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Analysis of the Effects of Fuel Type Selection on the Performance and Fuel Consumption of a Steam Power Plant

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***Abstract*— Fossil energy sources are used as fuel in the combustion process at thermal power plants. The reduced supply of fossil fuels often becomes a problem for electricity generators in the production process. This condition can affect the efficiency value of the Power Plant. To maintain the power plant efficiency, it is possible to regulate the fuel type in the combustion process. The difference in the heating value of the fuel can produce different values of combustion. The results of the combustion process can affect the value of cycle thermal efficiency and fuel consumption requirements. Cycle Tempo software is used in the thermodynamic cycle simulation process in power plants. This software is useful to make a model of a particular thermodynamic cycle or energy conversion systems such as a generator and cooling system. This program can analyze the mass and energy flow measures in the system, including thermodynamic properties, the composition of the processed gas, and the mass flow rate. In the simulation process, first, a cycle model is made based on existing piping data. After that, thermodynamic data such as temperature and pressure are input into each apparatus in the simulation. After making some adjustments, the simulation is run until the right results are obtained. Natural gas, Biosolar B30, and MFO (Marine Fuel Oil) fuel this study. Biosolar B30 is the result of mixing fuel between FAME (Fatty Acid Methyl Ester) and diesel. Biosolar B30 is made with a mixing ratio of 70% diesel fuel and 30% of FAME. FAME is oil from oil palm plants that has been processed to become a biofuel. Based on research results, Biosolar B30 produced the highest cycle thermal efficiency of 31.78%. The least fuel consumption is required by natural gas fuels, which is 277 million liters/year. The simulation results show that the lowest heating value of Boiler is generated by the variation of Biosolar B30 fuel, which results in high thermal efficiency. The amount of fuel needed during the combustion process using Biosolar B30 is increased because the heating value of Biosolar B30 is the lowest. The highest heating value of fuel is Natural Gas, requiring less fuel consumption than MFO and Biosolar B30.**

***Keywords*— Fuel consumption; steam power plant; energy; Natural Gas; Marine Fuel Oil (MFO); Biosolar B30.**

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I. INTRODUCTION

During 2017-2050, there was an increase in the demand for electricity in the community, achieving an average of 6% per year. This happened due to population growth and rapid economic development. [1]. Within Southeast Asia, Indonesia has developed and become the largest energy-consuming country. According to the 2015-2019 National Mid-Term Development Plan (RPJMN), the Government will utilize various forms of energy sources that can be used to build more power plants in Indonesia. [2].

The supply of fossil fuels is decreasing from year to year. Several factors cause this: the various and the amount of fossil fuels for the combustion in the boiler. The increase in the number of power plants built from year-to-year results in an increase in the need for fossil fuels for fuel consumption in power plants. The condition causes the supply of fossil fuels to decrease at any time so that it can interfere with the operation of power plants. It also contributes to the increase in the price of fossil fuels, leading to increased operating costs for power plants. There are various kinds of efforts to reduce the costs of operating power plants, such as increasing the efficiency of generators, performing maintenance activities on generating components, or changing the main fuel [3]. As much as 75% of the plant operating costs are spent on fuel distribution. This shows that changing the type of fuel used can be a solution to reduce the operating costs of Power Plant.

Syukran *et al.* conducted an experiment to calculate the cost savings of several fossil fuels in power plants [4]. HSD (High-Speed Diesel) and MFO, which are the main fuels for power plants, are changed to LNG (Liquid Natural Gas) and Coal to see the amount of cost-saving of fuel consumption needed. The results showed the highest cost of fuel consumption required by HSD with a value of IDR890 billion/year. MFO requires a fuel consumption cost of IDR530 billion/year. LNG requires a fuel consumption cost of IDR154 billion/year. The lowest cost of fuel consumption required by coal is IDR87 billion/year.

Basuki *et al.* conducted research to compare cost forecasts saving some fuel on power generation. The research was conducted using several variations in the load on the power plant [5]. MFO and HSD are the main fuels that are then changed to LNG and coal to see the great savings. This study uses the Least Square method to obtain a more accurate analysis for each load.

Hetharia *et al.* conducted research to design a Power Plant by Cycle Tempo software to analyze the power and energy of the Power Plant [6]. Based on simulation results, the energy required from burning coal in the boiler is 36,088 kW. The energy produced by the generator is 8,351 kW. The generator output power that the pump power consumption has reduced is divided by the boiler input energy to calculate the thermal cycle efficiency. The value of the cycle thermal efficiency is 22.44%.

Research by Syukran *et al.* [4] and Basuki *et al.* [5] has similarities. Their research objective is to determine the amount of cost savings of fuel consumption that can be generated by changing the main fuel at a boiler. The difference is Basuki *et al.* [5] used several types of loads. In addition, they also added the Least Square method to the calculation of the steam power plant performance at each load to produce more precise and accurate results.

