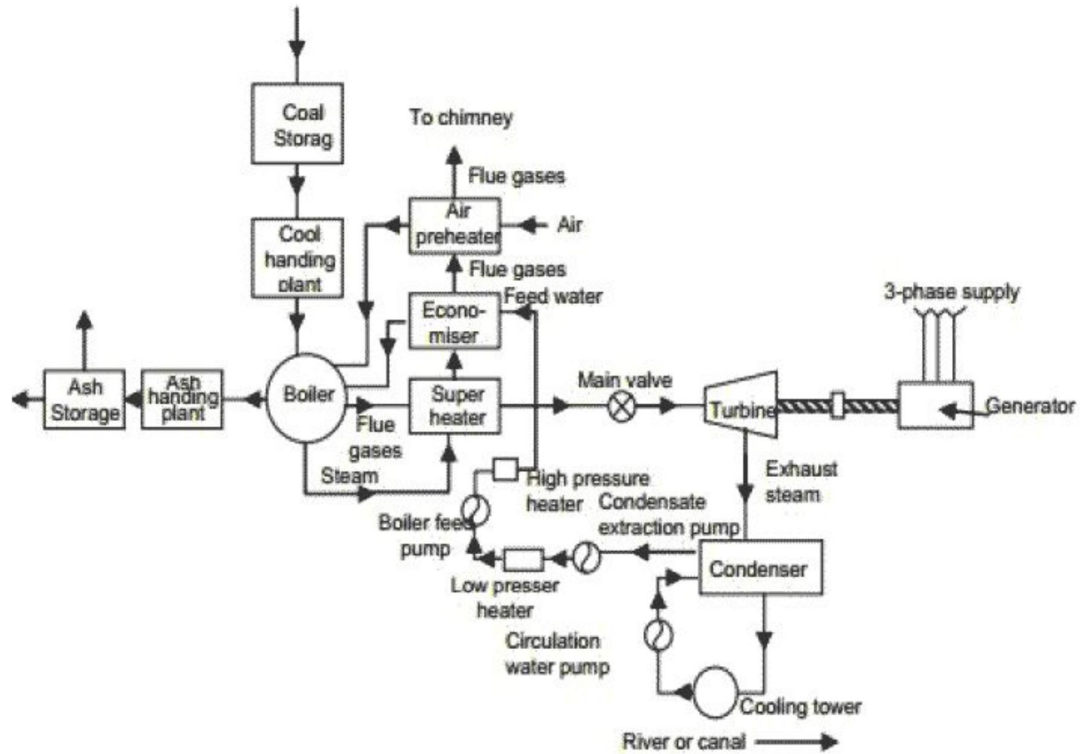


Figure2.2: Line Diagram of Different Components of Thermal Power Plant [2].

2.4Boiler definition:

Boiler (or steam generator, as it is commonly called) is a closed Vessel in which water, under pressure, is transformed into steam by the application of heat. One of the important components in this cycle is Boiler which is the second tallest element after the chimney. These are closed vessel in which chemical energy of fuel is utilized to increase energy content of water to further use it for heating and power applications [3]. According to A.S.M.E. a boiler is a steam generating unit which is a combination of apparatus for producing and recovering heat together with transferring it to the working fluid to be heated. The vaporized working fluid being used to run the turbines which are connected to the generators to produce power and the electricity is thus supplied to the grid.

2.5 Boilers Type and Classification:

The boilers used in the industries are classified on the following basis:

1. On the basis of axis of boiler:

(i) Horizontal (ii) Vertical (iii) Inclined

2. On the basis of passage through boiler tubes:

(i) Water Tube Boiler (ii) Fire Tube Boiler

3. On the basis of method of fabrication [3]:

(i) Packaged Boilers (ii) Shop-Assembled Boilers

4. On the basis of nature of fuel source used:

(i) Gas-fired Boilers (ii) Oil-Fired Boilers (iii) Solid Fuel Fired Boilers

5. On the basis of working pressure of:

(i) Low pressure Boilers (ii) High pressure Boilers

6. On the basis of circulation method:

(i) Natural circulation (ii) Forced Circulation

2.5.1 Fire tube or (*fire in tube boilers*):

Contains long steel tubes through which the hot gasses from a furnace pass and around which the water to be converted to steam circulates. Fire tube boilers typically have lower initial cost, are more fuel efficient and easier to operate , but they are limited generally to capacities of 25ton/hr. and pressure of 17.5kg/cm².

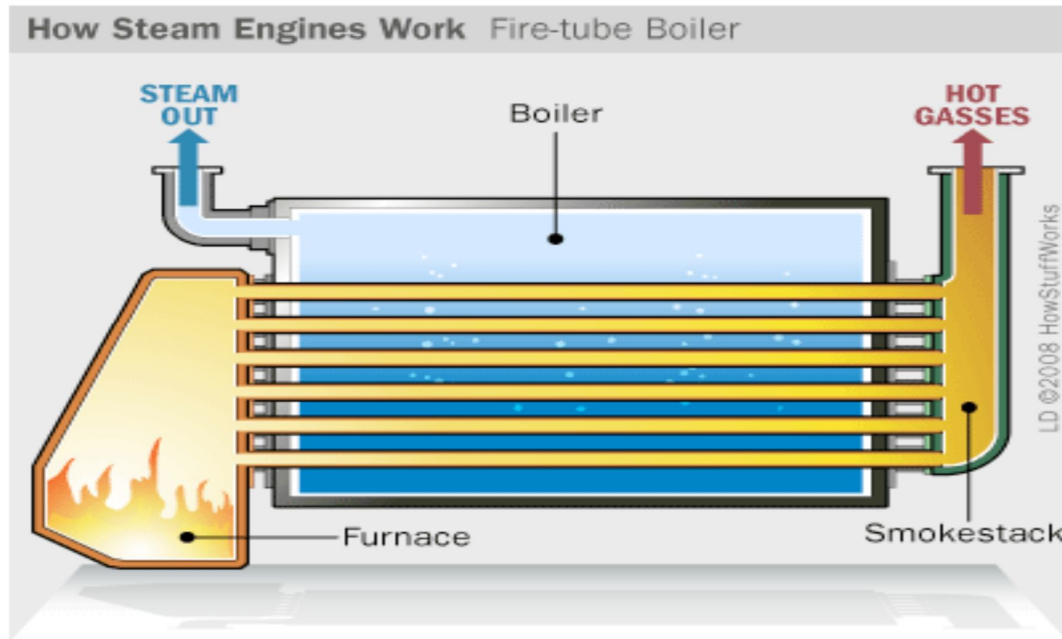


Figure2.3: Diagram of Fire tube boilers [3].

2.5.2 Water tube or (*water in tube boilers*):

In which the condition is reversed with the water passing through the tubes and the gasses passing outside the tubes. These boilers can be of single-or multiple-drum type .these boilers can be built to any steam capacities and pressure, and have higher efficiencies than fire tube boiler.

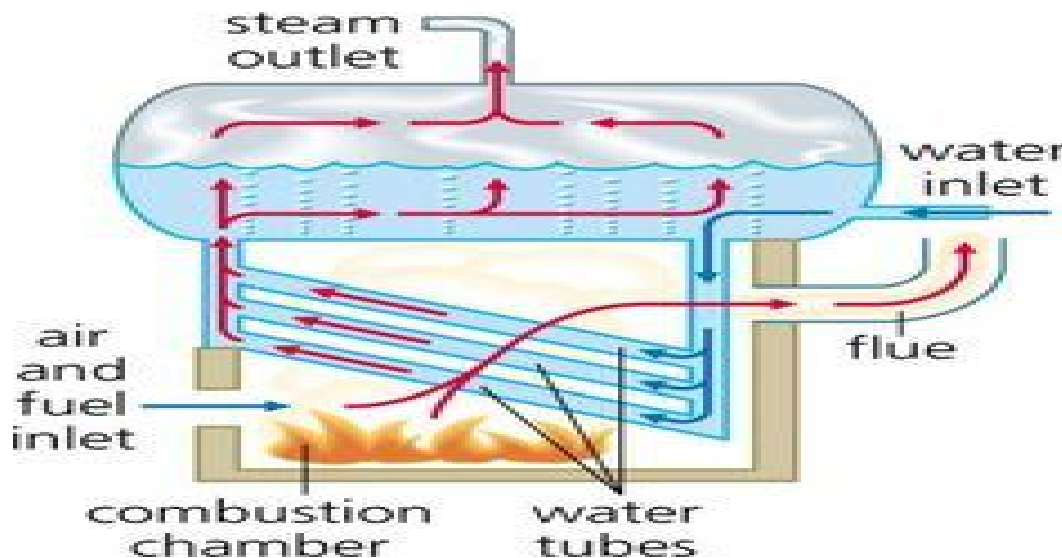


Figure2.4: Diagram of Water tube boiler [3].

2.6 Principles of Heat Transfer:

The design of a furnace and boiler is largely related to heat transfer. Heat flows from one body to another by virtue of a temperature difference, and it always flows in the direction of higher temperature to lower temperature. This heat flow takes place through the use of one or more of three methods: conduction, convection, and radiation boiler should be designed to absorb the maximum amount of heat released in the process of Combustion, the percentage of each depending on the boiler design.

2.6.1 Radiant heat:

Is heat radiated from a hot to a cold body and depends on the temperature difference and the color of the body that receives the heat. Absorption of radiant heat increases with the furnace temperature and depends on many factors but primarily on the area of the tubes exposed to the heat.

2.6.2 Conduction heat:

Is heat that passes from the gas to the tube by physical contact the heat passes from molecule of metal to molecule of metal with no displacement of the molecules the amount of heat transfer depends on the conductivity or heat-absorption qualities of the material through which the heat must pass.

2.6.3 Convection heat:

Is heat transmitted from a hot to a cold body by movement of the conveying substance In this case, the hot body is the boiler flue gas; the cold body is the boiler tube containing water or the super heater tube containing steam.

2.7 Fundamentals of Steam Generation

2.7.1 Boiling:

The process of boiling water to make steam is a phenomenon that is familiar to all of us. After the boiling temperature is reached (e.g., 212°F at an atmospheric pressure of 14.7psia), instead of the water temperature increasing, the heat energy from the fuel results in a change of phase from a

liquid to a gaseous state, i.e., from water to steam. A steam-generating system, called a boiler, provides a continuous process for this conversion.

2.7.2 Circulation:

For most boiler or steam generator designs, water and steam flow through tubes where they absorb heat, which results from the combustion of a fuel. In order for a boiler to generate steam continuously, water must circulate through the tubes. Two methods are commonly used:

1. Natural or thermal circulation and.
2. Forced or pumped circulation.

2.7.2.1 Natural circulation:

For natural circulation, the rate of circulation depends on the difference in average density between the unheated water and the steam-water mixture.

The total circulation flow rate depends on four major factors:

1. **Height of boiler.**
2. **Operating pressure:**

Higher operating pressures provide higher density steam and higher-density steam-water mixtures. This reduces the total weight difference between the heated and unheated segments and tends to reduce flow rate.

3. **Heat input:**

A higher heat input increases the amount of steam in the heated segments and reduces the average density of the steam-water mixture, thus increasing total flow rate.

4. **Free-flow area:**

An increase in the cross-sectional or free-flow area (i.e., larger tubes and down comers) for the water or steam-water mixture may increase the circulation rate.

2.7.2.2 Forced circulation:

For a forced circulation system pump is added to the flow loop, and the pressure difference created by the pump controls the water flow rate. These

circulation systems generally are used where the boilers are designed to operate near or above the critical pressure of 3206psia, where there is little density difference between water and steam.

2.7.3 Steam-water separation:

The steam-water mixture is separated in the steam drum. In small, low-pressure boilers, this separation can be accomplished easily with a large drum that is approximately half full of water and having natural gravity steam-water separation. In today's high-capacity, high-pressure units, mechanical steam water separators are needed to economically provide moisture-free steam from the steam drum.

2.8 Boiler components:

2.8.1 Furnace (combustion chamber):

The furnace portion of a boiler provides a place for the combustion of the fuel, contains the combustion gases, and then directs those gases to the heating surfaces of the boiler. In nearly all modern boilers, furnaces are water-cooled enclosures and therefore absorb heat from combustion and cool the combustion gases (flue gas) before they enter the convection heating surfaces of the boiler. The heating surface that forms the walls of a water-cooled furnace is often considered to saturated surface in a boiler because only one side of be the most expensive this surface absorbs heat. Therefore, a good, economical design must be the smallest furnace allowable to burn the fuel completely, with consideration given to containing and directing the flue gas to the heating surfaces of the boiler.



Figure 2.5: Furnace (combustion chamber).

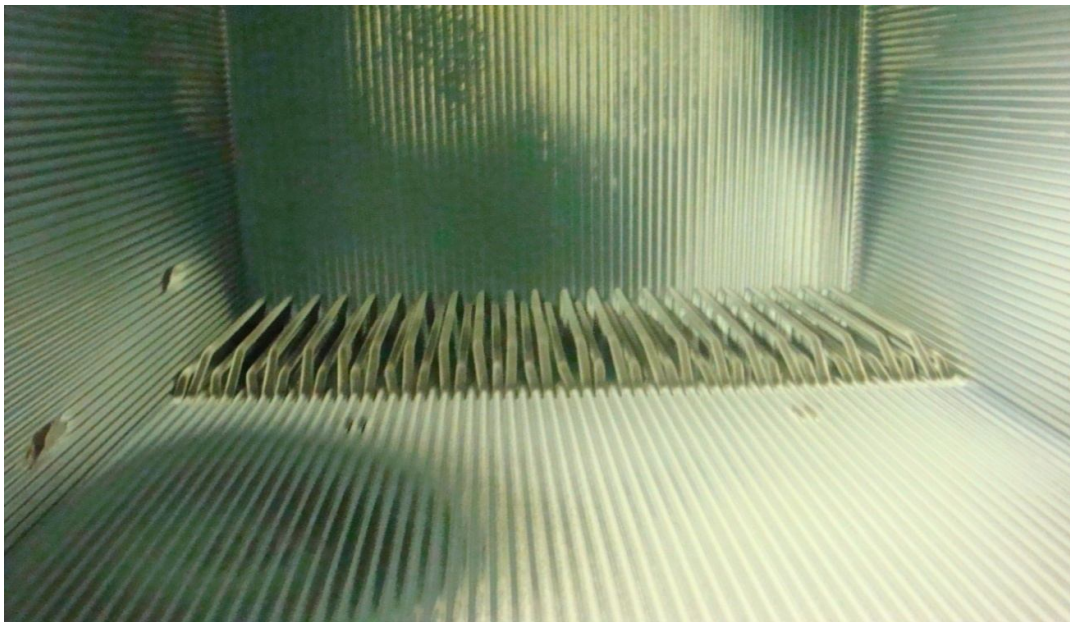


Figure 2.6: side wall of Furnace (combustion chamber).

