ECONOMIC FEASIBILITY STUDY OF HIGH-CAPACITY BOILER TECHNOLOGY FOR PALM OIL INDUSTRY

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2024

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This report is submitted in accordance with requirement of the University Teknikal Malaysia Melaka (UTeM) for Bachelor Degree of Manufacturing Engineering (Hons.)

by

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990208-05-5541

FACULTY OF INDUSTRIAL AND MANUFACTURING TECHNOLOGY AND ENGINEERING

2024

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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Tajuk: **ECONOMIC FEASIBILITY STUDY OF HIGH-CAPACITY BOILER TECHNOLOGY FOR PALM OIL INDUSTRY**

Sesi Pengajian: **2023/2024 Semester 2**

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I hereby declare that this report entitled "Economic Feasibility Study of High-Capacity Boiler Technology for Palm Oil Industry" is the result of my own research except as cited in references.

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Date : 21 June 2024

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for Degree of Manufacturing Engineering (Hons). The members of the supervisory committee are as follow:

……………………………………………………

(PROFESOR MADYA IR. DR. LOKMAN BIN ABDULLAH.)

ABSTRACT

Boiler technology is a main component that participated for continuously processing for palm oil mill which as a provider steams, electricity, and hot water into the systems Palm oil mill (POM) processing heavily relies on efficient boiler performance for maintaining high productivity. However, current boiler performance has declined over time, resulting in low efficiency, reduced capacity, and high maintenance costs. Furthermore, POM has not conducted a thorough examination of boiler performance nor a financial feasibility analysis to decide whether to procure new boilers or recondition existing ones. Therefore, the objective is to evaluate the performance of the existing boiler, estimating the financial implications, and computing economic indicators are the three research procedures that need to be finished before conducting a feasibility study based on an economic evaluation. The scheme 1-22 method was employed for this study to assist in making a decision either to procure new boiler or recondition existence boiler by going through the analysis from the technical and financial aspect which focusing on boiler efficiency, investment cost on new boiler and maintenance also the economic indicator such as net present value, internal rate of return and payback period are used to support the decision making on consideration investment. The result suggests schemes 4 and 10, are financially superior to investing in new boilers, with shorter payback periods and higher IRR, making reconditioning the more viable option both technically and financially. In conclusion, this study provides the insight for decision makers for boiler technology in palm oil mills by put the consideration of the boiler technical and economic feasibility study. As a future recommendation that is proposed it to improve boiler performance, economic viability, and sustainability in the palm oil industry and engage stakeholders such as repair contractors and consultants for successful reconditioning. Finally, the future recommendations is to Refurbish existing boilers with significant refurbishment potential to achieve cost savings and improve performance, avoiding the higher costs of new boilers.

ABSTRAK

Teknologi dandang adalah komponen utama yang mengambil bahagian untuk pemprosesan berterusan untuk kilang kelapa sawit yang sebagai pembekal wap, elektrik, dan air panas ke dalam sistem pemprosesan kilang minyak sawit (POM) sangat bergantung pada prestasi dandang yang cekap untuk mengekalkan produktiviti yang tinggi. Walau bagaimanapun, prestasi dandang semasa telah menurun dari semasa ke semasa, mengakibatkan kecekapan rendah, kapasiti berkurangan dan kos penyelenggaraan yang tinggi. Tambahan pula, POM tidak menjalankan pemeriksaan menyeluruh terhadap prestasi dandang mahupun analisis kebolehlaksanaan kewangan untuk memutuskan sama ada untuk mendapatkan dandang baharu atau membaik pulih yang sedia ada. Oleh itu, objektifnya adalah untuk menilai prestasi dandang sedia ada, menganggar implikasi kewangan, dan mengira penunjuk ekonomi adalah tiga prosedur penyelidikan yang perlu diselesaikan sebelum menjalankan kajian kebolehlaksanaan berdasarkan penilaian ekonomi. Kaedah skim 1-22 digunakan untuk kajian ini untuk membantu dalam membuat keputusan sama ada untuk mendapatkan dandang baharu atau membaik pulih dandang kewujudan dengan melalui analisis dari aspek teknikal dan kewangan yang memfokuskan kepada kecekapan dandang, kos pelaburan dandang baharu dan penyelenggaraan. juga penunjuk ekonomi seperti nilai semasa bersih, kadar pulangan dalaman dan tempoh bayar balik Hasilnya mencadangkan skim 4 dan 10, adalah lebih baik dari segi kewangan berbanding pelaburan dalam dandang baharu, dengan tempoh bayaran balik yang lebih pendek dan IRR dari segi teknikal dan kewangan. Kesimpulannya, kajian ini memberi gambaran kepada pembuat keputusan untuk teknologi dandang di kilang kelapa sawit dengan mengambil kira kajian kebolehlaksanaan teknikal dan ekonomi dandang. Sebagai cadangan masa depan yang dicadangkan untuk meningkatkan prestasi dandang, daya maju ekonomi, dan kemampanan dalam industri minyak sawit dan melibatkan pihak berkepentingan seperti kontraktor pembaikan dan perunding untuk pemulihan yang berjaya.

DEDICATION

I dedicated this project to my beloved family which my parents Kefli Bin Zuber and Laili Binti Md Dom, also not forgotten my siblings whose sacrifices the foundation of my inspiration and support my journey with encouragement. Thank you for the guidance and assistance in order for me to complete this project.

Specially thanks to Assoc. Prof. Ir. Dr. Lokman Bin Abdullah for his encouragement, his guidance and assists in order to finish this project.

Thank you.

ACKNOWLEDGEMENTS

With the utmost gratitude to ALLAH, the most gracious and merciful, I am able to successfully finish this final year project with trouble-free as possible without facing any difficulties.

I would like to thank my esteemed supervisor, Profesor Madya Ir. Dr. Lokman Bin Abdullah, for his excellent mentoring during the project and for his kind supervision, counsel, and exposure to worthwhile experiences during the study.

In addition, I want to thank my closest friends for their inspiration and emotional support as I finished my report. I would especially want to thank my friends for their critical suggestions, comments and throughout my research. Thanks for the great friendship.

Lastly, I would like to apologize for not being able to personally thank each and every person who helped with this FYP report and to thank everyone who contributed both directly and indirectly

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LIST OF ABBREVIATIONS

POM	-	Palm Oil Mill
CFB	-	Circulating Fluidized Bed
PID	-	Proportional Integral Derivative
NPV	-	Net Present Value
PP	-	Payback Period
IRR	-	Internal Rate of Return
PKS	-	Palm Kernel Shells
EFB	-	Empty Fruit Branches
POME	-	The Palm Oil Mill Effluent
FFB	-	Fresh Fruit Brunch
CFB	-	Circulating Fluidized Bed

CHAPTER 1

INTRODUCTION

The first chapter of the content of report corresponds to the background of the research, the problem statement, the objectives, the scope, and limitation of the study. The background of the research depicts the relation of boiler technology with the palm oil mill industry. The problem statement expresses the problems faced by the industry that encouraged this research. The objectives speak for this research's main goal, while the scope of the study shows the focus of the study and limitations of this research participate with the challenges due to the performing research.

1.1 Background Research

Economic feasibility study of high-capacity boiler technology for palm oil mill refers to the study of several components in palm oil mill which is more focused on the boiler technology and economic for boiler itself. The boiler technology is described as a system involved in design, construction, installation, and operation which is a closed system to generate steam or hot water. A boiler also is defined as a closed vessel system that produces high pressure steam from water through fuel combustion is known as a boiler device (Purseth et al., 2021) Basic terms for a steam generator are boilers, which are constructed from premium steel. There are several types of boilers including fire tube boilers, water tube boilers, electric boilers, condensing boilers, and circulating fluidized bed (CFB) boilers. Meanwhile, the economic feasibility refers to the assessment or investment to evaluate the economic if it will yield positive return and provide benefits to the organization or individuals involved.

The boiler in the palm oil mill (POM) is the most significant technology for the sustainability of the crude palm oil processing process since it supplies all steam and electrical demands. Steam is significantly used in the process of palm oil extraction and processing of palm oil while in production it is especially used to heat and dry palm oil. It has generated significant direct and indirect revenue in terms of usage of energy cost and their emissions. Palm oil milling is basically the processing of oil palm fresh into crude palm oil and palm kernel and approximately 33% of global fats and oils production is supplied by palm oil and palm kernel oil (A. Kushairi, S.K. Loh, et al., 2018).

Generally, the existing boiler is not in peak performance condition and due to its lengthy operational life, poses a danger to the continuity of POM processing. Several alternatives have been taken to assist the success of the processing, high-capacity boiler technology, such as a water tube boiler which is already available and frequently used in the POM. This technique has the potential to boost efficiency and consequently overall energy supply. However, replacing the existing boiler with a high-capacity boiler cannot be done immediately considering that the boiler is one of the components with the largest investment value in POM.

Therefore, it is necessary to study the feasibility of investment in POM boilers in order to ensure several factors is taken into consideration such as the continuity of the process, especially at the maximum processing capacity, meet the demand for steam, and plan to build a Cofiring Boiler Biogas Power Plant in POM. Based on the study of the evaluation of the existing new boiler performance, it can be achieved while considering the estimation of the financial feasibility of the new boiler technology. The criteria that have been considered are the internal rate of return, net present value and payback period. The results of the study will be used as a basis for consideration in making decisions to procure new boilers or recondition the existing boilers at POM.

Thus, the method that has been used to solve the decision-making is by focusing on the data of existing water tube boilers and financial data that is collected and recorded. Further studies are focusing on investment either to determine the number of boilers that suitable for the palm oil mill in specific locations that mentioned or maintenance on the existing boiler technology to meet the requirements at the maximum capacity of the

process. Economic feasibility plays a crucial role in providing strong evidence to support the decision of research which is based on numbers of data gained. All the determination is based on the theoretical and calculations process to ensure comprehensive understanding of the decision-making on investment to procure new boiler or recondition existing boiler.

1.2 Problem Statement

The Palm Oil Mill (POM) has been experiencing deteriorating performance of its existing boiler technology over time. Despite its critical role in maintaining efficient palm oil production, the current boiler system faces several significant challenges. Firstly, the efficiency of the existing boilers has declined, evidenced by a reduction in effective processing capacity, which currently stands at an average of 83%, with frequent operational interruptions. Additionally, the boilers exhibit high levels of maintenance and operational costs, driven by frequent damage and repairs necessary to sustain operations.

Furthermore, the boilers are plagued by low thermal efficiency, with significant energy losses attributed to suboptimal fuel utilization and poor steam conversion rates. The types of boilers used, such as water tube and fire tube boilers, have different efficiency ranges influenced by their design and materials, adding complexity to the optimization efforts. The efficiency measurement conducted using the direct method reveals inefficiencies due to minimal fiber residue and low steam generation per air inlet, necessitating improvements in fuel consumption and steam production processes.

Compounding these technical challenges, the existing boiler systems also struggle with high emissions and non-compliance with environmental regulations, posing risks to both operational sustainability and regulatory adherence. This situation underscores the urgent need for a comprehensive evaluation of the current boiler performance and the financial feasibility of investing in new boiler technology or reconditioning existing systems.

In light of these issues, this research aims to assess the technical performance and economic viability of the current boiler technology. By evaluating key financial parameters such as Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PP), the study seeks to determine the most cost-effective approach to achieving optimal boiler performance while ensuring regulatory compliance and minimizing operational costs.

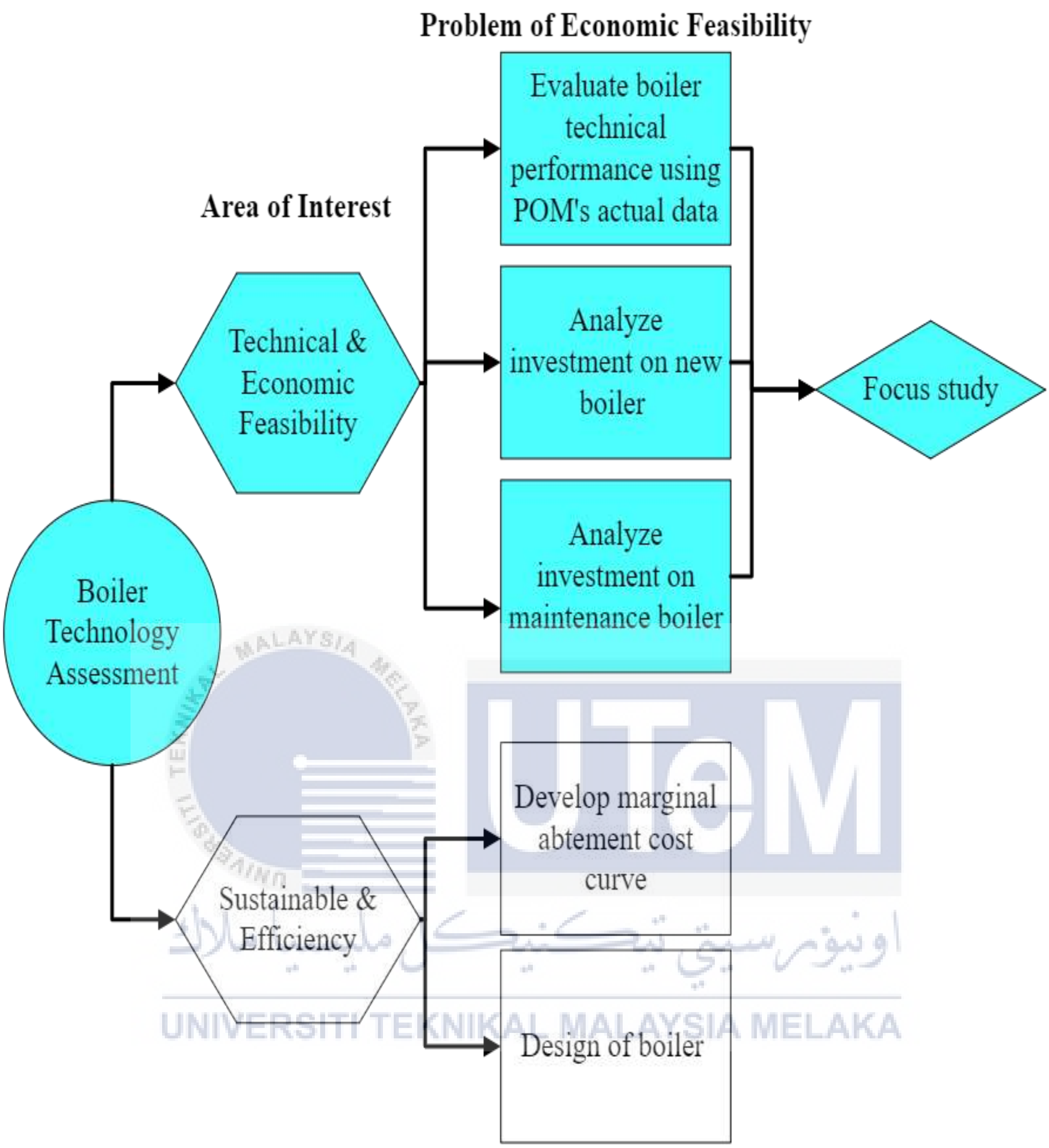


Figure 1.1: Focus area of problem statement.

1.3 Research Objectives

This study objectives are as follows:

i. To evaluate the existing boiler performance based on efficiency parameter using the POM’s actual data.

ii. To assess key financial parameters, including internal rate of return (IRR), net present value (NPV), and payback period (PP) for the implementation of new boiler technology at the POM.

iii. To determine the financial feasibility of consideration boiler investment whether to procure new boiler or to recondition existence boiler.

Table 1.1: Relationship between problem statement and objective.

Problem statement	Objective
Poor existing boiler performance	To evaluate the existing boiler performance based on efficiency parameter using the POM’s actual data.
Financial challenges economic feasibility in replacing the boiler	To assess key financial parameters, including internal rate of return (IRR), net present value (NPV), and payback period (PP) for the implementation of new boiler technology at the POM.
	To determine the financial feasibility of consideration boiler investment whether to procure new boiler or to recondition existence boiler

1.4 Scope and Limitations of Research

The main scope components that are observed into palm oil mill (POM) are based on economic feasibility of high-capacity boiler technology. The examination of existing water tube boilers is concentrating based on boiler technical and financial analysis of internal rate return, net present value and payback period. The limitations of the study will focus on a single palm oil mill industry and all the completeness of the available data that has been collected come from in a specific area which is the palm oil mill Sei Rokan, Indonesia. Nevertheless, the study will not cover possible factors that could impact the financial feasibility of the investment such as market conditions and interest limitations of the article stem from the fact that the feasibility of the project was determined using data gathered from a single chemical industry organization; hence, generalizations to other enterprises in the sector are not possible.

1.5 Research Organizational

The research has been presented in six chapters which is in chapter 1 known as introduction is present about the background of the study, the problem statement, the objective, and the scope. Afterward, chapter 2 come up with literature review which covered the overview of the existing researcher to identify the gaps of the study based on the related topic of the economic feasibility study of high-capacity boiler technology for palm oil industry. Next, methodology which explained in chapter 3 has described the process or methods that has been used in the study including design, data collection and data analysis to ensure the objective of the study has been achieved. Moreover, the result in chapter 4 that carried out from the experimental and observation that been conducted around research. Last but not least, the conclusion and recommendations in chapter 5 which summarize the research that be examined.

CHAPTER 2

LITERATURE REVIEW

Critical analysis and synthesis of existing research based on economic feasibility boiler technology is reviewed in this chapter. Gaps analysis of the research is one of the crucial objectives of the reason of the literature review been conducted. It exposed and mentioned existing research based on the systems, problems, and method that has been used by previous researchers to apply the new idealization based on loopholes that exist. Boiler technology performance, methods and mechanism have been reviewed in this chapter. Besides that, economic factors that contribute to the investment of boilers are also mainly discussed in this chapter.

2.1 Palm Oil Process

The process of palm oil mill basically grouped into several categories based on their throughput and degree of complexity of overall production and been divided into numerous operational which bunch reception, sterilization, threshing, digesting, pressing, clarification (Kwasi Poku, 2002). All the operations shared with the same objective and output which is at the end of the overall process is to extract palm oil from fresh fruit brunch (FFB). For instance, the reception refers to the activity of collecting the FFB and convey by the trucks to pour the fluster into discharge door after passing through weighed. Proceed to the sterilizations which the main idea for this operation is to prevent enzymes from breaking down and causing problems to the process of produce oil by sealed and sterilized during the milling process. Threshing refers to the operation of separating the palm fruit from the FFB and commonly used the drum type thresher as a main machine. Separation of the pulp and nut is basically involved in the operation of digesting. The pressing operation mainly to crush the palm pulp to send to continuous screw press. Next operation that involved in the process of POM is oil clarification which the functional of this is to separate from the sludge the tree oil and the coarse oil droplets.