Syukran *et al.* research results show that the largest amount of fuel consumption savings occurs when the main fuel is changed to coal [4]. Meanwhile, the results of Basuki *et al.* research show that the greatest amount of savings resulted from changing the main fuel to HSD [5]. With the Least Square method, they calculate the mass flow rate generated at each load. Low fuel calorific value can cause high fuel consumption in the boiler. Coal which has the lowest fuel calorific value results in the highest amount of fuel used in the boiler.

In Basuki *et al.* [5] research, coal's large fuel mass flow rate causes the high cost of total fuel required. In choosing the type of fuel for a power plant, the calorific value of the fuel used needs to be considered because it affects the performance of the steam power plant that will be produced. The price of fuel is not the main determinant of the low cost of fuel consumption.

With the existence of other determinants such as the heating value of fuel and the performance value of the steam power plant, it is necessary to research by paying attention to the condition of the steam power plant. The research of Hetharia *et al.* can be a reference to determine the design and steam power plant performance [6]. The use of Cycle Tempo software can simplify the analysis process.

This software can calculate the mass flow rate and the total power or energy produced. The research shows that the designed power plant model can run when stimulated and produces a thermal efficiency of 22.44% [6]. In the cycle tempo software, the function to change the fuel can be found in the boiler apparatus. This shows that changes in the power plant efficiency can be seen when the main fuel is replaced with this software.

Some of these studies show that replacing the main fuel in the boiler can reduce the amount of fuel consumption cost of power plants. To make it easier to see the power plant performance after the main fuel has been changed, it can be analyzed by using the tempo cycle software. Some of the performances that can be observed are the mass flow rate, the value of energy, and power generated in the power generation cycle.

In this study, the performance value of power plants and the amount of fuel consumption generated from various types of fuel were also analyzed. This study uses three different types of fuel. The fuels are natural gas, Marine Fuel Oil (MFO), and biosolar B30. The government is promoting on the use of biosolar B30 as the main fuel in the power generation industry and transportation. This is because this fuel is a fuel made from a mixture of bio oils. Biosolar B30 is the result of mixing fuels between FAME (Fatty Acid Methyl Ester) and diesel. Biosolar B30 is made with ratio of 70% diesel fuel and 30% FAME.

II. Material and Method

A. Simulation Using Cycle Tempo Software

Delft Technische University in the Netherlands created and developed a software that can model a thermodynamic analysis in a work cycle. [7]. It is a program that can be used to model work cycles and optimize systems for the production of heat, cooling and electricity [8]. The system consists of various cycles that are connected several components in power plant through pipes.

The main purpose of Cycle Tempo simulation is to calculate the amount of energy and mass flows in a system. There are many models of equipment and pipes that can be used in accordance with the required cycle model. If the cycle consists of many component models, it will form a complex energy flow.

Figure 1 shows the modeling of the power generation cycle used in the study. The power plant model used is a steam power plant. Several apparatuses such as boilers, reheaters, turbines, generators, condensers, heaters and pumps are assembled and connected using pipes and shafts as needed. HP (High Pressure) Turbines, IP (Intermediate Pressure) Turbines, and LP (Low Pressure) Turbines were used in the research. This simulation used different types of heaters, such as three Low Pressure Heaters (LPH), three High Pressure Heaters (HPH), and one Deaerator. The heater gets heat from the extraction of the Steam Turbine. This turbine extraction steam will be used for preheating the feedwater that enters the boiler.

