SUPERVISOR DECLARATION

"I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Plant and Maintenance) with honours"

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Date :

DECLARATION

"I hereby declare that the work in this thesis is my own except for summaries and quotations which have been duly acknowledged"

Signature : ....

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Date :

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ABSTRACT

Failure analysis of structures has gained a considerable interest in many engineering areas. The aim of this research is to determine the root cause of the structural failures which can reduce the failure risks and prevent similar failures in the future. This thesis presents experimental investigations for the failure of a super-heater tube of a coal-fired power plant using several failure analysis procedures. The failure analysis comprised of visual inspection, optical microscopic, ultrasonic thickness measurement test and hardness test. A sample of a total-fractured super-heater tube obtained from an industry was used in this investigation. Initial visual investigations found that the super-heater tube had a longitudinal crack. This fracture appearance is called fish mouth stress rupture. The ultrasonic thickness test is to detect a significant oxide layer that occurs in the steam side surface. The optical microscopy were used to identify intergranular cracks, voids, elongated grain and deposit layers. The hardness test is to determine the resistance of material to penetration after being heated. The results for the hardness test and ultra-thickness test used to determine the rupture temperature and estimate the life period of the fail tube using Larson Miller Parameter.

ABSTRAK

Analisis kegagalan struktur telah menjadi satu keutamaan dalam bidang kejuruteraan. Tujuan kajian ini adalah untuk menentukan punca kepada kegagalan struktur yang boleh mengurangkan risiko kegagalan dan mengelakkan kegagalan yang serupa pada masa hadapan. Tesis ini menceritakan tentang uji kaji terhadap kegagalan tiub pemanas loji janakuasa arang batu menggunakan beberapa prosedur analisis kegagalan. Analisis kegagalan terdiri daripada pemeriksaan visual, mikroskopik optik, ujian ultrasonik pengukuran ketebalan dan ujian kekerasan. Satu sampel tiub pemanas yang diperolehi daripada industri telah digunakan dalam penyiasatan ini. Siasatan awal iaitu pemeriksaan visual mendapati tiub pemanas mempunyai retak. Ini menunjukkan kegagalan yg telah berlaku pada tiub pemanas dipanggil "*fish mouth stress rupture*". Ujian ultrasonik pengukuran ketebalan adalah untuk mengesan lapisan oksida yang berlaku di permukaan tiub di sebelah luaran. The mikroskop optik telah digunakan untuk mengenal pasti kegagalan sejenis "*intergranular cracks*", *"voids"*, "*elongated grain*" dan "*deposit layers*". Ujian kekerasan adalah untuk menentukan ketahanan bahan untuk penembusan selepas dipanaskan. Keputusan bagi ujian kekerasan dan ujian ultrasonic pengukuran ketebalan telah digunakan untuk menentukan suhu pecah dan anggaran tempoh hayat tiub gagal menggunakan "*Larson Miller Parameter"*.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Kapar Energy Venture or also known Stesen Janaelektrik Sultan Salahuddin Abdul Aziz a subsidiary of Tenaga Nasional Berhad (TNB) located in Kapar Klang Selangor. This plant is the largest power producer in Malaysia with triple type of fuel which is gas, oil and coal for primary fuel. The 2420 MW power produced were from four generating facilities or phases.

Phase 1: Consist of 2 units with 300 MW capacities and can use natural gas or bunker oil for primary fuel. Operation started in 1981 and thermal plant type consisting of a boiler and a turbine. The boiler manufactured by Riley Mitsui Japan and the turbine from Mitsubishi Heavy Industry Japan.

Phase 2: Consist of 2 units with 300MW capacity power and can use natural gas, bunker oil or coal for primary fuel. Operation started 1985 and thermal plant type consisting of a boiler and a turbine. The boiler manufactured by Ishigawa Heavy Industry Japan and turbine from Mitsubishi Heavy Industry Japan.

Phase 3: Consist of 2 units with 500 MW capacity power and can use natural gas, bunker oil and coal for primary fuel. Operation started in 1995 and thermal plant type consisting of a boiler and a turbine. The boiler manufactured by Ishigawa Heavy Industry Japan and turbine by General Electric.