2.8.2 Burners:

Combustion requires three components (Fuel, Oxygen (air), and Ignition). In its simplest form a burner can be considered as an arrangement to combine these three components in a controlled manner. The burners must be selected to deliver the required quantity of oil to the furnace in a fine

mist to ensure quick and thorough mixing with the air. The burner consists of an air register for controlling the flow of combustion air, and fuel injectors for controlling the flow of gaseous or liquid fuels.

2.8.3 Fuel Oil Guns:

Liquid fuel must be atomized into very small droplets to permit rapid intermixing of air and fuel. Atomization is achieved by the use of steam atomizers. The determined fuel rate must be passed at the specified input pressure.

2.8.4 Combustion Air Register:

The design of the air register in which the burner is fitted is of considerable importance in obtaining efficient combustion. In addition to overall combustion efficiency, the air registers must produce a stable, self-propagating flame, capable of withstanding varying burner outputs and air pressures. Any alteration in burner output must always be accompanied by a corresponding adjustment of forced air pressure in the register to provide just sufficient air to allow complete combustion of the fuel. With motor fans, which generally run at constant speed, the air pressure is adjusted by opening or closing dampers in the air duct either on the suction or discharge side of the fan, otherwise air pressure can be adjusted by using variable motor speed.

2.8.5 Flame Shape:

The primary air provides the major influence on flame stability the remaining combustion (air, secondary air) used in controlling of the flame shape.



Figure 2.7: Shape of oil burner of flame.

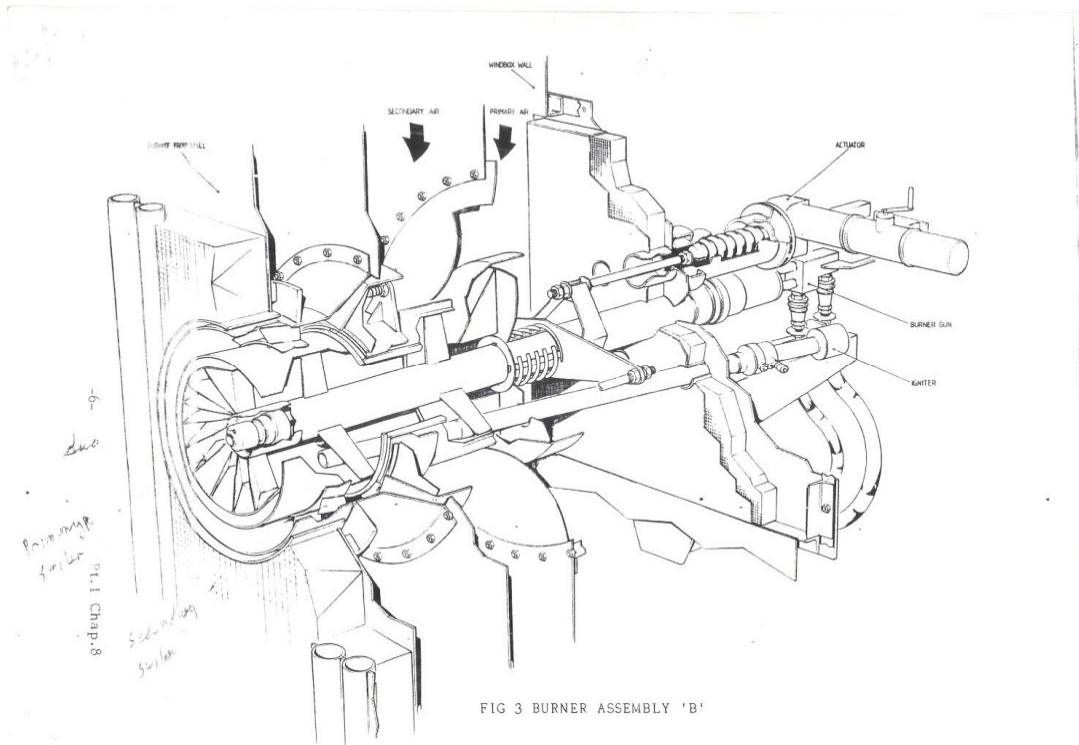


Figure 2.8: Burner Assembly.

2.8.6 Super heaters:

Steam that has been heated above the saturation temperature corresponding to its pressure is said to be *superheated*. This steam contains more heat than does saturated steam at the same pressure and the added heat provides more energy for the turbine for conversion to electric power. For example, steam at a pressure of (700Pisa) has a saturation temperature of (503°F) the heat content of this steam is (1201 Btu/lb.). If this steam is heated further to, say (700°F), the steam is now superheated and its heat content is (1345 Btu/lb.). The degrees of super heater the number of degrees above the saturation (or boiling) temperature at that pressure. In this example, the degrees of Superheat are (503-700) °C. A superheated surface is that surface which has steam on one side and hot gases on the other. The tubes are therefore dry with the steam that circulates through them. Super heaters are referred to as *convection*, *radiant*, or *combination* types. The convection super is placed somewhere in the gas stream, where it receives most of its heat by convection. As the name implies, a radiant super heater is placed in or near the furnace, where it receives the majority of its heat by radiation. Superheated steam has many advantages:

- 1.** It can be transmitted for long distances with little heat loss condensation is reduced or eliminated.
- 2.** Superheated steam contains more heat (energy in Btu per pound of steam), and hence less steam is required; and erosion of turbine is reduced because of the elimination of moisture in the steam. Super heaters can be designed as parallel flow, counter flow, or a combination of the two arrangements. A counter flow arrangement results in the least amount of surface; however, for high-temperature requirements, this could be the highest-cost super heater arrangement. This is possible because of high alloy metal requirements as a result of the hottest steam in contact with the hottest gas.



Figure 2.9: tube of super heater.

2.8.6.1 Superheat Steam Temperature Control:

High turbine efficiency over a wide load range depends a great deal on having a constant steam temperature over that load range. Therefore, it is necessary to design a boiler that can provide this constant steam temperature over the load range, which can be 50 percent of full load or more. There are three basic methods to obtain constant steam temperature:

1. Attemperation (control steam temp).
2. Flue gas bypass (or flue gas proportioning).
3. Flue gas recirculation.

2.8.6.2 Attemperation (control steam temp):

This method is used predominantly to control steam temperatures. The basic theory of control by attemperation is that if a super heater is made large enough to give the desired steam temperature at low loads; it will give a steam temperature at high loads that is higher than that desired if there is no method of control. However, if some means of reducing this temperature at high loads is used, a constant steam temperature over the range from low to full load may be obtained. This is the function of

attenuation, to reduce the steam temperature at high loads there are two types of attenuators:

1. drum-type.

2. spray-type.

1. Drum-type attenuators (not used at KNPPS):

This type uses tubes through which the steam flows, and these tubes are located in a drum (usually the lower drum) and surrounded by water at a lower temperature than the steam. Heat is transferred from the steam to the water in the drum, and the temperature of the steam is thus reduced.

2. Spray-type attenuators-(desuperheaters):

This type uses the principle that if water is sprayed into steam, the water will evaporate, forming steam, with the temperature of the final mixture lower than the initial steam temperature. For the super heater design where the attenuator is located at some intermediate point, the section of the super heater ahead of the attenuator is called the primary super heater, whereas the section located after the attenuator is called the secondary super heater.

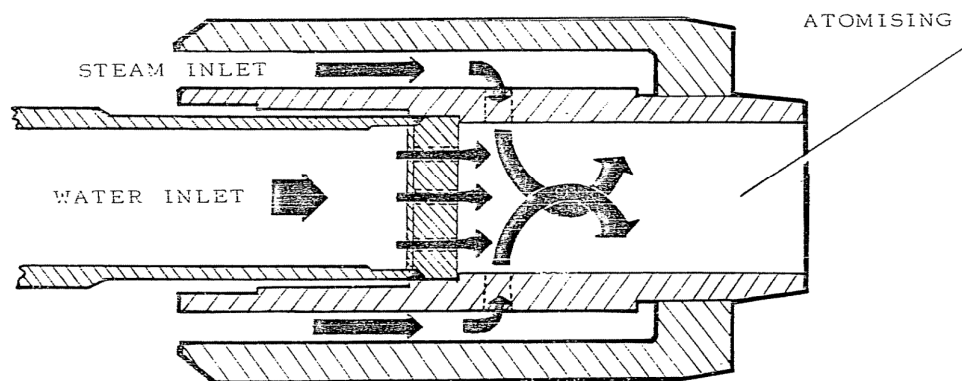


Figure 2.10: Spray-type attenuators-(desuperheaters).

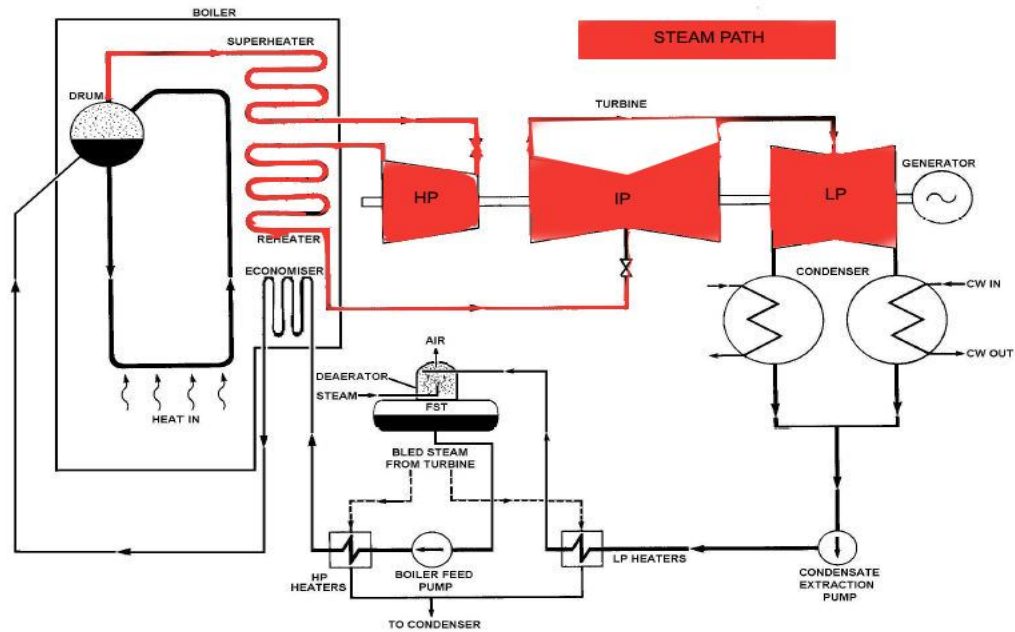


Figure 2.11: Circuit of water and steam.

2.8.7 Steam drum:

The steam drum provided in all modern steam generators where feed water from the economizer is fed, saturated steam is separated from the boiling water, and the remaining water is recirculated. The drum may also be used for chemical water treatment and blow down to reduce solids in the water. The drum also must be of sufficient volume to accommodate water level changes caused by load changes and to prevent a dangerously low level or the 'carryover' of water toward the super heater. This would cause deposits of entrained solids in the super heater tubes and thus water materially increases their temperature, which would lead to their distortion or burnout. Carryover of solids with the steam has also been known to have far-reaching effects. Such as deposit problems on turbine blades (the most troubles some being silica deposits, which are not easily removed by water washing). The most important steam-drum function is separating the steam from the boiling water. The simplest method is gravity separation if the steam velocity leaving the water surface is low enough gravity separation is strongly affected by the difference in steam and water densities.



Figure 2.12: Internal side of boiler drum.

2.8.8 Heat-Recovery Equipment:

In the boiler heat balance, the greatest loss results from heat loss in the exit flue gases. In order to operate a boiler unit at maximum efficiency, this loss must be reduced to an absolute minimum. This goal is accomplished by installing economizers and air pre heater. Theoretically, it is possible to reduce the exit flue gas temperature to that of the incoming air. Certain economic limitations prevent carrying the temperature reduction too far, since the costs of the added investment to accomplish this goal may more than offset any savings obtained. Furthermore, if reduction in temperature is carried below the dew point (the temperature at which condensation occurs), corrosion problems may be experienced. Therefore, savings resulting from the installation of heat-recovery apparatus must be balanced against added investment and maintenance costs.

2.8.9 An economizer:

Is a heat exchanger located in the gas passage between the boiler and the stack, designed to recover some of the heat from the products of combustion. It is located after the super heater, and it increases the

temperature of the water entering the steam drum. It consists of a series of tubes through which water flows on its way to the boiler.

Economizer's maybe *parallel-flow* or *counter flow* types or a combination of the two. In parallel-flow economizers, the flue gas and water flow in the same direction; in counter flow economizers, they flow in opposite directions. For parallel flow, the hottest flue gases come into contact with the coldest feed water; for counter flow, the reverse occurs. Counter flow units are considered to be more efficient, resulting in increased heat absorption with less heat-transfer surface.