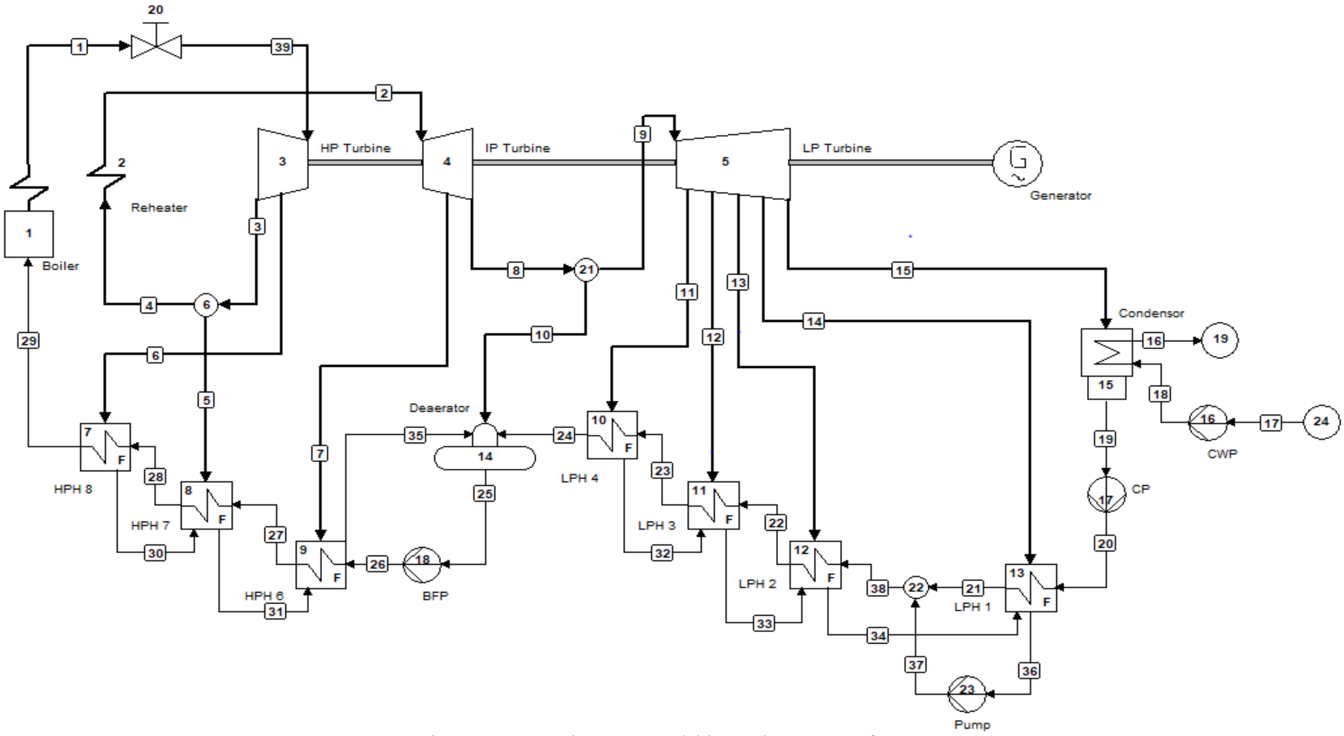

Fig. 1 Power Cycle Steam model in Cycle Tempo software

After designing the cycle model had been completed, the data input process for each apparatus was conducted. All equipment had an input function for several thermodynamic parameter values such as inlet temperature, outlet temperature, inlet pressure, outlet pressure, and efficiency. The input value of each apparatus is then adjusted manually. Adjustments had to continue until no warnings and errors were generated. The thermodynamic properties, exergy, mass flow rate, heating value, and power in each piece of equipment can be calculated using this software. [9]. This research uses Cycle Tempo software to get the cycle performance value when the main fuel is replaced. All the modeling and simulation stages at the tempo cycle are depicted using a flow chart, as shown in Figure 2.

Figure 2 shows the simulation steps using Cycle Tempo software. The first is designing a model of the thermodynamic cycle of power plants. After the power plant cycle model is had been completed, data input was carried out to each apparatus. The data entered during the simulation process was obtained from actual data from the steam power plant company. The next stage is to run the simulation. If errors and warnings appear, read the information in the warning panel whether the error is in the power plant model or the input parameter value of each apparatus. If there are no errors and warnings, the data is validated with the power plant's actual data. After the error of the validation, results are less than 10%; the simulation results are analyzed.

Data validation is an important step in the simulation process. It is to ensure that the simulation results obtained are correct and can be used as analysis material. The simulation result data in the software is validated by comparing the simulation result data with the actual data obtained in the steam power plant company.

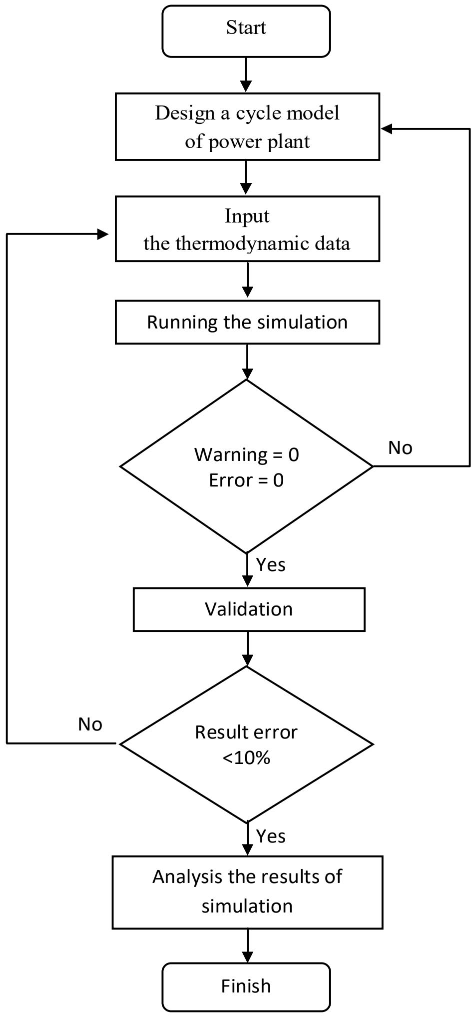

Fig. 2 Simulation flow chart using Cycle Tempo software

Table 1 shows some of the reference data used as input in this simulation. The data shown in Table 1 are the thermodynamic data of the main apparatus in the power generation cycle. Boilers, reheaters, generators, turbines, and condensers are the main components of the steam power generation plant. Data were taken when the power plant operated at a load of 180 MW. The steam temperature and pressure values from boiler at a load of 180 MW are 540 oC and 165.8 bar. The values of temperature and pressure of the steam from the reheater are 539 oC and 26.53 bar. The pressure and temperature values coming out from the turbine to the condenser are 0.12 bar and 47 oC.

