PALM OIL MILL BOILER FEED WATER (BFW) QUALITY DATA ANALYSIS FOLLOWING ASME SPECIFICATIONS FOR THE STATE OF PERAK

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by

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TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

Page

LIST OF ABBREVIATIONS

BFW	Boiler Feed Water
ASME	American Society of Mechanical Engineers
POM	Palm Oil Mill
SDG	Sustainable Development Goal
TDS	Total Dissolved Solids
POME	Palm Oil Mill Effluent
DOSH	Department of Occupational Safety and Health
ND	Not detectable
NS	Not specified
PPM	Part Per Million
USM	Universiti Sains Malaysia

LIST OF APPENDICES

PALM OIL MILL BOILER FEED WATER (BFW) QUALITY DATA ANALYSIS FOLLOWING ASME SPECIFICATIONS FOR THE STATE OF PERAK

ABSTRAK

Dandang merupakan nadi industri kilang kelapa sawit untuk melaksanakan proses perindustrian dengan berkesan. Di sinilah air umpan dandang memainkan peranannya. Kecekapan dan produktiviti dandang sangat bergantung pada kualiti air umpan dandang yang dimasukkan ke dalam dandang. Kualiti air umpan dandang merosot apabila kepekatan kekotoran yang ada meningkat. Dalam kajian ini, 37 kilang kelapa sawit dari negeri Perak dipilih untuk melakukan analisis kualitatif air umpan dandang berdasarkan standard yang disyorkan oleh American Society of Mechanical Engineers (ASME). Sebanyak 1427 data bersumber dari Department of Safety and Health (DOSH) dengan keseluruhan tujuh parameter air umpan dandang sedang diteliti dalam kajian ini. Pemboleh ubahnya merangkumi nilai pH, jumlah pepejal terlarut, kealkalian hidrat, kekerasan total, jumlah klorida, total silika dan besi total. Jenis kegagalan dandang yang paling umum dipengaruhi oleh kepekatan tinggi kekotoran yang dikaji adalah kakisan dan pembentukan skala pada dandang yang mempengaruhi fungsi dandang. Dari hasil analisis, selain nilai pH air umpan dandang, parameter yang tersisa menunjukkan penyimpangan utama dari piawaian ASME. Oleh itu, rawatan yang betul terhadap air umpan dandang yang terdiri daripada penapisan, pembekuan dan flokulasi, osmosis terbalik, pertukaran ion dan rawatan dalaman kimia untuk mensasarkan kekotoran dibincangkan untuk memastikan prestasi yang lancar dari dandang.

PALM OIL MILL BOILER FEED WATER (BFW) QUALITY DATA ANALYSIS FOLLOWING ASME SPECIFICATIONS FOR THE STATE OF PERAK

ABSTRACT

Boilers are the heart of the palm oil mill industry in order to perform industrial processes effectively. This is where boiler feed water plays its role. Boiler's efficiency and productivity is highly dependent on the quality of the boiler feed water fed into boilers. The quality of the boiler feed water degrades as the concentration of the impurities present increases. In this study, 37 palm oil mills from the state of Perak is chosen to conduct the qualitative analysis of boiler feed water based on the American Society and of Mechanical Engineers (ASME) recommended standards. Total of 1427 data was sourced form Department of Safety and Health (DOSH) with an overall of seven parameters of the boiler feed water is being investigated in this study. The variables are inclusive of pH value, total dissolved solids (TDS), hydrate alkalinity, total hardness, total chloride, total silica and total iron. The most general type of failure of the boilers that is affected by high concentration of impurities being studied is the corrosion and formation of scale in the boilers that affects the functionality of the boilers. From the results of the analysis, other than pH value of the boiler feed water, the remaining parameters shows major deviation from the ASME standards. Therefore, proper treatment of boiler feed water that consists of filtration, coagulation and flocculation, reverse osmosis, ion exchange and chemical internal treatment to target the impurities is discussed to ensure smooth performance from boilers.

CHAPTER 1

INTRODUCTION

1.1 Background Study

Malaysia can be considered as one of the biggest palm oil producers, globally. This fact brings a lot of economic benefits to Malaysia as palm oil can be taken as the highly traded oil in the whole world because it almost consists of 35 % of the global vegetable oil market (GreenPalm, 2015). The efficiency and the versatility of palm oil massively contributes to this phenomenon. In comparison with rapeseed, sunflower and soya crop, palm oil exhibits tremendously higher production capacity, an approximate of 10 tonnes per hectare of land. This made justification to the efficiency of palm oil production as it requires almost ten times lesser land in contrast to the remaining three major oil production in Malaysia. In terms of versatility, palm oil is greatly versatile. This is because various of products possessing distinguishable characteristics can be formed by processing palm oil trees.

In 1870, 150 years ago, oil palm also known in its scientific name *Elaeis guineesis* was freshly introduced to Malaysia as an ornamental plant. Ever since, the plantation area of palm oil mill has rapidly raised over these years and has been presented as the most vital commodity crop existed in Malaysia. Food related product comprises 90% of palm oil and the remaining 10% is utilised as the basic raw material for the production of soap. Combination of Indonesia and Malaysia owns more than hundred palm oil mills in total.

It is studied that Malaysia uses small boilers for the purpose of generation of electricity and processes for the extraction of palm oil. Usage of boiler is rising in the chemical industry as years passed as it produces steam in huge quantities. The steam generated from boilers are mainly used for heating and in electric power supply

stations (Water and Performance, 2016). In general, a boiler can be described as an enclosed vessel that converts pressured water into steam by applying heat. The chemical energy from the fuel used in the boiler furnace transforms to heat energy that enables transfer of heat from boiler to the water in it, efficiently. The heat is transferred from the boiler to boiler feedwater via three ways which are radiation, convection and conduction (Abdalla, Musa and Babiker, 2017).