Phase 4: Consist 2 units with 100MW capacity power and can use natural gas or distillate oil for fuel. Started operation in 1994 and gas turbine open cycle type. All systems manufactured by Nouvo Pignone GE.

Defective boiler tube can affect the operation process at this plant because boiler tubes are very important component in boiler system. Boiler tube is energy conversion component where heat energy from combustion of fuel are absorbed by the tubes and transferred to the water to produce steam. Heat energy is obtained from combustion gas. The combustion gas will evaporate the water into steam in the water wall tubes and there after passes over to the super-heater tube to produce super-heated steam. The boiler tubes were designed for a specific period of time of operation in a complex situation involving high temperature, pressure and corrosive environment.

1.2 PROBLEM STATEMENT

The function of boiler is to convert water to steam. In high capacity power generation industry, water tube boilers were used to absorb thermal energy from burning of fuel such as coal. Coal fuelled boiler dominates the electric power plant by providing superheated steam to drive the steam turbine. In a coal fire with fire tube type boiler, the super-heater tube is exposed to high temperature flue gas to 1000 °C. A boiler at Kapar Energy Venture SDN BHD power plant was shut down due to final super-heater tube failure with running hours of 40258. The type of failure has been detected was tube burst. There were no sign of significant corrosion or erosion to the tube. The tube also shows no indication suffering from creep.

1.3 PROJECT OBJECTIVE

The shutdown of a power plant is a major event. When it is scheduled, all maintenance procedure focuses on shortening the period of shutdown. Unscheduled shut-down is disruptive and costly. While the causes of failures have been documented by the manufacturer, the root of these failures can be due to localised irregularities. It is therefore very sensible to transform this industrial problem as a project with the following objective:

- To investigate the root cause failure (tube burst) of final super heater tube.
- To suggest a new maintenance procedure to avoid failure

CHAPTER 2

LITERRATURE REVIEW

2.1 BOILER

By definition, steam generator or a boiler is a closed pressure vessel in which a water is heated by combustion and being converted into steam for heating purpose or as a mobile power source (Harry Jr, 1981). A boiler is also known as a tool to convert the chemical energy in the fuel to heat energy and from heat energy to potential energy available in the steam. In the modern world where power generation is an absolute must and a need to be produced at astronomical quantities, boiler becomes an important tool due to its capabilities to generate steam from relatively cheap and easily available entity, water. Steam is important for power generating facilities because it can be produced anywhere in the world as long as there are fuel as the heat source in the area because of steam is produced from water and it is non-toxic and also can be recycled from steam to water to steam again by the use of a condenser. Today boiler is engineered to used steam efficiently as well economically feasible. Boiler can be divided by two major type, fire tube boiler and water tube boiler. Boiler can be operated using two important elements, fuel and water.

2.1.1 Fire Tube Boiler

A fire tube boiler is a type of boiler in which hot gases from a fire pass through one or more tubes running through a sealed container of water, Figure 2.1. The heat of the gases is transferred through the wall of the tube by thermal conduction, heating the water and ultimately creating a steam (Harry Jr, 1981).

