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RESEARCH ARTICLE

Technical Analysis Using 100 Percent Palm Kernel Shell as Fuel in Circulation Fluidized Bed Boiler Type

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Abstract

Energy is a basic human need that has increased in use. Given the limited energy resources, it is necessary to manage energy appropriately and efficiently. Energy efficiency not only has an impact on reducing production costs, but also on reducing emissions. As a concrete step to support the government's net zero emission program by 2060, the company is trying to use alternative biomass fuels, namely: palm kernel shell. The purpose of this study is to conduct a technical and economic analysis of the use of 100 percent palm kernel shells as fuel in a circulation fluidized bed boiler type power plant. This research was conducted at power plant unit 2 of PT XYZ with net capacity 125 MW, located in Cilegon, Banten Province. The parameters measured are limited to boiler efficiency, thermal efficiency, and heat rate. The results showed that when using palm kernel shells, boiler efficiency decreased 0.49 percent, thermal efficiency decreased 0.78 percent, and heat rate increased 22 kcal/kWh or 0.79 percent. By considering of three operational parameters (boiler efficiency, thermal efficiency, and heat rate) it can be concluded that technically the use of 100 percent palm kernel shells as fuel in the plant can be implemented as long as the availability of palm kernel shells is stable, and the price is still reasonable. There is no major impact on boiler performance regarding the transition of coal to palm kernel shells. The impact of long-term use of palm kernel shells on equipment is beyond the scope of this research.

Keywords: palm kernel shell, boiler efficiency, thermal efficiency, heat rate

1. Introduction

Energy is a basic human need that has increased in use and has an important role along with increasing human needs. Indonesia is one of the countries that has diverse and complete energy sources. According to its source, energy is divided into 2 types, namely renewable energy sources and non-renewable energy sources. Renewable energy sources are energy sources that can be produced again by nature in a short time through a sustainable process, such as sunlight, water, wind, and energy sources taken from the process and / or residual production such as biomass. While non-renewable energy sources are energy sources whose formation process by nature goes through a very long process and its availability will be depleted if used continuously. Non-renewable energy sources are also commonly referred to as fossil energy, such as petroleum, coal, natural gas and so on [1].

Coal has long been the main fossil fuel used to generate electricity in steam power plants. According to operator of transmission and distribution system statistics in 2021 [2], total coal consumption was 68.5 million tons or 94.7% of the total fuel consumption of 72.2 million tons. Therefore, the Government of Indonesia has a commitment to reduce

greenhouse gas emissions by 26 percent from this year's business level and by 29 percent by 2030 in line with the net zero emission program by 2060 based on the 2015 Paris Agreement. To reduce the carbon footprint in the framework of net zero emission, the government implements five main principles including the utilization of renewable energy and the reduction of fossil energy [3].

Given the limited energy resources, it is necessary to manage energy appropriately and efficiently, hence the need for energy management. Energy management is defined as a systematic and integrated approach to the effective, efficient, and rational use of energy resources without compromising the quantity or quality of the main functions of buildings and facilities [4]. PT XYZ is a chemical plant located in Cilegon, Banten province, which is an integrated petrochemical industry consisting of 13 chemical plants. In operation, it uses electrical energy from the operator of transmission and distribution and from its own plant, namely the steam power plant with circulation fluidized bed (CFB) boiler type, which consists of 2 units with a total net capacity of 2 x 125 MW. The power plant uses coal as its fuel to operate the boiler to produce steam, which is then used to drive turbines that produce electrical energy and steam for production process activities.

As a real step to reduce gas emissions that can cause greenhouse effects and in line with the government's net zero emission program by 2060 [5] [6] [7] the company is trying to use biomass fuels, including palm kernel shell, saw dust, wood chip, coffee grounds and others [8]. With consideration of supply ability and sustainability in large quantities [9], [10], since 2022, PT XYZ has focused on conducting a series of palm kernel shell cofiring trials in stages ranging from 5% to 20%. The conclusion of the technical analysis of the trial is considered successful with some notes. Therefore, to find out more and ensure the potential of palm kernel shells as a substitute fuel for coal in the PT XYZ power plant, a further trial of using 100 percent palm kernel shells as fuel for a certain period at power plant unit 2 was carried out. The main objective of this research is to determine and analyze the feasibility of the technical aspects of using of 100 percent palm kernel shells in the CFB boiler type power plant PT. XYZ. The parameters analyzed in the technical aspect are boiler efficiency, thermal efficiency, and heat rate.