TABLE I
STEAM POWER PLANT OPERATIONAL DATA AS INPUT DATA IN THE SIMULATION

Main Components	Parameter	Value
Generator	Load (MW)	180
Boiler	T in (°C)	270
	T out (°C)	540
	P out (bar)	165.8
	M (kg/s)	165.79
Reheater	T in (°C)	300
	P in (bar)	26.53
	T out (°C)	539
	P out (bar)	26.53
Turbine	T out (°C)	47
	P out (bar)	0.12
Condensor	T in seawater (°C)	28
	T out seawater (°C)	42
	T hotwell (°C)	46

Boiler is a component that functions to carry out the fuel combustion process. The high power generation, the combustion of fuel in the boiler in large quantities can result in high temperature and pressure values in the boiler. In this study, the boiler temperature and pressure values of 540 °C and 165.8 bar need to be included in the simulation to lock in the results of the temperature and exit pressure on the boiler. It is intended that the temperature and steam pressure of the boiler output do not exceed predetermined limits.

B. Type of Fuel

This study aims to compare the performance value and fuel consumption at a steam power plant with the use of different fuels in the boiler. This research uses three types of fuel, there are natural gas, MFO and biosolar B30. Each fuel has different heating value depending on the content in the fuel.

TABLE II
CALORIE VALUE IN EACH TYPE OF FUEL

Type of Fuels	HHV	LHV
Natural gas (kJ/kg)	59,869	59,586
MFO (kJ/kg)	43,531	43,262
Biosolar B30 (kJ/kg)	38,190	37,932

Table 2 shows the heating value in each type of fuel. When combustion takes place, heat energy will be released from each unit of fuel. This heat energy is called the heating value. Heating value has two types. There are HHV or High Heating Value and LHV or Low Heating Value. During the combustion process, the condensation of steam releases latent heat. The heating value which includes this latent heating value in the calculation is called HHV. If the latent calorific value is not included, it is called LHV. Combustion results can also affect the HHV and LHV values of a fuel. If all the water from combustion is liquid, then the HHV value will be obtained, and if all the water from combustion is steam, then the LHV value will be obtained.

Based on the Table 2, it can be seen that highest heating value is obtained by natural gas with an HHV value of 59,869 kJ/kg and LHV value of 59,586 kJ/kg. The HHV value of MFO is 43,531 kJ/kg and the LHV value is 43,262 kJ/kg. The fuel with the lowest heating value is Biosolar B30 with an HHV value of 38,190 kJ/kg and LHV value of 37,932 kJ/kg. It shows that the actual HHV and LHV values are not that much different. Usually, each power plant has its own standard calculation in using the HHV and LHV values to calculate power plant performance based on the existing theories.

Natural gas has HHV value of 59,869 kJ/kg and LHV value of 59,586 kJ/kg. The HHV and LHV values for natural gas are quite high when compared to the other two types of fuel. Several hydrocarbon mixtures bind to form natural gas. Methane gas (CH_4) is the main element in natural gas. There are also several gases such as Propane (C_3H_8) and Butane (C_4H_{10}) in small amounts [10].

In general, natural gas consists of a mixture of several types of gases with the main composition of methane and ethane gases reaching 80-90%. Methane gas has flammability characteristics. The high content of methane gas in natural gas results in natural gas having almost the same characteristics as methane gas. Natural gas is flammable with flammability between 4.5% to 14.5%. Natural gas is odorless, so, for safety purpose an additional odor is used [11].

Based on the Table 2, MFO has an HHV value of 43,531 kJ/kg and an LHV value of 43,262 kJ/kg. MFO has a lower heating value than natural gas. MFO comes from crude oil refining. During the crude oil refining process, MFO is generated before asphalt and after residue [12]. MFO is currently used as fuel in various industries such as fuel plant and marine diesel engines. Liquid fuel is considered cheaper than kinds of fuels.

Although the MFO is black, it is not the result of distillation [13]. Compared to diesel oil, MFO has a higher viscosity level. Therefore, MFO cannot be used directly in the combustion process. MFO must be preheated to reduce its viscosity. This aims to prevent fuel clogging in the burner holes.

Based on the Table 2, HHV and LHV values of Biosolar B30 were 38,190 kJ/kg and 37,932 kJ/kg, respectively. Biosolar B30 is made by mixing diesel and bio oil in a certain ratio. Currently, the government has begun to socialize the use of Biosolar B30 in various industries, especially in the transportation and power generation industries. This is to promote the oil palm plantation sector as a raw material for bio-oil to reduce fossil fuel consumption.