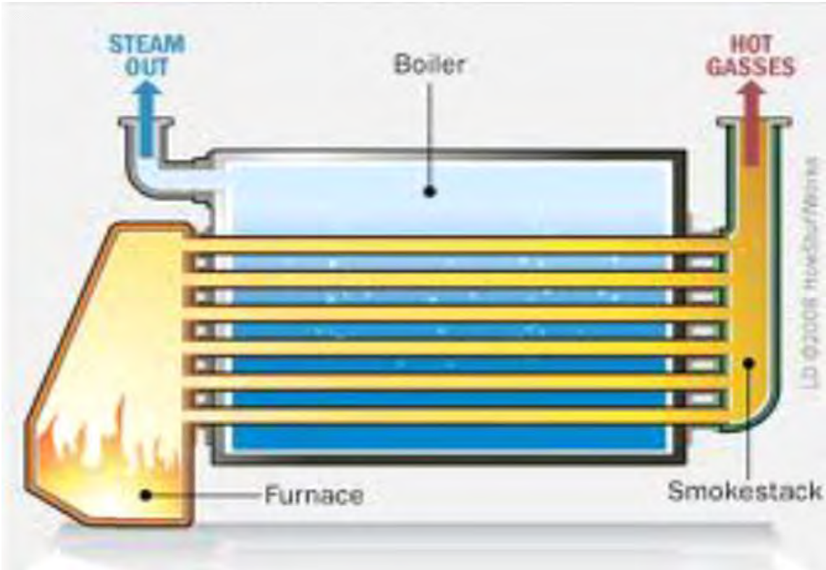

Figure 2.1 : Simple process of boiler fire tubes (IHS Engineering 360, 2014)

2.1.2 Water Tube Boiler

A water tube boiler is a type of boiler which water circulates in tubes heated externally by the fire. Fuel is burned inside the furnace, creating hot gas which heats water in the steam generating tube (Harry Jr, 1981). In smaller boilers, additional generating tubes are separate in the furnace, while larger utility boilers rely on the water filled tubes that make up the walls of the furnace to generate steam. The heated water then rises into the steam drum. Here, saturated steam is drawn off the top of the drum. In some service, the steam will recycle the furnace through super-heater tubes to become superheated. Figure 2.2 shows a simple process in water tube boiler.

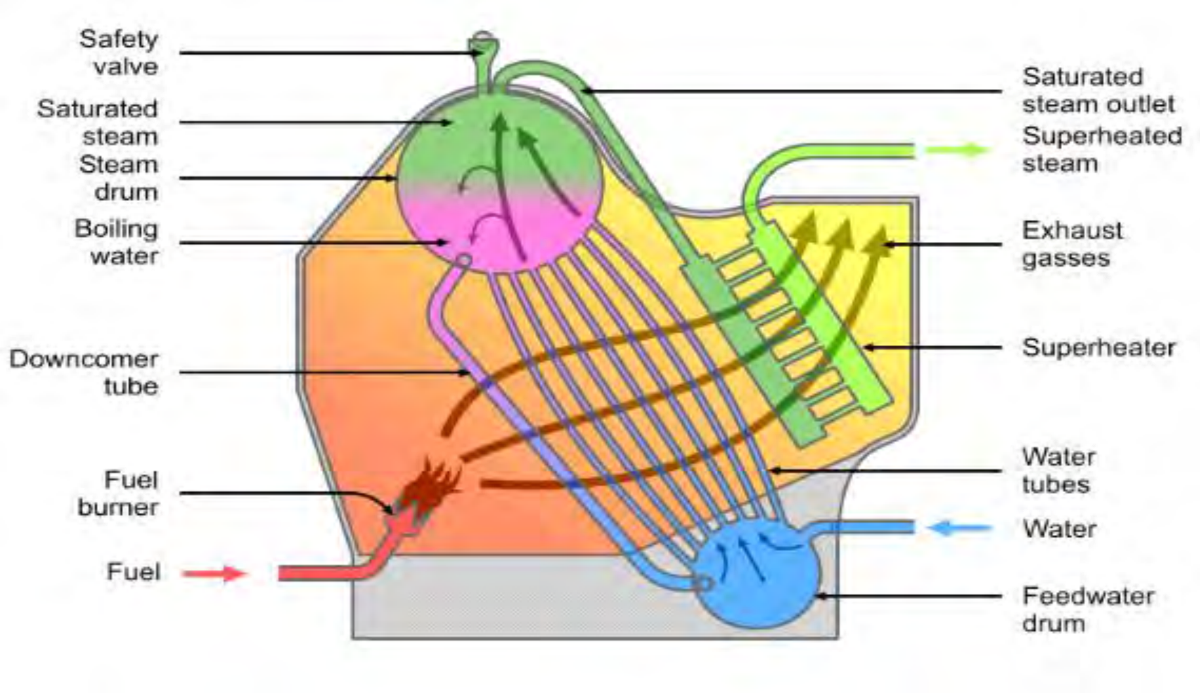

Figure 2.2 : Simple process boiler water tubes (IHS Engineering 360, 2014)