Based on study by Azam Akhbari, 2020, aerobic and anaerobic methods that applied in the palm oil to treat palm oil mill effluent (POME) can produce high production rate with low energy consumption and flexibility in using wide range of organic waste due to high growth rate of microorganisms in aerobic condition. Additionally, the other researchers also found that the anaerobic ponding system successfully reduced the levels of COD (100–1725 mg/L), BOD (100–610 mg/L) and ammoniacal nitrogen (100–200 mg/L) to a certain range (Sharifah Mohammad, et al, 2021). The methods used have impacted the process of palm oil in terms of improving performance of production and reduction of cost. Hence, the integration of anaerobic system was coupled with aerobic degradation to meet the discharge standard of the palm oil mill effluent (POME).

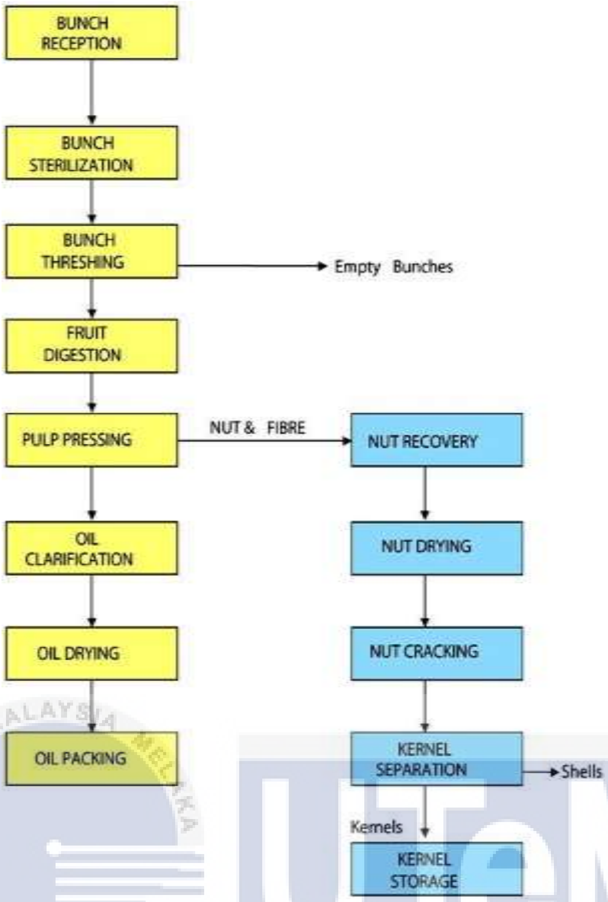


Figure 2.1: Operational palm oil mill (Kwasi Poku, 2002).

2.2 Boiler Technology in Palm Oil Mill

Boilers as integral components of palm oil mills which facilitate the extraction of oil from the fruit through several processes. The evaluation of the boiler given a huge impact in the processing of the palm oil compared to the traditional method that been used before the emergence of the boiler. Boiler technology is a closed vessel water heated to produce steam or hot water then used for a variety of purposes. As mentioned above about the functionality of boiler technology in palm oil mill, the boiler plays a crucial role in processes and contributing to overall efficiency and profitability which covered the main objective of the research of economic feasibility study of high-capacity boiler technology. The selection of boiler technology significantly affects the feasibility of a palm oil mill. The previous researcher motivates for exploring the details of boiler in palm oil mill to considers factors such as the cost involves and regulatory compliance.

Several types of boilers that are typically used in palm oil mills which water tube boilers, fire tube boilers, biomass boilers, and fluidized bed boilers. Water tube boilers are mainly commonly used especially in Malaysia and Indonesia palm oil mills. Simple working principles of operations are heating transfer from the combustion gases to water flowing through tubes then produce steam and hot water. The main reasons are based on the high characteristics in terms of efficiency, flexibility, and capacity option of this boiler. Next, the other options are fire tube boilers which have a simpler design and coincide of economic boiler in terms of lower initial cost compared to boiler tube boilers. The working principles of these boilers where the gases produced by combustion is pass through the tubes that are surrounded by water then heat and generate steam. Advantages of used fire tube boilers are it is easy to operate and maintain, has a lower operating pressure and temperature than this boiler is suitable for smaller steam capacities.

Moreover, the biomass boilers which specialized in utilize renewable resources such as empty fruit branches (EFB), palm kernel shells (PKS), and any waste of agricultural. This method more focus on sustainable and environmentally friendly but the lack of this method is it require higher maintenance budget due to certain factors such as abrasive nature of fuel. Fluidized boilers are also one of the commonly used for efficient combustion and heat generation. The working principles of these boilers is unique combustion where fuels are burned within suspended particles by faced fuel feeding that crushed solid fuel into small and direct to fluidization where the mixture of air and steam is injected to distributor. The fuel ignited within the bed and combustion occurs throughout the entire bed.

2.3 Boiler Technology Performance in Palm Oil Mill

Performance of boiler refers to the level and ability of the boiler to functional along the process to produce palm oil from the extraction of brunch palm oil. The relationship of the performance boiler and the quality of palm oil is proportional to each other which describe if the performance of the boiler good, the quality result of the process also good and vice versa. Evaluation of the performance boiler is crucial to the process of palm oil because several factors affect in terms of cost, quality and safety and health. The performance of the boiler is basically measured based on the boiler efficiency, and boiler equipment. Incorporating energy performance indicators and tools into an operational control, maintenance management, and production management action plan will help make these measures more focused on organizational management and ISO 50001 compliance rather than requiring the purchase of new technologies (Ochoa et al., 2019).

2.3.1 Boiler Efficiency

The meaning of boiler efficiency can be summarized as a ratio of the heat output of the boiler to the heat input that applied into the systems. Based on several research, fuel is one of the main components that is typically used to measure the efficiency of a boiler. One of the researchers has conducted the main of the use of fuel on water temperature which enter the boiler associated with superior oil palm seed varieties, and to determine the correlation of variations in water temperature which enter the boiler, and the boiler efficiency variation on fuel use (Zulham Effendi et al, 2021). The finding of the researcher is the highest and lowest of fuel that be used in Yangambi derivative variety.

Several factors also contribute to affecting the efficiency of the boilers based on boiler types such as water tube, fire tube, biomass, and fluidized boilers. All the boilers have a different range of efficiency because of the material, design and automated control systems that influence the value and output of the boilers.

(Sudhir and Rahul Dev Gupta, 2011) are doing a case study on "Strategies for improving energy efficiency in industrial boilers." The outcome here demonstrates that boiler efficiency increased from 80.98% to 81.94% by reducing extra air. Accordingly, this investigation concludes that the overall boiler efficiency has increased by 2%, from 80.98% to 82.98%, as a result of all improvement recommendations.

2.3.2 Boiler Equipment

The review about boiler equipment plays a crucial role in the study of economic feasibility of high-capacity boiler. This literature review aims to explore the findings of previous research and identify the loophole that exists for improving sustainability. Boiler equipment refers to the machinery or the components used in the operation and maintenance of boilers which more focus on water tube boilers. Several examples that categories as boiler equipment such as steam boilers, condensing boilers, waste heat boilers, boiler economizers and boiler feedwater systems.

2.4 Boiler Parameters in Palm Oil Mill

The studies focused on the diverse approaches used to measure, analyze, and assess boiler efficiency by comprehensive overview of the recent study and knowledge by previous researcher. Measuring the amount of energy available in the fuel utilized can be done through energy efficiency (Chen et al., 2021). Typically, the efficiency of the boiler is measured based on the effectiveness of the boiler to convert fuel into usable heat. The traditional method took a long period of time and costly to make analyse when testing the boiler efficiency (Linghao Yu, et al, 2012). There are two methods that basically been used of assessing boiler efficiency which by indirect method and direct method. Based on several researcher, numerous mathematical modelling techniques and computational implementations can be used to calculate efficiency, depending on the measurements available in a boiler and the frequency at which the efficiency and type of efficiency to be calculated vary (Mojica-Cabeza et al., 2021)

Boiler energy efficiency and the environmental impact of the energy industry are discussed by Barma et al. (2017). They also show how increasing boiler efficiency can lead to significant decreases in CO2 emissions and fossil fuel consumption. Based on study by (Kljajić & Gvozdenac, 2012) established a technique that relies on operational performance measurement to determine a boiler's efficiency. After selecting 65 boilers at random from 50 sites in Northern Serbia, they employed the neural network technique to analyze the boilers' performance and efficiency. In order to rationally investigate energy, new methodologies were used. The uncontrolled setup of the neural network model leads to a problem with unpredictability, even though the model demonstrated high learning capacity.

2.4.1 Indirect Method

Recent studies found that indirect methods or heat loss methods from the boiler are due to several factors such as high temperature flue gas leaving the stack, radiation from boiler surfaces, combustion of hydrogen and moisture in fuel by (A. Bhatia, 2020). An analysis of the indirect method in fire tube steam boilers was mentioned in (Ahmad Mahmoudi Lahijani, 2020). The efficiency analysis of fire tube steam boilers in relation to relevant parameters is provided in this research. The indirect technique is the most accurate way to measure boiler efficiency, according to the author's study, and the three most useful factors are ambient temperature, flue gas temperature, and the impact of fuel type on efficiency.

A case study for calculating boiler efficiency using an indirect method was conducted by Celen and Erdem (2017). The present investigation employs an indirect method to ascertain the impact of increasing fuel moisture content and excess air coefficient on boiler efficiency. In this case, the outcomes come as Boiler efficiency dropped from 0.92 to 0.90 with an increase in excess air coefficient of up to 25% when lignite's moisture content increased. This is because increased moisture content of lignite causes a reduction in lower heating value, which in turn causes a decrease in boiler efficiency. In order to compute the loss terms included in the modelling for the indirect efficiency calculation, measurements of the flue gas temperature, GCV, surplus air, thermal characteristics of the flue gas components, temperature, pressure, and ambient humidity are necessary ((Mojica-Cabeza et al., 2021).

2.4.2 Direct Method

The method of quantitative measurement is known as direct method in economic feasibility studies which involve several aspects of cost and parameters that affect the boilers. Study found that by defined direct method as the direct technique, sometimes called the input-output method, simply needs the heat input, or fuel, and the heat output, or steam, to assess efficiency (Tirumala Srinivas, 2017). It does this by comparing the energy gain of the working fluids, such as water and steam, to the energy content of the fuel.

Based on the result obtained between direct and indirect method by Tirumala Srinivas, 2017 shows that the study's comparative analysis shows that the indirect method produced a better boiler efficiency than the direct method did. More specifically, the indirect approach recorded a boiler efficiency of 91.96%, higher than the direct method's 83.94%. Moreover, Suntivarakorn and Treedet, 2016 have conducted research to improve the efficiency of a fire tube boiler with a fixed gate and screw conveyor for feeding fuel. Boiler efficiency improved by using the recovery heat for fuel drying and installing a blower to recover flue gas a stack to blow directly on the fuel screw conveyor. The result shows that the fuel drying system, preheating system, and automatic combustion control system increased the boiler efficiency at 0.41, 0.72, and 4.34 %, respectively.

Study by Rakhoh, 2015 mentioned the advantages of using direct method is quick evaluation of efficiency, used few factors for calculation, and requires less instruments for testing while the disadvantages such as causes of low efficiency remain unspecified, does not calculate various losses at various stages and leas to incorrect evaporation efficiency due to wet steam.

2.5 Turbine Technology in Palm Oil Mill

Turbine is a technology or components in palm oil mill that category as energy generated from natural resources which play a crucial role in order to improving the overall efficiency of the process. The function of the turbine is to convert the kinetic energy of a fluid into mechanical energy which is used to generate electricity and other types of work. Existing turbine at the pom has the risk of hampering the continuity of the processing process at the palm kernel shell (PKS). There are several types of turbine technology that are typically used in palm oil mills such as steam turbines.

Steam turbines in water tube boilers are commonly used impulse turbines as a main tool to extract energy from one place to another which from high velocity steam that is produced by boiler. The prime movers of steam turbines are boilers that produce high-temperature, high-pressure steam, which the stator blades accelerate and swirl. The rotor blades of the steam turbines receive impulse and reaction forces from the accelerated and swirling steam (Tadashi Tanuma, 2022). A study by J. Tominaga,2019 defined that three improvements have been made which are by increasing the extraction of regenerative cycle optimization, improvement vacuum pressure and selecting large size of blade.

2.6 Financial Feasibility Analysis

Financial feasibility analysis refers to the methods used to support the decision making of investment by providing a comprehensive evaluation in terms of calculation of the economics on boiler in POM. Study by (Gunjal et al., 1999) the literature has identified a number of techniques for weighing the costs and benefits of investments with the goal of recovering capital expenses and maximizing profitability. The projects were assessed using two methods. The first method was calculating and assessing the three processes' yearly equivalent costs. When the advantages of the alternative projects are either equivalent or unknown, this cost analysis is helpful. In the second method, the present values of costs and benefits were combined, and the overall profitability of all three projects was assessed throughout the course of their anticipated lives. There are several methods used to enhance the financial decision support which net present value (NPV), payback period (PP), and internal rate of return (IRR).

2.6.1 Net Present Value

One of the key financial metrics that is typically used is net present value which plays a crucial role in evaluating the profitability of investment by putting the time value of money into consideration. A project's net present value (NPV) can be used to assess whether it will result in a profit (positive NPV indicates that the investment will add value to the company and the project may be approved) or a loss (negative NPV indicates that the investment will deduct value from the company and the project should be (Gaspars-Wieloch, 2019).

Following an extensive review by (Chen, 2022) it is discovered that, over the previous 25 years, the majority of research on net present value has concentrated on evaluating the benefits and drawbacks of the approach in relation to alternative investment decision-making schemes and determining how to apply it to particular industries. There has been less investigation into the real-world outcomes of these projects. Nonetheless, in contrast to the conventional NPV method, the derivative approach frequently addresses one of the NPV method's shortcomings. One way to address the shortcomings of the classic NPV technique in an unpredictable environment is to combine actual alternatives with the NPV approach. The NPV approach's shortcomings in the face of unpredictable time risk, however, are addressed by the decoupling NPV approach. Overview by Qixiang Sun, 2022, the NPV method uses an estimated discount rate, and since the rate assumed today applies to future returns, a spike in interest rates in the future will cause the estimated return for that period to be overvalued. It is also impossible to accurately apply a percentage number to a project in order to represent its risk premium.

2.6.2 Payback Period

The payback period is the amount of time that an investment's original outlay should be reimbursed by the cash inflows it produces. It is among the most straightforward methods for appraising investments (Muchelule Yusuf, 2021). (Alaba Femi & Olawale, 2008) To gain an understanding of the significance of the payback method in capital budgeting, this thesis employs theories regarding the payback period and its impact on organizational decision-making. Additionally, previous research on the techniques employed by companies to evaluate investments is utilized as secondary data

2.6.3 Internal Rate of Return

An investment will break even at a specific rate, known as the internal rate of return (IRR), when the present value of all future cash flows equals the initial investment, according to Paltrinieri, N., & Khan, F. I. (2016). Moreover, Arjunan (2017) claims that a novel technique based on the capital amortization schedule (CAS) can estimate IRR without the need for the discounted cash flow method. His research demonstrates that the interest rate makes cash inflows equal to the return of capital is equal to IRR, indicating that IRR expresses the highest return on investment possible in percentage terms and truly reflects the full potential of the cash inflows from investment to recover the return of capital. In a CAS, the cash inflows are allocated towards recovery of the return of capital and return on investment, with the balance being the terminal year closing balance.

Thus, when comparing projects that differ greatly in scope, the IRR may be deceptive. When comparing two projects, one with a smaller capital investment and a slightly higher return in percentage than the other with a much larger capital investment, the IRR will advise investors to select the smaller project rather than the larger one, and the larger project will undoubtedly yield a higher profit (Patrick & French, 2016)

2.7 Summary of Literature Review

Based on the study that has been conducted, the loophole that has been identified based on boiler technical performance has been examinate by several researchers which focused on improvement of efficiency of boiler technology as shown in table 2.1.

Table 2.1: Boiler technical literature review.

No.	TITLE	OBJECTIVE	METHOD	RESULT
Boiler Technical				
1.	Fuzzy modeling of boiler efficiency in power plant. (Behera et al., 2022)	To measuring boiler efficiency byimproved fuzzy rule extraction method	The uncertainty and non-real-time property of indirectmethod were analyzed by used SCADA and PLC assist in controlling crucial parameters using Proportional Integral Derivative (PID) control	Improved by a gradient descent andincrements fuzzy sets. The chemical plant operator can run smoothly and help increase the efficiency of a boiler
2.	Calculation methods of steam boiler operation factors under varying operating conditions with theuse of computational thermodynamic modeling (Madejski & Żymełka, 2020)	To calculate the energy efficiencyof the boiler To analyze the steam boiler operation under varies operating conditions.	Indirect method and individual boiler losses computation for calculating boilerenergy efficiency. Calculation of total boiler efficiency and boiler losses based onenergetic and exegetic analysis	The highest efficiency value wasobtained for the middle boiler load (load 80%) and the lowest value for the nominal load (load 100%)
3.	Optimization of thermal efficiency and unburned	Improving thermal efficiency	Optimizing operating parameters via a novel high-efficient swarm intelligence optimization algorithm	The thermal efficiency (91.8%), the optimization results obtained by ga, pso and gwo approaches are

Next, overview of summary from literature on economic feasibility as shown in table 2.2 show the study form previous researcher on economic feasibility and it was found that the method that typically used among the researchers is based on net present value, internal rate of return and payback period was efficient to be used to support the decision on some cases.

Table 2.2: Economic feasibility literature review.