2.8.10 the air pre heater (or air heater):

Consists of plates or tubes having hot gases on one side and air on the other the heat in the flue gas leaving the boiler or economizer is recovered by the incoming air, thereby reducing the flue gas temperature and increasing efficiency. There are generally two types of air pre heaters:

1. Recuperative.

2. Regenerative.

- 1. Recuperative air pre heater** has heat transferred directly from the hot gases to the air across the heat exchanger surface. They are commonly tubular The tubular type consists of a series of tubes through which the air pass inside the tubes and flue gases passes outside .baffles are provided to maximize air contact with hot tubes Air-bypass dampers are used to ensure that the exit flue gas temperature does not fall below a minimum temperature. At low loads, air is bypassed to maintain this minimum temperature.



Figure 2.13: Internal side of Air heater.

2. Regenerative air heaters are in which heat is transferred from the hot flue gases, first to intermediate heat storage medium, then to the air. The most common is the rotary air heater known as the air pre heater. It is composed of a rotor driven by an electric motor through reduction gearing so that it rotates slowly and continuously within housing at 1-3 rpm depending on diameter. The rotor has between 12 and 24 radial members that form sectors. The sectors are filled with a heating service composed of steel corrugated sheets. Half of the rotor sectors are exposed at any one instant to the hot gases, which are moving in one direction, the other half are exposed to the air which is move in opposite directions the rotating sectors enter the hot gases, zone they are progressively heated by the gas, the store that heat as sensible heat. When they enter the air zone the progressively give up this heat to the air. The seal system reduces leakage. For the air pre heater, a low air inlet or low exit gas temperature or a combination of the two may result in corrosion when fuels containing sulfur are burned should the metal temperature fall below the dew point. Two dew points need to be considered: the water dew point, which occurs

at approximately 120°F(48.88°C), and the flue gas dew point, which varies with the quantity of sulfur trioxide in the flue gas .The acid dew point occurs at a higher temperature than the water dew point. The metal temperature is considered to be approximately the average of the air-gas temperature at any given point. Corrosion may be prevented by preheating the air before it enters the pre heater, by bypassing a portion of the air around the pre heater, and by using alloys or corrosion-resistant metals. Steam coil air heaters are used when required to preheat the air prior to the air entering the air heater, and the steam coil air heater is located after the forced draft (FDF) fan.



Figure 2.14: Internal side of Rotary Air heater.

2.8.11 how dose water tube boiler works?

The water tube boiler is one in which the products of combustion (flue gases) pass around tubes containing water. The tubes are interconnected to common water channels and to the steam outlet. Water at (450 to 500) F from the plant high-pressure feed water heater enters the economizer and leaves saturated or as a two-phase mixture of low quality. It then enters the

steam drum at midpoint Water from the steam drum flows through down comers, to a lower header, which connects to the water tubes that line the furnace walls and act as risers. The water in the tubes receives heat from the combustion gases and boils further. The density differential between the water in the down comer and that in the water tubes helps circulation, so light mixtures of steam and water enters steam drum as heavy mixture of low quality from steam drum flows through water tubes. Steam is separated from the bobbling water in the steam drum and goes to the super heater for superheating before goes to steam turbine.

Atmospheric air from a *forced-draft* (FD) fan is preheated by the flue gases just before they are exhausted to the atmosphere. From there it flows into the furnace, where it mixes with the fuel and burns to some 3000F. The combustion gases impart portion of some of their energy to the water tubes and then the super heaters, economizer and leave the latter at about 600F. From there they reheat the incoming atmospheric air in the air heater, leaving it at about 300°F.

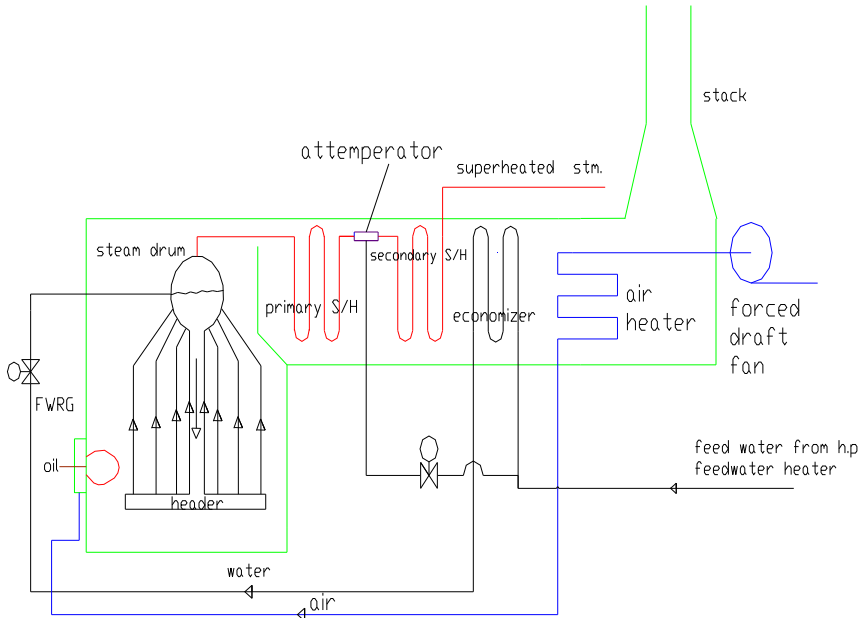


Figure 2.15: Schematic flow diagram of boiler.

2.8.12 Soot blower system:

Boiler tubes and heating surfaces get dirty because of an accumulation of soot, slag deposits, and fly ash. These substances are excellent insulators and reduce the effectiveness of the heating surface. Therefore, they must be removed to ensure the continuation of optimal boiler performance. Removal can be accomplished by using a soot blower. Soot blowers are mechanical devices that are used for on-line cleaning they direct a cleaning medium through nozzles and against the ash that has accumulated on the heat transfer surfaces of boilers in order to remove the ash deposits and maintain the effectiveness of the heat-transfer surfaces. Soot blowers basically consist of:

1. A tube element or lance that is inserted into the boiler and carries the cleaning medium.
2. Two nozzles in the tip of the lance to direct the cleaning medium and increase its velocity.
3. A mechanical system for insertion and rotation of the lance.
4. A control system.

2.8.13 How does soot blower works?

The lance tube moves into the flue gas pass, changes its direction of movement in the front end position and returns to initial position. Thereby the two nozzles carry out a helical movement. Since the nozzles are offset by 180° , the distance of the helicoids formed by the blow jets is only half of this distance. Owing to the conical spreading of the blow jets a closed cleaning effect across the entire blowing distance is ensured.

The lance tube is driven by the soot blower carriage which is guided in the track beam. The blowing medium is fed to the lance tube through the soot blower valve and the fixed feed tube. The blowing process of the soot blower is as follows:

In idle condition the soot blower carriage is in its rear end position, the lance tube is retracted; its two nozzles are placed in the wall box. When the drive motor is switched on, the soot blower carriage moves forward and pushes the lance tube helically into the flue gas pass. The soot blower valve is opened as soon as the two nozzles have passed the boiler wall. Blowing process starts. The soot blower carriage continues to push the lance tube into the flue gas pass until the two nozzles have reached the front end position. At this point the soot blower carriage changes its direction of travel and retracts the lance tube helically. The soot blower valve is closed before the nozzles reach the boiler wall. Now the soot blower moves back to its rest position without blowing. The motor will be switched off.



Figure 2.16: over all outside of boiler.

2.9 The Causes and Types of Boiler Tube Failure:

2.9.1 Introduction:

For any power plant, it is prime importance to generate electricity without forced outages. Failure of super heater tube of boiler is the major concern of forced outages at coal fired or fossil fuel thermal power plant. Flue gas passes over super heater tubes leading to damage over the time of operation and termed as fireside damage/corrosion. Again the extent of damage is dependent on quality of coal or fossil fuel, materials Used, operation and maintenance. Interior of these tubes are also vulnerable and primarily dependent on quality of water used for Generating high pressure steam, Continuous/steady flow of steam through these tubes is necessary to maintain tube materials under Prescribed temperature, otherwise, there is a possibility of shoot-up of temperature causing fast deterioration of materials and subsequent failure. In that case overall efficiency of the plant is dropped. Therefore, the study of tube failure and finding the solution is needed to avoid such incident in future. Boiler tubes of a fossil fuel fired plant faced harsh environment all the way from inside steam to outside flue gases. Tubes are exposed to temperature in the range of (540-1000°C) varying along length of tubes i.e. from base toward elevation. According to service condition, outside of tubes are exposed to high temperature. High pressure steam flows through inside and is discharged at a temperature more than 500°C depending on nature and capacity of plant. Temperature shoot up above specification is most common reason of failure for boiler tubes [5]. The reason is either scale formation on internal and/or external surfaces under prolonged exposure at elevated temperature or non-uniform steam flow through partially blocked tubes [6]. Internal scale formation reduces heat transfer rate across tube wall. Moreover, scale formation causes non-linear (non-uniform) heating, resulting in the retardation of heat transfer further and reduction of thermal efficiency. External oxide

formation generally depends on type/quality of coal, which produces flue gas. Mostly complex alkali sulfate scales are formed. This effect raises the temperature of tube locally and longtime exposure results in thicker oxide formation, subsequent exclusion of the same. The later phenomenon escalates wall thinning and rupture of the tube. Material de-generation and subsequent failure due to thermal fluctuation have been studied by a number of investigators in recent past [7, 8]. It is to be noted, that in many cases a thin protective Fe_3O_4 layer is deposited on waterside of tubes. Protectiveness of this thin layer depends on pH level and degree of contamination of water. There are many failure mechanisms that have been reported depending upon the presence of contamination with flowing steam. These are primarily related with caustic corrosion, hydrogen damage or pitting [9, 10].

2.9.2 Boiler Pressure Component failures:

One of the most complex, critical, and vulnerable systems in fossil power generation plants is the boiler pressure components. Boiler pressure component failures have historically contributed to the highest percentage of lost availability. Failures have been related to [7]:

1. Poor original design.
2. Fabrication practices.
3. Fuel changes.
4. Operation, maintenance, and
5. Cycle chemistry.

2.9.3 Prominent reasons for tube failures:

2.9.3.1 Poor water quality:

With increases in operating pressure, feed water quality becomes even more critical. Some industrial plants encounter periodic returned condensate contamination, which eliminates boiler water alkalinity.

Occasionally, regeneration acid from an ion exchange process is discharged accidentally into the boiler feed water system. Cooling water contamination of condensate can depress boiler water pH and cause severe deposition and pitting in areas of high heat flux. Damage can be quite severe if immediate steps are not taken to neutralize the acid. In the case of industrial process contamination, it is possible for organic contaminants to decompose under boiler temperature and pressure to form organic acids.

2.9.3.2 Coal or fossil fuel quality:

Using a different type of coal or fossil fuel for emission or economic reasons has adversely affected the capability, operability, and reliability of boiler and boiler auxiliaries.

2.9.3.3 Cycling operation:

Many base-load-designed boilers have been placed into cycling duty, which has a major impact on the boiler reliability as indicated by occurrences of serious corrosion fatigue in water-touched circuitries, economizer inlet header shocking, thick-wall header damages, and others.

2.9.3.4 NO_x emission:

Deep staging combustion for NO_x reduction has produced serious water wall fire corrosion for high sulfur-coal firing, especially in supercritical Units.

2.9.3.5 Age-ing:

A large percentage of existing fossil-fired units are exceeding (design life) without plans for retirement. These vintage units are carrying major loads in power generation.

Table 2.2: Result test of Fuel oil, Heavy Fuel Oil (HFO) [11]:

TEST ITEM	TEST RESULT	UNIT	
Flash Point	192	C	
Kinematic Viscosity (50C)	451.5	mm ² /s	
Pour Point	42	C	
Carbon Residue	7.48	Wt %	
Water & Sediment	1.000	Vol %	
Ash	0.204	Wt %	
Sulfur	0.08	Wt %	
Density @15C	904.5	Kg/m ³	
Water	0.500	Vol %	
Elemental Analyzer	C	85.43	Wt %
	H	11.81	Wt %
	N	0.17	Wt %
Heat of Combustion	44150	J/g	
Net Heat of Combustion	41470	J/g	

*Sample: National Electricity Corporation Khartoum power Station (HFO).

Table 2.3: Result test of Fuel oil, Heavy Cock Gas Oil (HCGO)[11]:

TEST ITEM	TEST RESULT	UNIT	
Flash Point	115	C	
Kinematic Viscosity (50C)	17.71	mm ² /s	
Pour Point	20.00	C	
Carbon Residue	1.16	Wt %	
Water & Sediment	1.005	Vol %	
Ash	0.008	Wt %	
Sulfur	0.12	Wt %	
Density @15C	908.7	Kg/m ³	
Water	0.025	Vol %	
Elemental Analyzer	C	87.04	Wt %
	H	11.37	Wt %
	N	0.22	Wt %
Heat of Combustion	44510	J/g	
Net Heat of Combustion	41940	J/g	

*Sample: National Electricity Corporation Khartoum power Station (HCGO).

2.10 Common boiler tube materials:

Boiler tubes are usually manufactured using alloy materials which can withstand both high temperature from the flue gases and high pressure steam generation within the tube. The use of high temperature heat resistant alloys not only improves the supercritical steam quality for better boiler efficiency, they also allow reduction in volumes of material for fabrication, both which promotes positive economy benefits.

Economizers and water wall sections are usually constructed with a mild or medium carbon steel, Low alloy ferrite steels are used for most super heater and re heater sections, with austenitic stainless steels specified for the highest-temperature circuits or corrosion performance. Each manufacturer specifies a maximum operating temperature for each material, based on laboratory oxidation experiments. The ASME code is based on the mid-wall tube temperature.

Table 2.4: Most Frequently Material Used Steels (specification with maximum temperatures)[12]:

ALLOY	SPECIFICATION (ASME)	MAX.USEFUL TEMPERATURE(°C)
Carbon-Steel	SA178,SA192 SA210,SA106 SA515,SA516	850
Carbon- ½ Molybdenum	SA209	900
1- ¼ Chromium- ½Molybdenum	SA213 T-11 SA335 P-11	1025
2- ¼ Chromium- ½Molybdenum	SA213 T-11 SA335 P-11	1075
18Chromium-10Nickel	SA13 TP304(H), 321(H),347(H)	1500

* ASME (American Society of Mechanical Engineering Code).