Biosolar B30 fuel is produced from the process of mixing diesel fuel with FAME. The mixing composition ratio used to make Biosolar B30 is 70% of diesel and 30% of FAME. Palm oil that is processed into vegetable oil is called FAME. The presence of the FAME causes Biosolar B30 to act as a solvent. The high solvent properties can dissolve dirt stuck to the walls of the machine so that it can make the machine clean.

Therefore, the ability of Biosolar B30 to dissolve impurities in the walls of the combustion pipe will be higher if the FAME content in biodiesel is higher. The heat transfer process in combustion will also get better [14]. However, the solvent in this fuel can result in the dissolving of dirt on the machine walls so that the dirt or sludge is carried into the filter. Proper handling is needed in the use of Biosolar B30 fuel.

Bio Oil has a cetane number of 51 while diesel has a cetane number of 48. Mixing bio-oil and diesel which has a high cetane number will also produce a high cetane number. Therefore, Biosolar B30 has a high cetane number. This will make the Biosolar B30 fuel more flammable. Bio oil in FAME has hygroscopic properties. This also affects the Biosolar B30 fuel. Biosolar B30 can turn into a gel if stored too long in cold temperatures. Therefore, it requires a special storage area that can maintain the temperature to prevent the fuel from turning into a gel.

C. Calculation Several Parameters

Main performance to be analyzed in this study is the thermal efficiency of the cycle and the heat rate. The process of calculating the value of thermal efficiency and heat rate was carried out after the simulation process. The power plant cycle simulation will produce some thermodynamic data, power, and energy for each apparatus. The thermal efficiency of the cycle and the power plant heat rate will be calculated using this data.

First, in determining the efficiency value, turbine output net power and the heating value of boiler are needed. These two values can be seen in the Cycle Tempo simulation results. Net power output of the turbine is the turbine power produced after subtracting the auxiliary power of the pump. The equation of turbine output net power is shown in equation (1).

$$W_{nett} = W_t - W_p \tag{1}$$

After determining the turbine output net power, the next step is to calculate the value of the thermal cycle efficiency of the power plant. Thermal efficiency shows the ratio of how much working fluid energy enters the boiler is converted into net output of work in the system [15]. The equation of thermal efficiency can be seen in equation (2).

$$\eta_{th} = \frac{W_{nett}}{Q_{boiler}} \tag{2}$$

The second step is calculating the value of the heat rate in each fuel variation. Heat rate of Power Plant is the result of dividing the amount of heat energy in the system by the amount of power the system generates. Heat rates are divided into two types, namely NPHR (Net Plant Heat Rate) and GPHR (Gross Plant Heat Rate). How to calculate the NPHR is by using the generator output power which is measured after the generator power is reduced by the auxiliary power of various equipment such as motors, pumps, water treatment, compressors and others. Meanwhile, the heat rate calculated without reducing the generator power with auxiliary power is called GPHR [16]. The equation of NPHR can be seen in equation (3).

$$HR_N = \frac{Q_{boiler}}{P_{nett}} \tag{3}$$

Then, the equation of GPHR used is written in equation (4).

$$HR_G = \frac{Q_{boiler}}{P_{gross}} \tag{4}$$

Besides calculating the power plant performance, this study also analyzes the effect of replacement the main fuel on the fuel consumption in power plants. After calculating the power plant performance in the form of thermal efficiency and heat rate, the next step is to calculate the required fuel consumption for each fuel variation.

The first thing that needs to be calculated is the amount of fuel mass flow rate needed. It shows how much the fuel used at one time in the combustion process. Heat energy of the boiler and LHV value are needed to calculate the fuel mass flow rate. Heat energy of the boiler can be seen from the simulation results, while the LHV value of the fuel is obtained in accordance with the results of research in the laboratory at power plants. Equation (5) is the equation for calculating the fuel mass flow rate.

$$m_{fuel} = \frac{Q_{boiler}}{LHV_{fuel}} \tag{5}$$

Then, the fuel consumption that used for combustion process in the power plant can be calculated. The equation for calculating the amount of fuel consumption is shown in equation (6).

$$\text{Total fuel consumption} = \dot{m}_{fuel} \text{ x 24 hours x 320 days} \tag{6}$$

Equation (6) is used to calculate the total fuel consumption for one year. This is also to calculate and find the day when the equipments in the Power Plant equipment needs maintenance or overhaul so that the power plant does not work. This is why the number of days used in equation (6) is 320 days instead of 365 days in one year. The cost of using the required fuel for one year can be calculated once the fuel consumption in one year is known. The equation used to calculate the fuel required for a year is shown in equation (7).

$$\text{Total fuel costs} = \text{total fuel consumption x fuel prices} \tag{7}$$

Each fuel has a different price. Equation (7) shows that the things that affect the total cost of fuel consumption at power plants are fuel consumption and fuel prices. It means that cheap fuel prices do not determine the total cost of fuel consumption to decrease because the amount of fuel consumption used can be very high. On the other hand, expensive fuel prices do not necessarily result in high fuel consumption costs, depending on the amount of fuel consumption required.