As stated, palm oil mill in Malaysia most generally utilises small boilers. Small boilers are boiler with low volumetric capacity. The most common boiler used in palm oil mill in Malaysia is water tube boiler. The water tube boilers principally utilized for creating steam with high temperature and pressure. This boiler's internal structure incorporates a small steam drum and small width tubes. Water tube boilers differs from shell type boilers because in water tube boilers, water is circulated along the tubes with the presence of heat source encompassing them. Water tube boilers possesses tubes with smaller diameters. Thus, a lot of higher pressure can be endured with the similar stress (Spirax Sarco, 2020).

The main operating principle of the water tube boiler is thermal siphoning in other words, circulating natural water around. Water tube boiler mainly consists of two drums, that is steam and lower (mud) drum as depicted in Figure 1.1. These drums are connected via tubes like riser and downcomer. Firstly, water pump is used to feed water to the steam drum of the boiler. As fuels gets burned, hot gases will be produced. The gases will convert the water into steam as the concentration increases along with temperature. In the steam drum, water and steam in present will be parted based on difference in concentration. Due to low concentration, steam will be passed upward whereas water downwards because it exhibits higher value of concentration (ElProCus, 2020).

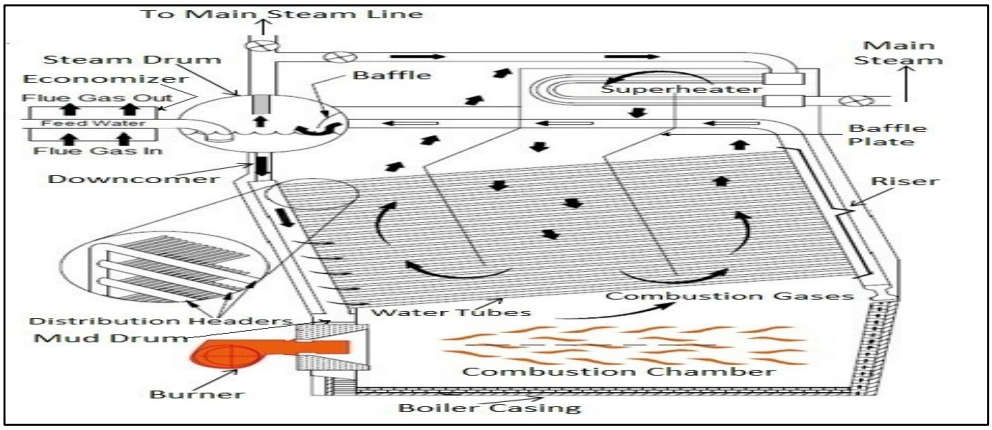

Figure 1.1 Schematic diagram indicating the operating principle of water tube boilers (ElProCus, 2020).

Moving on, the water that travelled downward from the steam drum will be fed to the mud drum via downcomer tube. When cool water is supplied to the steam drum, it travels downwards as it has high concentration. As hot water transferred from mud drum to steam drum via riser tubes, water circulation occurs in the water tube boiler. The force existing in the drum increases as generation of steam is added to the boiler. Hence, with addition steam the water being supplied to the drum undergoes reduction and eventually reduces the flow of steam too. In a different scenario, low rate of production will decrease the force in the boiler. Thus, the water supplied will rise and elevate the rate of production of the boiler. This is basically how the water tube boiler controls and operates (ElProCus, 2020).

1.2 Problem Statement

Treating boiler feed water before it enters its boiler is a necessity in all industrial applications that is present globally. Water treatment acts as an essential technology that should be practised in any chemical industry. Poor water treatment of feed water may lead to very dangerous scenarios especially in terms of economic and environmental aspect. The demand of the quality of` boiler feed water is constantly

varying from its type and working pressures boiler exhibits. In general, colourless and clear water should be ensured by averting suspended solids, contaminants, oils, aggressive and toxic chemicals (Čuda, Pospíšil and Tenglerová, 2006).

The Department of Occupational Safety and Health known as DOSH is a department under the Ministry of Human Resource of Malaysia. DOSH is a primary government agency that deals with the administrating and enforcing legislations that is related to occupational safety and health of Malaysia. The main aim and vision of DOSH is to turn into an organisation that leads Malaysia in making it a compulsory to create a safe and healthy working environment that amplifies the quality of working life of the national citizens. In specific, DOSH is a department in Malaysia that holds the responsibility in making sure the safety, health and welfare of people in their workplace. Also, ensuring to provide protection to other people from any safety and health hazards possessed by activities sectors such as Hotel and Restaurant, Construction, Manufacturing, Agriculture, Forestry and Fishing, Transport, Storage and Communication, Utilities, Finance, Insurance, Real Estate and Business Services, Wholesale and Retail Trades, Mining and Quarrying, Public Services and Statutory Authorities (DOSH, 2021).

Mostly, all feed water for that enters the boiler in Malaysia are from raw source such as raw water from rivers, wells or even lakes surrounding the plant. In specific for the state of Perak, most of the palm oil mill industry was nestled around natural rivers as presented in Figure 1.2. The amounts of suspended solids and dissolved gases available in natural waters varies with the source of the raw water and the location of the source being situated. The main reason behind the requirement pre-treatment of water is to avoid deposition, corrosion of the boiler system and avert carryovers at all cost. This is due to the fact that evaporation of water in boiler leads to concentration

of impurities. Poor quality of feed water engenders the quality of steam being produced by the boiler and may also reduce the quality of the end product of a particular process. In many industrial applications, pre-treating the feedwater has exhibited positive and successful operations.