2.11 Steel user in boiler tube a cording to ASME code:

Steel are alloys of iron and carbon, usually with one or more alloying elements added to improve some properties of the material (strength, high-temperature strength oxidation or corrosion resistance, for example).By definition, steels contain at least 50% iron.

For welded construction, the ASME Boiler and pressure vessel code limits the carbon content to less than 0.35%. Thus, virtually all the materials used in the construction and repair of pressure parts of boilers fall into this classification. Some high-temperature, corrosion-resistant alloys of nickel and chromium with less than 50% iron are not, strictly speaking, steels, but are still occasionally used. Further, steels are divided into two subcategories: ferrite steels and austenitic steels, depending on the arrangement of atoms within the solid.

Steel are used in boiler construction because they are inexpensive, readily available, easily formed and welded to the desired shape and, within the broad limits, are oxidation-and corrosion-resistant enough to provide satisfactory service for many years. Table 3.3 lists the most frequently used steels, some common tubing specification and the maximum recommended service temperatures [12].

2.12 Boiler Typical Failure mechanisms:

The boiler tubes are under high pressure and/or high-temperature conditions. They are subject to potential degradation by a variety of mechanical and thermal stresses and environmental attack on both the fluid and fireside. Mechanical components can fail due to creep, fatigue, erosion, and corrosion, the type of failure details below:

2.12.1 Creep:

Creep is a time-dependent deformation that takes place at elevated temperature under mechanical stresses. Such failure results in overheating

or overstressing the tube material beyond its capabilities for either a short-term or a long-term period.



Figure 2.17: typical of creep.

2.12.2 Failure caused by Short-term overheat:

Furnace tube internal heat circulation is not smooth; no effective heat transfer makes the temperature of tube wall greatly exceed the permissible maximum temperature. Pipe under high temperature mechanical properties, physical properties, the allowable stress and oxidation resistance will be greatly reduced, the furnace tube is cannot withstand the media pressure inside the tubes, tube explosion. Short-term burst pipes burst generally trumpet-shaped, very thin edge. The causes are: pipe within the pipe blockage could not form normal thermal cycle caused by; pipe (water wall, screen too prominent, contact) high temperature flue gas, pipeline absorbs radiant heat increasing, the tube wall temperature rise, short-term overheating tube furnace tube.

Failure results in a ductile rupture of the tube metal; it is characterized by (fish mouth) opening in the tube where the fracture surface is a thin edge.

Causes: Short-term overheat failures are most common during boiler start up. Failures result when the tube metal temperature is extremely elevated from a lack of cooling steam or water flow.

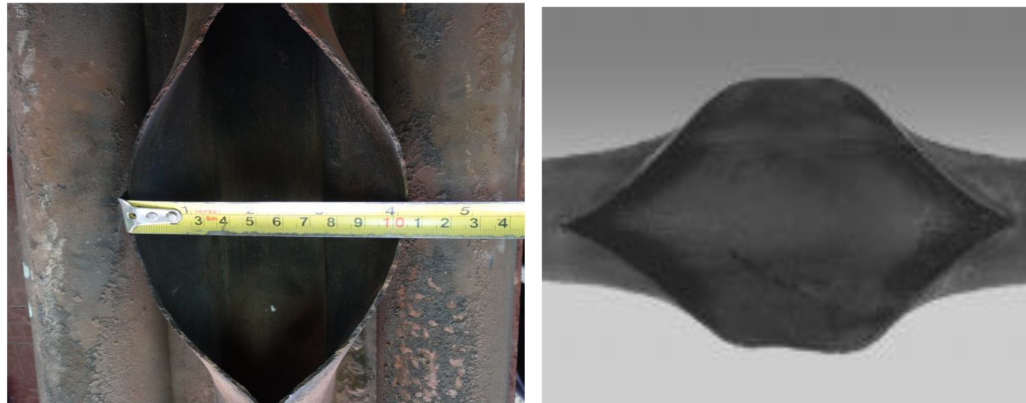


Figure 2.18: Failure caused by Short-term overheating.

2.12.3 Failure caused by Long-term overheating:

Long-term overheating boiler tube in the long-term than the allowable tube wall temperature environment, the oxidation resistance of the tube wall decreased, oxidation corrosion rate increased greatly, at the same time, the mechanical properties of furnace tube basic allowable stress and physical characteristics is also reduced, the tube cannot reach the stress that should bear, will lead the tube to burst. Long tube explosion explosive export general trumpet-shaped, edge is thick, and the tube wall is similar to [13].

Tube metal often has heavy external scale build-up and secondary cracking. Super heater and reheat super heater tubes commonly fail after many years of service, as a result of creep. During normal operation, alloy super heater tubes will experience increasing temperature and strain over the life of the tube until the creep life is expended. Furnace water wall tubes also can fail from long-term overheating.

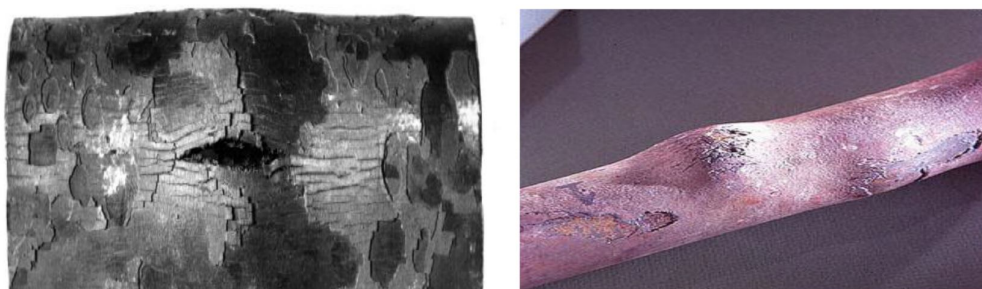


Figure 2.19: Failure caused by long-term overheating.

2.12.4 Fatigue:

Fatigue is a phenomenon of damage accumulation caused by cyclic or fluctuating stresses, which are caused by mechanical loads, flow-induced vibration. Components are subjected to cyclic temperature and flow fluctuations *restrict thermal expansion*. Thermal fatigue is classified in two categories, corrosion fatigue and thermal fatigue:

2.12.4.1 Corrosion fatigue:

Corrosion fatigue Occur by The fluctuations in circulation of water in the boiler tube.



Figure 2.20: Failure caused by Corrosion fatigue.

2.12.4.2 Thermal fatigue:

Frequent starts and stops. Typically occurs at areas such as header ligaments, welded attachments, tube stub welds, circumferential external surface cracking of water wall tubes in supercritical units, and fabrication notches.



Figure 2.21: Failure caused Thermal fatigue.

2.12.5 Failure caused by external erosion:

External scouring by pressure parts of leakage is mainly because the external medium wall flushing of the pipeline, such as steam boiler ash ejector by the installation position is not correct, soot blower nozzle deformation or blowing dust device not back, to wash out of the economizer, super-heater, water wall tube soot blower, resulting in leakage caused by. Preventive measures: strengthen the anti-wear maintenance checks on water wall tube blowing dust device location, and check the soot blower nozzle position, angle change. Operation according to the ash, appropriate to reduces the soot blowing frequency, prolong the time of hydrophobic soot blowing [14].

2.12.6 Failure caused by internal erosion:

Pipeline internal medium erosion is one reason the pipeline leakage on pipe wall, because of the medium inside the tubes for high temperature and high pressure steam, steam flow rate soon, steam flow rate can reach (30-50m/s) high-speed medium erosion on the tube wall, especially advantageous for serious pipe bend. Because the coal economizer tube in high temperature water flow velocity is slower, the erosion of the coal economizer occurred less, but the super heater, re heater elbow, water wall high elbow internal scour the situation more [9].



Figure 2.22: Failure caused by internal erosion.

2.12.7 Corrosion:

Deterioration and loss of material due to chemical attack, there are two basic categories in boiler tubes:

2.12.7.1 Failure Caused by Internal corrosion:

The internal corrosion of boiler pressure parts mainly has four forms: steam corrosion, oxygen corrosion, corrosion and corrosion under the scale. One is steam corrosion. Steam surface metal at higher than 400°C iron contact with steam to form Fe_3O_4 film, this is the steam corrosion. Two is oxygen corrosion. The boiler feed water and oxygen in the process of electrochemical corrosion of the cathode polarization, electrochemical etching speed, the higher the temperature, the corrosion is block. Preventive measures: feed water DE aerator, control water content; control the coal economizer tubes of water speed of not less than 0.3m/s, to prevent air bubbles trapped in the pipe wall. Three is alkali corrosion. When the temperature is high, accelerated electrochemical corrosion, the higher the temperature, the greater the more strongly alkaline, corrosion, internal corrosion such, Hydrogen damage, acid phosphate corrosion, caustic gouging, and pitting[15].



Figure 2.23: Failure caused by internal corrosion

2.12.7.2 Failure Caused by External corrosion:

Tube exerted, external medium to long time corrosion on a pipe Solutions should strengthen insulation antiseptic treatment. External corrosion such, Water wall fireside corrosion, super heater (SH), re heater (RH) fireside corrosion, and ash dew point corrosion [16].

2.12.8 Internal Corrosion-Hydrogen Damage:

Hydrogen damage is most commonly associated with excessive deposition on ID tube surfaces, coupled with a boiler water low pH excursion. Water chemistry is upset, which can occur from condenser leaks, particularly with salt water cooling medium, and leads to acidic (low pH) contaminants that can be concentrated in the deposit. Under-deposit releases atomic hydrogen which migrates into the tube wall metal reacts with carbon in the steel (decarburation) and causes inter granular separation.

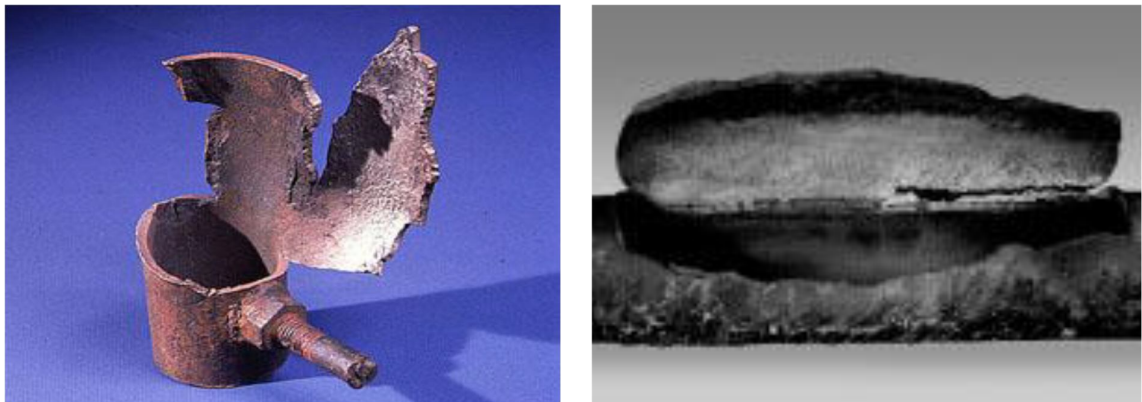


Figure 2.24: Failure caused Internal Corrosion-Hydrogen Damage.

2.12.9 Water wall Fireside Corrosion:

Causes: Corrosion occurs on external surfaces of water wall tubes when the Combustion process produces a reducing atmosphere (subsoil chi metric). This is common in the lower furnace of process recovery boilers in the pulp and paper industry. For conventional fossil fuel boilers, corrosion in the

burner zone usually is associated with coal firing. Improper burners or operating with staged air zones to control combustion are more susceptible to larger local regions possessing a reducing atmosphere, resulting in increased corrosion rates.



Figure 2.25: Water wall Fireside Corrosion.

2.12.10 Dissimilar Metal Weld (DMW) Failure:

Dissimilar Metal Weld (DMW) Failure Material fails at the ferrites side of the weld, along the weld fusion line. A failure tends to be catastrophic in that the entire tube will fail across the circumference of the tube section. Causes: DMW describes the butt weld where an austenitic (stainless-steel) material joins a ferrite alloy, such as SA213T22, material. These failures are attributed to several factors: high stresses at the austenitic to ferrite interface due to differences in expansion properties of the two materials, excessive external loading stresses and thermal cycling, and creep of the ferrites material.

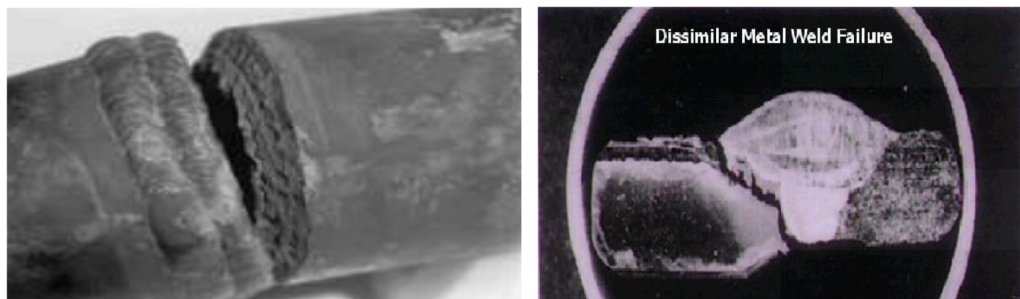


Figure 2.26: Dissimilar Metal Weld (DMW) Failure

2.12.11 Waterside Corrosion Fatigue:

Causes: Tube damage occurs due to the combination of thermal fatigue and corrosion. Corrosion fatigue is influenced by boiler design, water chemistry, boiler water oxygen content and boiler operation, Leads to the breakdown of the protective magnetite on the ID surface of the boiler tube. The loss of this protective scale exposes tube to corrosion. The locations of attachments and external weldments, such as backstay attachments, seal plates and scallop bars, are most susceptible. The problem is most likely to progress during boiler start-up cycles.