III. Results and Discussion

A. Validation

The first stage of numerical simulation is validation. Validation is used to ensure that the numerical model is correct. It determines how much error occurred during the simulation process. Validation is performed by comparing the value of the simulation results with the actual value obtained from the power plant company [17].

Table 3 is the result of data validation. It shows the steam power plant (PLTU in Bahasa), generator, boiler, reheater, turbine, and condenser. The five apparatus are displayed to represent the results of data validation. The resulting data is too much due to many components simulated in the Cycle Tempo. The main data validated in each component are thermal data regarding temperature (T), enthalpy (h), pressure (P), and mass flow rate (m). These simulation results are quite acceptable when compared with similar studies using Cycle Tempo [18].

TABLE III
VALIDATION OF THE SIMULATION RESULTS COMPARED WITH POWER PLANT OPERATIONAL DATA

No	Main Components	Data	Op. Data	Cycle Tempo	Error (%)
1	Generator	Load (MW)	180	183.43	1.90
2	Boiler	T in (°C)	270	270.05	0.02
		h in (kJ/kg)	1,185.2	1,182.6	0.22
		T out (°C)	540	540	0
		P out (bar)	165.7	165.7	0
		h out (kJ/kg)	3,405.5	3,405.7	0.06
		m (kg/s)	165.7	165.79	0
3	Reheater	T in (°C)	300	300.2	0.07
		P in (bar)	26.53	26.53	0
		h in (kJ/kg)	3,046.4	3,005.5	0.01
		T out (°C)	539	539	0
		P out (bar)	26.53	26.53	0
		h out (kJ/kg)	3,548.2	3,548.1	0.003
4	Turbine	T out (°C)	47	49.49	5.54
		P out (bar)	0.12	0.12	0
		h out (kJ/kg)	2,585.9	2,573.9	0.47
5	Condenser	T in (°C)	28	28	0
		T out (°C)	42	42	0
		T hotwell (°C)	46	49.42	7.43

The actual power plant data is taken when the power plant is working at a load of 180 MW. After the simulation process, the resulting generator load is 183.43 MW so that there is an error of 1.9%. In the boiler component, the pressure and temperature are adjusted according to the actual value. The results between the actual data and the simulation data do not change. This aims to prevent the boiler from producing output that exceeds the safe limit, especially when variations in fuel types are carried out.

Bramantya [19] conducted a study on the effect of the mass flow of steam extraction for HP (High Pressure) feedwater heater on power plant using Cycle Tempo software. In the validation process, several components in that research also produced errors. In Table 3, the amount of error generated at the boiler entry temperature is 0.02%, while in Bramantya [19] research, the error is 0.78%.

The highest error occurs in the condenser apparatus at the exit temperature of the condenser to the feedwater heater. The resulting error is 7.43%. Bramantya [19] research also experienced an error in this section, where the error generated at the condenser exit temperature to the feedwater heater was 1.87%. Although the amount of error in this study is higher than in previous studies, the resulting error does not exceed 10% so that it is still acceptable.

B. The Effect of Fuel Replacement on Performance of Steam Power Plant

After the simulation and validation process is complete, it is continued with the process of analyzing the research results. The first analysis was carried out on the plant performance. The power plant performance values shown in Table 4. Table 4 shows some of the power plant performance on three variations of fuels. Simulation on the software is to determine the heat energy of the boiler, pump power, turbine power, and generator power. The results are then used to calculate the thermal cycle efficiency.

TABLE IV
OUTPUT DATA FROM SIMULATION USING CYCLE TEMPO SOFTWARE

Performance	Natural Gas	MFO	Biosolar
Boiler Heat Energy (kW)	597,416	580,634	568,496
Turbine Power (kW)	188,149	188,636	185,416
Pump Power (kW)	4,841	4,820	4,770
Generator Output (kW)	185,330	185,810	182,638
Efficiency (%)	30.68	31.65	31.78
NPHR (kJ/kWh)	11,659	11,319	11,281
GPHR (kJ/kWh)	11,972	11,621	11,584

The boiler heat produced by the three types of fuel has different values. Natural gas fuel produces a boiler heat energy value of 597,416 kW. Furthermore, MFO fuel produces boiler heat of 580,634 kW while Biosolar B30 fuel produces a boiler heat value of 568,496 kW. The value is different because of each fuel has different heating value. Natural gas has a heating value producing the highest boiler heating value, while biosolar fuel produces the lowest boiler heat energy.

The amount of heat energy released from each mass unit of fuel is called the heating value. This causes a greater heating value of a fuel, leading to greater heat energy produced by the boiler from burning the fuel. The highest heating value of fuel is natural gas then Biosolar B30 fuels gain the lowest heating values of fuel. Therefore, the highest boiler heat energy is produced by natural gas, followed by MFO and biosolar B30 producing the lowest boiler heat energy.

Natural gas fuel produces turbine power of 188,149 kW; MFO fuel produces turbine power of 188,636 kW; Biosolar B30 fuel produces turbine power of 185,416 kW. The superheated steam mass flow rate to the turbine can affect the turbine power produced. The type of fuel that changes causes the combustion conditions in the boiler to change. This results in a change of the steam mass flow rate that come out of the boiler.