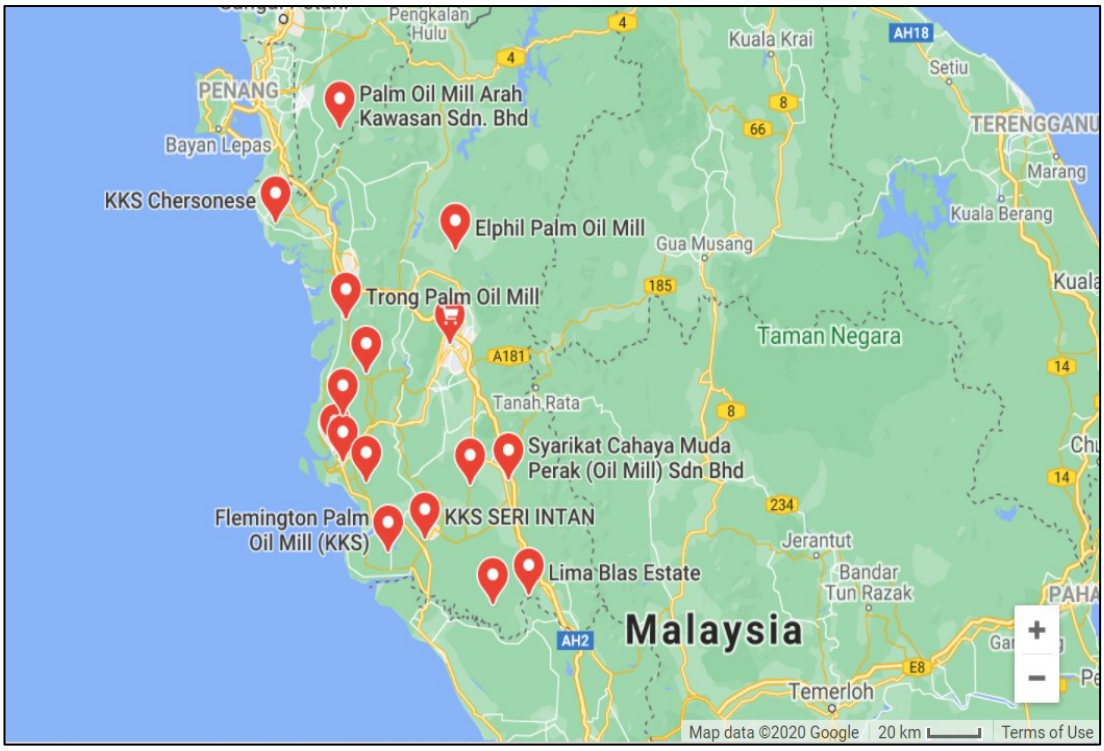

Figure 1.2 Google Map image of the palm oil mill in the state of Perak (Google Maps, 2020).

Water is made of hydrogen and oxygen. The physical properties of water are tasteless, colourless and odourless. Water plays an ideal medium to generate power and to conduct heat too. This is because water can be easily converted to steam provided it occurs at the appropriate temperature. The boiling point of water is highly dependent on the factor of pressure. The boiling point of water is 373.15 Kelvin at sea level whereas water boils at 646.483 Kelvin. As boiling point of water increases along with the increase in pressure (Sedifilt, 2011).

ASME guidelines is extremely important in defining the quality of boiler feed water. Treatment of boiler feedwater is undeniably critical. Many problems can be

emanated from boiler feedwater that do not ASME guidelines. This boiler feedwater problems are inclusive of poor efficiency when dealing with transfer of heat. Lower efficiency also leads to elevated fuel costs. Next, boiler feedwater should abide ASME guidelines and be treated fairly well in order to avert corrosion and fouling. Escalated occurrence of corrosion is engendered by rise in the amount of dissolved gases in the boiler feedwater. In a serious note, there's a high potential of the occurrence of a calamitous event that is resulted by unexpected failure of pressure valve due to thermal shock or overheating. Thus, palm oil mill boiler feedwater quality data analysis following ASME specifications for the state of Perak may depict the importance of abiding the ASME guidelines.

The main causes of impure water of palm oil mill boilers in the state of Perak can be due to utilising river water situated nearby as raw feed water for the boiler used in palm oil mills. It has been declared that generate on of waste produced by palm oil mills leads to environmental pollution (Hosseini & Wahid, 2015). Among all liquid and solid wastes produced by palm oil mills, POME which is the palm oil mill effluent can be categorised as the most troublesome waste in terms of expenses and difficulty on waste management. It could be due to the waste disposal of POME to the natural resources of water surrounding the palm oil mills that contribute to the poor quality of the boiler feed water quality. Almost two million tonnes of sewage, agricultural and industrial waste is being discharged into world's natural resource of water without any limitation. Thus, it is extremely important to ensure that the quality of the feedwater is on par with the present ASME guidelines. For palm oil mills that do not abide the ASME guidelines, adequate mitigation steps and proper treatment to enhance the quality of the boiler feed water quality utilised in palm oil mills.

1.3 Scope of Thesis

In this case study, we are focusing on the quality data analysis of boiler feed water of palm oil mills in the state of Perak, Malaysia. The analysis will be carried out for a total of 37 palm oil mills in total. Most of this palm oil mills are located around surrounding natural resources of water. Thus, it is presumed that the boiler feed water utilised in the boilers of these palm oil mills are originated from these rivers. The palm oil mill boiler feed water data of all these 37 palm oil mills of the state of Perak was provided by Department of Safety and Health, Malaysia also known as DOSH. The scope of this thesis is to identify the boiler feed water quality used in all these palm oil mills by investigating and analysing the data obtained from these palm oil mills qualitatively in order to identify the inadequate and insufficient treatments or maintenance done to the boiler feed water and the boilers. Lastly, proposing appropriate boiler feed water treatments to ensure the boilers in all these palm oil mills of Perak runs efficiently at the same the environmental safety is ensured.