No.	TITLE	OBJECTIVE	METHOD	RESULT
		Economic Feasibility		
1.	Feasibility of palm oil mill effluent elimination towards sustainable Malaysian palm oil industry (Tan & Lim, 2019)	To propose an integrated palm oil complex concept that promotes sustainability and economic feasibility.	Analyzing the payback period, operational expenditure, and potential revenue generation from each scenario	Demonstrated economic feasibilitywith a shorter payback period (4 years) compared to POME utilization scenarios (4.3–8.3 years)
2.	Analysis of the feasibility of small-biomass power generation from the palm oil mill – study case: palm oil mill in Riau, Indonesia (Nuryadi et al., 2019)	To present an analysis of the feasibility of usingthe biomass resulting from residues palm oil	The feasibility analysis includes calculating the Internal Rate of Return (IRR) and comparing it to the Weighted Average Cost of Capital (WACC)	Internal Rate of Return (IRR) of 22.70%, which is higher than the Weighted Average Cost of Capital (WACC) of 15.61%. This indicates that the Biomass Power Plant based on solid waste palm oil is feasible tobe implemented under the BOT scheme. The total balance sheet is positive in the fifth year, fulfilling the payback period of 5 years and

Based on several review from other researcher, it was found that the method on boiler technical of direct method and financial feasibility to identify cost effectiveness on consideration investment to procure new boiler or recondition existing boiler is not yet done comprehensive examination. The summary of this study is shown in table 2.3.

Table 2.3: Summary of this study.

Title	Objective	Method	Result
Economic feasibility study of high-capacityboiler technology for palm oil industry (This study, 2024)	To evaluate the existing boiler performance and technical using thePOM's actual data. To assess key financial parameters, including internal rate of return (IRR), net present value (NPV), and payback period (PP) for the implementation of new boiler technology at the POM. To determine the financial feasibility of consideration boiler investment whether to procure new boiler or to recondition existence boiler	Boiler technical parameter by using direct method such asboiler efficiency and thermal efficiency. Financial analysis by study NPV, IRR, andPP	Cost effectiveness on consideration investment to procurenew boiler or recondition existing boiler

CHAPTER 3
METHODOLOGY

This chapter outlines the suggested methodology for the study, which consists of the general procedures that will be followed in order to finish the investigation. The fundamental tenet of methodology is offering appropriate approaches, suggested instruments, and procedures to finish this study on conduct a feasibility study based on an economic evaluation. The primary goals of the methodology are to allow the sequence of the research to meet the desired objective and maintained in the scope and limitations of the field of study.

3.1 Overview

Consideration to procure investment on new boiler technology or recondition existing boiler needs the wide integration of theoretical and practical of the boiler especially in palm oil mill. Further studies of the research have been completed which estimation of the performance of the current boiler, financial estimation, and calculation of economic indicators to fulfil the requirement in the considerations. Existing boiler performance is assessed by estimating boiler efficiency using the direct technique. The financial components employed include initial investment and net cash flow. Furthermore, economic data are utilized to assess the financial viability of investing in or reconditioning boilers.

Based on the flow chart constructed in figure xx shows the overall flow of methodology to meet the objectives of study within the scope and limitation. The first phase of flow chart presenting the methods used to define the gaps or loopholes based on previous study that has been investigated by others researcher. Overview on the multiple research thesis of boiler at palm oil mill (POM) has been acknowledges certain gaps which can be fulfil in order to enhance the current boiler in the industry especially at POM. After objectives have been determined, the focused-on boiler performance evaluation, cost analysis and economic indicator has been observed to identify the finding meet the requirement in the objective before continuing for the deeper study. Nevertheless, the research which is outstanding will turn over deeply into an objective to ensure the continuity of the study is aligned with main findings.

Furthermore, the comprehensive examination has been undertaken by identifying new boiler technology in the market, boiler technology efficiency and net cash flow as shown in flow chart in phase 2 in figure 3.1. Afterward, data from the examined has been collected to carried out the quantify of the cost for new boiler and maintenance which to proceed the analysis of investment that has a lower value either more prefer on investment for the new boiler or maintenance the existing boiler.

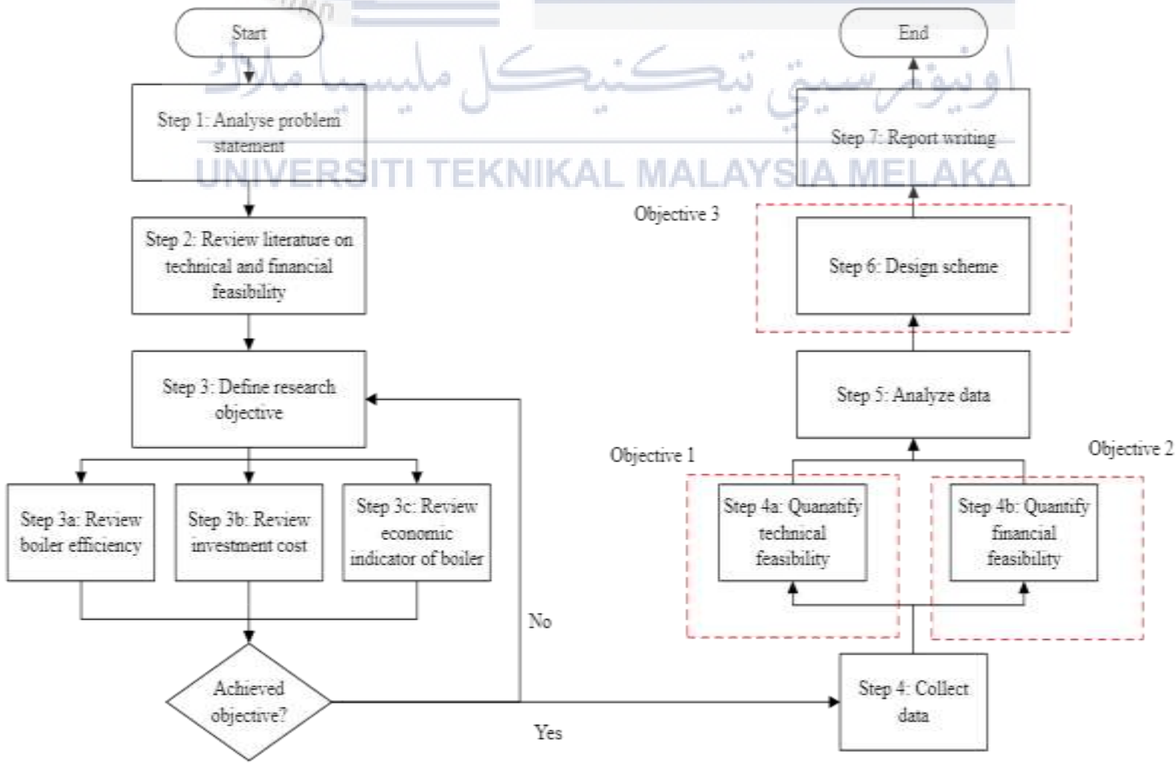


Figure 3.1: Flow chart methodology.

3.2 Research Design

Conceptual idea is synonym with the research design which focused on study various aspects of boiler technology. The aspects such as performance, efficiency, safety, and cost play a crucial role in consideration in designing the boiler especially at palm oil mill. Water tube boilers is a main component for study the requirements need of the technical and economic financial which to evaluate based on consideration of procure investment on new boiler technology or maintenance existing boiler.

3.2.1 Water Tube Boilers

The observations on water tube boilers are based on the components that contribute to qualitative and quantitative perspectives which identify the factors influenced decision making processes and perceptions of the economic feasibility. Various components consist of water tube boilers but the main components that affect the consideration in research design such as heat exchangers, burner, boiler tube, and water treatment systems.

3.3 Boiler Performance Description

The evaluation data of the existing boilers in the palm oil mill in Palm Oil Mill Sei Rokan, Indonesia was gathered via site visits, document review, collaboration with industry partners and expert consultations. Every boiler-related detail is based on the sorts of boilers, namely water tube boilers, which the function is to support the decision making after passing through the integration of theoretical and analytical approaches. In particular, data collection was focused on the year of manufacturer, capacitance, workload, working temperature, book value per year and estimation cost of recondition for each water tube boilers at the palm oil mill.

Table 3.1: Data of existing boiler in POM.

No	Description	Boiler 1	Boiler 3	Boiler 4
1.	Name	Takuma	Takuma	Advance
2.	Type	N 600 SA	N 600 STD	BS 5 1113-1999
3.	Year of manufacture	1995	1987	2012
4.	Serial number	1077/SAS/95	1031/SA/85	WT.0450
5.	Capacitance (ton/hr)	20	18	30
6.	Workload (kg/cm^2)	23	22	24
7.	Working temperature (℃)	220	220	220
8.	Last in 2019 condition	50	20	80
9.	Statement per Jun 2020	Not operating	Currently recondition	Operating
10.	Last recondition	2018	2012	2019
11.	Book value per 2019	3,083,750,346	4,765,713,748	8,429,505,561
12.	Planning reconditions	2020	June 2020	2020
13	Estimation of recondition	5,969,709,900	7,644,159,600	598,622,000

3.3.1 Boiler Efficiency

The secondary data available at PKS SRO and visual observations during visits serve as the basis for the methodology of evaluating the condition of the existing boiler. PKS SRO has 3 existing boilers with different capacities and performances. As of June 2020, only Boiler Advance No. 4 is used to meet the steam requirements for processing capacity of 42 tons of FFB per hour. The specifications of the existing boilers at PKS SRO can be seen in Table 3.3. Based on information from PKS SRO management, Boiler Takuma No. 1 is no longer operational due to damage to the water pipes and superheater. Meanwhile, Boiler Takuma No. 3 is undergoing refurbishment and will be equipped with installation for biogas cofiring boilers.

A direct method has been used to calculate the boiler efficiency in the palm oil mill by focusing on the data collected. The output value of the efficiency is produced by the difference between the energy in steam and the energy in boiler feed water as a percentage of the energy in fuel as shown in equation 3.1.

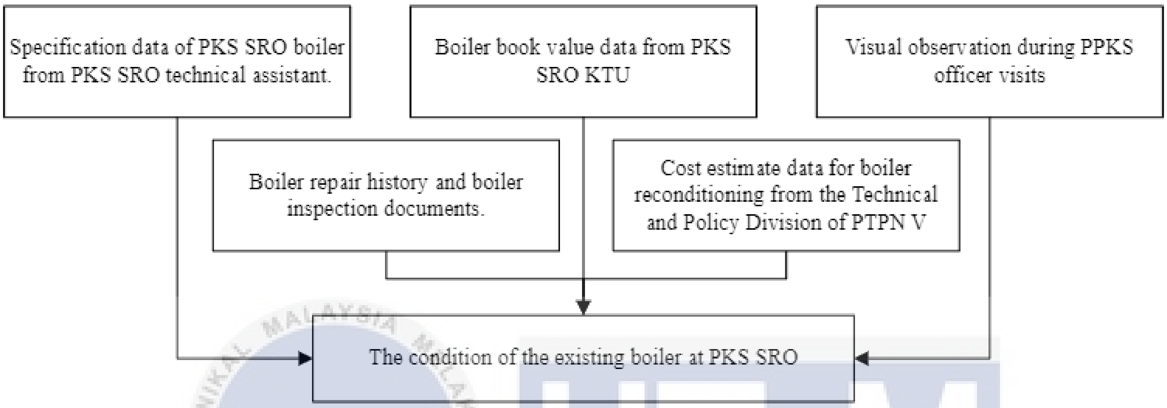


Figure 3.2: Methodology for evaluating the condition of the existing boiler.

Formula:

$$\eta boiler = \frac{energy\ output}{energy\ input} \times 100\% \quad \text{Equation 3.1}$$

Where:

- $\eta = boiler\ efficiency$ (%)
- Energy output = heat content of the steam produced by boiler
- Energy input = heat content of the fuel consumed by boiler

3.4 Methodology for Evaluate the Existing Turbine at PKS SRO

The methodology for evaluating the existing turbine at PKS SRO was carried out through visual observation and the collection of secondary data from technical reports.

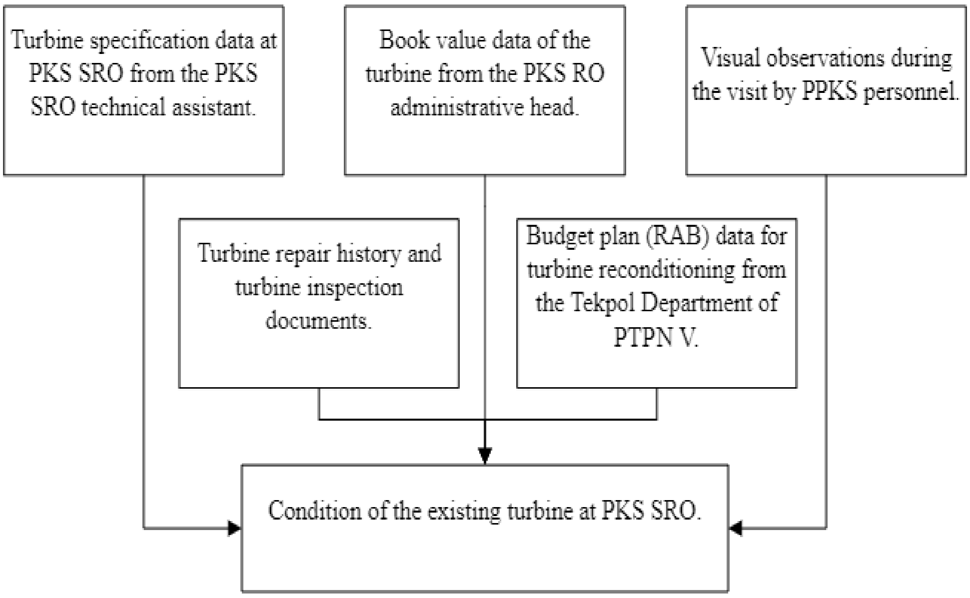


Figure 3.3: Methodology for Evaluating the Condition of the existing turbine.

PKS SRO has 4 existing turbine units with different capacities. All turbines have fairly good performance. Since January 2020, the operation of Turbine No. 4 has been sufficient to meet the electricity needs of PKS SRO. Specifications and conditions of the existing turbines. Turbine No. 4 is budgeted for reconditioning in 2020, which includes oil and gear coupling replacement.

3.5 Financial Investment

Analysis cost of project or decision expected which to determine the probability output of the result whether it worthwhile or vice versa is refers to the definition of cost benefit analysis. On the other hand, this technique is widely used to compare the expected decision making of the project. The quantitative method is used to consider and support the output decision by considering the intangible benefits of the finding of boiler in palm oil mill. Based on data collection, the further study on initial investment, operating and maintenance cost has been deeply through

3.5.1 Initial Investment Cost

The definition of initial investment refers to the total expenses at the early or beginning of a project or business. This cost is basically generated once at the early stage and not contributed after the ongoing operation of boiler in palm oil mill. The components that contribute to the initial investment cost such as supplier quotations for procurement or reconditioning costs, installation expenses, infrastructure modification, training, and skills development cost.

3.5.2 Operating and Maintenance Cost

Operating and maintenance costs is totally different with the initial investment where it is typically referred to the ongoing expenses that contribute along the ongoing operational of boiler. The operating costs that contribute such as utilities, labour, and fuel while the maintenance costs such as routine maintenance, repair and replacement parts is the critical cost that needs to ensure the continuity of the operation and performance of the productivity.

3.6 Economic Indicators

Indicator financial of boiler in palm oil mill is defined in terms of the aggregate size of the economic field which consists of piece of data that helps to understand the current state and upcoming trajectory of a cash flow focusing on palm oil mill industry. The functional as an indicator to help gauge the level of productivity, forecast future economic growth, and identify the potential risks and opportunities. Several methods have been used to identify and analyze perspectives on the profitability and suitability formulations for enhance the decision-making.

3.6.1 Internal Rate of Return

The terms internal rate of return (IRR) is an indicator of an investment's profitability that take into account the time value of money which represents all future cash flows and understands the rate of return expected over the long term and the formula is shown in equation 3.2. Moreover, IRR also the discount rate at which NPV investment is equals to goes to zero that represents the annualized rate of return investment is expected to generate.

Formula:

$$IRR = R1 + \frac{NPV1\ X\ (R2 - R1)}{(NPV1 - NPV2)} \qquad \text{Equation 3.2}$$

Where:

- R1= Lower discount or return rate
- R2= Higher discount or return rate
- NPV1= Higher net present value
- NPV2= Lower net present value

The criteria for determine the used tools of internal rate return by considering the several aspects as follows:

- If the IRR > discount rate, the investment is accepted.
- If the IRR < discount rate, the investment is rejected.

3.6.2 Net Present Value

Net present value (NPV) is also known as the difference between the present value of the future cash inflows and the present value of future cash outflows that align with an investment that has been made and the formula is shown in equation 3.3. In other words, it represents the total net gain or loss expected from the project. NPV is the most popular approach to capital budget analysis which offers more thorough analysis compared to IRR computations due to its ability to discount project cash flows independently, contributing to its increased popularity.

Formula:

$$NPV = \frac{cash\ flow}{(1-i)^t} - initial\ investment \qquad \text{Equation 3.3}$$

Where:

- i = Estimated discount or return rate
- t = Number of timer periods

The criteria for determine the used tools of net present value by considering the several aspects as follows:

- If NPV > 0, the investment is accepted.
- If NPV <0, the investment is rejected.
- If NPV = 0, the investment remains even either is accepted or rejected.

3.6.3 Payback Period

The amount of time takes for investment to recover the initial cost from the generated cash inflows is described as the meaning of payback period (PP) and formula is shown in equation 3.4. Basically, it focuses on liquidity, the speed of return compared to overall profitability that possible to gain.

Formula:

$$Payback\ period = \frac{cost\ of\ investment}{average\ annual\ cash\ flow} \qquad \text{Equation 3.4}$$

The criteria for determine the used tools of internal rate return by considering the several aspects as follows:

- If PP < maximum acceptable PP, the investment is accepted.
- If PP > maximum acceptable PP, the investment is rejected.

3.7 Feasibility Studies

Overall, a positive internal rate of return (IRR) shows the strong profitability while an increase of the number of investors depends on if the net present value is positive and a shorter payback period refer to the initial investment is recovered more quickly that can enhance the liquidity. Based on figure 3.3 show the summary of the investment analysis that supports the decision making of procure the investment on new boiler or recondition existing boiler.