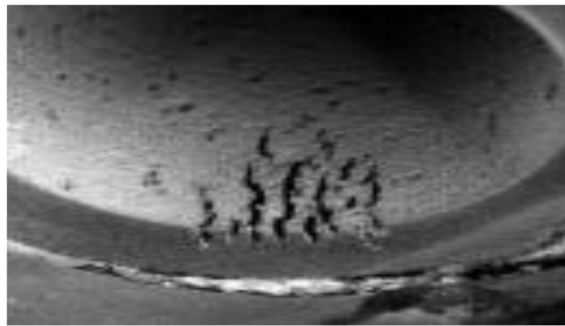


Figure 2.27: Waterside Corrosion Fatigue.

2.12.12 Failure caused by Operation adjustment:

2.12.12.1 Failure caused by startup, shutdown:

Cold water when the water temperature or inlet velocity is not in conformity with the provisions; startup boost heating or loading speed too fast; shutdown cooling too fast, release early, will make the furnace tube is uneven, excessive thermal stress resulting in boiler tube leakage [17].

2.12.12.2 Failure caused by operation load changing too quickly:

The boiler load mutation operation, hand pressure suddenly increased, easy to make the original heating water wall tube water circulation weak slow or stagnant; on the other hand, weakened combustion furnace, in the outage of spray combustion water wall device around the tube heat load dropped sharply, may also cause water circulation stagnation phenomenon that some tube [17].

2.12.12.3 Failure caused by running regulation improper:

Operation of the burner is not adjusted properly, causing the flame center excursion, or furnace coking phenomenon, are easy to make the water wall tube, superheated steam and reheated steam local overheating damage [17].

2.12.13 Steam Blanketing:

A number of conditions permit stratified flow of steam and water in a given tube, which usually occurs in a low heat input zone of the boiler. This problem is influenced by the angle of the affected tubes, along with the actual load maintained on the boiler. Stratification occurs when, for any reason, velocity is not sufficient to maintain turbulence or thorough mixing of water and steam during passage through the tubes. Stratification most commonly occurs in sloped tubes (Figure 2.28) located away from the radiant heat zone of the boiler, where heat input is low and positive circulation in the tubes may be lacking.



Figure 2.28: Steam Blanketing

2.12.14 other failure causes:

2.12.14.1 Failure caused by design defects:

Due to lack of design and technical force, in the pipeline design, thermal calculation, there are some defects in design, so that the boiler pressure parts cannot be long-term and stable operation, left the accident hidden danger to plant, power plant overhaul opportunity only by inspection, analysis and transformation, to the extent possible, a result of reduce design Defects[18].

2.12.14.2 Failure caused by welding quality:

Welder welding level is not high, there is sand hole, crack, weld undercut, the weld has potential risks, causing the weld leakage squib. Pipeline aligning is not in accordance with the provisions. In strict accordance with the pipe weld requirements, ensure weld quality. Preparation Pipe break forms rather strict, break the form and size also has strict requirements, pipe diameter, wall thickness, the medium temperature pressure, welding and other factors vary. Without pre heating before welding without heat Treatment. Some pipe before and after welding is required, such as alloy steel need to be preheated before welding, after welding heat treatment in need, to improve material weld ability, eliminate large internal stress of weld [19].

2.12.14.3 Failure caused by foreign bodies when installation:

Four tubes of a boiler have many weld joints, in the manufacture, transportation, installation of pipelines, pressure, maintenance when there are errors, foreign body remains in the bearing internal components. Preventive measures: strict implementation of the construction supervision procedures, improve the installation process quality, improve the quality of construction personnel [19].

2.12.14.4 Failure caused by Misuse of pipe:

Boiler pressure parts using what steel is selected according to bearing temperature, pressure and the flow of the medium .Preventive measures: equipment installation, strictly the quality pass, pipes for pressure parts must meet the design requirements Analysis of pipe material in the pipe segment replacement, to prevent misuse. Grinding the explosion-proof inspection and a full range of pressure parts by maintenance opportunity, pay particular attention to the pipe creep and tube wall colour change [19].

2.13 Current Studies on Boiler tube failure:

From current Studies to prevent or reduce boiler tubes failure, the critical considerations during design of Boiler Material selection deficiencies in the design: Material and fabrication flaws, and welding flaws. The primary consideration in material choice is a function of expected tube temperature of operation. Economizers and water wall sections are usually constructed with a mild or medium carbon steel, Low alloy ferrite steels are used for most super heater and re heater sections, with austenitic stainless steels specified for the highest-temperature circuits or corrosion performance. Each manufacturer specifies a maximum operating temperature for each material, based on laboratory oxidation experiments. The ASME code is based on the mid-wall tube temperature [20].

2.14 Modern techniques for flaw detection of boiler tube:

2.14.1 RFET and LFET-Magnetic Technique:

1. RFET-Magnetic Technique:

Remote Field Electromagnetic Technique (RFET) can be used to detect, ID or OD flaws on the hot side half of the boiler water wall tubes. No surface preparation is needed in this technique more than high pressure water cleaning. It uses a low frequency signal which diffuses through the tube wall twice before being detected by the receiver. Anomalies at any location along the energy transmission path cause change to both the amplitude and phase of the signal, thereby enabling the detection of defects [20].

2. LFET-Magnetic Technique:

Low Frequency Electromagnetic Technique (LFET) is used for tube scanning; 120 degree of tube circumference can be scanned and can be

used for water wall tubes form inside furnace. OD scanning of super header & Re heater and even economizer can also be done using this technique.

2.14.2 Time of Flight Diffraction:

The TOFD (Time of Flight Diffraction) technique is ultrasonic inspection method for detection of flaws in thick wall components like headers & pipe joints. In TOFD technique transmitter & receiver are placed on equal distances of weld joint and are focused at the joint. The transmitter sends compression waves into the material towards receiver. Where thickness is more than 6mm & diameter 80 mm. verify the cracks & lack of fusion which are not detectable with radiography.

2.14.3 CFD Modeling and CAVT testing:

1. CAVT Testing:

The purpose of CAVT (Cold Air Velocity Test) is to predict the flow profile of flue gas flow by manually measuring the velocity of cold air inside the boiler at pre-defined locations [21].

2. CFD Modeling:

Water walls of furnace can be checked by THERMOGRAPHY for any suspected chocking/blockage of tube, the goose neck area after overhauling of boiler [21].

2.14.4 Advance Inspection techniques:

1. Robotic inspection using magnetic flux:

This technique can be used to find out thickness loss in water wall tubing and other areas.

2. Boroscopic inspection:

The internal surface of header which is inaccessible can be inspected by Boroscope. This technique is called Fibroscopy. Headers exposed to temperature cycling may experience internal cracking due to thermal fatigue. This technique is useful to examine the internal scaling.

2.15 Monitoring Techniques Boiler Operation (MTBO):

1. Temperature Excursion Monitoring:

Monitoring of temp excursion of PI SH & RH area and trending

2. Five Core Chemical Parameters (pH,Na,DO,NH3&PO4):

Operation Engineers & Chemists are required to monitor 5 core chemical parameters shift wise daily. These are water & steam pH. Sodium in saturated Steam, Dissolved oxygen in de aerator& condenser, ammonia in water and phosphate in drum [21].

3. Dissolved Oxygen in Condenser/De aerator:

Level of dissolved oxygen in DE aerator & condenser is to be regularly checked and actions are to be taken to bring down within limits. Reducing Oxygen level in condensate water reduces corrosive action. It has been experienced that attachment failures & weld joint defect failures are reduced by maintaining low DO.

4. ASLD Installation (Acoustic Steam Leak Detection):

In order to have early detection of BTL and stoppage of unit at early stage to reduce secondary damages particularly in RH, PI SH & div SH area, It has been experienced that in the units where ASLD is not installed secondary damages causes heavy loss of generation due increased time of repair.

2.16 Life time monitoring:

The life time monitoring module calculates the remaining life of thick components in boiler. This depends upon how stressful the life of equipment has been so far in terms of temperature and pressure which effect fatigue and creep [21].

CHAPTER THREE
METHODOLOGY & EXPERIMENTAL

3.1 Preface:

This chapter Explain methodology and Experimental methods used up in this study, In order to compare the difference in the material properties, and behavior of boiler tube, for reveal causes and types of tube failures occurs in (KNPPS), there are two sample using in all test, Original (new tube) and (failed tube), analyzed in this study, several analyses, including:

1. Visual examination (Naked eye, Digital camera).
2. Dimensional measurement.
3. X-ray diffraction study.
4. Metallurgical Examination.
6. Micro structural examination.
7. Chemical Composition examination.
8. Mechanical Properties measurement (Tensile Test, Hardness Test).
9. Fractography.
10. Evaluation of hoop stress.
11. Microscope Examination.
12. Bore scopes Examination.

3.2 Experimental Methods:

Due to lack of equipment in the laboratory, more precise tests and analysis could not be done. The following test work was done to identify the probable cause/causes of failure:

1. Visual examination (Naked eye, Digital camera).
2. Dimensional measurement.
3. Chemical Composition examination.
4. Mechanical Properties measurement (Tensile Test, Hardness Test).
5. Bore scopes Examination.

The Below two (Specimens) boiler tubes were performed. In addition, the fracture surface of the failed tube was also inspected to explore the fracture type.



Figure3.1: New sample (Original), before test.



Figure3.2: Failed sample.

The All detailed experimental process is described in below:

3.2.1 Visual examination (Naked eye, Digital camera):

3.2.1.1 Instrument/apparatus:

1. Naked eye
2. Digital camera

3.2.1.2 Procedure of Visual Examination (Inspection):

Visual Examination (inspection) was done. This is the most basic failure investigation procedure where the naked eye is the tool used for observing. A digital camera to capture the images of the failed component is required.

3.2.2 Dimensional measurement:

3.2.2.1 Instruments/Apparatus:

1. Inside calipers.
2. Outside calipers.

3.2.2.2 Procedure of Examination:

A sample of the failed tube was taken and the inside and outside diameter measured using calipers or (vernier Caliper) for measured. The unfired (original tube) sample was also measured. And Comparison, Dimension of tubes belongs to the essential characteristics of tubes. In this regard tube dimensions must be given in such a way that can completely determine the tube. For tubes with circular cross section the three main dimensions except for the length are: outside diameter (OD), inside diameter (ID) and wall thickness (WT). For circular tubes are given two of these values. According to the type of tubes also belong the appropriate dimensions and the dimensional tolerances.

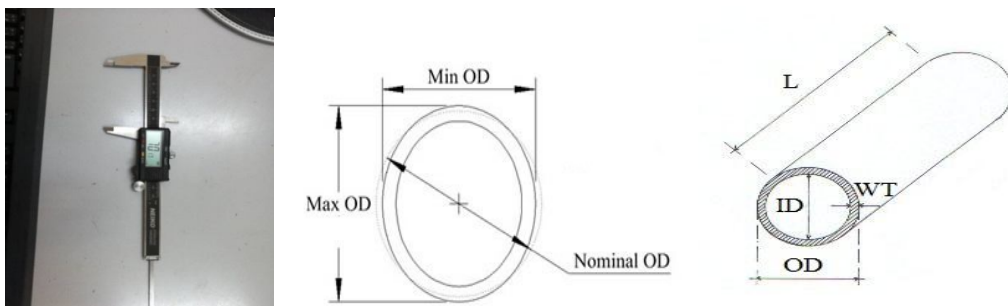


Figure 3.3: Explain Dimensional Measurement Method.

3.2.3 Chemical Composition examination:

3.2.3.1 Instruments/Apparatus:

Inductively Coupled Plasma Spectrometry (ICP- OES).



Figure 3.4: (ICP- OES) Chemical Composition Measurement.

3.2.3.2 Procedure of Examination:

The materials of the Boiler tube were claimed to be in accordance with the ASME SA178-A standard. The chemical composition of the failed Boiler tubes was confirmed by (ICP-OES) analysis (Inductively Coupled Plasma - Optical Emission Spectrometry), one unused Boiler (New tube) was also analyzed for comparison. The (ICP-OES) analysis, (Inductively Coupled Plasma Spectrometry) Is an analytical technique used for detection of chemical elements it is a type of emission spectroscopy (ICP-AES) that uses the inductively coupled plasma to produce excited atoms and ions that emit electromagnetic radiation at wavelengths characteristic of a particular element. It is flame technique with a flame temperature in a range from 6000K to 10000K. The intensity of this emission is indicative of the concentration of the element within the sample.

3.2.3.3 Method of test:

Taking Two sample from alloy of boiler tube, one sample (New tube), however other one (Failed tube) and determine the chemical composition for each one, by (ICP) analysis several times in different location of specimen (New tube and Failed tube), after taking average result for each element, from two tube, then comparison by ASME standard of alloy.

*(ICP-OES, Inductively Coupled Plasma Spectrometry).

*(ASME, American Society and Mechanical Engineering Code).

3.2.4 Mechanical Properties measurement:

3.2.4.1 Instruments/Apparatus:

1. Tensile test Apparatus.
2. Hardness tests (Brinell Apparatus).

3.2.4.2 Tensile test:

3.2.4.3 Procedure of Examination:

In this study, the mechanical properties of the Boiler tubes were evaluated by employing the tensile test and hardness test. The preparation of the specimen and the testing procedure of the tensile test were in accordance with ASTM E8 standard. The magnitude of the ultimate tensile stress (UTS), yield stress (YS) and elongation (EL) obtained from the tensile test was collected.