The steam turbine utilizes the boiler's large superheated steam mass flow rate to rotate the turbine blades. Different values of superheated steam mass flow rate can affect the value of turbine power to be generated. The simulation results show that there is no big difference between the values of the resulting turbine power. This means that the small difference in the steam mass flow rate value does not really affect the cycle in the simulation. However, the resulting generator power is slightly different. This occurs due to differences in the value of the turbine power.

Based on Table 4, the amount of generator power generated by each type of fuel is different. This is influenced by the amount of turbine power produced. In addition, turbine power, generator power, power, and energy in each apparatus in the simulation are also calculated by the system from Cycle Tempo using the input functions to influence several other factors. The highest error value generated by the difference between the generator power of the simulation results and the actual data occurs in the simulation on MFO fuel with an error of 4.5%. The resulting error does not exceed 10% so that the results of this simulation can be analyzed.

After the simulation results for each variation of the type of fuel are analyzed, the next step is to calculate the performance of power plants. The calculated power plant performance is thermal cycle efficiency and heat rate. First, the thermal cycle efficiency value of the power plant is calculated based on the net turbine power and heat energy in the boiler. The magnitude of the power plant thermal efficiency can be seen in Figure 3.

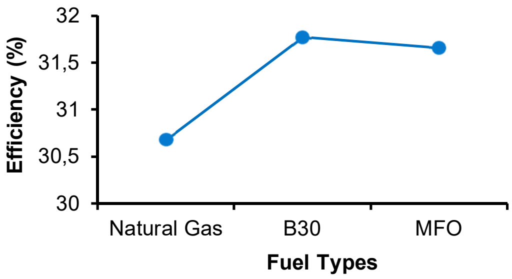

Fig. 3 The effect of fuel type on the power plant efficiency

The value of the cycle thermal efficiency of a Steam Power Plant can be seen in Figure 3. The thermal efficiency produced by natural gas is 31.78%. MFO resulting in an efficiency of 31.65% and an efficiency of 30.68% is resulting by Biosolar B30. It is shown that Biosolar B30 produces the highest cycle thermal efficiency; meanwhile, natural gas produces the lowest thermal cycle efficiency.

Equation (2) shows the value of the thermal efficiency of the power plant is directly proportional to the net power of the turbine and in contradiction to the heating value of the boiler. In Table 4, the highest value of boiler heat energy is produced by natural gas compared to MFO and Biosolar B30. The value of turbine power does not differ much. It means that high boiler heat in natural gas will result in low thermal efficiency. Conversely, the lowest heat boiler is resulting from Biosolar B30 so that Biosolar B30 fuel produces a high thermal efficiency value.

The thermal efficiency value is influenced by the heat boiler, which is also influenced by the heating value of the fuel used in the boiler. Padillah *et al* [13]. conducted research on the use of HSD and MFO fuels on the performance of diesel engines. HSD fuels have a higher heating value than MFO fuels. The results showed that the thermal efficiency produced by MFO was greater than the efficiency produced by HSD [13]. It also shows that the calorific value of the fuel influences the thermal cycle efficiency.

The next performance to be analyzed is the value of the power plant heat rate, which is calculated using data on the amount of LHV fuel and the amount of power generated by the generator. Two types of power plant heat rates are calculated; there are NPHR and GPHR. NPHR is calculated using generator power that has been reduced by auxiliary power, while GPHR is calculated using generator power without being reduced by auxiliary power. The NPHR and GPHR values generated by each fuel can be seen in Figure 4.

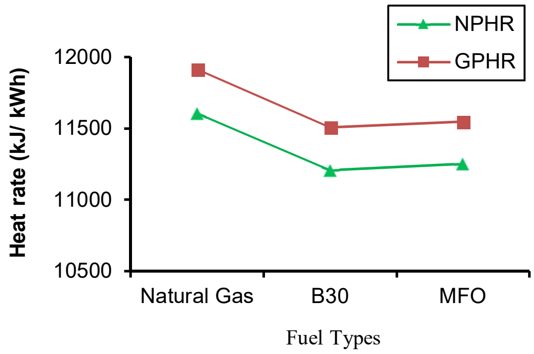

Fig. 4 The effect of fuel type on heat rate values

The values of NPHR and GPHR can be seen in figure 4. It can be seen that the highest NPHR and GPHR values are generated by natural gas of 11,604 kJ/kWh and 11,916 kJ/kWh. The NPHR and GPHR values produced by MFO fuel are 11,249 kJ/kWh and 11,549 kJ/kWh. The lowest values are generated by the variation of Biosolar B30 fuel of 11,205 kJ/kWh and 11,506 kJ/kWh.

Heat rate value shows how much heat energy the cycle needs to generate work output. If the heat rate value is high, the system needs more heat to be converted into work output. This shows that a high heat rate is not good at the system. The heat rate value based on the following explanation is inversely proportional to the amount of thermal efficiency in a cycle.