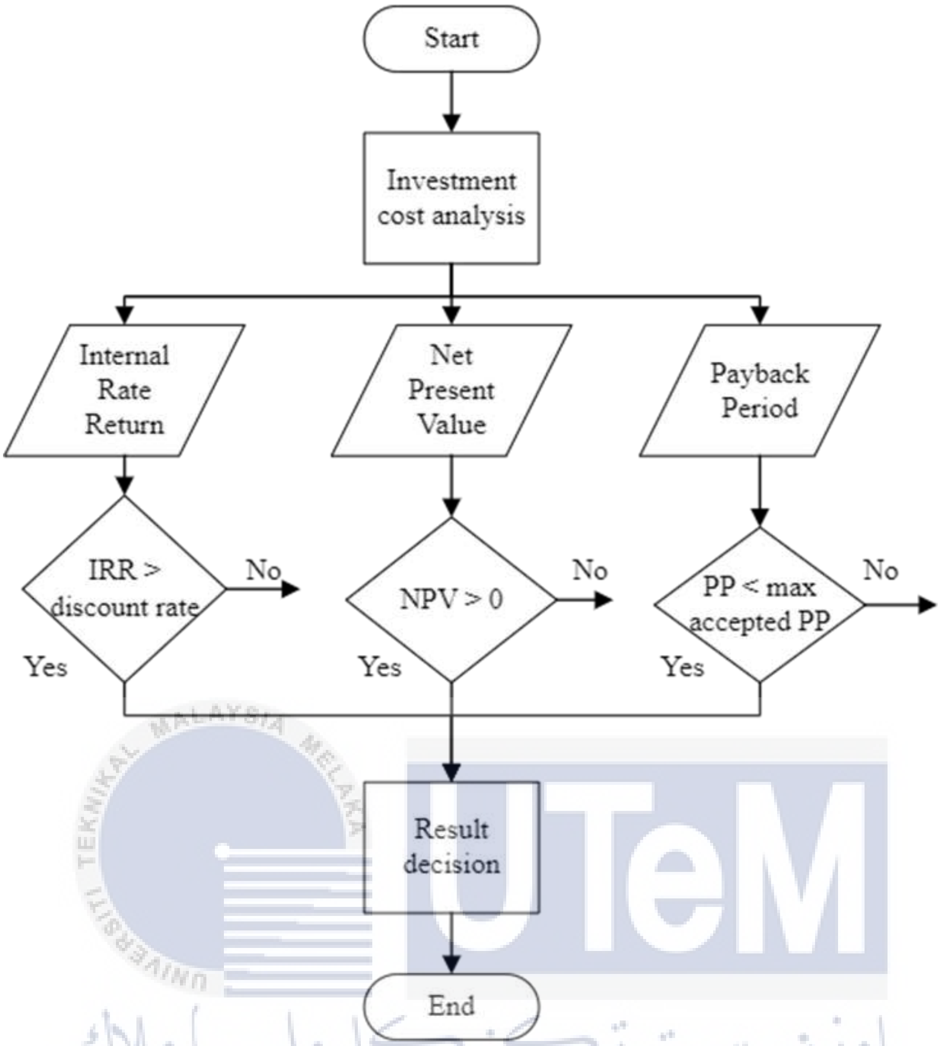


Figure 3.4: Summary investment analysis.

3.8 Summary of Methodology

This chapter discusses the related methodology used for the study which covered several components to support the outcome of determination on investment for the boiler in palm oil mill. The components that contributed such as data collection of water tube boilers and cost analysis such as internal rate return (IRR), payback period (PP), and net present value (NPV). The result produced as shown in table 3.2 will be analyzed via the next procedure.

Table 3.2: Summary of methodology.

Objective	Method	Result
To evaluate the existing boiler performance based on efficiency parameter using the POM's actual data by focusing on direct technique.	Boiler technical parameter by focusing on direct and indirect technique.	
To assess key financial parameters, including internal rate of return (IRR), net present value (NPV), and payback period (PP) for the implementation of new boiler technology at the POM.	Initial investment boiler, maintenance, and operating cost	Cost effectiveness investment of procure new boiler technology or maintenance existing boiler
To determine the financial feasibility of consideration boiler investment whether to procure new boiler or to recondition existence boiler	Internal rate of return, net present value, and payback period,	

CHAPTER 4

RESULTS AND DISCUSSION

In Chapter 4, the focus is on deciding whether a palm oil mill should invest in a new, high-capacity boiler or maintain its existing one. This decision hinges on both technical and financial considerations. The technical analysis methodically evaluates the current boiler's performance, including its efficiency, steam production capacity, and environmental impact. By directly assessing these factors, the study determines if the existing boiler can adequately meet the mill's operational requirements. Furthermore, a comprehensive financial analysis is conducted, considering metrics like Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period. Comparing these financial indicators for both scenarios help determine the most profitable and financially sound option for the palm oil mill. Ultimately, this chapter provides a thorough evaluation to guide the crucial decision-making process.

4.1 Overview

Palm oil mill Sei Rokan (POM SRO) has limitations in processing capacity, including issues with the 1-door sterilization system limiting processing to a maximum of 37 tons of FFB per hour, projected core plantation FFB production at a maximum of 51 tons per hour, and installed kernel station capacity at 48 tons of FFB per hour.

As of June 2020, Boiler Takuma No. 1 (20 tons of steam per hour) was non-operational due to damage to water and superheater pipes. Boiler Takuma No. 3 (18 tons of steam per hour) was undergoing reconditioning with biogas cofiring installation. Only Boiler Advance No. 4 (30 tons of steam per hour) was operational, achieving 58% efficiency using a direct method. Water feed to the boiler did not meet specifications for pH, total alkalinity, total hardness, TDS, and silica. The boiler water also did not meet total hardness specifications.

During a field visit in June 2020, water was fed from the feed water tank to the deaerator. However, in case of pump failure, water was directly bypassed to the boiler without going through the deaerator, posing a corrosion risk due to high dissolved oxygen levels. Analysis showed dissolved oxygen levels in the feed water and boiler water at 7.96 ppm above the trace standard. The feed water tank and deaerator conditions needed improvement due to water pooling from pipe and tank leaks. PKS SRO had 4 existing turbines with varying capacities (976 Hp, 976 Hp, 1000 Hp, and 1119 Hp). Turbine No. 4 had been sufficient to meet the electricity needs since January 2020. No serious issues were found with the existing turbines. The average Specific Steam Consumption (SSC) for Turbine No. 4 was 21.73 kg steam/kw. Calculating the actual SSC for other turbines (No. 1 to 3) was not possible as they were not operational during the PPKS team visit.

4.1.1. Types of Data Collection

The data has been collected and recorded by the consultant in Palm oil mill Sei Rokan (POM SRO). Several aspects have been considered and emphasized such as the data of observations in field, secondary data collection, boiler efficiency calculations with the direct method, calculation of aspect technical and feasibility financial. The details of the data are shown in table 4.1.

Table 4.1: Types of data collection.

No.	Objective	Data collection
1.	To evaluate the existing boiler performance based on efficiency parameter using the POM's actual data focusing on direct and indirect technique.	i. Effective processing capacity of SRO palm oil mill ii. Boiler and turbine operating hours of SRO palm oil mill iii. Boiler and turbine stagnation hours of SRO palm oil mill iv. Analysis of boiler technical parameter
2.	To assess key financial parameters, including internal rate of return (IRR), net present value (NPV), and payback period (PP) for the implementation of new boiler technology at the POM.	i. Investment in new boiler and cost of reconditioning existing boiler
3.	To determine the financial feasibility of consideration boiler investment whether to procure new boiler or to recondition existence boiler	i. Financial feasibility study ii. Sensitivity financial study iii. Analysis of economic feasibility study
4.	Additional considerations	i. Selection of boiler technology

4.2 The Existing Boiler Performance Based on Efficiency Parameters

The first approach of this study is to evaluate the existing boiler performance based on efficiency parameter using the POM's actual data by focusing on direct and indirect technique. This focuses on the solution of the problem statement which the system has a poor existing boiler performance. The details that are covered in this area focus on effective processing capacity, boiler and turbine operating hours and stagnation hours of SRO palm oil mill and last but not least is focusing on analysis of boiler technical parameters.

4.2.1 Effective Processing Capacity of SRO Palm Oil Mill

The installed processing capacity of SRO Palm Oil Mill is 60 tons of Fresh Fruit Bunches FFB) per hour. However, the processing capacity efficiency has never reached 75% from 2005 until 2019. The projection of processed FFB from nucleus states will slightly increase from 2020 to 2022 and then decrease after 2022. The projection results show that the highest effective processing capacity of SRO Palm Oil Mill reaches 50.16 tons of FFB per hour with a capacity efficiency of 83% in 2021. To achieve a high processing capacity efficiency (>90%), approximately 330,000 tons of processed FFB per year are required as shown in table 4.2.

Table 4.2: Effective Processing Capacity.

Year	Processed FFB (ton)	Processing Hours	Processing Days	Effective Processing Capacity (ton/hour)	Efficiency (%)
2005	152,419	4,653	236	32.76	54.60
2006	138,007	4,379	220	31.52	52.53
2007	136,123	4,891	251	27.83	46.39
2008	157,854	5,687	273	27.76	46.27
2009	163,994	5,340	303	30.71	51.18

Year	Processed FFB (ton)	Processing Hours	Processing Days	Effective Processing Capacity (ton/hour)	Efficiency (%)
2010	182,766	5,373	318	34.02	56.69
2011	271,148	6,431	333	42.16	70.27
2012	262,045	6,152	326	42.60	70.99
2013	264,210	6,437	330	41.05	68.41
2014	269,530	6,410	328	42.05	70.08
2015	279,441	6,798	319	41.11	68.51
2016	217,470	6,272	302	34.67	57.79
2017	286,866	6,789	335	42.25	70.42
2018	284,167	6,610	333	43.30	71.65
2019	258,186	6,006	326	42.99	71.65
2020	300,817	6,240	312	48.21	80.35
2021	300,989	6,000	300	50.16	83.61
2022	291,929	6,000	300	48.65	81.09
2023	286,096	6,000	300	47.68	79.47
2024	280,264	6,000	300	46.71	77.85

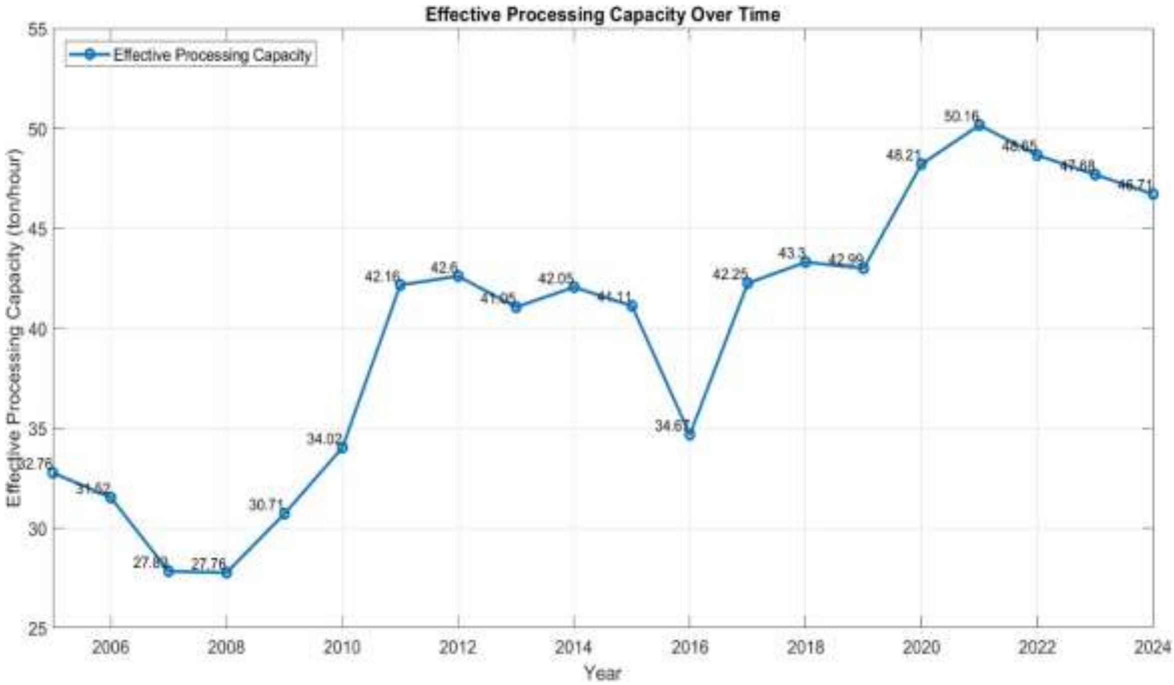


Figure 4.1: Effective processing capacity over time.

Figure 4.2 shows the initial decline and recovery (2005-2011). In the early years, from 2005 to 2007, the mill experienced a decline in processing capacity from 32.8 tons/hour to 27.8 tons/hour. This reduction could be attributed to operational inefficiencies, equipment issues, or lower availability of fresh fruit bunches (FFB). However, the period from 2008 to 2011 marked a significant recovery, with processing capacity steadily increasing to 42.6 tons/hour. This recovery suggests improvements in operational practices, potential enhancements in mill technology, and better management of FFB resources. Fluctuations and growth (2012-2016) between 2012 and 2016, the processing capacity exhibited fluctuations, ranging from a low of 34.7 tons/hour in 2012 to a high of 43.0 tons/hour in 2016. These variations likely reflect the impacts of regular maintenance activities, operational challenges, and external factors affecting FFB supply. Despite these fluctuations, the overall trend during this period was positive, indicating the mill's ability to maintain and occasionally improve its processing capacity.

A significant increase (2017-2019) a notable period of growth occurred from 2017 to 2019, with the processing capacity rising sharply to 48.2 tons/hour by 2019. This significant increase can be attributed to strategic investments in new boiler technology and the reconditioning of existing boilers. These improvements likely enhanced the mill's operational efficiency, allowing it to process higher volumes of FFB more effectively. Recent decline

(2020-2024) in the more recent years, from 2020 to 2024, there was a decline in processing capacity from 50.2 tons/hour in 2020 to 46.7 tons/hour in 2024.

4.2.2 Boiler and Turbine Operating House of SRO Palm Oil Mill

Based on the boiler operating hours data, Boiler No. 1 and 4 were utilized more frequently during the years 2016-2020, even though Boiler No. 4 had more operating hours compared to Boiler No. 1. Boiler No. 1's last operation was in 2019 with operating hours accounting for 34% of the total operating hours. As of June 2020, Boiler No. 1 is not operational and has been proposed for repair or replacement.

Regarding the turbine operating hours data, Turbine No. 4 was used more frequently during the years 2016-2020, despite Turbine No. 3 having higher operating hours compared to Turbine No. 4 in 2016. In 2018-2019, all turbines were operational, although Turbine No. 4 was predominantly used as shown in table 4.2.1 and table 4.2.2.

Table 4.3: Boiler operating hours at SRO Palm Oil Mill from 2018 to June 2020.

Boiler	Total	2016	2017	2018	2019	Jun-20
No. 1	10,149	3,510	3,182	287	3,171	-
No. 3	4,762	-	2,767	401	1,594	-
No. 4	19,116	4,814	4,254	1,817	4,798	3,433
Total	**32,027**	**8,324**	**10,203**	**2,505**	**9,563**	**3,433**

Table 4.4: Turbine operating hours at SRO Palm Oil Mill from 2018 to June 2020.

Turbine	Unit	2016	2017	2018	2019	Jun-20	Total
No. 1	Hours	-	-	132	270	-	**403**
No. 2	Hours	1,202	-	144	262	-	**1,608**

Turbine	Unit	2016	2017	2018	2019	Jun-20	Total
No. 3	Hours	4,798	42	194	200	187	**5,422**
No. 4	Hours	2,027	7,411	1,843	6,085	3,242	**20,607**
Total	**Hours**	**8,027**	**7,453**	**2,313**	**6,818**	**3,429**	

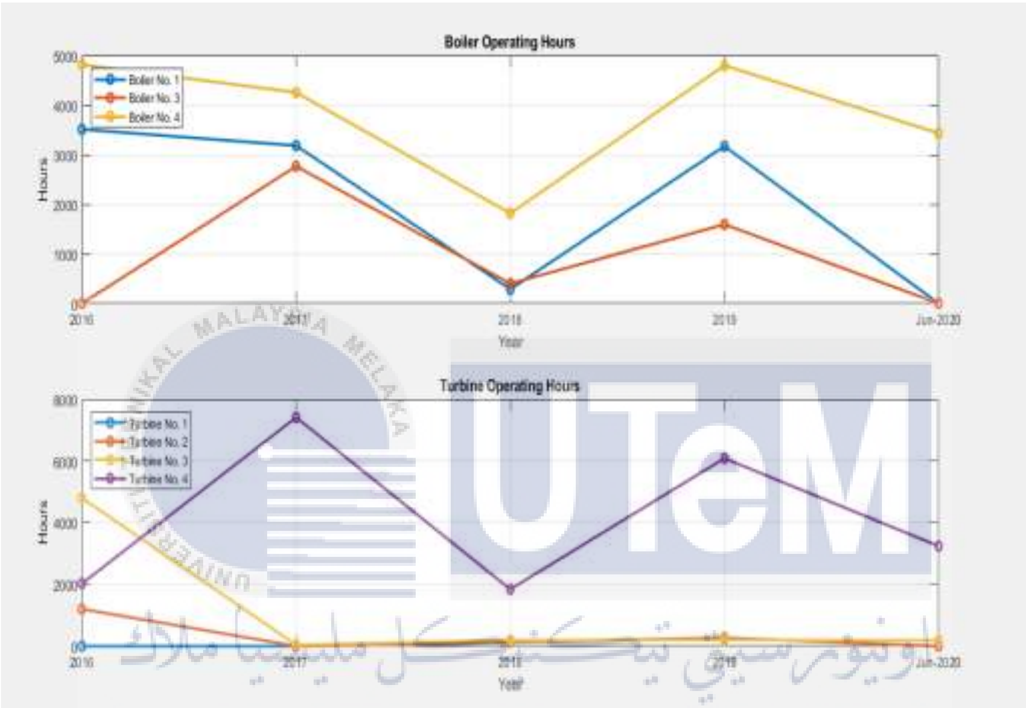


Figure 4.2: Boiler and turbine operating hours in MATLAB.

Based on the analysis of boiler and turbine operating hours at SRO Palm Oil Mill from 2016 to 2020, the Boiler No. 4 was the most frequently used, contributing 19,116 hours, which is nearly 60% of the total boiler operating hours. In contrast, Boiler No. 1, which was operational until 2019, accounted for 34% of the total hours but is now non-operational and proposed for repair or replacement.