1.4 Thesis Organization

This research study thesis is categorised into five chapters. The five chapters are inclusive of Chapter 1 Introduction, Chapter 2 Literature Review, Chapter 3 Research Methodology, Chapter 4 Results and Discussion and finally Chapter 5 Conclusions and Recommendations. In Chapter 1 Introduction, the background study, problem statement, objectives and the scope of the thesis was defined. The general and specified objective was listed to set the goal of the research study. In Chapter 2 Literature Review documented and reviewed related studies of BFW palm oil that consists of palm oil mill in Malaysia, processes involved in palm oil mill, generation of waste, boiler fundamental operation, type of boilers, chemical and physical

properties of water, characteristics of BFW, treatment for BFW, ASME for BFW, data analysis for BFW, sustainability of BFW and lastly Gap analysis relating to the research study. Chapter 3 Research Methodology described methods and procedures used in this study. The detailed case study of BFW for palm oil mill in Perak was listed, the analysis procedure starting from Pre-Analysis Data Screening, Correlation Analysis followed by Histogram Plot Analysis and Box Plot Analysis and summed up with proper treatment suggestion for BFW, Chapter 4 Results and Discussion covers the results and the discussion on the results obtained from the research study, which includes raw data analysis using MATLAB. Lastly, Chapter 5 presents the conclusion of the findings of the study and related to the main objectives of the study and a few recommendations were made for future research reference.

1.5 Objectives

1.5.1 General Objectives

To study the importance of appropriate feed water treatment prior to entering to boiler**.**

1.5.2 Specified Objectives

I. To study the profiles of each Boiler Feed Water (BFW) quality from each plant in the state of Perak towards ASME specification.

II. To suggest or recommend what is the proper treatment of the raw water to improve and enhance the quality of Boiler Feed Water.

1.6 Sustainability of Boiler Feed Water

The Sustainable Development Goals (SDGs) consists of 17 global goals altogether. The objective of these SDGs is to act as blueprint to be able to achieve a better future in terms of sustainability for all. These goals are structured to eradicate poverty and other existing deprivations by cooperating sustainable strategies that would mitigate health issues, education, alleviate inequality, elevate economic growth, mitigating climate change and at the same time prioritising to preserve natural sources such as lands, underwater and forests. The 17 Sustainable Development Goals are goals are (SDG1) No Poverty, (SDG2) Zero Hunger, (SDG3) Good Health and Well-being, (SDG4) Quality Education, (SDG5) Gender Equality, (SDG6) Clean Water and Sanitation, (SDG7) Affordable and Clean Energy, (SDG8) Decent Work and Economic Growth, (SDG9) Industry, Innovation and Infrastructure, (SDG10) Reducing Inequality, (SDG11) Sustainable Cities and Communities, (SDG12) Responsible Consumption and Production, (SDG13) Climate Action, (SDG14) Life Below Water, (SDG15) Life On Land, (SDG16) Peace, Justice and Strong Institutions and (SDG17) Partnership For The Goals.

The crude palm oil industry plays an important role in the economic development of Malaysia. Undoubtedly, palm oil industry brings multiple positive impacts to the nation. However, it does also noticeably alter and contributes to the degradation of environmental quality. This is as a result of heavy usage water and energy in the production process of palm oil. Other than that, the crude palm oil production in Malaysia also significantly contributes to the generation of large quantities of waste that may lead into unforeseen pollution (Chavalparit *et al.*, 2006). Thus, this research study can be closely related to Goal 12 which is Responsible Combustion and Production to ensure sustainable patterns of production and

consumption. This can be supported by sufficient treatment of BFW can ensure the efficiency of boiler is in place in order to alleviate heavy usage of energy and BFW to compromise the loss of productivity of the boilers to keep the process running.

Also, the importance of the boiler feed water in accordance to the ASME specification is particularly stressed to ensure the parameters of boiler feed water constituents are in acceptable range. The boiler feed water decides the overall boiler efficiency. Thus, proper treatment should be carried out in order to alleviate effect and consequences of harmful particulates, minerals and gases. As release of these impurities can damage the lives of the underwater species. This point can be closely be related to Goal 14 Life Below Water. This SDG is to ensure to conserve the usage of seas, oceans and marine resource in sustainable manner. Release of the impurities directly to inland waters may tremendously affect the lives underwater. Hence, BFW should be treated adequately to protect the biodiversity and the lives of aquatic animals and the same time the quality of the water that they survive in. This also helps provide a sustainable future for the fishing industry in Malaysia.