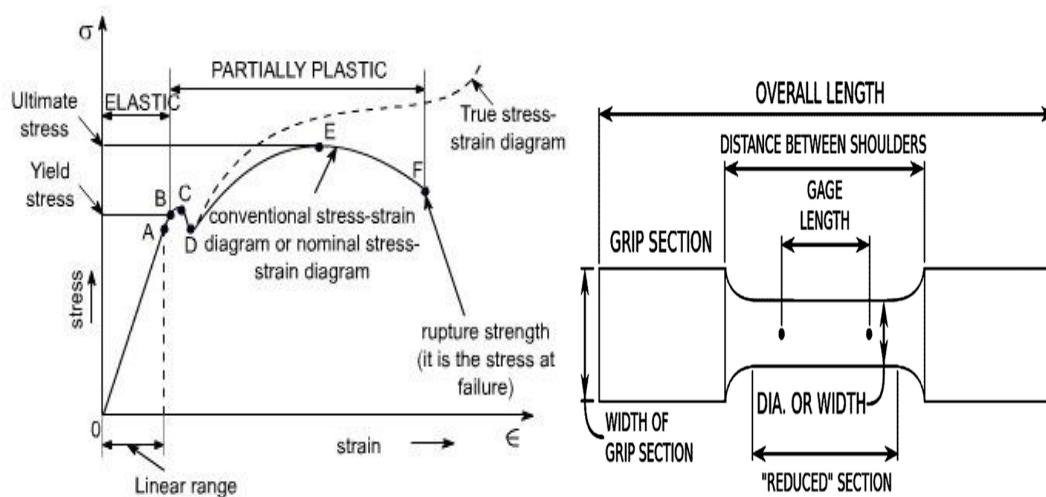


Figure 3.5: Diagram of Tensile (Stress-Strain) Test & Specimens (Cross section) used in test.

Table 3.1: Initial Data of boiler tube (Plate Specimens) before test:

<i>SPECIMENS (ALLOY)</i>	<i>Width (B) (mm)</i>	<i>Thickness(t) (mm)</i>	<i>L_{over all(1)} (mm)</i>	<i>A_o (mm²)</i>
New Tube (A)	20	5	530	100
New Tube (B)	20	5	530	100
Failed Tube (A)	20	5	550	100
Failed Tube (B)	20	5	550	100

Gauge length : (L_o =200mm)& load:(F=45.95KN)

Table 3.2: Final Data of boiler tube (Plate Specimens) after test:

<i>SPECIMENS (ALLOY)</i>	<i>Width (B) (mm)</i>	<i>Thickness(t) (mm)</i>	<i>L_{over all(2)} (mm)</i>	<i>L_f (mm)</i>	<i>A_f (mm²)</i>
New Tube (A)	14	4	620	233.96	56
New Tube (B)	15	3	600	226.42	45
Failed Tube (A)	16	3.5	600	218.20	56
Failed Tube (B)	14	3	590	214.545	42

3.2.4.4 Mathematical Expiration [17]:

This is equation below use also to calculate these properties:

1. Percentage Reduction of Area (A):

$$A = \frac{A_0 - A_f}{A_0} \quad [\%] \dots\dots\dots (5.1)$$

2. Percentage Elongation after Fracture (ε):

$$\varepsilon = \frac{L_f - L_0}{L_0} \quad [\%] \dots\dots\dots (5.2)$$

3. Stress (σ):

$$\sigma = \frac{F}{A_0} \quad [\text{MPa}] \dots\dots\dots (5.3)$$

4. Tensile Strength (R_m):

$$R_m = \frac{F_m}{A_0} \quad [\text{MPa}] \dots\dots\dots (5.4)$$

5. Yield Strength (R_y):

$$R_y = \frac{F_y}{A_0} \quad [\text{MPa}] \dots\dots\dots (5.5)$$

3.2.4.5 Hardness Test:

.Hardness is measure of how resistant solid matter is to various kinds of permanent shape change when compressive force is applied. The hardness of the tubes was recorded through the entire thickness with the same spacing. The average value of the measured hardness of the individual tubes was also calculated for each respective tube.

3.2.4.6 Brinell hardness Test:

The brinell scale characterizes the indentation hardness of materials through the scale of penetration of an indenter, load on a material test-piece. It is one of several definition of hardness in materials science.

3.2.4.7 Procedure of Examination:

A sample of the (failed tube and original tube) was taken to found the value of **BH:** (Hardness) for each tube, by using Brinell hardness device or mathematical expiration below.

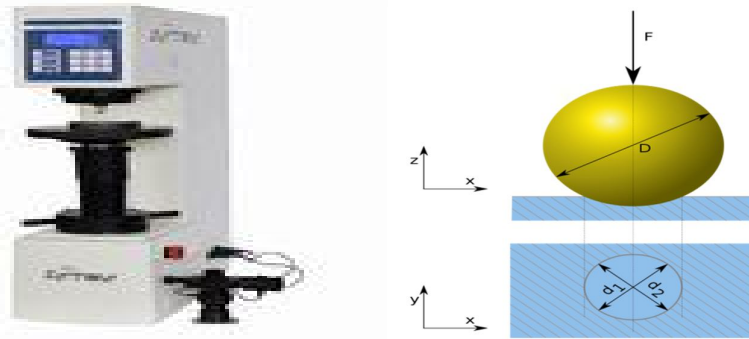


Figure 3.6: Brinell hardness devise & force diagram.

3.2.4.8Mathematical Expiration [17]:

$$BHW = 0.102 \frac{2F}{\pi D(D - \sqrt{D^2 - d^2})} [BH] \dots \dots \dots (5.6)$$

BHW: Brinell Hardness number (kgf/mm²).

F: applied load in (kg.f).

D: diameter of indenter (mm).

d: average diameter of indentation (mm).

W: indicates that carbide ball was used.

3.2.5 Bore scopes Examination:

3.2.5.1 Instruments/Apparatus:

XL LV Bore scope Apparatus.

3.2.5.2 Procedure of Examination:

A bore scope is an optical tool used to view areas that would otherwise not be visible. A bore scope is inserted into the item being evaluated without destroying the item of interest. A bore scope can consist of:

- Rigid or flexible working length.
- Light source to illuminate the target under inspection.
- Optical system that may consist of a relay lens system, rod lens system, fiber optic image guide a CCD or CMOS camera.
- Eyepiece or Monitor to view the image.



Figure 3.7: XL LV Bore scope (inspection device).

3.2.5.3 Method of test:

After start operation Bore scope device above, Let the Rigid or flexible working length in the internal surface of pipe, failure tube and also in original tube.(XL LV bore scope) utilizes (LED illumination) to display excellent image quality. You can save images, and motion video to the internal flash memory or removable USB Thumb Drive. This method use for inspection of damage in internal surface of boiler tube.

CHAPTER FOUR
RESULTS & DISCUSSIONS

4.1 Preface:

This chapter is present all results achieved for (KNPPS), from all experimental test in (chapter three), Results of experimental test and the effects of boiler tubes failure on efficiency of plant also investigation.

4.2 Visual examinations test:

The sampling and analysis of furnace tube of boiler is processed after inspection of boiler tube, the visual examination of the failed tubes reveals that the failure in The Photographs of the tubes as received conditions is shown in (Fig4.1) Visual inspection was carried out on the tube. The inside of the tube was found to contain a black thin layer of Magnetite, soft layer black deposits with whitish spots and small black particles Fig 4.1[22].

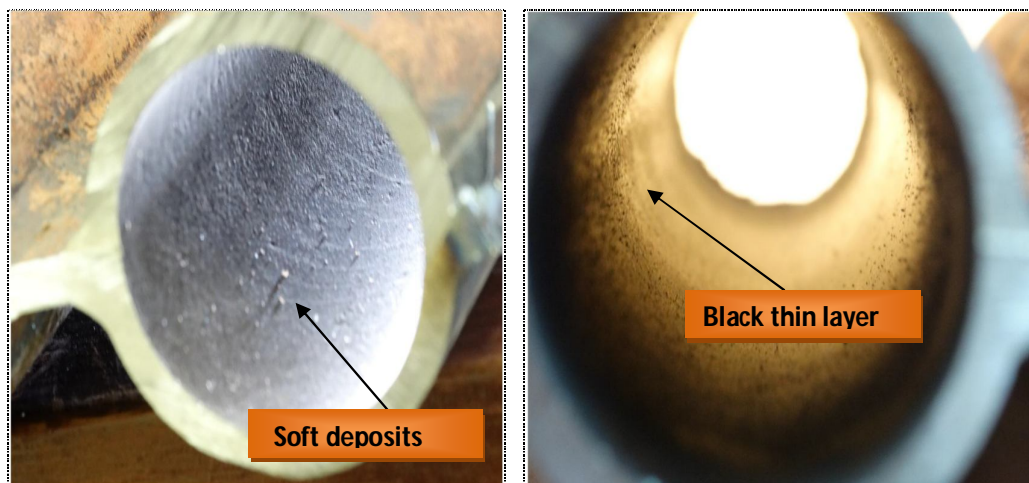


Figure4.1: deposit and black thin layer in side tube.

The tubes were also examined after removing the deposit from the internal surfaces as shown in Figure 4.2the photograph of the internal surface shows the presence of small pits. Beside contain a black- reddish thin layer.

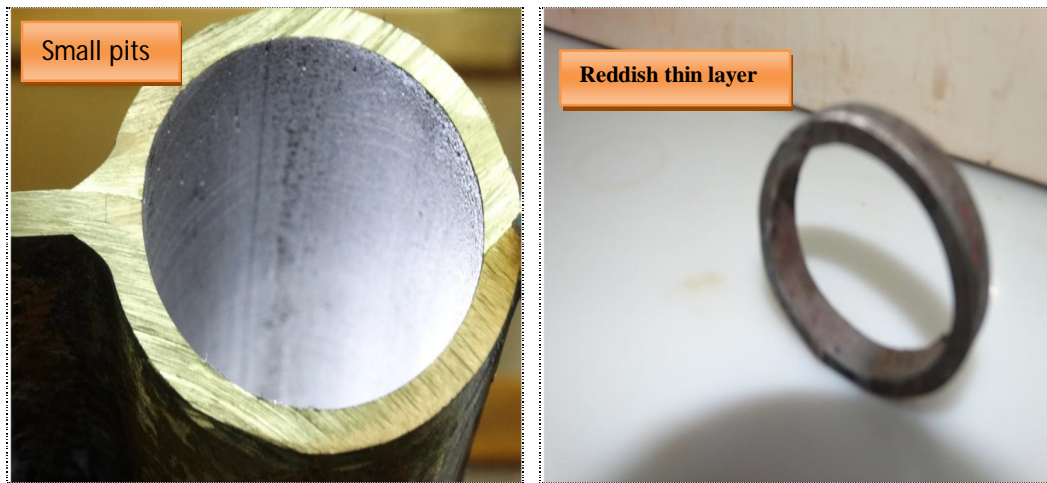


Figure 4.2: tube after removing of soft deposits and after chemical cleaning

The failed tube reveals bulging and thick inner side scale with longitudinal scale cracking and pitting at the inner surface Figure 4.3(A&B) [22].

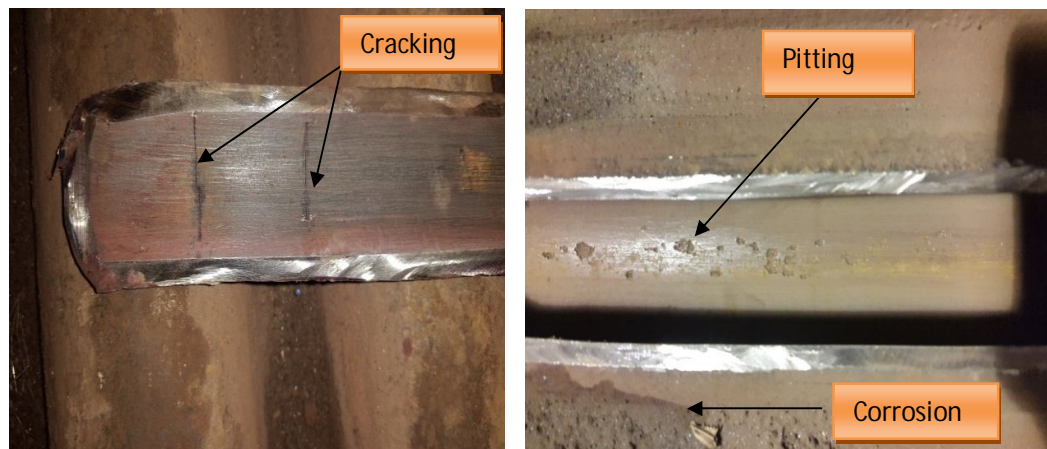


Figure 4.3: Cracking inside tube (A) and pitting & corrosion inside tube (B).

4.2 Dimensional measurement:

Table 4.1 Result of Dimensional Measurement

sample (ALLOY)	Outer Diameter (OD) (mm)	Inner Diameter(ID) (mm)	Wall Thickness(WT) (mm)
Original Tube	70.0	60.0	50.00
Failed Tube	78.6	68.2	38.0

From table (4.1) above Dimensional measurement Show the outer diameter (OD) at the zone of the failure of the failed tube is found 78.6mm against the original diameter (OD) 70.0 mm. The inner diameter (ID) of the failed tube found 68.2mm while original tube (ID) 60.0mm. The wall thickness (WT) found at the region of failure is 38.0mm against the nominal wall thickness (WT) 50.0mm. The reduction in wall thickness is by (24%).

4.3 Chemical Composition Confirmation:

Table4.2: Results of Chemical composition Component of different tube (wt. %)

SPECIMENS (ALLOY)	ELEMENTS (Average %)						
	C	Si	Mn	Cr	S	P	Fe
ASME SA178 GA Criterion	0.06~0.18	--	0.27~0.63	--	0.03 5max	0.035 Max	--
New Tube	0.522	1.34	1.62	0.218	0.0068	0.0159	93.9
Failed Tube	1.500	0.250	0.626	0.142	0.0020	0.0063	98.2
Difference Between New & Failed Tube	0.978	1.090	0.994	0.076	0.0048	0.0096	4.30

Unit: wt. %

From table (4.2) above, the chemical composition of tube material conforms to ASME SA178-GA (Carbon Steel). The chemical compositions of the specimen, new and failed tubes are shown in Table 4.2 It reveals obvious differences in Fe, C, Si, Mn, and S between these two specimens. In general, the materials properties are greatly affected by the contents of C and S. A decrease in mechanical strength always corresponds to a decrease in C content. However, the toughness is generally related to the quantity of Mn. For the Original (New) tube, the Mn content increased to 162ppm which was almost twice the standard value (63ppm). The degradation in toughness for the failed tube due to the higher S content is expectable. Also the content of carbon in failed (150ppm) tube more than original tube (52.2ppm) and standard value (18ppm) [23].