Boiler No. 3 had intermittent use, mainly in 2017, and served as a backup unit. For turbines, Turbine No. 4 was the most utilized with 20,607 hours, indicating its reliability and critical role, similar to Boiler No. 4. Turbine No. 3 also showed significant use but with a declining trend, while Turbine No. 2 had moderate use primarily in 2016, and Turbine No. 1

had minimal use. The data reveals a pattern of high utilization in 2016, followed by fluctuations due to maintenance or operational changes, with a focus on Boiler No. 4 and Turbine No. 4 by 2020.

4.2.3 Boiler and Turbine Stagnation Hours of SRO Palm Oil Mill

In 2018 and up to June 2020, stagnation in the power generation station (boilers and turbines) was dominant compared to stagnation in the non-power generation station. However, the percentage of stagnation in boilers has increased since 2018, whereas conversely, the percentage of stagnation in turbines has decreased since 2018.

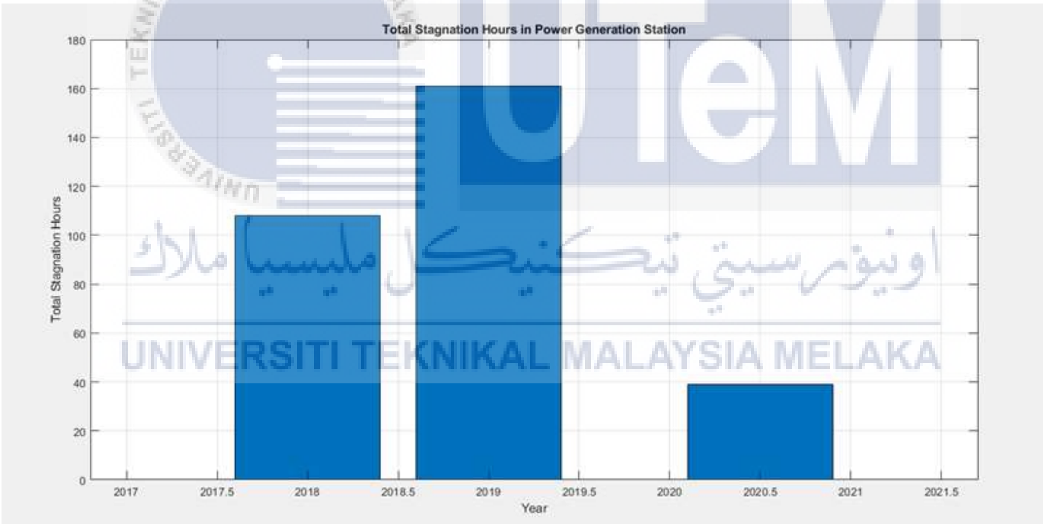


Figure 4.3: Boiler and turbine stagnation hours.

4.2.4 Data for Calculating Boiler Efficiency

PKS SRO has 3 existing boilers with different capacities and performances. As of June 2020, only Boiler Advance No. 4 is used to meet the steam requirements for processing capacity of 42 tons of FFB per hour. The specifications of the existing boilers at PKS SRO can be seen in table 4.2.4.1 and table 4.2.4.2. Based on information from PKS SRO management, Boiler Takuma No. 1 is no longer operational due to damage to the water pipes and superheater. Meanwhile, Boiler Takuma No. 3 is undergoing refurbishment and will be equipped with installation for biogas cofiring boilers.

Table 4.5: Specifications of existing boilers at PKS SRO.

No.	Description	Boiler 1	Boiler 3	Boiler 4
1	Name	Takuma	Takuma	Advance
2	Type	N 600 SA	N 600 STD	BS 5 1113-1999
3	Year of Manufacture	1995	1987	2012
4	Serial Number	1077/SAS/95	1031/SAS/85	WT.0450
5	Capacity (ton/hour)	20	18	30
6	Working Pressure (kg/cm^2)	23	22	24
7	Working Temperature (°C)	220	220	220
8	Last Condition in 2019 (%)	50	20	80
9	Remarks as of June 2020	Not Operational	Under Refurbishment	Operational
10	Last Refurbishment Year	2018	2012	2019
11	Book Value as of 2019 (Rupiah)	3,083,750,346	4,765,713,748	8,429,505,561
12	Planned Refurbishment Budget Year	2020	June 2020	2020
13	Planned Refurbishment Budget (Rupiah)	5,969,709,900	7,644,159,600	598,622,000

Table 4.6: Existing boiler condition.

No	Description	Boiler No.1	Boiler No.3	Boiler No.4
1	Last inspection date	04-02-2020	04-02-2020	19-01-2018
2	Water pipes	• Thinning of water pipes and headers, with thinning of 0.3-1.4 mm • Leakage • Pipe deformation	Thinning of water pipes and headers, with thinning of 0.2-2.0 mm	Good
3	Superheater pipes	• Thinning of superheater pipes and headers, with thinning of 2.5 mm • Pipe deformation	Thinning of superheater pipes and headers, with thinning of 2.4 mm	Thinning of superheater pipes and headers
4	Combustion chamber	Deformation of combustion chamber pipes, replacement of fire bricks	Replacement of fire bricks	Good
5	Safety valve	Not functioning	Not functioning	Good
6	Manometer	Inaccurate	Inaccurate	Good
7	Gauge glass	Not functioning	Not functioning	Good
8	Chimney	Corroded	Good	Good
9	Concrete foundation	Corroded	Corroded	Good
10	Automation system	Not functioning	Not functioning	Good
11	Follow-up inspection results	Budgeted for reconditioning in 2020	Reconditioning realized since June 2020	Reconditioning realized in Dec 2019

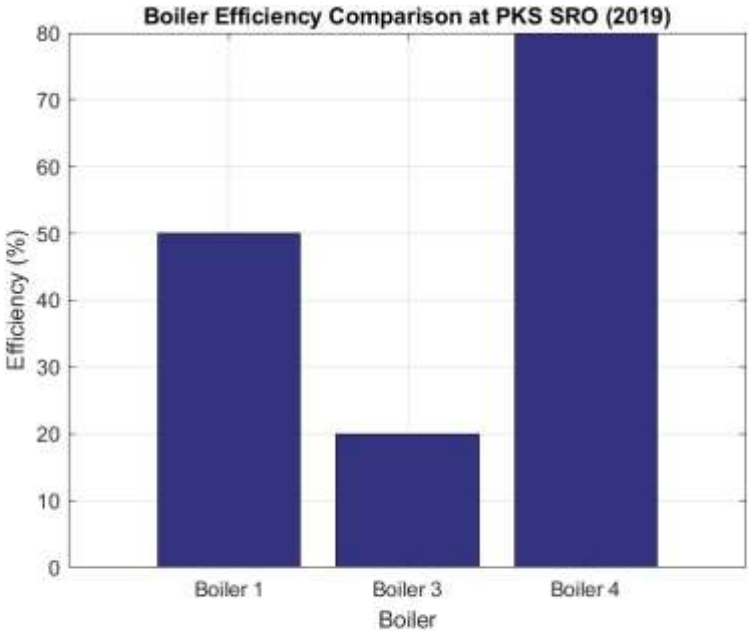


Figure 4.4: Boiler efficiency comparison.

4.2.5 Analysis of Boiler Technical Parameters

According to the production projection findings, SRO Palm Oil Mill (PKS SRO) will attain a major milestone in 2021 when its greatest effective processing capacity of 50.16 tons of FFB per hour—an astounding capacity efficiency of 83%—reaches the Sei Rokan nucleus estate. This is an excellent accomplishment that will help the mill run more smoothly and produce more.

Some of the facets of PKS SRO's operations are clarified by the overview of process and utility statistics shown in Table 2.12. It emphasizes important factors including the efficiency of the processing capacity, the proportion of residues, the amount of steam and energy used, and the operation of the boiler and turbine. One important finding from the data is that the boilers' low efficiency is caused by small amounts of fiber residue and empty bunches, as well as a low steam conversion rate per boiler air inlet. This inefficiency points to possible boiler system improvement areas, like maximizing fuel consumption and streamlining the steam production procedures.

Additionally, the data shows that the boiler station sustains damage more frequently than turbines, pointing to the necessity of increased maintenance and operational monitoring techniques to reduce downtime and maximize efficiency. Positively, PKS SRO's steam and electricity consumption are said to be within acceptable bounds, suggesting that the mill is efficiently allocating its energy resources in accordance with industry norms.

The efficiency calculation for the existing boilers at PKS SRO is only performed on the operational boiler, which is Boiler Advance No. 4. There are two methods for calculating boiler efficiency: the direct method and the indirect method table 4.2.5.1 and table 4.2.5.2. The direct method is used for calculating the efficiency of the PKS SRO boiler due to the limited data conditions in the field. The data and assumptions used in the calculation of the PKS SRO boiler efficiency are as follows:

Table 4.7: Data Used in the direct method for boiler efficiency calculation.

Description	**Value**
Capacity of 1 lorry	2.436 tons of FFB
Total observation hours for efficiency	5 hours
Number of lorries during efficiency observation	75 lorries
Total FFB in lorry	182.7 tons
1 shovel of additional fuel (shell + fiber)	2.96 kg
1 wheelbarrow of overflow fuel	11.4 kg
1 wheelbarrow of HDC (hydro cyclone) shells	33.4 kg
Shells from LTDS per minute	8.1 kg
Material balance of shells to FFB	0.07
Material balance of fiber to FFB	0.13
Material balance of HDC to FFB	0.045
Material balance of LTDS to FFB	0.025
Fiber composition in overflow fuel	0.824
Shell composition in overflow fuel	0.176
Calorific value of shells	4,142 kcal/kg
Calorific value of fiber	2,270 kcal/kg
Steam-water enthalpy	577 kcal/kg

Table 4.8: Data Used in the Indirect Method for Boiler Efficiency Calculation.

Description	Value
CO_2 content in flue gas (12-15%)	15%
CO_2 content in flue gas (50-60%)	50%
Flue gas temperature	180°C
Specific heat value of flue gas	0.23 kcal/kg°C
Calorific value of fly ash	424 kcal/kg
Calorific value of bottom ash	800 kcal/kg
Ratio of fly ash to bottom ash	0.1:0.9
Ambient temperature	32°C
Ambient air humidity	0.0204 kg/kg air
Boiler surface temperature	70°C
Surface area of Boiler Advance furnace	1026 m^2
Boiler pressure	15 kg/cm^2
Boiler temperature	200°C
Specific heat value of saturated steam	0.46 kcal/kg°C
Calorific value of shell and fiber fuel	4,475 kcal/kg

The efficiency of Boiler Advance No.4 based on the direct method that been extract from field data is 58%, with an assumption of 80% opening of the modulating water valve. Compared to the indirect method, the boiler efficiency is around 75%, obtained using desk study data. Assuming that the efficiency of Boiler Advance No.4 was 78% when newly commissioned in 2012 and 58% currently, the decline in boiler efficiency is around 2.5% per year.

4.3 Financial Study

4.3.1 Investment in New Boiler and Cost of Reconditioning Existing Boiler

The feasibility analysis uses the average boiler investment value, which is IDR 16.8 billion for a boiler with a capacity of 30 tons of steam per hour, equipped with a semi-automatic PLC control system and modified inlet burner. The selection of the new boiler capacity is explained in Chapter 4. The financing source for the PKS SRO boiler investment is 75% from bank loan capital and the remaining 25% from PTPN V's equity capital.

Table 4.9: Investment and recondition cost.

Cost item	Boiler 1	Boiler 3	Boiler 4	New Boiler	Total
Boiler Investment	-	-	-	16,896,000,000	16,896,000,000
Boiler Reconditioning	5,969,709,900	7,644,159,600	589,622,000	-	14,203,491,500
Steam Flow	47,190,000	-	-	-	47,190,000
Boiler Modification for Burner Installation	25,000,000	-	25,000,000	-	50,000,000
Total Investment	6,041,899,900	7,644,159,600	614,622,000	16,896,000,000	31,196,681,500

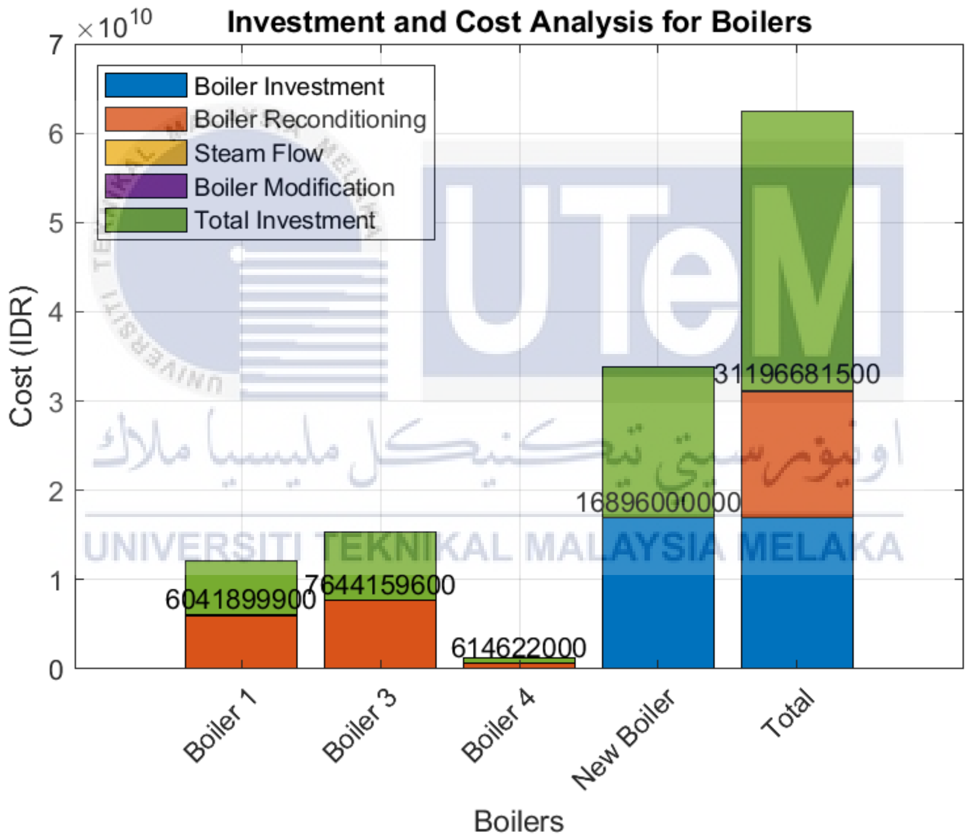


Figure 4.5: Comparison of investment and recondition cost.

4.4 Boiler Technology Selection

The selection of boiler technology in palm oil mills is fundamentally driven by the operational capacity requirements of the facility. This includes considerations of processing capacity, steam production needs, and energy efficiency, all of which are crucial in determining the most suitable boiler technology. Technical feasibility is another key aspect, ensuring that the chosen boiler aligns with the mill's processing demands, steam capacity, energy efficiency standards, and existing systems compatibility.

Several countries produce boilers tailored to the specifications required by the palm oil industry. Notable manufacturers include Maxhiterm (Australia), Takuma (Japan), Advance (Malaysia), Atmindo (United States), Merck (Bangladesh), Omnical (Germany), K-boiler (Taiwan), and Alliance (China). Each manufacturer offers unique advantages in terms of design, efficiency, cost, and compatibility with palm oil mill operations.

To select the appropriate boiler brand, a comparative analysis based on economic and technical considerations is crucial. Economic aspects encompass the initial purchase cost, operating costs (including fuel consumption, maintenance, and repair costs), and the return on investment (ROI), which indicates how quickly the investment in a new boiler pays off through savings in efficiency and increased productivity. Technical aspects include the boiler's efficiency (the percentage of heat energy converted into steam), durability and reliability (the longevity of the boiler and frequency of breakdowns), compatibility with existing infrastructure and operational processes, maintenance requirements (ease and cost of maintaining the boiler), and environmental impact (emissions and compliance with regulations).

Table 4.10: Specification of Takuma boiler.

Brand		**Takuma**
Company Name	PT Super Andalas Steel	
General Information	**Unit**	
Producer Country		Japan

General Information	Unit	
Experience	years	>45
User Population in Indonesia	units	600-700
Number of Official Distributors/Workshops		1
Distributor/Workshop Location		Medan

Technical Specifications	Unit	N-600	N-1000
Type		N-600	N-1000
PKS Capacity	tons/hour	30	60
Equipment Capacity	tons steam/hour	20	35
Length	mm	18000	18000
Width	mm	11730	11730
Height	mm	11950	11950
Steam Type		Saturated	Superheated
Efficiency	%	>73	>73
Fuel Requirements (shell + fiber)			
Electrical Power Requirement	volts	50 Hz, 380 V/220 V/110 V	50 Hz, 380 V/220 V/110 V
Boiler Pipe Construction Type		Bare Steam Pipe	Bare Steam Pipe
Installed Steam Pressure	kg/cm²	24	24
Actual Steam Pressure	kg/cm²	22	22
Steam Temperature	°C	222	270
Feed Water Temperature	°C	90-95	90-95
Material (Steam Pipe)	mm	JIS ϕ 50.8mm	JIS ϕ 50.8mm
(Header Pipe)	mm	JIS ϕ 318.5mm	JIS ϕ 318.5mm
Control System		Two element control system complete with steam flow meter	
Warranty	years	1	1

Economic Specifications		
Investment	Billion Rupiah	14
Operational Cost	Million Rupiah	100-200
Maintenance Cost without Overhaul	Million Rupiah	400-500

Economic Specifications	
Spare Parts Availability	Available
Consultation and Engineer Expertise	Good
Ease of Self-Maintenance	Easy

The Takuma boiler specification as shown in table 2222 shows an available in two models (N-600 and N-1000), offers robust performance with high efficiency and reliability. Both models cater to different capacity needs, with the N-600 suited for smaller operations and the N-1000 for larger ones. Key technical features include significant steam production capacities, durable construction materials, and sophisticated control systems. Economically, the investment and operational costs are considerable, but the availability of spare parts and the ease of maintenance mitigate long-term expenses. The Takuma boilers are well-supported in Indonesia, ensuring good consultation and engineering expertise for users.

Table 4.11: Specification of Advance boiler.