Moving on, securing appropriate treatment of boiler feed water should be mandatory to avert fouling, corrosion and scaling in the boiler. In this way, the financial aspect of the crude palm oil is also sustainable as the life span of the boiler can increase without frequent upgrades. This can be related to Sustainable Development Goal 8 on Decent Work and Economic Growth where aspiring youths can achieve productive employment due to the great economic growth of POM industry when sustainable measures are taken.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Manufacturing industries in Malaysia is categorised into resource and non-resource based industry (Rodríguez *et al.*, 1989). The palm oil industry is a resource based industry. The palm oil industry contributes a major part in the national economy of Malaysia. Indonesia is the largest palm oil producer followed by Malaysia as the second largest country in terms of production of palm oil, globally (Othman *et al.*, 2014). This is because oil palm is a tropical plant, thus it can be planted easily in Malaysia favoured by the conducive climate for cultivating palm oil crops. In general, fresh fruit bunch from palm oil plantation can be harvested after three years. The total life span of oil palm plants it is up to 20 decades where their economic life lasts from 20 to 25 years. Fleshy mesocarp is utilised to extract oil that yields 45-56% of fresh fruit bunch of palm oil while the oil extracted from kernel ranges from 40-50%. Both kernel and flesh mesocarp exhibits a potential yield of 17 t ha-1 year -1 of extracted palm oil (Corley, 1983). Since, the production of palm oil is massive, the by-products of palm oil can also be found abundantly in Malaysia. If these formed by-products are not properly managed it may lead to unforeseen environmental damages and pollution (Othman *et al.*, 2014).

In this section, the palm oil in Malaysia, processes involved in production of palm oil, introduction on boiler used palm oil mill, fundamental operation of boiler, types of boiler utilised in palm oil mill, impurities in boiler feed water, treatment for boiler feed water and ASME guidelines for boiler feed water is reviewed. In the chemical industry that utilises boiler, feed water with high purity is a necessity to avert

any least expected events that would the operation or the functionality of the boilers. Multiple advantages can be achieved with utilising boiler feed water that exhibits low impurities. Lower impurities found in the feed water of boiler will lead into reduction of chemicals used in boiler to satisfy the blow down requirements. Also, high purity of feed water of boiler can immensely reduce the occurrence erosion of turbine blade as boiler can also be used to run steam turbine. Adding to the previous statement, corrosion can be alleviated in boilers provided that boiler feed water exhibits low impurities. Another key advantage in maintaining a high purity boiler feed water is that the scale build up in the boiler decreases along with the increase in purity of the boiler (Theodore H. Meltzer, 1993).

2.2 Palm Oil Mill in Malaysia

The first oil palm estate commercialised in Malaysia was situated in Tennamaran Estate, Selangor in the year 1917 (MPOC, 2021). The global demand of palm oil has been gradually increasing in the past few decades. Hence, area utilised for the cultivation for palm oil crop in Malaysia has increased as well. In the year 2019, the oil palm industry in Malaysia faced elevated performance compared to the previous year. Almost 5.90 million hectares of oil palm is planted in the year 2019 (Kadir, 2020). Palm oil industry has been widely recognised for the role plays in enhancing the economic growth of our country. As stated above, both Malaysia and Indonesia are the countries that produces palm oil due to their tropical atmosphere. 87% of the world's palm oil production is conquered by Malaysia and Indonesia (Yacob *et al.*, 2005).

Taking into account the planted area of palm oil in Malaysia, Sarawak holds the state with the largest planted oil palm with 1.59 million hectares, Sabah takes the second position with 1.54 million hectares and Peninsular Malaysia being the last 2.77 million

hectares. West Malaysia amounts up 53% whereas Peninsular Malaysia 47 %. This data is presented in Table 2.1. Table 2.2, the overall performance of palm oil industry in Malaysia for the year 2018 and 2019 is depicted. The comparison and the difference from the year 2019 and 2018 is presented in percentage (Lau *et al.*, 2019).

Table 2.1 Oil Palm planted area in the year 2018 and 2019 (million hectares) (Kadir, 2020).

	2019	**2018**	**Difference**	
			Vol.	**%**
Peninsular Malaysia	2.77	2.73	0.04	1.5
Sabah	1.54	1.55	(0.01)	(0.6)
Sarawak	1.59	1.57	0.02	1.3

Table 2.2 Overall performance of palm oil industry in Malaysia for year 2018 and 2019 (Kadir, 2020).

	2019	**2018**	**Difference**	
			Vol./Value	**%**
Planted area (mil hectares)	5.90	5.85	0.05	0.9
CPO production (mil tonnes)	19.86	19.52	0.34	1.8
FFB yield (t ha^{-1})	17.19	17.16	0.03	0.2
Oil extraction rate (%)	20.21	19.95	0.26	1.3
Palm oil exports (mil tonnes)	16.88	15.36	1.52	9.9
Palm oil imports (mil tonnes)	0.98	0.84	0.14	16.1
Closing stocks (mil tonnes)	2.01	3.22	(1.21)	(37.6)
CPO price (RM t^{-1})	2.08	2.23	(0.15)	(6.9)
Export revenue (RM million)	64.84	67.52	(2.68)	(4.0)

2.3 Processes Involved in Palm Oil Production

There are two type of oil that can be extracted from oil palm. Firstly, the palm oil that extracted from the fibrous mesocarp and another is the palm oil extracted from palm kernel. The overall unit operation that is involved in palm oil production is depicted in Figure 2.1. The palm oil production comprises of the following processes.

2.3.1 Sterilization

The first process that involves in the palm oil production is sterilisation. The main objective of this process is to monitor the formation of free fatty acid and aid the following processes. Fruit bunches taken from palm oil was stored for a few days where a part of the fruit naturally loosens and can be easily shaken off the fruit bunches of the palm oil. Small quantity of oil that contains very high free fatty acid can be extracted by pounding the fruits using mortar. This is because the enzymes that is found the palm oil pericarp would not lose its activity and result in the hydrolysis of oil that is extracted from the mortar. The sterilisation process takes place in an autoclave for two hours with the operating temperature ranges from 120°C to 130°C by using pressurised steam in order destroy and damage the oil splitting enzyme present (Hosseini and Wahid, 2015).