4.4 Mechanical Property Measurement:

4.4.1 Tensile test:

Table 4.3: Result of the tensile test for different tubes after test

<i>SPECIMENS (ALLOY)</i>	<i>ULTIMATE TENSIL STREGTH(ST)</i>	<i>YILED STRENGTH(YS)</i>	<i>ELONGAT ION(ε)</i>	<i>Percentage Reduction of Area (A)</i>
	<i>(MPa)</i>	<i>(MPa)</i>	<i>(%)</i>	<i>(%)</i>
ASME SA178 GA Criterion	325.0	180.0	35.00	N/A
New Tube (A)	495.5	345.0	17.00	44
New Tube (B)	452.5	340.6	13.20	55
Failed Tube (A)	450.5	270.5	9.09	44
Failed Tube (B)	334.4	244.5	7.27	58

Gauge length :($L_0 = 200\text{mm}$)& load:($F=45.95\text{KN}$)

From Table (4.3) above shows the experimental results of mechanical properties of the two tubes were examined by using tensile tests. The experimental results, including the mechanical properties, yield stress(YS), ultimate tension stress (TS) and elongation (ϵ), and *Percentage Reduction of Area (A)* are listed in Table(4.3), from results we found the value of mechanical properties of original and failed tube more than standard value of ASME, but failed tube are less than those of the new one. On other hand, the mechanical properties of the failed tube still satisfactory met the criterion requirement, even though the properties were affected by the high temperature [23].

4.4.2 Hardness Test (Brinell hardness Test, BH):

The experimental result of mechanical properties by using brinell hardness test of the two tubes (New tube and failed tube) was also listed in Table (4.4) below [22].

Table 4.4: Result of Brinell hardness test of two samples (BH)

SPECIMENS (ALLOY)	Position cross section of the tube				
	Outer side		Inner side		Ave
New Tube (A)	470.6	462.3	356.3	396.0	421.30
Failed Tube (B)	396.2	389.0	348.6	395.2	382.25

Loading weight: 1500kg.f

From Table 4.4 above show the experimental results of the Brinell hardness Test for two tubes. It is clear that the average value of the failed tube (**BH: 382.25**) is much lower than that of the new one (**BH: 421.30**). That is means the failure maybe occur in failed tube, also the forced of hardness and tenacities and strength of failed tube decreasing to facing several problem, comparison with original tube[23].

4.5 Bore scopes Examination:

The Bore scope Result of internal surface of both tubes (Failed tube & original tube) is displayed in figure below (Bore scope testing and failure analysis



Figure 4.4 -A: Corrosion inside tube Figure 4.4 -B: pitting inside tube

In some regions cracked thick skin of oxide layer was found and also the inside of the tube was found Corrosion and fatigue Figure 4.4-A above, and the internal surface exposed to pitting also Figure 4.4-B [22].

4.6 Effect of boiler tubes failure on efficiency of plant:

Boiler tubes in power plants have finite life because of prolonged exposure to high temperature, stress and aggressive environment. Boiler tube failures are predominantly the major cause of forced outages of (KNPPS) Fossil Fuel thermal power generating units. The forced outage leads to reduction in power generation and hence reduction in plant load factor and increased oil consumption due to multiple cold startup of boilers.

Overstressing, Starvation, Overheating of tubes, Creep life exhaustion, Stress corrosion, Waterside Corrosion, Fireside Erosion, Hydrogen embrittlement, Age embrittlement, Thermal shocks, Improper operating practices, Poor maintenance, Welding defects etc. are the major causes for boiler tube failure.

4.6.1 Boiler tube failure zones:

Boiler tube failures continue to be the major cause of forced outages. Statistically these are responsible for an overall availability loss of the units:

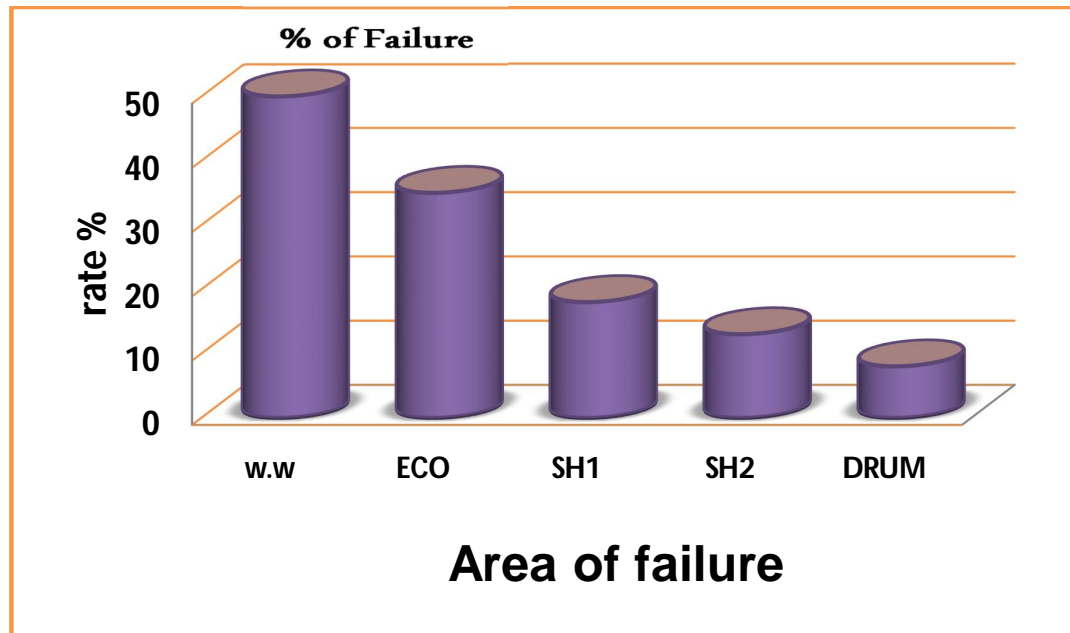


Figure4.5: Distribution of area of failure in boiler [26].

Table 4.5: Compare between Generation done and planned Generation for all thermal power plants (2016) (GW.h) [27]

PLANTS (THERMAL)	PLANNEDGENERATION	GENERATION DONE	RATE OF DONE
	(GW.h)	(GW.h)	(%)
ALSHAHEED(KNPS)	967.283	409.405	42.3%
GARRY (1,2)	357.636	842.189	235.5%
GARRY (4)	197.280	112.228	56.9%
KOSTI(UMDAB)	1304.816	1605.613	123.1%
DESIL GENERA	330.336	157.569	47.7%
TOTAL	3157.351	3127.004	99.0%

*(Annual report for year 2016)

From table found, the rate of generation done in (KNPPS) 42.3% only, that is means decrease in the generation by reason of forced outage repeated, and effects of the boiler tube failure on efficiency of plant.

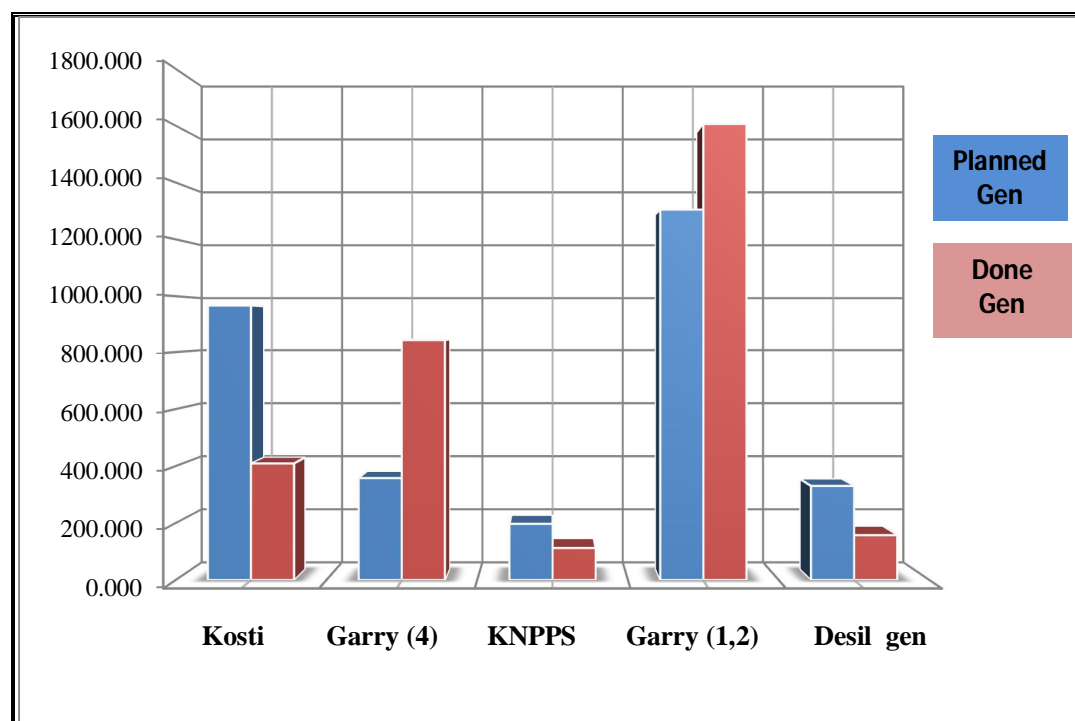


Figure 4.6: Contribute Generation of each plant (all thermal power plants).

4.6.2 Loss Classifications (Generation 2016):

Table 4.6 Losses Generation by several causes of (KNPPS)[27]

UNITS	Unplanned Out GW.H	Planned Out. GW.H	Trips GW.H	Performance & Others	Total Losses	Remarks
UNIT#1	63282.4894	668123991	4927.0311	23130.7304	158152.6500	
UNIT#2	237168.0000	0.0000	0.0000	0.0000	237168.0000	U2 N/A all year
UNIT#3	95601.6483	34800.0000	3601.6300	89114.3120	223117.5903	
UNIT#4	21137.5135	37265.0000	4302.4705	117936.5124	180641.4964	
UNIT#5	386400.0000	482503.3000	1515.0000	2537.0000	872955.3000	
UNIT#6	102524.0607	42096.7000	34973.6220	256937.6203	436532.0030	
Station	906113.712	663477.399	49319.754	489656.175	2108567.040	

*Sours (KNPPS, Annual report for Year 2016)

From table above found the losses of generation unplanned outage by several causes equal (906113.712GWh), and total losses generation equal to (2108567.040 GWh).

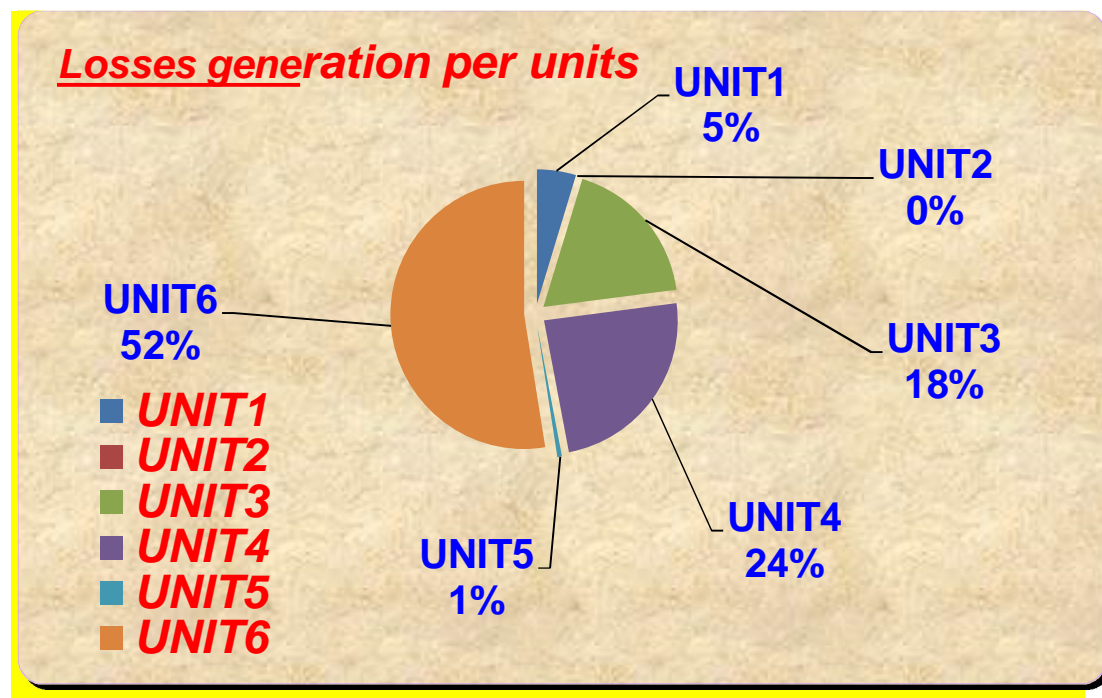


Figure 4.7: Distribution of Loss Generation for each Unit.

4.6.3 Losses Generation by Unplanned Outage [25]

Table 4.7: losses generation due to (forced outage of boiler equipment)

Unplanned Outage (Cause)	Energy losses (GWh)	frequency of Occurrence
Unit 5 oil starvation incident	787.2	2
Unplanned PM extension	102.7	3
Outages following TV trips	64.1	5
Boiler tube failure	24.3	4
Outages following other trips	17.3	3
Others	13.2	5
Boiler water contamination	11.4	2
Boiler gas leaks	11.4	1
Turbine Fire Incidents & oil leaks	11.2	3
PH3 lube oil filters	10.4	2
Turbine outages	7.6	2
Boiler outages (others)	4.6	2
PH2 HPH leakages	2.2	3
Water/steam leakages	1.8	2
Electrical supplies loss	1.3	1
total forced outage	1070.589	53.5
		40
		11

The value of losses generation due to forced outage of boiler equipment only, equal to **(53.5GWh)**, and frequency of occurrence equal to **(11time)** of those period by forced outage.

Table4.8: Number of Trips Classifications

Trip Category	No	Analyzed	Percentage
External	10	4	40.00%
Plant Failure(STM)	71	28	39.44%
Human Error	3	2	66.67%
Plant Failure(FTGTs)	13	8	61.54%
Total	97	42	43.29%

From table units trip **71time** by causes of plant failure percentage of repair **39.44%** only.