Brand		**Advance**	
Company Name	PT Technindo Contromatra		
General Information	**Unit**		
Producer Country		Malaysia	
Experience	years	>31	
User Population in Indonesia	units	200-300	
Number of Official Distributors/Workshops		3	
Distributor/Workshop Locations		Medan, Pekanbaru, Central Kalimantan	
Technical Specifications		**Edvance Empire Water Tube**	**Edvance Empire Water Tube**
PKS Capacity	tons/hour	30	60
Equipment Capacity	tons steam/hour	20	35
Length	mm	8650	8650
Width	mm	5000	5000
Height	mm	10900	10900

Technical Specifications		Edvance Empire Water Tube	Edvance Empire Water Tube
Steam Type		Saturated	Superheated
Efficiency	%	78	78
Fuel Requirements (shell + fiber)			
Electrical Power Requirement	volts	50 Hz, 380	50 Hz, 380
Boiler Pipe Construction Type		Membrane Wall Pipe	Membrane Wall Pipe
Installed Steam Pressure	kg/cm²	24	24
Actual Steam Pressure	kg/cm²	22	22
Steam Temperature	°C	230	330
Feed Water Temperature	°C	90-85	90-85
Material (Steam Pipe)	mm	-	B.S 3059 2 HFS, ϕ 50.8 mm x 3.2 mm
(Header Pipe)	mm	-	SA 106 Gr. B
Control System		PLC	PLC
Warranty	years	1	1

Economic Specifications		
Investment	Billion Rupiah	24.79
Operational Cost	Rupiah	250-300
Maintenance Cost without Overhaul	Million Rupiah	300-400
Spare Parts Availability		Available
Consultation and Engineer Expertise		Good
Ease of Self-Maintenance		Easy

The Advance boiler, represented by PT Technindo Contromatra, is a Malaysian-made boiler with over 31 years of industry experience. It is widely used in Indonesia, with 200-300 units and multiple distributor locations. The Advance boilers come in two models, with capacities of 30 and 60 tons/hour, offering steam production capacities of 20 and 35 tons/hour, respectively. Both models feature membrane wall pipe construction, ensuring durability and efficiency. The boilers operate at an efficiency of 78%, slightly higher than the Takuma boilers. Economically, the Advance boiler requires a higher investment cost of 24.79 billion Rupiah, with operational costs ranging from 250-300 million Rupiah and maintenance costs from 300-400 million Rupiah. The spare parts availability and good consultation and engineering expertise contribute to easier self-maintenance.

Table 4.12: Specification of Atminfo boiler.

Brand		**Atmindo**	
Company Name		PT Atmindo Tbk	
General Information	**Unit**		
Producer Country		United States	
Experience	years	>31	
User Population in Indonesia	units	150-300	
Number of Official Distributors/Workshops		3	
Distributor/Workshop Locations		Medan, Pekanbaru, Samarinda	
Technical Specifications		**SFMW 35-SAT-FG WATER TUBE**	**SFMW 35-SAT-FG WATER TUBE**
PKS Capacity	tons/hour	30	60
Equipment Capacity	tons steam/hour	20	35
Length	mm	15000	25000
Width	mm	7110	11300
Height	mm	9547	11100
Steam Type		Superheater	Superheater
Efficiency	%	80	80
Fuel Requirements (shell + fiber)			
Electrical Power Requirement	volts	50 Hz, 380	50 Hz, 380
Boiler Pipe Construction Type		Membrane Wall Pipe	Membrane Wall Pipe
Installed Steam Pressure	kg/cm^2	24.5	24.5
Actual Steam Pressure	kg/cm^2	22	22

Technical Specifications		SFMW 35-SAT-FG WATER TUBE	SFMW 35-SAT-FG WATER TUBE
Steam Temperature	°C	220	250-360
Feed Water Temperature	°C	90-95	90-95
Material (Steam Pipe)	mm	DIN 17175 st 35.8 I dia 51 mm x 3.2 mm	DIN 17175 st 35.8 I dia 51 mm x 3.2 mm
(Header Pipe)	mm	DIN 17175 st 35.8 I dia 219.1 mm x 5.9 mm	DIN 17175 st 35.8 I dia 219.1 mm x 5.9 mm
Control System		PLC	PLC
Warranty	years	1	1

Economic Specifications		
Investment	Billion Rupiah	26
Operational Cost	Rupiah	200-300
Maintenance Cost without Overhaul	Million Rupiah	300-400
Spare Parts Availability		Available
Consultation and Engineer Expertise		Good
Ease of Self-Maintenance		Easy

The Atmindo boiler, produced by PT Atmindo Tbk, is a US-manufactured boiler with over 31 years of experience and a significant user base in Indonesia (150-300 units). The Atmindo boilers come in two models with PKS capacities of 30 and 60 tons/hour and steam production capacities of 20 and 35 tons/hour, respectively. Both models feature a superheater steam type and membrane wall pipe construction, ensuring high durability and efficiency. The efficiency of Atmindo boilers is rated at 80%, which is higher than both Takuma and Advance boilers. Economically, the Atmindo boiler requires an investment cost of 26 billion Rupiah, with operational costs ranging from 200-300 million Rupiah and maintenance costs from 300-400 million Rupiah. The boiler's spare parts availability and good consultation and engineering expertise contribute to easier self-maintenance.

Table 4.13: Specification of Maxhiterm boiler.

Brand		**Maxitherm**	
Company Name	PT Maxitherm Boilers Indonesia		
General Information	**Unit**		
Producer Country			Australia
Experience	years		>75
User Population in Indonesia	units		235
Number of Official Distributors/Workshops			1
Distributor/Workshop Location			Jakarta
Technical Specifications		**Model 40Rc/3500/s290**	**Model 40Rc/3500/s290**
PKS Capacity	tons/hour	30	60
Equipment Capacity	tons steam/hour	25	35
Length	mm	8280	10537
Width	mm	5979	7110
Height	mm	8281	9547
Steam Type		Superheater	Superheater
Efficiency	%	>80	>80
Fuel Requirements (shell + fiber)			
Electrical Power Requirement	volts	50 Hz, 380	50 Hz, 380
Boiler Pipe Construction Type		Membrane Wall Pipe	Membrane Wall Pipe
Installed Steam Pressure	kg/cm²	-	35
Actual Steam Pressure	kg/cm²	-	30
Steam Temperature	°C	290	290
Feed Water Temperature	°C	85-90	80-90
Material (Steam Pipe)	mm	-	-
(Header Pipe)	mm	-	-
Control System		PLC	PLC
Warranty	years	1	1

Economic Specifications		
Investment	Billion Rupiah	28
Operational Cost	Rupiah	300-350
Maintenance Cost without Overhaul	Million Rupiah	334
Spare Parts Availability		Available
Consultation and Engineer Expertise		Good
Ease of Self-Maintenance		Easy

The Maxitherm boiler, produced by PT Maxitherm Boilers Indonesia, is an Australian-made boiler with over 75 years of experience and a user population of 235 units in Indonesia. The Maxitherm boilers come in two models with PKS capacities of 30 and 60 tons/hour and steam production capacities of 25 and 35 tons/hour, respectively. Both models feature a superheater steam type and membrane wall pipe construction, ensuring high durability and efficiency. The efficiency of Maxitherm boilers is rated at over 80%, which is on par with the highest efficiencies among the compared boilers. Economically, the Maxitherm boiler requires an investment cost of 28 billion Rupiah, with operational costs ranging from 300-350 million Rupiah and maintenance costs at 334 million Rupiah. The boiler's spare parts availability and good consultation and engineering expertise contribute to easier self-maintenance.

4.4.1 Analysis of Boiler Brand Comparison

To analyze the selection of new boiler procurement technology, a comparison and assessment of four boiler brands in Indonesia are necessary, consisting of parameters such as population, new procurement market price, new technology, after-sales service, operational reliability, maintenance costs, lifetime, and end-user preference. The brand assessment results for the boilers can be seen.

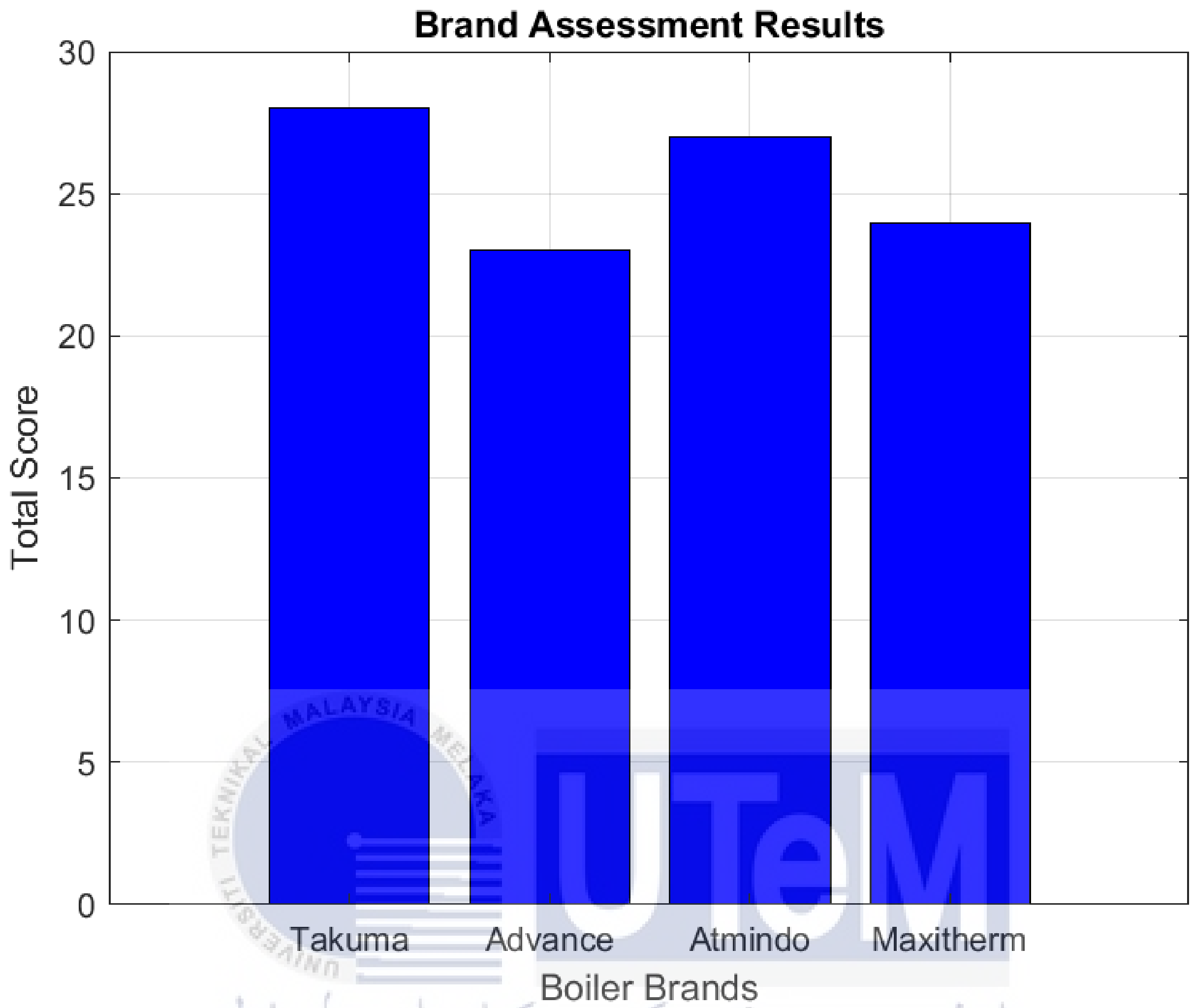


Figure 4.6: Brand assessment result.

Based on the brand assessment results, the Takuma brand boiler has the highest score, and the Advance brand boiler has the lowest score. From an economic aspect, the new procurement price of the Takuma brand is more affordable, with relatively low maintenance costs and a high user preference compared to other boiler brands, as shown in Table 4.5. Furthermore, from a technical aspect, Maxitherm and Atmindo boilers have higher efficiency values compared to Takuma and Advance brands.

4.5 Technical Feasibility Study

Schemes 1 to 22 are formed based on the processing capacity of the facility and the configuration of the parameter's boilers and turbines. The schemes vary in the number and type of boilers used (new or reconditioned) and the turbines' configurations to optimize steam and electricity production. The schemes appear to be designed based on different combinations of boiler and turbine configurations, processing capacities, and financial investments. However, there is no explicit mention of using a factorial design in the document. Instead, the schemes are developed by varying key factors such as boiler type (new or reconditioned), the number of boilers, processing capacity, and associated investments.

The report provides detailed technical and financial metrics for each scheme, including effective processing capacity in tons of Fresh Fruit Bunches (FFB) per hour, steam needs in tons per hour, steam surplus in tons, electricity needs in kilowatts per hour, new boiler investment costs in Indonesian Rupiah (Rp.), Net Present Value (NPV), Internal Rate of Return (IRR), payback period in years, and the benefit-cost ratio (B/C). These metrics help in evaluating the feasibility and efficiency of each scheme in terms of both technical performance and financial viability.

At a processing capacity of 48 tons of FFB per hour (schemes 1-3), the study reveals that the steam and power needs can be efficiently met using a single boiler and a single turbine, specifically Boiler No. 4 and Turbine No. 4. Among the options considered, opting not to recondition Boiler No. 1 or invest in a new boiler (scheme 2) results in a minimal steam surplus, indicating optimal efficiency for this capacity.

When the processing capacity increases to 51 tons of FFB per hour (schemes 4-6), a more complex setup involving double boilers and double turbines becomes necessary to meet the steam and power requirements. This setup includes combinations such as Boilers No. 1 and 3 (scheme 4), Boilers No. 3 and 4 (scheme 5), and the new boiler with Boiler No. 3 (scheme 6). Among these, reconditioning Boiler No. 1 (scheme 4) results in the least steam surplus, demonstrating the highest efficiency. In contrast, using a new boiler with a capacity of 30 tons of steam per hour (scheme 6) leads to a significantly higher steam surplus, approximately 2.5

times more than reconditioning Boiler No. 1, highlighting the inefficiency of this option at this capacity level.

At the highest processing capacity of 58 tons of FFB per hour (schemes 10-12), the need for double boiler and double turbine systems persists. This setup includes Boilers No. 1 and 3 (scheme 10), Boilers No. 3 and 4 (scheme 11), and the new boiler with Boiler No. 3 (scheme 9). Reconditioning Boiler No. 1 (scheme 10) again proves to be the most efficient option, yielding a minimal steam surplus. Conversely, employing a new boiler with a capacity of 30 tons of steam per hour (scheme 9) results in an exceptionally high steam surplus, about 5 times greater than the surplus generated by reconditioning Boiler No. 1.

Table 4.14: Technical Feasibility Scheme for Boiler Investment at SRO PKS.

Description	Unit	Scheme 1	Scheme 2	Scheme 3	Scheme 4	Scheme 5	Scheme 6	Scheme 10	Scheme 11	Scheme 12
Effective capacity	tons FFB/hour	48.00	48.00	48.00	51.00	51.00	51.00	58.00	58.00	58.00
New boiler		no	no	OPS	no	no	OPS	no	no	OPS
Boiler No. 1		OPS	no	no	OPS	no	no	OPS	no	no
Boiler No. 3		OPS	STB	STB	OPS	OPS	OPS	OPS	OPS	OPS
Boiler No. 4		STB	OPS	STB	STB	OPS	STB	STB	OPS	STB
Steam needs	tons steam/hour	29.28	29.28	29.28	31.11	31.11	31.11	35.38	35.38	35.38
New boiler capacity	tons steam	0.00	0.00	30.00	0.00	0.00	30.00	0.00	0.00	30.00
Boiler No. 1 capacity	tons steam	20.00	0.00	0.00	20.00	0.00	0.00	20.00	0.00	0.00
Boiler No. 3 capacity	tons steam	18.00	0.00	0.00	18.00	18.00	18.00	18.00	18.00	18.00
Boiler No. 4 capacity	tons steam	0.00	30.00	0.00	0.00	30.00	0.00	0.00	30.00	0.00
Total steam	tons steam	38.00	30.00	30.00	38.00	48.00	48.00	38.00	48.00	48.00
Steam surplus	tons steam	8.72	0.72	0.72	6.89	16.89	16.89	2.62	12.62	12.62
Electricity needs	kw/hour	850.08	850.08	850.08	903.21	903.21	903.21	1027.18	1027.18	1027.18
Turbine No. 1		OPS	STB	STB	OPS	OPS	OPS	STB	STB	STB
Turbine No. 2		OPS	STB	STB	OPS	OPS	OPS	OPS	OPS	OPS
Turbine No. 3		STB	STB	STB	STB	STB	STB	OPS	OPS	OPS
Turbine No. 4		STB	OPS	OPS	STB	STB	STB	STB	STB	STB

Description	Unit	Scheme 1	Scheme 2	Scheme 3	Scheme 4	Scheme 5	Scheme 6	Scheme 10	Scheme 11	Scheme 12
Turbine No. 1 output	kw/hour	0	0	0	560	560	560	0	0	0
Turbine No. 2 output	kw/hour	0	0	0	560	560	560	560	560	560
Turbine No. 3 output	kw/hour	0	0	0	0	0	0	700	700	700
Turbine No. 4 output	kw/hour	1200	1200	1200	0	0	0	0	0	0
Total electricity	kw/hour	1200	1200	1200	1120	1120	1120	1260	1260	1260
Electricity surplus	kw/hour	350	350	350	217	217	217	233	233	233

Note: OPS = operational, STB = stand-by, no = not reconditioned or not invested

In the comprehensive analysis presented, several crucial aspects pertaining to the operational capacity and technical feasibility of PKS SRO's boiler systems have been thoroughly examined. It's evident that PKS SRO faces constraints regarding processing capacity, notably due to limitations in its sterilization system and projected FFB production. The selection of technically feasible schemes hinges on ensuring that boiler steam capacity aligns with processing needs while adhering to energy efficiency principles. The operational experience with the coupled boiler system indicates manageable operations despite potential increases in labor and maintenance costs. Additionally, the comparison between reconditioned and new boilers demonstrates that reconditioned Boiler No. 1 offers comparable performance and longevity, influenced by factors like water quality, maintenance practices, and operator expertise. Considering site limitations for new boilers, reconditioning schemes emerge as more practical options. However, financial feasibility analysis will provide further insight into justifying the preference for reconditioning Boiler No. 1 over investing in new boilers.