1.1 Power Plant's Principles and Working Method

The operating of a steam power plant begins with heating water in the boiler. The water is then put into the deaerator to remove oxygen. This water is pumped by the boiler feed pump and enters the economizer. This water flows into the pipes and is heated in the boiler tubes. In this section, the water is heated to produce water vapor (steam). This water vapor is collected back in the steam drum and further heated in the superheater to become high- pressure dry steam. This steam is used to drive the turbine. The rotation of the turbine shaft rotates the generator shaft which is connected through a clutch. It is this rotation that produces electrical energy. The electrical energy produced by the generator is channeled and then distributed to customers. Free steam from the turbine is condensed in the condenser. Together with water from the make-up water pump, this steam is pumped again by the condensate pump into the lo pressure heater, deaerator, boiler feed water pump, high pressure heater, economizer, and finally to the boiler to be heated into steam again. This process will occur repeatedly and is the cycle of a steam power plant [11].

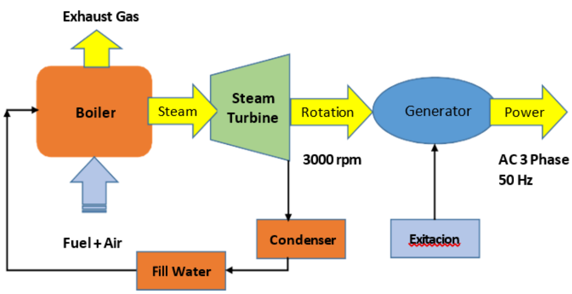

Figure 1. Main Components of Steam Power Plant

1.2 Boiler

Boilers for power plants are one of the key components in the thermal power generation process. These boilers are responsible for converting water into steam, which is then used to turn turbines that generate electricity [11]. This process is commonly referred to as the steam cycle. There are several types of boilers used in power generation, including tank-type boilers, water tube-type boilers, and thermal fluid boilers. Each type has certain advantages and disadvantages depending on the application and requirements of the power plant. There are several types of boilers used in various industrial applications, including for power generation, heating, and other industrial processes, such as: fire tube boiler, water tube boiler, packet boiler, circulation fluidized bed boiler, atmospheric fluidized bed combustion boiler, atmospheric circulating fluidized bed combustion boiler, pulverized fuel boiler, and pressurized fluidized bed combustion boiler [12]. CFB boiler is a combustion technology that uses a fluid "bed" with active circulation to generate heat. In a CFB, solid particles such as sand are mixed with heated air or gas to form a fluid "bed". The circulation process allows these particles to move in a continuous loop along the system, carrying heat and facilitating efficient combustion [13].

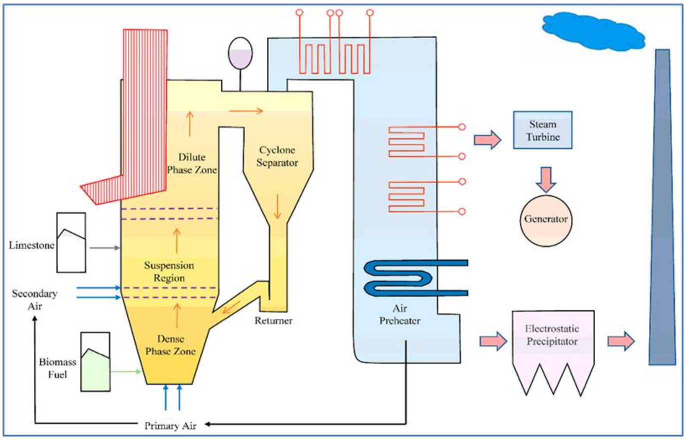

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Figure 2. CFB Boiler Components