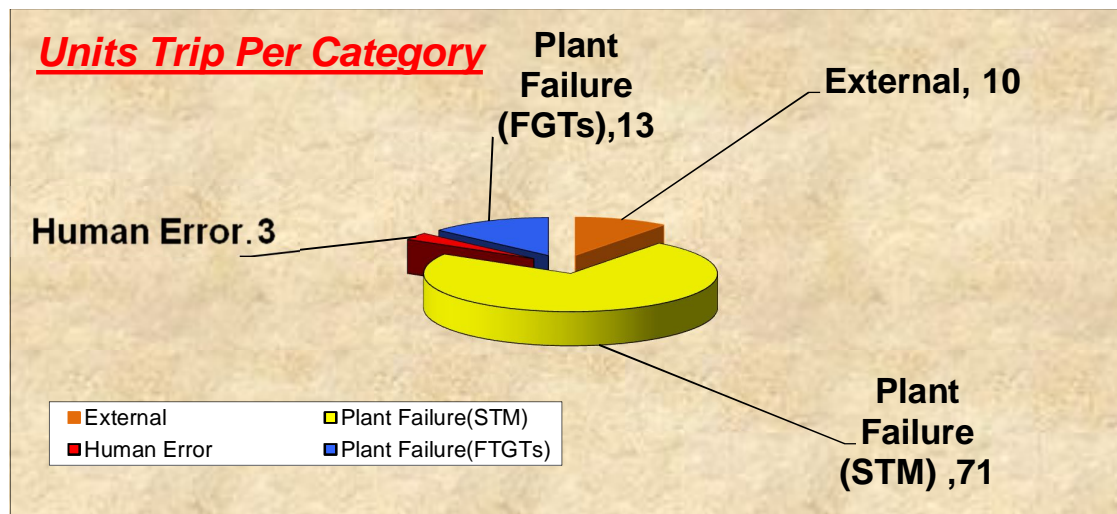


Figure 4.8: Distribution of Units Trip per Category.

4.7 Performance of Thermal Power Generating Units:

The installed capacity of the thermal power generating units contributes for about **30.93%** of the total installed capacity. The performance of the thermal power generating units, therefore play a significant role in meeting the demand supply gap. Based on the Central Electricity Authority annual report for the years (2012-2016) the few of the average performance parameters of the (KNPPs) thermal power plants for the past **5 years** are listed below [27].

Table 4.9: Performance reviews of (KNPPs) thermal power stations (2012-2016)

Description (Performance)	Units	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017
Number Forced outage	No	25	58	40	33	40
Forced outage (Energy Losses)	GWh	270.918	1096.422	1825.661	575632.46	1070.589
Total (Energy Losses)	GWh	1280.853	1496.491	2235162.3	2063160.2	2108567.04
Fuel Oil Consumption	Tons	279646.1	292582.4	8032.954	313968.95	284709
Energy Generated	MWh	1004816	1023810	778146	1024364	1038054
Auxiliaries	MWh	84413	89742	71554	87891	88717

Consumption						
Total Opera time	Hrs	24230	24317	21374	27511	28425
Availability Factor	%	64.33	46.79	40.66	52.34	45.10
Capability Factor	%	58.45	46.78	29.92	36.24	36.56

*(Source: Annual report – Performance review of (KNPPs) thermal power stations 2012 - 2016)

4.8 Cost of boiler tube failures:

1. The cost of boiler tube failures is comprised of three main components:

- The cost of the repair.
- The cost of startup oil to return unit to service.
- And the cost of lost Production.

2. Average loss of availability of 1% translates to approximately 3.6 days

Out of Service per leak.

3. Loss of generation (depends on the size of the unit).

4. Morale of the O&M staff and Morale of the stake holders.

CHAPTER FIVE
CONCLUSION
&
RECOMMENDATION

5.1 Preface:

In this study, the failure cause of the boiler tube of the (KNPS) boiler has been investigated by using (Experimental Methods) on boiler tube (original and failed tube).to reducing Unavailability of plant due to forced outage of boiler by reason boiler tube failure occurrence.

5.2 Conclusions:

The above test (Experimental methods) analysis of the main types of boiler Tubes leakage (water/steam), through the analysis of leakage on the pressure components of the boiler, the boiler tube installation, maintenance, operation and provide help and reference. To reduce the accident rate of tube boiler, making the equipment to obtain the controllable, in control, to ensure long-term stable and safe and economic operation of boilers. From the investigation and subsequent inferences on root cause, sequences of final failure can be illustrated as follows:

- 1.** Poor thermal conductivity of the deposit found on the inner surface of the tube adversely affects the heat transfer and led to higher tube metal temperature causing premature failure of the tube, and also chemistry parameters addition on feed water, causes corrosion. The effect of forced outage of boiler by reason of boiler tube failure, leads to reduction in power generation and hence reduction in plant load factor (PLF) and increased oil consumption due to multiple cold startup of boilers, And also effect on availability of units.

- 2.** The experimental results of mechanical property of the two tubes were examined by using tensile tests and Hardness Test. The experimental results, of tensile test including yield stress (YS), ultimate tension stress (TS) and elongation (ϵ), While the Hardness Brinell test got the average value of the failed tube (BH: 382.25) is much lower than that of the new one (BH: 421.30).The chemical compositions examination of the specimen (new and failed tubes)it reveals obvious differences in Fe, C, Si, Mn, and S

between these two specimens, the content of carbon in failed tube(150ppm) more than original tube (52.2ppm) and standard value (18ppm), also the toughness is generally related to the quantity of Mn. For the Original (New) tube, the Mn content increased to 162ppm which was almost twice the standard value (63ppm).

3. To detect& protection boiler tubes, and control of boiler tube leakage, there are three basic methods to obtain constant and control steam temperature to avoid overheating and thermal stress, Attemperation (control steam temp), Flue gas bypass (or flue gas proportioning), Flue gas recirculation, also Boiler tubes and heating surfaces get dirty because of an accumulation of soot, slag deposits, and fly ash. These substances are excellent insulators and reduce the effectiveness of the heating surface, to treatment this problem can be accomplished by using a soot blower system. The internal surface of header which is inaccessible can be inspected by Boroscope. This from modern technique is called Fibroscopy. Headers exposed to temperature cycling may experience internal cracking due to thermal fatigue. This technique is useful to examine the internal scaling.

5.3 Recommendations:

In order to increase the efficiency of power generation, most of the power plants opt for higher quality superheated steam, which can be produced by increasing the operating conditions. Since boiler tube life is greatly dependent to its tube temperature, it is suggested that constant monitoring should be carried out on the flue gas temperature. This is to ensure that the boiler could operate within the recommended manufacturer design temperature. This precaution step is necessary to reduce the possibility of overheated tubes from occurring which may accelerate the oxide-scale growth and creep rate. Besides that, the increase in the loading conditions to achieve better steam quality may accelerate the wall thinning on the tube. Therefore, it is important to operate the boiler within the

recommended optimum range specified by the manufacturer in order to attain both high quality steam and a shorter boiler maintenance interval. Operating the boiler above the design specifications will result in frequent maintenance, thus incurring more maintenance cost and downtime per year of operation. A boiler typically operates at a fluctuating trend due to uncertain demand from consumers. Therefore, the boiler tubes may also experience cyclic thermal stresses due to metal expansion and contraction which leads to fatigue failure. It is recommended the feed water used for attemperation in the super heater of the boiler are properly subjected chemical treatment to avoid such undesired white deposits, which is responsible for increase of tube metal temperature and subsequent failure of the tube. Since boiler tubes are also exposed to elevated temperature, the combined effect of both creep and fatigue failure; termed as creep-fatigue interaction can be studied in the future project. The program can be expanded to include this interaction to estimate the remaining life of the boiler tube.

5.4 Best practices in fossil fuel fired power stations to arrest Boiler tube leaks:

- 1.** Controlling the tube metal within design value by sacrificing the steam temperatures.
- 2.** Let soot blower system in service always.
- 3.** Periodic monitored metal temperature of super heater tube to avoiding (over heating).
- 4.** Providing protection shields over top banks of economizer, super heater, and vertical hanging tubes of rear walls.
- 5.** Changing of fossil fuel burner in every overhaul which plays key role in combustion.
- 6.** Maintaining chemistry parameters of feed condensate and steam and very monitoring of parameters to avoid water corrosion (effect of sea water).

7. Controlling the excess of SH and RH area air to avoid high velocity and high flow gases exit temperature.

8. During commissioning stage, flushing and chemical cleaning plays important role to clear any blockages in the circuit, otherwise these blockages will lead to tube failure (overheating), Providing thermal drain in soot blower steam line.

Reference:

- [1] Bhowmick, S., 2011. Ultrasonic Inspection for Wall Thickness Measurement at Thermal Power Stations. *International Journal of Engineering*, 4(1), pp.89-107. Available at: http://www.researchgate.net/publication/233971057_Ultrasonic_Inspection_for_Wall_Thickness_Measurement_at_Thermal_Power_Stations/file/9fcfd50d9c1480af18.pdf.
- [2] Bamrotwar, S.R. & Deshpande, V.S., 2014. Root Cause Analysis and Economic Implication of Boiler Tube Failures in 210 MW Thermal Power Plant. *Journal of Mechanical and Civil Engineering*, 2014, pp.6–10.
- [3] Y.f. Dong, L.J. Chi, Power plant boiler water wall bulge explosion, causes and treatment measures of tube. *Journal of Northeast Dianli University*, (2000), 4, p.5-12.
- [4] Y. Dou, the plant corrosion and example selection, Beijing: Chemical Industry Press, (2012), p.126-167.
- [5] China Institute of Business Research Institute, China power station boiler industry investment planning and future development trend forecast report in, Chinese Research Institute, (2013), p.5-20.
- [6] ASME, 2004. Section II Part D - Material Properties. ASME Boiler & Pressure Vessel Code. New York, NY: The American Society of Mechanical Engineers.
- [7] Z.L. Jia, The formation and prevention, Analysis of Hot Water Boiler Oxygen Corrosion, (2012), 10, p.3-6.
- [8] Y. Dou, the plant corrosion and example selection, Beijing: Chemical Industry Press, (2012), p.126-167.
- [9] Boiler operation regulations revision group in Shandong Jining Yunhe Power Generation Co. Ltd., 1, 2# unit operating procedures, (2010), p.101-166.

- [10] Bamrotwar, S.R. & Deshpande, V.S., 2014. Root Cause Analysis and Economic Implication of Boiler Tube Failures in 210 MW Thermal Power Plant. *Journal of Mechanical and Civil Engineering*, 2014, pp.6–10.
- [11] Fuchs HO, Stephens RI. *Metal fatigue in engineering*. John Wiley & Sons, Inc.; 1980. p. 7–33.
- [12] ASM International, 2002. *Introduction to Steels and Cast Irons - Metallography's Guide: Irons and Steels (#06040G)*. Ohio: ASM International.
- [13] Q.Z. Han, X.K. Xue, Analysis of thermal power plant boiler heating surface leakage causes and prevention measures of, *Application of Energy in*, (2011), 4, p.5-14.
- [14] Y. Dou, *the plant corrosion and example selection*, Beijing: Chemical Industry Press, (2012), p.126-167.
- [15] China Institute of Business Research Institute, *China power station boiler industry investment planning and future development trend forecast report in*, Chinese Research Institute, (2013), p.5-20.
- [16] Z.L. Jia, *The formation and prevention, Analysis of Hot Water Boiler Oxygen Corrosion*, (2012), 10, p.3-6
- [17] H. Xu, *Alkali corrosion diagnosis and mechanism of high pressure boiler water wall tube*, *Chinese Journal of Rock Mechanics and Engineering*, (2003), 2, p.20-26.
- [18] Y.f. Dong, L.J. Chi, *Power plant boiler water wall bulge explosion, causes and treatment measures of tube*. *Journal of Northeast Dianli University*, (2000), 4, p.5-12.
- [19] J.L. Li, X.B. Yang, *Steel and welded boiler*, Beijing: Science and Technology Press, (1988), p.20-30.
- [20] *Boiler tubes failures Journal of Physics E: Scientific Instruments, Overview on Intelligent Technique of Fault Diagnosis*.
- [21] [www.cropak.com/cfd- modeling thermal- simulation](http://www.cropak.com/cfd-modeling-thermal-simulation).

[22] Failure Analysis for the Economizer Tube of the Waste Heat Boiler, TSUNG-FENG WU New Materials Research and Development Department China Steel Corporation.

[23] Failure investigation of super heater tubes of coal fired power plant
A.K. Pram nick, G. Das, S.K. Das, M. Ghosh.

[24] Chia-Ching Chiang and Hsin-Hao Wang: Welding and Cutting, 10(2), 2000, p. 41.

[25] Performance Review of Thermal Power Stations, (Ministry of Power, Govt. Of sudan).

[26] ASME, 2004. Section II Part D - Material Properties. ASME Boiler & Pressure Vessel Code. New York, NY: The American Society of Mechanical Engineers.

[27] Central Electricity Authority annual report for the years (2012-2016).

[28] Guidelines for Feed Water, Boiler Water and Steam Quality for Power Plants/ Industrial Plants, VGB-R 450 Le, second ed., VGB Power Tecke. V., Essen, Germany, 2004.

[29] Cast Iron: Physical and Engineering Properties – by H.T. Angus, 1972, pp. 68–79.

[30] ASM Hand Book - Volume-15 (Casting), Fifth Printing, March 2004, pp. 681–684.

[31] Atlas of Time-Temperature Diagrams for Iron and Steels – Edited by George F. Vander Voort (ASM), pp.732.

[32] ElieTawil, P.E, Leed AP. Boiler Classification and Applications.

[33] Bruce W. Christ- Fracture and Deformation Division Center for .Materials Science, National Bureau of standards , Effect of Specimen Preparation, setup, and Test Procedures on Test Results.

[34] Study of Boiler Maintenance for Enhanced Reliability of System A Review.