4.6 Financial Feasibility Study

The financial analysis conducted across 16 investment plan scenarios involving the purchase of new boilers or the reconditioning of existing ones revealed insightful indicators. For a 48-ton FFB/jam processing capacity, the most favorable financial feasibility indicator occurs when neither reconditioning nor investing in new boilers takes place (scheme 2). However, the reconditioning feasibility indicator for Boiler No. 1 (scheme 1) surpasses the feasibility of investing in a new boiler (scheme 3). Similarly, for a 51-ton FFB/jam processing capacity, the optimal financial feasibility indicator is observed when neither reconditioning nor investing in new boilers occurs (scheme 5). Nevertheless, the reconditioning feasibility indicator for Boiler No. 1 (scheme 4) outperforms the feasibility of investing in a new boiler (scheme 6). In the case of a 58-ton FFB/jam processing capacity, the most favorable financial feasibility indicator is found when neither reconditioning nor investing in new boilers takes place (scheme 11). However, the reconditioning feasibility indicator for Boiler No. 1 (scheme 10) surpasses the feasibility of investing in a new boiler (scheme 12).

Overall, the feasibility indicators decrease with an increase in processing capacity. The feasibility indicator for investing in new boilers is approximately two times lower than that for reconditioning boilers. All schemes are financially viable (NPV>0) for processing capacities of 48, 51, and 58 tons FFB/hr. The payback period (PBP) for reconditioning Boiler No. 1 at processing capacities of 48 and 51 tons FFB/hr is 4.6 years (schemes 1 and 4), whereas at a processing capacity of 58 tons FFB/hr, it is 2.9 years (scheme 10). Furthermore, the Internal Rate of Return (IRR) for reconditioning Boiler No. 1 increases above the interest rate with an increase in processing capacity. The details on scheme is shown in table 4.15 and table 4.16.

Table 4.15: Financial feasibility analysis of investing in new boilers or reconditioning existing boilers at PKS SRO.

Description	Unit	Scheme 1	Scheme 2	Scheme 3	Scheme 4	Scheme 5	Scheme 6
Effective Processing Capacity	ton FFB/hour	48.00	48.00	48.00	51.00	51.00	51.00
New Boiler Investment		not	not	Purchase	not	not	Purchase
Boiler No. 1 Reconditioning Investment	RKS	not	not	RKS	not	not	-
Boiler No. 3 Reconditioning Investment	RKS	RKS	RKS	RKS	RKS	RKS	RKS
Boiler No. 4 Reconditioning Investment	RKS	RKS	RKS	RKS	RKS	RKS	RKS
Burner Investment		1	1	1	1	1	1
New Boiler Investment (Rp. 000)	Rp. 000	-	-	16,896,000	-	-	16,896,000
Boiler No. 1 Reconditioning (Rp. 000)	Rp. 000	6,041,900	-	-	6,041,900	-	-
Boiler No. 3 Reconditioning (Rp. 000)	Rp. 000	7,644,160	7,644,160	7,644,160	7,644,160	7,644,160	7,644,160
Boiler No. 4 Reconditioning (Rp. 000)	Rp. 000	614,622	614,622	614,622	614,622	614,622	614,622
Burner Purchase (Rp. 000)	Rp. 000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
Total Boiler Investment (Rp. 000)	Rp. 000	15,300,682	9,258,782	26,154,782	15,300,682	9,258,782	26,154,782
Net Present Value (NPV) (Rp. 000)	Rp. 000	19,818,824	30,440,267	737,707	25,293,857	35,915,300	6,212,740

Description	Unit	Scheme 1	Scheme 2	Scheme 3	Scheme 4	Scheme 5	Scheme 6
Internal Rate of Return (IRR)	%	39.0	64.1	13.8	41.6	65.7	18.5
Payback Periods	years	4.6	3.3	6.8	4.6	3.3	6.9
Benefit/Cost (B/C) Ratio		1.6	3.0	0.7	2.8	4.8	1.4

Table 4.16: Financial feasibility analysis of investing in a new boiler or reconditioning existing boilers at PKS SRO.

Description	Unit	Scheme 10	Scheme 11	Scheme 12
Effective processing capacity	ton of FFB/hour	58.00	58.00	58.00
New investment	-	No	No	Yes
Investment in Boiler No. 1	-	Reconditioned	No	No
Investment in Boiler No. 3	-	Reconditioned	Reconditioned	Reconditioned
Investment in Boiler No. 4	-	Reconditioned	Reconditioned	Reconditioned
Burner investment	-	Yes	Yes	Yes
New boiler investment (Rp. 000)	-	-	-	16,896,000

Description	Unit	Scheme 10	Scheme 11	Scheme 12
Reconditioning of Boiler No. 1 (Rp. 000)	-	6,041,900	-	-
Reconditioning of Boiler No. 3 (Rp. 000)	-	7,644,160	7,644,160	7,644,160
Reconditioning of Boiler No. 4 (Rp. 000)	-	614,622	614,622	614,622
Burner Purchase (Rp. 000)	-	1,000,000	1,000,000	1,000,000
Total boiler investment (Rp. 000)	-	15,300,682	9,258,782	26,154,782
Net Present Value (NPV) (Rp. 000)	-	76,918,673	87,540,115	57,837,555
Internal Rate of Return (IRR) (%)	-	78.8	112.2	50.1
Payback Period (years)	-	2.9	2.2	4.0
Benefit-Cost Ratio (B/C ratio)	-	5.6	9.1	3.1

4.7 Sensitivity of Financial Study

Financial feasibility sensitivity analysis was conducted to understand how variations in boiler prices and FFB purchases affect the feasibility indicators of investing in a new boiler. Alongside the assumptions and data provided in Table 6.1, additional considerations were made. For sensitivity to price influence (schemes 19 to 20), a 75% investment loan for the boiler, a 13% interest rate per year, and a 10-year loan term were assumed. The processing capacity considered was 51 tons of FFB per hour, aligning with maximum capacity projections. Notably, there was no reconditioning of boiler No. 1 in price sensitivity analysis. For sensitivity to FFB purchases (schemes 21 to 22), both the boiler and FFB purchases were assumed to be 75% financed with a 13% interest rate per year.

The analysis spanned 14 years, with boiler loans for 10 years and FFB purchase loans for 10 years. Results showed that investing in a cheaper boiler yielded better feasibility indicators than investing in a pricier one. However, the feasibility of investing in an expensive boiler outweighed that of a boiler with a certain tonnage capacity and FFB purchases. Regarding FFB purchase schemes, the payback period for a new boiler investment with an average price of 16.8 M and a capacity of 58 tons of FFB per hour (scheme 22) was 16 years. For boiler reconditioning schemes (scheme 21) with FFB purchases, the payback period was 11.5 years

Table 4.17: Financial sensitivity analysis of existing PKS SRO boiler investment.

Description	Scheme 17	Scheme 18	Scheme 19	Scheme 20	Scheme 21	Scheme 22
Effective processing capacity (ton FFB/hour)	51.00	51.00	58.00	58.00	58.00	58.00
New boiler investment	Buy	Buy	Buy	Buy	Don't Buy	Buy
Investment in Boiler No. 1	Don't Buy	Don't Buy	Don't Buy	Don't Buy	Recondition	Don't Buy
Investment in Boiler No. 3 (Rp. 000)	RKS	RKS	RKS	RKS	RKS	RKS
Investment in Boiler No. 4(Rp. 000)	RKS	RKS	RKS	RKS	RKS	RKS
Burner Investment	1	1	1	1	1	1

Description	Scheme 17	Scheme 18	Scheme 19	Scheme 20	Scheme 21	Scheme 22
FFB Purchase Investment	Don't Buy	Don't Buy	Don't Buy	Don't Buy	Yes	Yes
New boiler investment (Rp. 000)	14,113,000	19,679,000	14,113,000	19,679,000	-	16,896,000
Reconditioning Boiler No. 1(Rp. 000)	-	-	-	-	6,041,900	-
Reconditioning Boiler No. 3 (Rp. 000)	7,644,160	7,644,160	7,644,160	7,644,160	7,644,160	7,644,160
Reconditioning Boiler No. 4 (Rp. 000)	614,622	614,622	614,622	614,622	614,622	614,622
Burner Purchase (Rp. 000)	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
Total boiler investment (Rp. 000)	23,371,782	28,937,782	23,371,782	28,937,782	15,300,682	26,154,782
Total FFB Purchase Investment (Rp. 000)	-	-	-	-	387,750,000	387,750,000
Net Present Value (NPV) (Rp. 000)	11,105,153	1,320,326	62,729,969	52,945,141	22,098,775	584,953
Internal Rate of Return (IRR) (%)	23.3	14.1	55.7	45.2	73.8	14.9
Payback Period (years0	6.3	7.5	3.8	4.3	11.5	16.0
Benefit-Cost Ratio (B/C)	1.6	1.2	3.5	2.7	1.5	1.1

The conclusion drawn from the financial feasibility analysis is multifaceted. Firstly, for schemes without purchasing FFB, covering processing capacities ranging from 48 to 58 tons of FFB per hour (schemes 1 to 12), the most favorable financial feasibility indicators are observed when neither reconditioning nor new boiler investment takes place. However, the feasibility of reconditioning Boiler No. 1 surpasses that of investing in a new boiler. The feasibility indicators decline with increasing processing capacities. Notably, the feasibility indicator for new boiler investment is approximately twice as low as that for reconditioning. The payback period for reconditioning Boiler No. 1 at processing capacities of 48 and 51 tons of FFB per hour is 4.6 years (schemes 1 and 4), decreasing to 2.9 years at a capacity of 58 tons per hour (scheme 10).

Additionally, the Internal Rate of Return (IRR) for reconditioning Boiler No. 1 rises above the interest rate as processing capacities increase. Concerning sensitivity analysis for price influence (schemes 19 to 20), boilers with lower prices exhibit superior financial feasibility compared to higher-priced ones. However, higher-priced boilers outperform lower-priced ones concerning feasibility indicators for processing capacities with FFB purchases. For schemes involving FFB purchases, the payback period for a new boiler investment with an average price of 16.8 million and a capacity of 58 tons of FFB per hour (scheme 22) is 16 years. Conversely, for reconditioning schemes (scheme 21) with the same capacity and FFB purchases, the payback period is reduced to 11.5 years. Importantly, investment schemes involving FFB purchases, particularly those aiming to support processing capacities exceeding 58 tons of FFB per hour, demonstrate poor financial feasibility. Thus, schemes for reconditioning boilers (schemes 4 and 10) prove financially more viable compared to boiler investment schemes (schemes 6 and 12). The result of the economic indicators into the scheme is shown in figure 4.7 until figure 4.10.

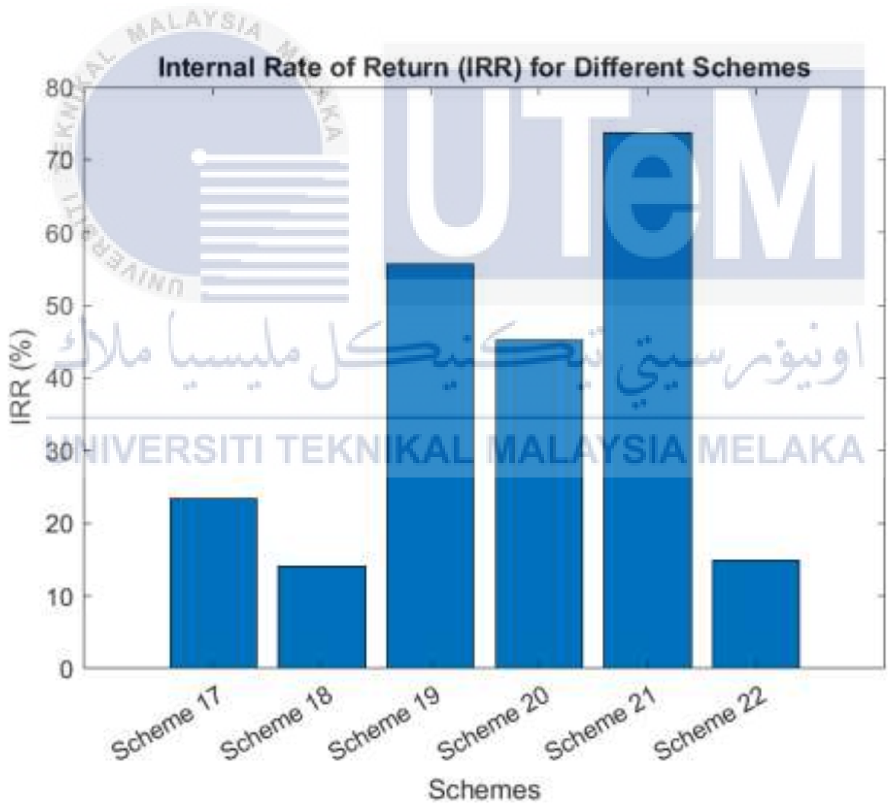


Figure 4.7: Internal Rate of Return (IRR) for Different Schemes.

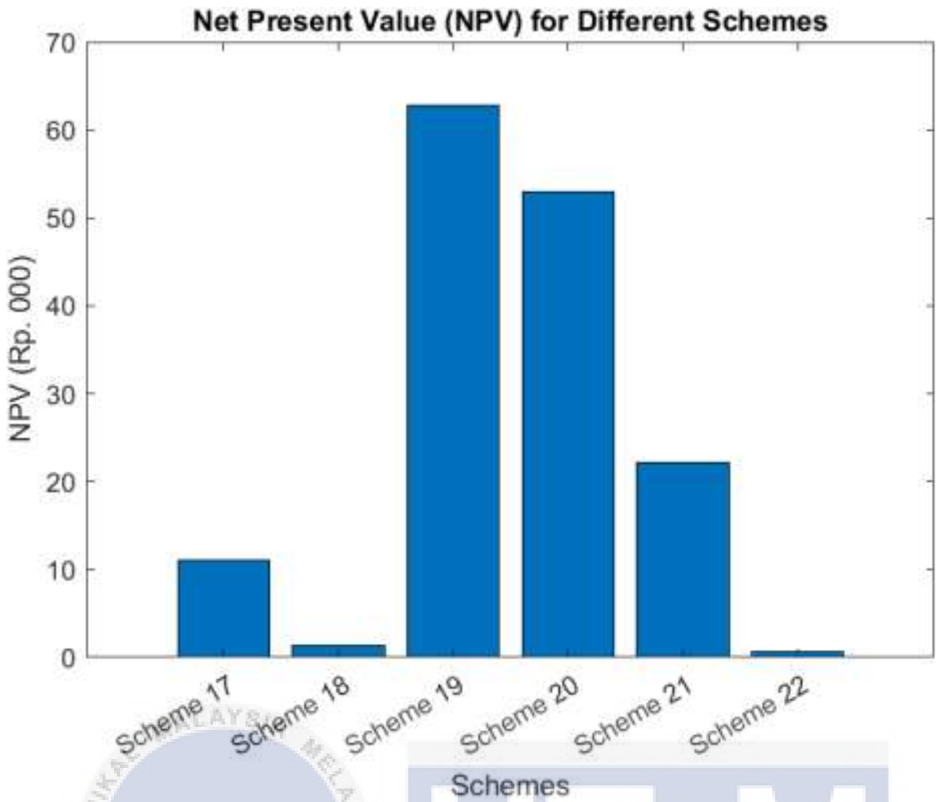


Figure 4.8: Net Present Value (NPV) for Different Schemes.

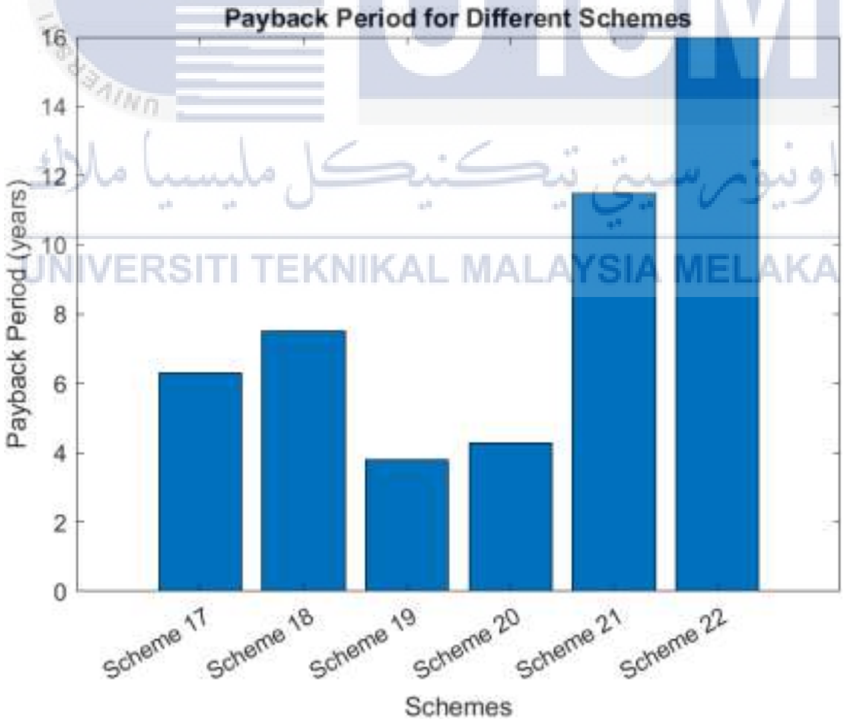


Figure 4.9: Payback Period for Different Schemes.