2.3.2 Stripping

After sterilisation process, stripping or also known as threshing process takes place. The main aim of this process is to obtained sterilised fruits from fruit bunch of oil palm. Where the fruits are stripped from the fresh fruit bunch by feeding the load of fresh fruit bunch of palm oil into the rotary drum. In this step, the generation of empty fruit bunches occurs. These fruits are then collected using a bucket conveyor. These fruits are then fed into a digester (Mahlia *et al.*, 2001).

2.3.3 Digestion

The fresh fruit obtained from the stripping process is discharged into a digester. The operating parameter of the digester is set to be at steam heated conditions using rotating or stirring arms that is known as kettle or digester to mash up the fruits. In this

process, sterilised fruit and calyx leaves are heated under the steam heated condition to loosen the pericarp to aid the following processes (Singh *et al.*, 2010).

2.3.4 Crude Palm Oil Extraction

Pressing is the most common method utilised in crude palm oil extraction from the digested palm oil fruit. Screw type press is the choice of press that is generally use in the pressing method. The mash from the previous step is passed through the screw press. After passing through the screw press, the stream is fed into a vibrating screen and finally to a decanter for the removal of water and fine solids. Before storing the oil in a storage tank, vacuum and centrifugal driers are used to increase the purity of the extracted oil. This crude oil slurry is next send to a clarification system for further separation of undesired by-products (Mahlia *et al.*, 2001).

2.3.5 Clarification

The crude palm oil extracted from pressing through the screw type press consists of large portions of water, palm oil and varying ratio of impurities that consists of vegetable matter that is found dissolved in water and in the form of insoluble solid. Passing the stream into centrifugation or decanter largely supports the removal of water. However, some of the water consists in the stream may be dissolved in the oil. Hence, the dissolved water can be separated using dehydrator via evaporation process (Mahlia *et al.*, 2001).

2.3.6 Nut/fibre Separation

In the digestion process where the fruit is digested in order to extract palm oil, a press cake made up of oily fibre, oily nuts, and also contains moisture. A depericarper is used to separate the oily fibre and nuts by utilisation of strong air current formed by

the suction fan. The separated fibre is used as boiler fuel in the boiler house. The separated nuts then pass through a rotating drum to further separate the fibre prior to nut cracking process (Singh *et al.*, 2010).

2.3.7 Nut cracking

Once the fibre that is left in nuts is separated, the nuts can be prepared for nut cracking. This nut cracking process can take place in a hydro cyclone or centrifugal cracker. Once the cracking process is over, the shells and kernels can be separated by the suspension of clay that occurs in the nut cracking. The shells can be used as fuel whereas kernels can be dried to extract oil. Both of these products can be sold to other mills to increase the profit and also reduce waste generated. It is extremely vital for kernel to carry out drying and cleaning process before further extraction (Mahlia *et al.*, 2001).

Figure 2.1 Schematic process involved in palm oil production (Cibubur, 2009).

2.4 Waste Generation of Palm Oil Mill

The number of palm oil mills nestled in Malaysia increases every year. However, high production of palm oil is results in massive generation of waste. In this case, the generation of fresh fruit bunch waste and palm oil mill effluent discharge increases as well. The high generated by-products formed during the extraction of oil from the palm oil mill results into unfortunate environmental impacts via pollutions. Palm oil mill effluent (POME) may serve as the primary source that results in pollution if palm oil mill effluent (POME) is directly discharged to the water sources like ponds or rivers in Malaysia (Othman *et al.*, 2014).

Based on the data of palm oil extracted from the Malaysian Palm Oil Board 2012, 99.85 million tonnes of fresh fruit bunch produced each year (MPOB, 2021). In the sterilisation stage which is the primary process in the palm oil production, up to 5.7 tonnes of water is utilised in this process. After the clarification process, almost 50% of the crude palm oil extracted comprises of water that forms as the palm oil mill effluent (POME) (Hosseini and Wahid, 2015). In the year 2013, 44 million m^3 mole of POME were generated as 19.66 million tonnes of total crude palm oil was produced (MPOB, 2021).

Biological treatment is utilised to treat POME discharge in about 85% of the oil palm mills (Tong and Jaafar, 2006). The biological treatment of POME consists of anaerobic, facultative and aerobic pons systems (Bagchi, Biswas and Nandy, 2010). The challenge here is that the final treatment in the biological treatment which is the aerobic pond system fails to abide the POME discharge standards set by Department of Environment (DOE), Malaysia. It is a need to have proper management of POME in order to preserve the air and water quality that surrounds the palm oil mill and avert environmental contamination (Kamyab *et al.*, 2013).

2.5 Boiler Fundamental Operation

The main functionality of boiler is to carry out combustion and transfers heat to water until it turns into steam or hot water. This formed steam or hot water then can be utilised to heat involved process under operating parameter that exhibits high pressure. This is a key equipment used in any chemical industry around the world. Generally, boilers around the word possess steam capacity of over three tonnes. Some chemical industry runs all day and some of them run half day which is 12 hours per day (Arachchige and Shm, 2020). A boiler in any chemical industry is device that generates steam particularly.

Every boiler owns three major systems that comprises of feed water system, fuel system and the system of fuel. The water from the feed water system is fed to the boiler. This water is regulated in the boiler to fit the requirements of steam. From the steam system, steam is directed out for further use in the plant where steam pressure is coordinated using valves and pressure gauges. The sole reasoning behind the choice of water as the primary raw material for any heating purposes can be related to ability of water to absorb heat in comparison to other inorganic substances as water expands 1600 times in atmospheric pressure when it converts to steam (Water and Performance, 2016). The feed water will be directed to the boiler make-up water after being purified in various type of degrees. Thus, the boiler feed water composition sole depends on the make-up water quality.