Fire tube boilers are designed with the tubes contained in the shell. The tubes of most water tube boiler are located outside the shell or drum. The advantage to this feature of the water tube boiler is a higher capacity may be obtained by increasing the number of tube independent of shell. The biggest advantage over fire tube boiler is the freedom to increase the capacities and pressure. The advantage and disadvantage of boiler water tube are showing in Table 2.1 compared with boiler fire tube. The ability of water tube boiler to generate superheated steam makes these boiler particularly attractive in application that require dry, high pressure, high energy steam including steam turbine power generation. Owing to their superb working properties, the use of water tube boiler is highly preferred in most power generating plants.

Table 2.1 : Water tube boiler versus fire tube boiler

No.	WATER TUBE BOILER	FIRE TUBE BOILER
1.	The water circulate inside tube	Water circulate outside the tube
2.	Can generate pressure up to 165 Bar	Only pressure up to 25 Bar
3.	Can generate steam up to 450 mt/hr	Only generate up to 10mt/hr
4.	Overall efficiency up to 90%	Overall efficiency 75%
5.	Various part can be separated	Erection is difficult
6.	High operation cost	Low operation cost
7.	Various type of fuel can be use	Only can use manufacturing design fuel
8.	The bursting chances are more	Bursting chances are less
9.	Use for large power plant	Not suitable for power plant
10.	Easy to done maintenance	Not easy to done maintenance

2.2 BOILER SUPERHEATER TUBE

Super-heater tubes are a bank of tubes in the exhaust gas duct after the boiler combustion and use to heat the steam above the saturation temperature (Harry Jr, 1981). Boiler super-heater tubes are energy conversion high pressure and temperature component in a boiler system. It is used to convert wet steam to dry steam which is at high pressure, superheated steam, then delivered to a turbine for generate electrical power in the power plant such as a Tenaga National Power Plant at Kapar, Klang. Heat energy is obtained from combustion gases produced by burning coal in the furnace. The flue gases evaporate wet steam into superheated steam in the super-heater tube bundle. The tubes designed for a specific period of time operated in a complex situation involving high temperature, pressure and corrosive environment. Figure 2.3 shows a bank of tube in boiler water tube at flue gas compartment.

Figure 2.3 : Super-heater tubes in boiler (Chong, Ahmad, & Purbolaksono, 2002)

2.2.1 Electric Resistance Weld Tube

Boiler super-heater tube is made in both seamless and electric resistance weld. Tubing made by either process is rigidly controlled and tested both during and after rolling to meet the exacting specification requirement of a pressure tube and environment condition (Chong, Ahmad, & Purbolaksono, 2002). Boiler tube have to comply with specification and meet allowable working pressure rating, are always expressed and sold as minimum wall. Whether to use seamless or electric weld boiler tube is largely a matter of personal preference. Electric weld boiler tubes are fully comparable to seamless by standard of ASME Boiler & Pressure Vessel code requirement and general acceptance.

2.2.2 Seamless Tube

Advocates of seamless tubing prefer no weld seam in the tube wall. This is true as a further protection in the heavier nominal of seamless due to the method of manufacture. Further, the piercing process in making seamless tube impart a tough mill scale to tube surface which appears to make it more resistance to corrosion. Specification in general use for boiler tube is showing in Table 2.2.