Steam power plant performance can be measured by boiler efficiency, thermal efficiency, and heat rate. Boiler efficiency refers to how efficient a boiler is at converting the energy contained in the fuel into usable heat energy. The higher the boiler efficiency, the less energy is wasted, and the more energy can be utilized. Boiler efficiency is measured in percentage, which is the ratio between the heat energy produced by the boiler and the energy contained in the fuel used. Boiler thermal efficiency refers to how well a boiler can convert heat energy from fuel into heat energy that can be utilized for specific purposes, such as heating or electricity generation. Thermal efficiency is the ratio between the heat energy produced by the boiler and the energy contained in the fuel used. Heat rate is the amount of fuel energy required to produce 1 kWh of electrical energy. To calculate the 3 parameters, the following equation formula is used:

a. Boiler Efficiency

There are 2 methods to calculate boiler efficiency, direct method and indirect method [14]. For direct method use the equation formula:

$$BoilerEfficiency(n) = \frac{Qx(Hg - Hf)}{BxHHV} x100\% \quad (1)$$

where
- Q : Amount of steam produced per hour (kg/hour)
- Hg : Enthalpy of saturated steam (kcal/kg steam)
- Hf : Feed water enthalpy (kcal/kg water)
- B : Amount of fuel used per hour (kg/hour)
- HHV : Calorific value of fuel/higher heating value (kcal/kg)

For indirect method use the equation formula [14]:

$$BoilerEfficiency(n) = 100 - (i + ii + iii + iv + v + vi + vii) \tag{2}$$

where
i. Heat loss of unburnt carbon in fly and slag ash (Lc).
ii. Heat loss of dry flue gas (Lg).
iii. Fuel moisture heat loss in the fuel (Lmf).
iv. Hydrogen moisture heat loss (LH).
v. Moisture heat loss of burner air (Lma).
vi. Loss in CO gas heat (LCO).
vii. Heat loss from radiation (Lr).

b. Thermal Efficiency

$$ThermalEfficiency = \frac{860}{PHR} x100\% \tag{3}$$

where PHR : Plant Heat Rate (kcal/kWh)

c. Heat Rate

$$TurbineHeatRate(THR) = \frac{M1x(H1 - H2)}{GGO} \tag{4}$$

where
M1 : Amount of steam produced per hour (kg/hour)
H1 : Enthalpy of saturated steam (kcal/kg)
H2 : Feed water enthalpy (kcal/kg (kcal/kg)
GGO : Power output generator (kW)

2. Research Methods

This research was conducted with a descriptive method approach which was carried out through taking secondary data on power plant operating parameters that had been documented in the distributed control system (DCS). The technical data required is in the form of plant technical data such as main steam flow, main steam pressure, main steam temperature, coal feeder flow and power generation and the parameters calculated and analyzed are boiler efficiency, thermal efficiency, and heat rate. Measurements were made when the power plant operated using 100 percent palm kernel shells for 1 month. And as comparison data, measurements and analysis were also carried out when the power plant was operating normally using coal. Data were collected as initial parameters for further analysis, such as main steam flow, main steam pressure, main steam temperature, coal feeder flow, power generation, as well as exhaust gas/emissions and the amount of fuel consumption (coal and palm kernel shell). Measurements were made following the boiler operational conditions (boiler maximum continues rate) from 55 percent, 60 percent to 70 percent of the total boiler capacity.

In order for this research to be carried out systematically and structured to obtain good research results, the writing in this study is divided into several stages, namely: the preparation stage, the data collection stage, the data processing and analysis stage, and the conclusion stage. The complete research flow chart can be seen in Figure 3 below:

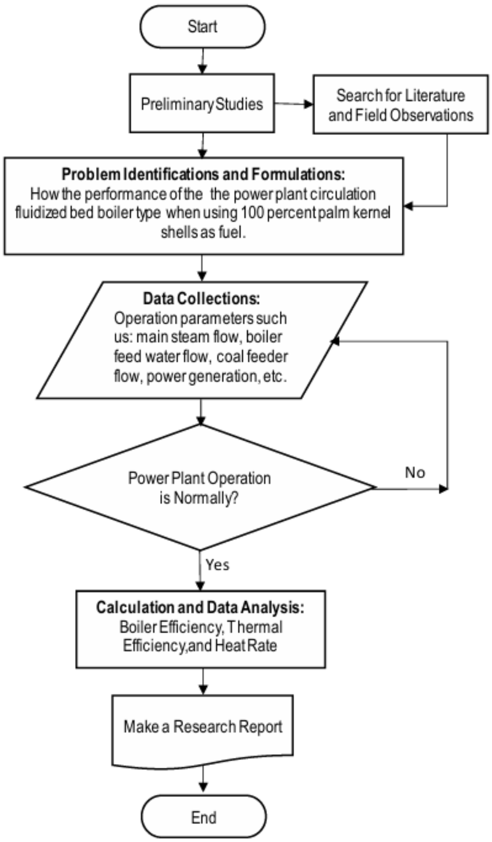

Figure 3. Research Flow Chart

3. Results and Discussion

This study was conducted to determine the performance of the power plant when using palm kernel shells as 100 percent fuel. Therefore, calculations and analysis are carried out in 2 conditions, namely when the power plant operates normally using coal fuel and when the plant operates using 100 percent palm kernel shells. Comparison of technical specifications based on the average results of coal and palm kernel shell analysis is shown in table 1 below:

Table 1. Comparison of Technical Specifications Coal and Palm Kernell Shell

Fuel	Proximate Analysis				Gross Calorific Value (ARB) *)	Total Sulfur	Ultimate Analysis			
	Total Moisture	Ash Content	Volatile Matter	Fixed Carbon			C	H	N	O
	%	%	%	%	kcal/kg	%	%	%	%	%
Coal	30,85	6,83	42,11	40,07	4.498	0,36	61,21	5,78	1,03	25,05
Palm Kernel Shell	17,64	4,49	70,13	17,91	4.065	0,11	49,62	6,31	0,75	38,72

*) ARB (As Received Basis): The analysis is reported based on the total moisture of the sample.

3.1 Power Plant Performance Measurement Results

The performance of an equipment is the ability of equipment in an operating system obtained from the results of assessments and or measurements taken. Steam power plant performance can be measured from boiler efficiency, thermal efficiency and heat rate. To calculate boiler efficiency, thermal efficiency and heat rate, parameter data is taken for 1 month each (palm kernel shell and coal). For the simplifying calculations and computations, data and calculations are carried out based on the average value of the parameters of the plant's operational capacity level.

3.1.1 Boiler Efficiency Calculation Results

a. Direct Method

By using the formula equation 1, the results of the calculation of boiler efficiency by direct method can be seen in the table 2 below:

Table 2. Boiler Efficiency Calculation (Coal)

Parameter	Unit	Boiler MCR *)			Average
		55%	60%	70%	
Main Steam Flow	ton/hour	276	302	375	318
Main Steam Enthalpy	kcal/kg	822,92	822,92	822,92	822,92
Feed Water Enthalpy	kcal/kg	164,72	164,72	164,72	164,72
Higher Heating Value	kcal/kg	4.498	4.498	4.498	4.498
Fuel	ton/hour	40,50	48,41	56,60	48,50
Power Generation	MW	62	74	90	75
Boiler Efficiency	%	**99,56**	**91,18**	**97,05**	**95,94**

*) MCR: Maximum Continuous Rate

Table 3. Boiler Efficiency Calculation (Palm Kernel Shell)

Parameter	Unit	Boiler MCR *)			Average
		55%	60%	70%	
Main Steam Flow	ton/hour	269	309	328	302
Main Steam Enthalpy	kcal/kg	823,91	823,91	823,91	823,91
Feed Water Enthalpy	kcal/kg	151,66	151,66	151,66	151,66
Higher Heating Value	kcal/kg	4.065	4.065	4.065	4.065
Fuel	ton/hour	47,69	52,35	56,90	52,31
Power Generation	MW	59	76	84	73
Boiler Efficiency	%	**93,36**	**97,70**	**95,33**	**95,47**

Table 4. Boiler Efficiency Comparison

Fuel	Boiler MCR *)			Average
	55%	60%	70%	(%)
Coal	99,56	91,18	97,05	95,94
Palm Kernel Shell	93,36	97,70	95,33	95,47

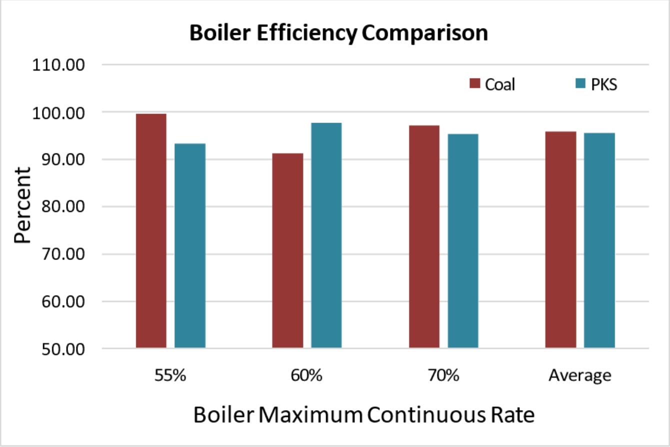

Figure 4. Boiler Efficiency Comparison Chart

b. indirect Method

The indirect method or heat loss method is also the standard method of reference for testing the performance of power plant. The guidelines used to test this method are British Standard, BS 845:1987 and USA Standard ASME PTC-4-1 Power Test Code Steam Generating Unit. Boiler efficiency is calculated by subtracting the heat loss part from 100, using the formula equation 2 [15]:

Table 5. Boiler Efficiency Calculation (Indirect Method)

Heat Loss	Fuel	
	Coal	PKS
1. Heat loss of dry flue gas	4,25%	4,87%
2. Fuel moisture heat loss in the fuel	3,73%	3,16%
3. Hydrogen moisture heat loss	6,30%	7,84%
4. Heat loss of unburnt carbon	0,71%	0,08%
5. Heat loss from radiation	0,22%	0,22%
6. Loss in CO gas heat	0,10%	0,10%
7. Moisture heat loss of burner air	2,08%	2,02%
8. Others	0,41%	0,98%
Total	**13,63%**	**15,23%**
Boiler Efficiency	**86,37%**	**84,77%**

Table 6. Boiler Efficiency Comparison Base on 2 Methods

Fuel	Method	
	Direct (%)	Indirect (%)
Coal	95,94	86,37
Palm Kernel Shell	95.47	84,77
Difference	0.47	1.60

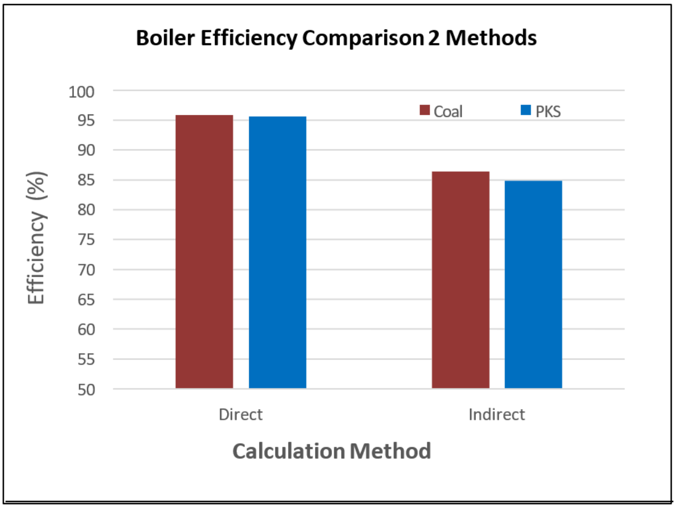

Figure 5. Boiler Efficiency Comparison Base on 2 Methods Calculation Chart

3.1.2 Heat Rate Calculation

Heat rate is the amount of fuel energy required to produce 1 kWh of electrical energy. To calculate the heat rate, the main steam flow data, main steam enthalpy, feed water enthalpy and the amount of electricity generated (power generation) are required. By using the formula equation 4, the following turbine heat rate calculation results are shown in the table below:

Table 7. Heat Rate Calculation (Coal)

Parameter	Unit	Boiler MCR *)			Average
		55%	60%	70%	
Main Steam Flow	ton/hour	276	302	375	318
Main Steam Enthalpy	kcal/kg	822,92	822,92	822,92	822,92
Feed Water Enthalpy	kcal/kg	164,72	164,72	164,72	164,72
Power Generation	MW	62	74	90	75
Heat Rate	**kcal/kWh**	**2.936**	**2.695**	**2.742**	**2.791**

*) MCR: Maximum Continuous Rate

Table 8. Heat Rate Calculation (Palm Kernel Shell)

Parameter	Unit	Boiler MCR *)			Average
		55%	60%	70%	
Main Steam Flow	ton/jam	269	309	328	302
Main Steam Enthalpy	kcal/kg	823,91	823,91	823,91	823,91
Feed Water Enthalpy	kcal/kg	151,66	151,66	151,66	151,66
Power Generation	MW	59	76	84	73
Heat Rate	**kcal/kWh**	**3.050**	**2.752**	**2.635**	**2.813**

Table 9. Heat Rate Comparison

Fuel	Boiler MCR *)			Average (kcal/kWh)
	55%	60%	70%	
Coal	2.936	2.695	2.742	2.791
Palm Kernel Shell	3.050	2.752	2.635	2.813