2.6 Type of boilers in palm oil mill and classification

A boiler acts like the engine of a car for any chemical industry. The size of the boiler should be apt for the suitability of the chemical process. Over-sized boilers, high amount of fuel will be wasted whereas undersized boilers will fail to generate sufficient

heat. Thus, the size of the boiler should be suitable with the power requirement of the process. Boiler comprises of two main parts, one being the burner that undergoes combustion to generate heat and another is the piping and pumps where heat is distributed. Classification of boiler can be based on low pressure, high pressure, hot water boiler or steam boiler. Boilers can be classified based on its type of fuel, mode of circulation of working fluid, mode of firing, nature of heat source, nature of working fluid, type of furnace, position of furnace, material of construction, boiler size, steam pressure, content of tubes, shape of tubes, tubes spatial position, general shape of boiler, purpose of utilisation and special features (Chattopadhyay, 2020).

The sole purpose of a boiler is to convert water into steam under pressure with heat. The furnace consisted in the boiler converted the chemical energy in the fuel to heat energy. This heat energy is then used to transform the water in the boiler to high quality steam (Arachchige and W, 2019). There are two main boilers profoundly used in industrial chemical plants which are water tube boilers and fire tube boilers. As stated above, water tube boilers are most commonly used in palm oil process plants. In water tube boilers, the products formed from combustion process travels around the tube surrounded by water as shown in Figure 2.2 and 2.3. In Figure 2.4 and 2.5, fire tube boilers are depicted. In fire tube boilers, products formed from combustion process travels around the tube consisting of water.

2.6.1 Water Tube Boilers

Water tube boilers exhibits many advantages. Some of them are water tube boilers needs lower time to increase the steam pressure, better flexibility in accordance to changes of load and possess the ability to function at high rate of steam generation. In water tube boilers, water will be found inside the tubes whereas the hot gases formed

from combustion will surround the exterior of the tubes. However, this type of boilers also exhibits disadvantages such as high capital cost and difficulty in cleaning process. Water in boiler flows via the tubes that are cased in furnace where the firing of burners occurs. These tubes of the boilers are linked two types of drum which is the steam drum and the mud drum. The upper drum converts the water to steam. Water tube boilers can be utilised in big sizes where they can facilitate million pounds of steam per hour. Additionally, water tube boilers are able to also withstand high operating pressure and temperature. Thus, this quality makes water tube boilers to be suitable to aid processes that required large amount of steam (Gilman, 2012).

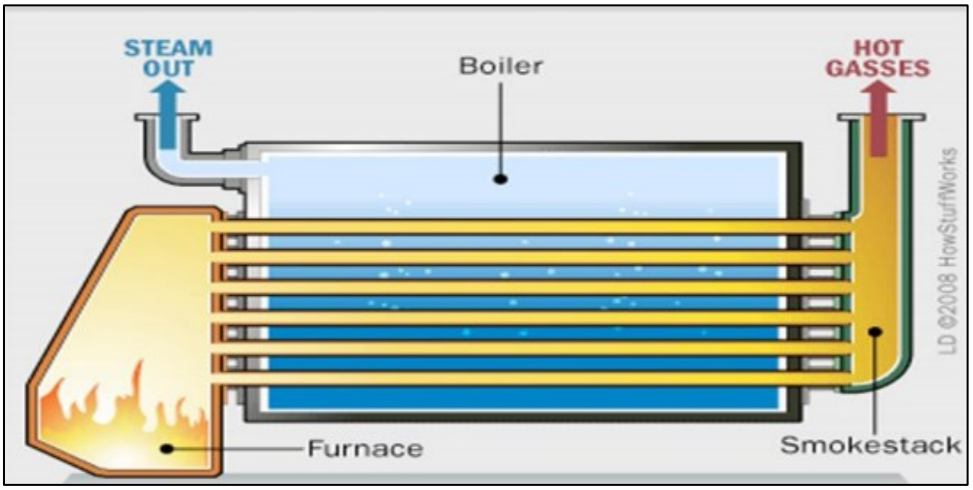

Figure 2.2 Schematic diagram of water tube boilers (Abdalla, Musa and Babiker, 2017).

Figure 2.3 Diagram of industrial water tube boilers (Babcock Wanson, 2020).

2.6.2 Fire-tube boilers

Just like water tube boilers, fire tube boilers also show casts a wide range advantages such as simpler construction, serious water treatment is not required, easier cleaning process and relatively cheaper compared to water tube boilers. In terms of disadvantages, large amount of time is needed to raise pressure of the steam, inability to provide immediate responds to load changes due to high volume of water is utilised, not suitable to operate at high temperature or pressure. The operating mechanism of fire-tube boilers is completely the opposite of water-tube boilers. In fire tube boilers, water flows in the exterior part of tubes while gases that formed due to combustion flows inside the tube of the boilers. Since fire tube boilers are small in size or compact, these tubes can be easily placed for industrial processes. These boilers can be found in size ranging from $6x10^5$ to $5x10^7$ Btu per hour (Gilman, 2012).