Table 2.2 : Specification in general use for boiler tube (ASTM International, 2014)

GRADE	SPECIFICATION
Low carbon seamless	A-192 / A-179
Low carbon electric weld	A-178 / A-214 / A-226
Medium carbon seamless	A-210
Medium carbon electric weld	A-178
Low alloy	A-423
Carbon molly seamless	A-209
Carbon moly electric weld	A-250
Alloy seamless	A-213 T series
Stainless seamless	A-213 TP series
Stainless electric weld	A-249 TP series

2.2.3 Alloys in Super-Heater Tube Material

Steels and cast iron are basically alloys of iron and various other elements in the periodic table. The vast majority of steel and all cast iron contain carbon as principal alloying elements. For example, manufacturing standard suggested boiler tube use material from carbon steel intermediate alloys with grade SA213-T22. This grade have 2-1/4 chromium, 1 molybdenum alloy with exceptionally high creep properties but is limited for application to 1125 °F because of possible higher temperature scale exfoliation. It is listed in the ASME boiler code for temperature to 1200 °F. The materials grade are listed by the author is based on the American society of Mechanical Engineers (ASME) standards. Some of the alloy grade that is commonly used as super-heater and re-heater tube listed in Table 2.3. For the first column, it shows the nominal compositions of Ferritic Alloys. The standard specification for Seamless Ferritic and Austenitic Alloy-Steel Boiler, Super-heater, and Heat-Exchanger Tubes are called SA213. The compositions represent the element in the Ferritic Alloys for example P (phosphorus), S (sulphur), Si (silicon), Cr (chromium) and Mo (molybdenum).

Table 2.3 : Feritic alloys used in boiler tube (ASTM international, 2014)

Feritic Alloys	Specs	Grade	Compositions (%)				
			P	S	Si	Cr	Mo
5Cr - 0.5Mo	SA213	T5	0.03	0.03	0.5	4.0-6.0	0.45-0.65
9Cr - 1Mo		T9	0.03	0.03	0.25-1.0	8.0-10.0	0.90-1.10
1.25Cr - 0.5Mo		T11	0.03	0.03	0.50-1.0	1.0-1.50	0.44-0.65
1Cr - 0.5Mo		T12	0.045	0.045	0.50	0.8-1.25	0.44-0.65
2.25Cr - 1Mo		T22	0.03	0.03	0.50	1.9-2.60	0.87-1.13

From Table 2.3, it shows that different material grades consist of different of percentages of compositions of alloying. These alloying elements are desirable as it help to improve the mechanical properties of the tube. Table 2.4 shows that the function of each alloying elements. This information will determine what alloying elements have to be adding to meet the specific requirement for the daily uses.

Table 2.4 : Functions of alloying element (Chase Alloys Ltd, 2011)

ALLOYING ELEMENT	FUNCTION
Carbon	Increase solid-strength, hardness and hardenability
Phosphorus	Improve machinability, aids strength and corrosion resistance, increase the tendency to cracking during welding
Sulfur	Considered as impurity in most steel, improve machinability
silicon	Deoxidizing agent, hardening of the feritic phase in steel
chromium	Increase strength, hardness, hardenability, increase resistance to corrosion and high temperature oxidation, improve wear and abrasive resistance, provide high temperature strength
molybdenum	Improve high temperature properties such as creep strength, counteracts temper embrittlement, enhance corrosion resistance in stainless steel

2.3 DEFINITION OF FAILURE ANALYSIS

Failure analysis is an engineering approach to determine how and why a component failed. Some general causes for failure are structure loading, corrosion, chemical effect, wear and latent defects (French, 2000). The goal of failure analysis is to understand the root cause of the failure so as to prevent similar failure in the future. In modern business analysis, it is very important due to involve with economic issues.

To verify the failure mode, it is important to determine the factor that explain the how and why the failure occurred such as identifying the root cause event of the failures in super-heated boiler system. The root cause event allows us to explain why the component failed. Many steps need to be followed to determine and carry out an investigation.

Step below is the procedure on how to process will begin:

1. Collect as much the information with possible concerning including part servicing history, part literature, part specification, engineering drawing and etc.
2. Performing non-destructive testing:
    - Check for any crack and internal flaws
    - Check for any crack and external flaw
    - Check metal thickness
    - Residual stress measurement
3. Select original sample of failed
4. Mechanical testing
5. Microscopic examination and analysis
6. Determine failure mode
7. Chemical analysis
8. Fracture mechanics consideration
9. Analysis of the evidence
10. Formulation of conclusion