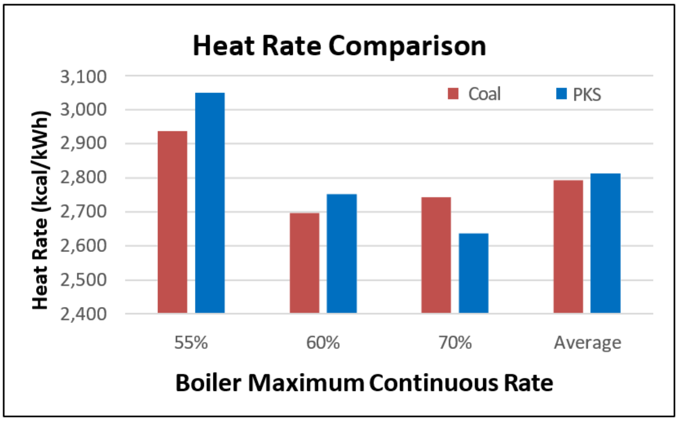

Figure 6. Heat Rate Comparison

3.1.3 Thermal Efficiency Calculation

The calculation of boiler thermal efficiency refers to how a boiler can convert heat energy from fuel into heat energy that can be utilized for specific purposes, such as heating or electricity generation. Thermal efficiency is the ratio between the heat energy produced by the boiler and the energy contained in the fuel used. By using the formulas of equations3, the following thermal efficiency calculation results are as shown in the table below:

Table 10. Thermal Efficiency Calculation (Coal)

Parameter	Unit	Boiler MCR *)			Average
		55%	60%	70%	
Heat Rate	kcal/kWh	2.936	2.695	2.742	2.791
Thermal Efficiency	%	29,29	31,91	31,36	30,81

*) MCR: Maximum Continuous Rate

Table 11. Thermal Efficiency Calculation (Palm Kernel Shell)

Parameter	Unit	Boiler MCR *)			Average
		55%	60%	70%	
Heat Rate	kcal/kWh	3.050	2.752	2.635	2.813
Thermal Efficiency	%	28,19	31,25	32,63	30,57

Table 12. Thermal Efficiency Comparison

Fuel	Boiler MCR *)			Rata-Rata
	55%	60%	70%	(%)
Coal	29,29	31,91	31,36	30,81
Palm Kernel Shell	28,19	31,25	32,63	30,57

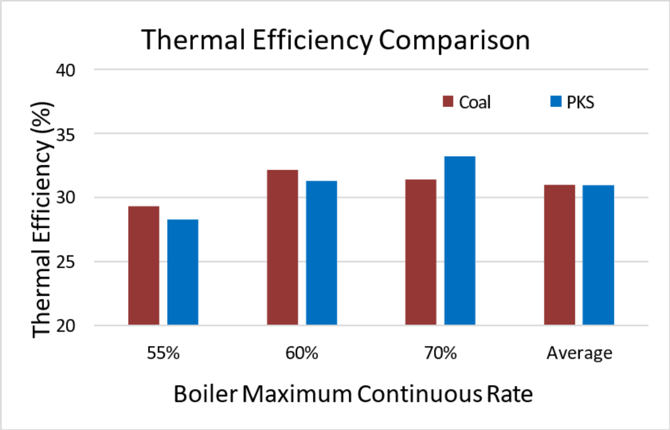

Figure 7. Thermal Efficiency Comparison

Table 13. Boiler Efficiency, Thermal Efficiency and Heat Rate Comparison

Fuel	Efficiency (%)		Heat Rate
	Boiler	Thermal	(kcal/kWh)
Coal	95,94	30,81	2.791
Palm Kernel Shell	95,47	30,57	2.813
Difference	(0,47)	(0,24)	22

4. Conclusion

The switching process from coal to palm kernel shell goes smoothly. Changes in the calorific value of the fuel can be treated well by the boiler manually. In general, 100 percent palm kernel shell combustion gives good parameter results that can be accepted by the boiler. Based on the results of calculations, analysis and comparison of boiler efficiency, thermal efficiency, and heat rate, it is concluded that when using palm kernel shells, boiler efficiency decreases 0.47 percent, thermal efficiency decreases 0.24 percent and heat rate increases 22 kcal/kWh or 0.78 percent. Overall, the use of 100 percent palm kernel shells as a substitute for coal in power plant type circulation fluidized bed boilers can be implemented as long as the availability of palm kernel shells is stable, and the price is still reasonable. The impact of long-term use of palm kernel shells on equipment is beyond the scope of this research.

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