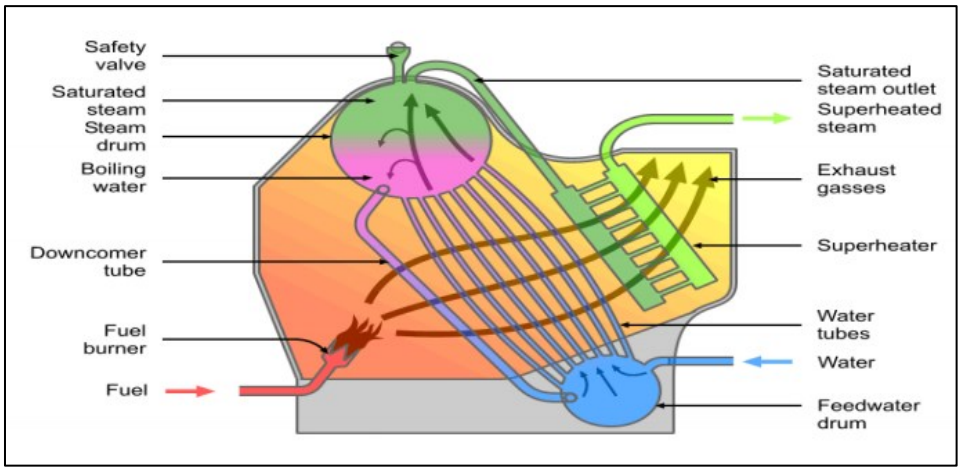

Figure 2.4 Schematic diagram of fire tube boilers (Abdalla, Musa and Babiker, 2017).

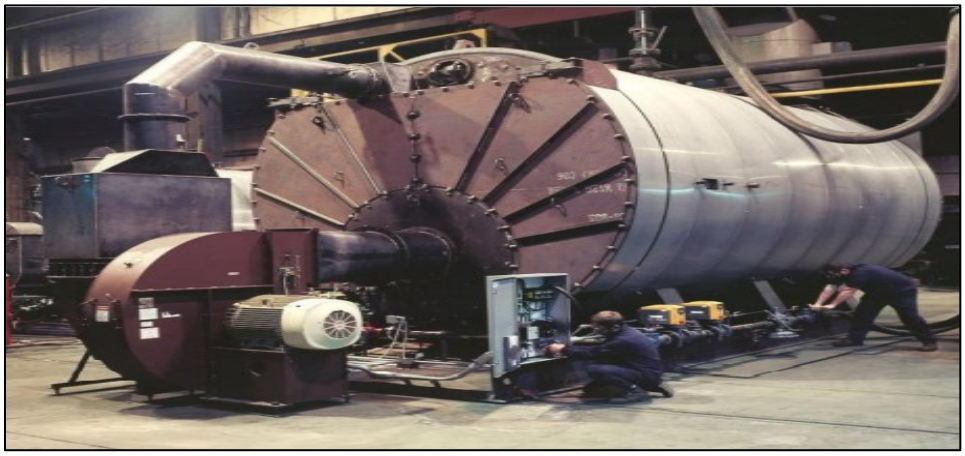

Figure 2.5 Diagram of industrial fire tube boilers (Harfst, 2011).

2.7 Chemical and Physical Properties of Water

Water consists of two elements which is oxygen and hydrogen that forms the chemical formula of water which is H_2O. Water takes up almost 75% of the surface of earth. Pure water is originally a colourless and transparent liquid. The freezing and boiling point at atmospheric pressure of 1 atm is 0°C and 100°C, respectively. As water boils or reaches its boiling point, the gaseous phase of water also known as steam is formed. Further heating the steam will generate superheated steam. In the chemical industry, water acts as a source that produces steam to generate energy for chemical

processes to take place in large scale. This is because water possess high heat of vaporisation that makes steam a suitable reservoir for storage of energy. The enthalpy of vaporisation of water is 40.65kJ/mole (Frank and Quist, 1961).

2.8 Characteristics of Boiler Feed Water

Water is a general choice in the utilisation of industrialised boiler because of the unique properties of it exhibits in order to generate heat and power. In comparison to other inorganic substance, water is able to absorb higher amount of heat at a particular rise in temperature. At atmospheric pressure, water expands about 1600 as it converts to steam that is able to hold large amount of heat.

Pure water is desirable for any steam generating processes but it is impossible to find pure water thus far. Most water utilised in boilers are received from natural sources such as rivers, ponds, and many other sources. Water that are obtained from natural resources will surely contain impurities in the water content. These common impurities and pollutants found in boiler feed water is listen in Table 2.3 alongside its description.

The range of amount of minerals that dissolved in water obtained from sea is almost 30g/L where as in fresh water supplies it is easily from 0.005 mg/L to 1500 mg/L. Impurities can be defined as substances that can be found confined in liquid, gas or solid that is exhibits different chemical composition of the compound. Some of the impurities that are found in boilers are Calcium (Ca), Iron (Fe), oil and carbon dioxide.

Calcium may react with other components to form calcium bicarbonate, calcium sulfate, calcium chloride, calcium carbonate and calcium nitrate. As evaporation occurs in the boiler, these compounds may scale on the tube of boilers. Scale do not conduct heat as presents non-conductor properties that results reduction in the heat transfer in

the boilers. Next, iron is not naturally found in raw water from natural resources but may be engendered by the occurrence of rusting in piping of the boiler.

Moving on, oil acts as heat insulator. Thus, high concentration of oil in boiler feed water may cause tube of the boiler to be damaged and overheating. The presence of carbon dioxide as an impurity in the boiler feed water carries high chances in reacting with the water to form carbonic acid that will result into corrosion (Svoboda and Bursik, 2019).

Table 2.3 These common impurities and pollutants found in boiler feed water (Arachchige and W, 2019).

Pollutants	**Description**
Iron and Manganese	Readily precipitates and possess high chance to cause fouling and discoloration.
Silica	Exist as anion or as colloidal suspension.
Dissolved gases	Carbon dioxide and oxygen that dissolved in water leads to corrosion of boiler.
Turbidity	Fine suspended particles that appear cloudy.
Hardness	Magnesium and calcium salt that results scale formation.
Total Suspended Solids	These suspended particles can be removed via filtration.
Total Dissolved Solids	There scale forming and non-scale forming solids present in water.