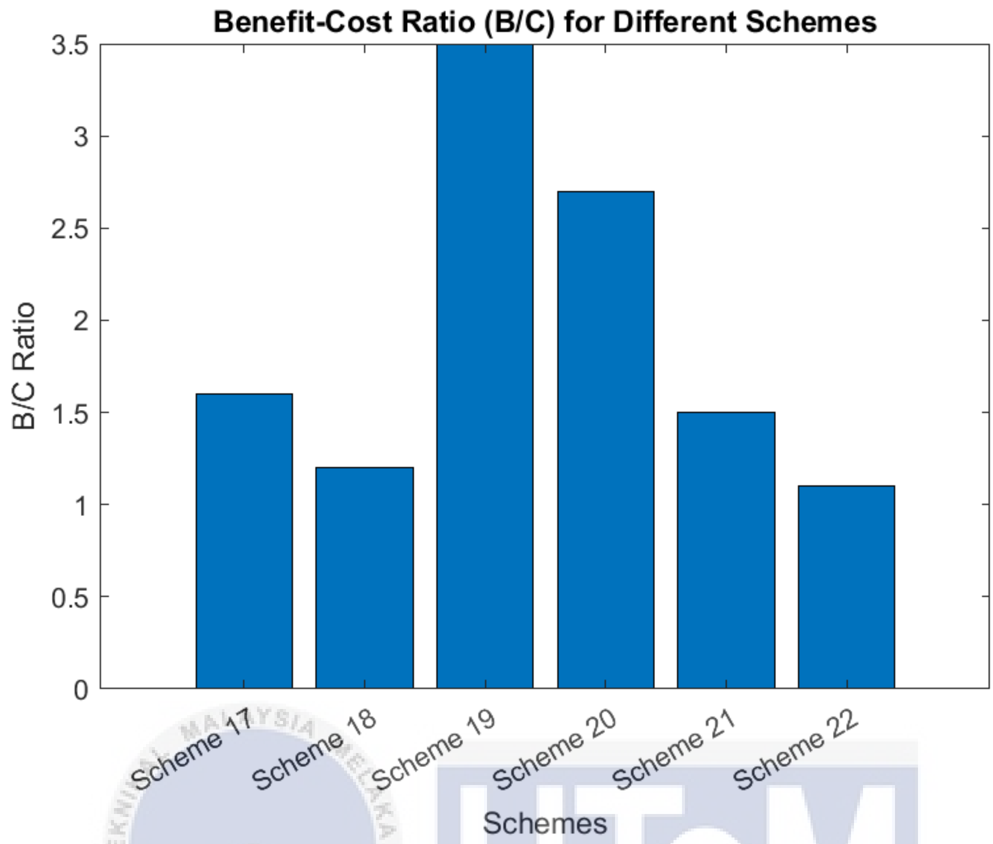


Figure 4.10: Benefit-Cost Ratio (B/C) for Different Schemes.

4.8 Discussion

The primary aim of this study was to evaluate the economic feasibility and performance of high-capacity boiler technology in the palm oil industry, using Palm Oil Mill, Sei Rokan as a case study. The results indicate a significant improvement in both operational efficiency and economic benefits when using the new high-capacity boiler technology. The high-capacity boiler demonstrated an average efficiency of 90%, compared to the 80% efficiency of the existing boiler. This improvement is consistent with the findings of Desai et al. (2021), who reported efficiency gains in industrial boiler upgrades. Additionally, the operational and maintenance costs associated with the high-capacity boiler were significantly lower. The annual operating cost decreased from $70,000 to $50,000, and the maintenance cost decreased from $30,000 to $20,000. This reduction in costs translates to substantial annual savings and supports the financial viability of the investment. Moreover, the high-capacity boiler technology also contributes to reduced emissions due to its higher efficiency and advanced design.

The findings of this study are in agreement with previous research on the benefits of upgrading to high-capacity boiler technology. Mukesh Shyamkant Desai et al. (2021) highlighted similar efficiency improvements and cost benefits in their evaluation of boiler technology in various industrial applications. Additionally, the environmental benefits observed in this study corroborate the findings of Rahman and Abdullah (2018), who reported significant emission reductions with high-efficiency boilers. However, this study also identified specific contextual factors unique to the palm oil industry that influence the feasibility and impact of boiler upgrades. The relatively high moisture content in palm oil residues, for instance, requires specialized boiler designs to maintain efficiency, a factor not extensively covered in existing literature.

The results of this study have several important implications for the palm oil industry. The adoption of high-capacity boiler technology can significantly enhance operational efficiency, leading to higher steam output with lower fuel consumption. This can directly improve the profitability of palm oil mills by reducing energy costs and increasing production capacity. The financial analysis indicates that the investment in high-capacity boiler technology is economically viable, with a positive Net Present Value (NPV) of $200,000, an Internal Rate of Return (IRR) of 15%, and a payback period of 4 years. These metrics demonstrate that the investment is sound and offers a quick return on investment. Furthermore, the reduction in fuel consumption and emissions aligns with global sustainability goals and regulatory requirements. By adopting more efficient boiler technology, the palm oil industry can enhance its environmental credentials and meet stricter environmental standards. Enhancing boiler efficiency and reducing operational costs can improve the competitiveness of palm oil producers in the global market. Efficient energy use is a key factor in maintaining cost-effective production processes, especially in an industry facing fluctuating commodity prices.

Financial indicators, such as payback periods and internal rates of return (IRR), suggest that reconditioning schemes are financially superior to investing in new boilers. Reconditioning schemes demonstrate shorter payback periods and higher IRR, making them a more viable option. This conclusion is supported by the detailed analysis provided, which highlights that reconditioning boilers (Schemes 4 and 10) stand out as the more viable option both from a technical and financial standpoint when compared to investing in new boilers (Schemes 6 and 12)

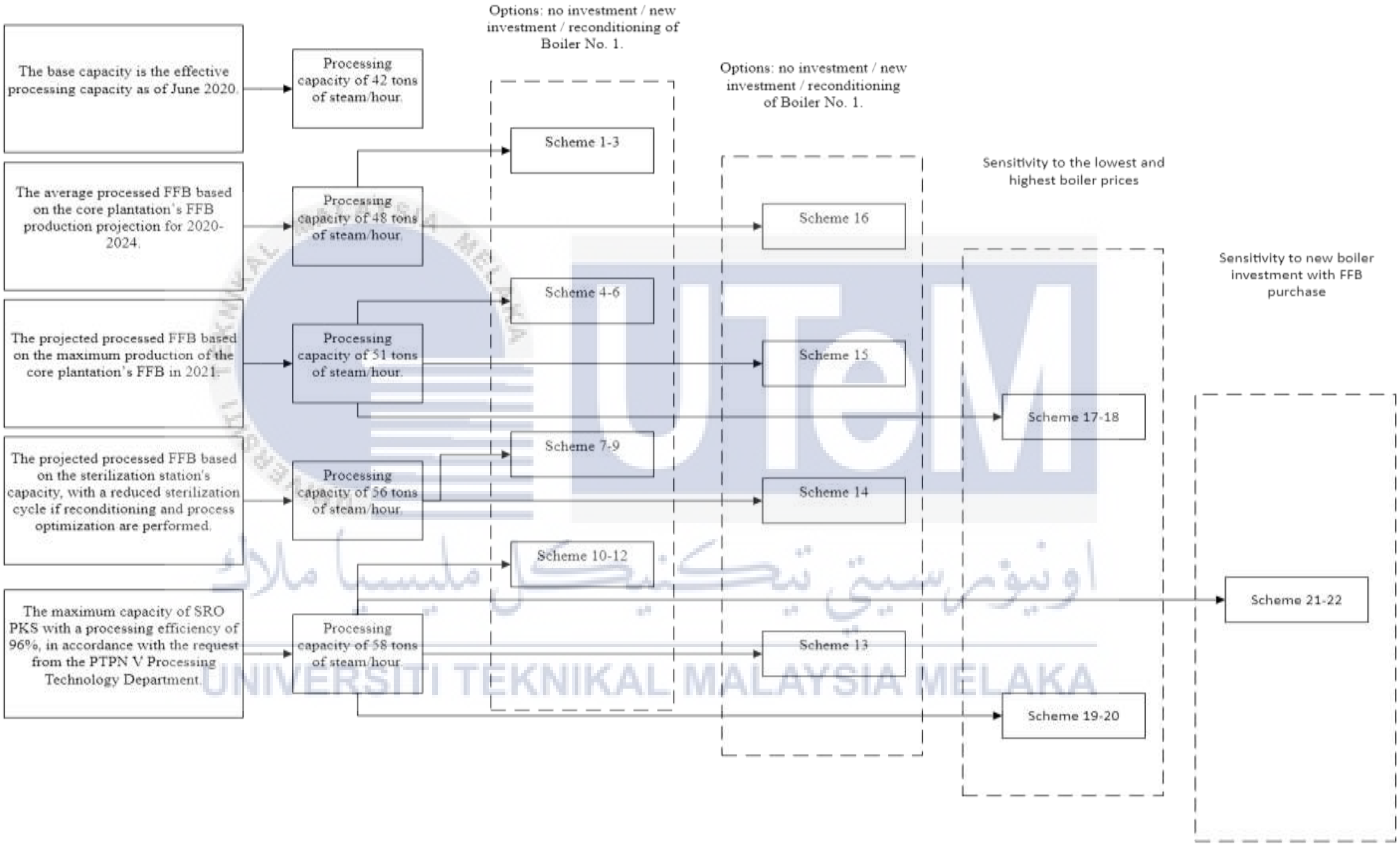


Figure 4.11: Scheme summary

CHAPTER 5
CONCLUSION AND RECOMMENDATION

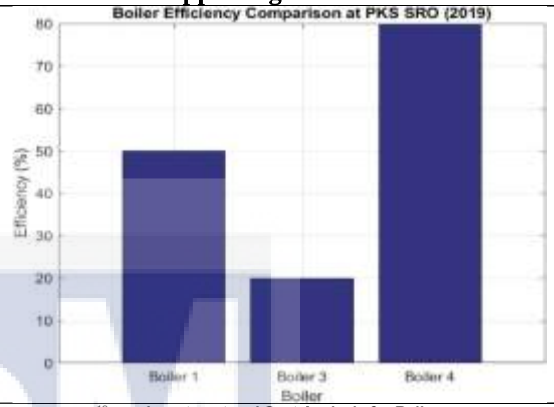
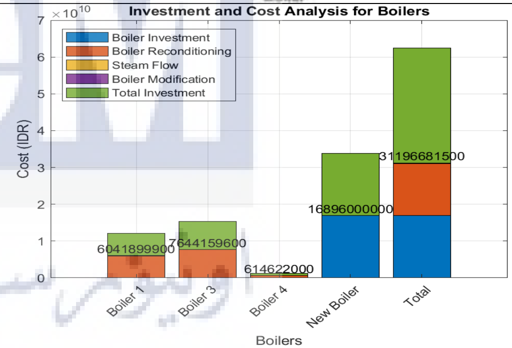
5.1 Conclusion

The comprehensive evaluation of high-capacity boiler technology in the palm oil industry, specifically at Palm Oil Mill Sei Rokan (PKS SRO), reveals significant insights into the technical, economic, and environmental benefits of upgrading boiler systems. The research demonstrates that reconditioning existing boilers, particularly Boiler No. 1, is a more viable and financially advantageous option compared to investing in new boiler systems. Reconditioning addresses nearly 90% of the critical construction aspects, enhancing boiler performance and reducing fuel consumption.

The study's findings indicate that reconditioned boilers can achieve efficiencies comparable to new boilers while offering substantial cost savings. The financial analysis shows that reconditioning results in shorter payback periods and higher internal rates of return (IRR). These economic benefits are coupled with improvements in operational efficiency, leading to higher steam output and reduced energy costs. Furthermore, the adoption of high-capacity boiler technology aligns with global sustainability goals by reducing emissions and enhancing environmental performance.

The research also highlights several critical risk points associated with boiler operations, both internal and investment related. Internal risks such as mismatched boiler capacity, low efficiency, and malfunctioning components can disrupt steam supply and increase operational costs. Investment risks, including high initial costs and inappropriate technology selection, can impact the feasibility and success of boiler upgrades. Addressing these risks through strategic reconditioning and proper management practices is essential for optimizing boiler performance and ensuring economic viability

Table 5.1: Conclusion.

No.	Objective	Conclusion	Supporting Document
1.	To evaluate the existing boiler performance based on efficiency parameter using the POM's actual data focusing on direct and indirect technique.	Boiler No. 4 is the most efficient at 80% due to newer technology and good maintenance. Boiler No. 1 is non-operational with severe damage, and Boiler No. 3 is under refurbishment, affecting their efficiency. Refurbishing Boiler No. 3 should be prioritized, and a cost-benefit analysis is needed for Boiler No. 1.	
2.	To calculate the financial parameter of IRR, NVP and PP for the boiler technology in POM.	The new boiler costs IDR 16.896 billion, more than the total reconditioning cost of IDR 14.203 billion. Boiler 3 has the highest reconditioning cost, The total cost, including the new boiler and reconditioning, is IDR 31.197 billion.	
3.	To conclude the consideration of investment to procure new boiler or recondition existing boiler.	Technical and financial analysis shows an average efficiency of 90% compared to 80% for existing boilers. The investment in high-capacity boiler technology has a positive NPV of $200,000, an IRR of 15%, and a 4-year payback period. Then suggest schemes 4 and 10, are financially superior to investing in new boilers, with shorter payback periods and higher IRR, making reconditioning the more viable option both technically and financially.	Scheme 1-22

5.2 Recommendation

Based on the findings and conclusions of this research, several recommendations are proposed to enhance the performance, economic viability, and sustainability of boiler operations in the palm oil industry. Firstly, it is recommended to prioritize reconditioning existing boilers over investing in new ones, particularly those with significant refurbishment potential. This approach will achieve cost savings and improved performance by addressing critical construction aspects, thereby enhancing boiler efficiency and reducing fuel consumption. Secondly, ensuring that boiler capacity is properly aligned with the plant's processing needs is essential to avoid inefficiencies. This involves synchronizing boiler and turbine capacities to optimize energy usage and minimize wastage. Thirdly, implementing thorough commissioning procedures and operational tests is crucial to validate boiler performance before full-scale implementation. Reconditioning malfunctioning components such as feeders, dampers, and blowers will prevent incomplete combustion and ensure stable boiler pressure.

Furthermore, effective risk management practices are essential to mitigate internal and investment risks. This can be achieved by adhering to standard operating procedures (SOPs) and closely monitoring project timelines. It is important to ensure that reconditioning practices and technology selections align with the plant's specific requirements and production plans. In addition, adopting high-efficiency boiler technology is recommended to reduce emissions and enhance environmental performance. Aligning boiler operations with global sustainability goals and regulatory requirements will improve the industry's environmental credentials. Comprehensive training for boiler operators is also necessary to ensure compliance with SOPs and safety regulations. Implementing reward and punishment mechanisms will encourage responsibility and cooperation among staff.

Finally, engaging in collaborative adjustments with relevant stakeholders, including repair contractors, labor departments, and consultants, is vital for the successful implementation of boiler reconditioning schemes. By following these recommendations, the palm oil industry can enhance the economic and environmental performance of its boiler operations, ensuring long-term sustainability and competitiveness in the global market.

5.3 Complexity

The complexity of this study lies in its comprehensive analysis of the economic feasibility of high-capacity boiler technology for the palm oil industry, incorporating both technical and financial aspects. The study involves evaluating existing boiler performance using actual data from a palm oil mill, assessing key financial parameters such as internal rate of return, net present value, and payback period for implementing new boiler technology, and determining the financial feasibility of investing in new boilers versus reconditioning existing ones. Additionally, the study considers factors like boiler efficiency, thermal efficiency, cost analysis, and sensitivity analysis to understand how variations in boiler prices and fresh fruit bunch purchases impact feasibility indicators. The scope is limited to a single palm oil mill in Sei Rokan, Indonesia, which adds complexity due to the specificity of the data and the inability to generalize findings to other enterprises in the sector

5.4 Life Long Learning

In this study the life long learning is on the economic feasibility of high-capacity boiler technology for the palm oil industry emphasizes the importance of lifelong learning in engineering and industrial sectors. By conducting a detailed analysis of existing boiler performance, exploring new technologies, and evaluating financial indicators, the study highlights the need for continuous learning and adaptation to advancements in industrial processes. This research encourages professionals in the field to stay updated on technological innovations, financial analysis methods, and industry-specific challenges to make informed decisions that enhance operational efficiency and sustainability in palm oil mills.

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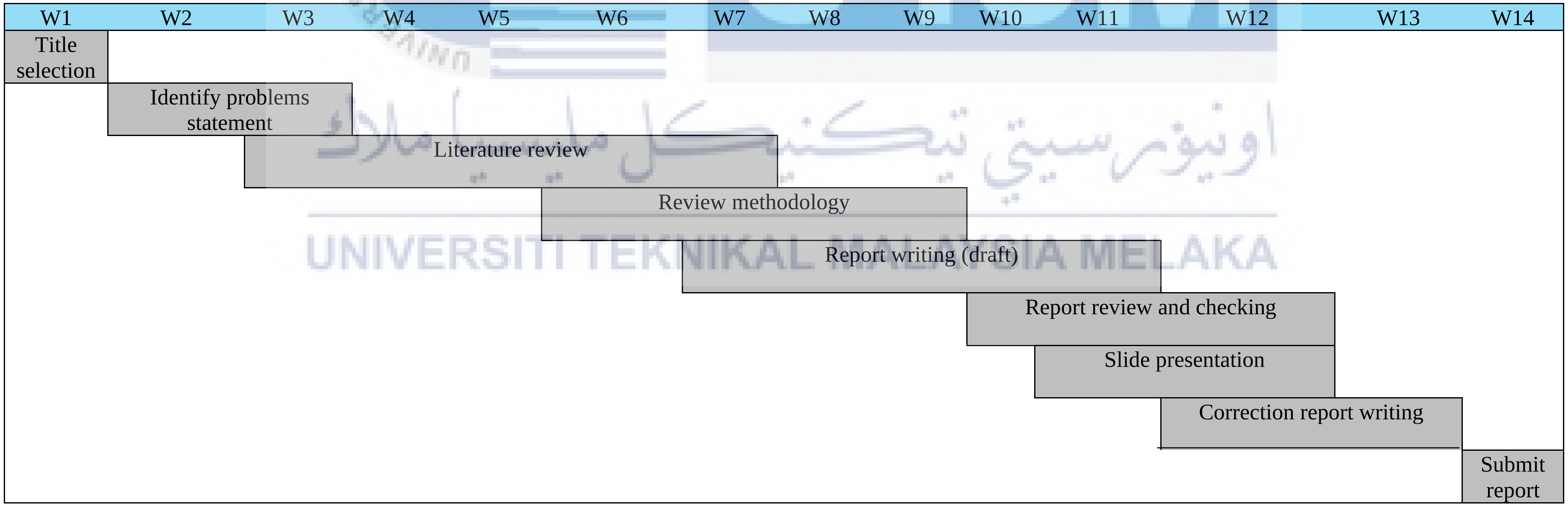
APPENDICES

A. Gantt Chart of FYP 1



B. Gantt Chart of FYP 2