Natural gas fuels produce the highest heat rate values. This is because the heat boiler resulting from burning natural gas is higher than the heat boiler resulting from MFO fuel and Biosolar B30 fuel combustion. Generator power produced by the three variations of fuel types is not too different so that the thing that affects the heat rate value is the heat boiler resulting from fuel combustion. Biosolar B30 produces a smaller heat boiler value than other fuels so that the Biosolar B30 heat rate value is small. With a small heat rate value, the fuel that has the best performance is Biosolar B30. In addition, Biosolar B30 also has the highest thermal efficiency value so that the results obtained for performance analysis are in accordance with the existing equations.

C. The Effect of Fuel Replacement on Total Fuel Consumption

Further analysis after the power plant's thermal cycle efficiency and heat rate are the analysiss of fuel requiredt for the three types of fuel. The calculated and analyzed consumption values are the fuel mass flow rate, the total fuel required, and the total costs of fuel for one year. The results of the calculation of fuel consumption shown in Table 5.

TABLE V
FUEL CONSUMPTION DATA RESULTS WITH SEVERAL TYPES OF FUEL

No	Data	Gas	MFO	B30
1	Price of Fuel (IDR/liters)	5,798	7,200	5,150
2	Mass Flow Rate Fuel (Thousand liters/hour)	36.09	48.32	53.90
2	Total Fuel Consumption (Million liters)	277	371	414
3	Total Fuel Consumption Costs (Trillion IDR)	1,607	2,671	2,133

Table 5 shows the price of each fuel and the calculation result of the consumption of each fuel. Each fuel has a different price. The price of each fuel was obtained from the Internet sources as of August 2019. MFO fuel is the most expensive fuel, while Biosolar B30 is the cheapest. MFO fuel price is IDR7,200/liter, natural gas fuel is IDR5,798/liter, then the Biosolar B30 fuel is IDR5,150/liter. The total cost of fuel for power plants is also influenced by the price of fuel used.

The fuel mass flow rate that has been calculated for each fuel are different. The fuel mass flow rate produced by natural gas fuel is 36.90 thousand liters/hour, MFO fuel 48.32 thousand/liter and Biosolar B30 fuel is 53.90 thousand/liter. Natural gas fuel produces the lowest mass flow rate value while Biosolar B30 produces the highest value. The comparison of the fuel mass flow rate is shown in Figure 5.

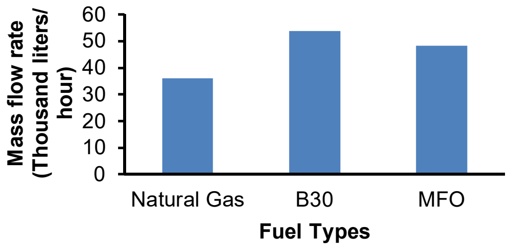

Fig. 5 Comparsion of mass flow rate with variation of fuel types

The comparison of the mass flow rate for each variation of fuel can be seen in Figure 5. The fuel that produces the lowest mass flow rate of fuel is natural gas, while the fuel that produces the highest mass flow rate is Biosolar B30. This is due to the higher heating value of natural gas. A higher heating value of the fuel results in a higher mass flow rate.

The mass flow rate of the fuel can be affected by the heating value of the fuel. Basuki's study [5] shows that the fuel with the highest mass flow rate is generated by the fuel with the lowest heating value. The lowest fuel mass flow rate is resulting from the fuel with the highest heating value [5]. The value of the fuel mass flow rate obtained in this study is in accordance with Basuki's study.

Based on equation (5), the value of the fuel mass flow rate is obtained based on the results of dividing the heat combustion of fuel with the LHV value. A large fuel heating value results in a small fuel mass flow rate that the heating value is indicates the amount of energy produced by burning the fuel. Therefore, a large fuel heating value will make it easier for the fuel to reach the specified combustion heating value during the combustion process. This results in less fuel consumption. In one year, the fuel consumption needs for each fuel variation is shown in Figure 6.

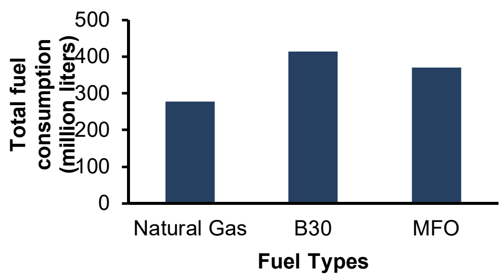

Fig. 6 Total fuel consumption on each type of fuel for one year

Figure 6 shows the comparison of the total fuel consumption of each variation for one year. In the calculation process, the number of days used in a year is 320. Because in one year it’s urgent to calculated and find the day when the power plant does not work due to maintenance or overhaul. The amount of fuel required by natural gas is 277 million liters/year, then for MFO fuel is 371 million liters/year and for Biosolar B30 fuel is 414. million liters/year.

Biosolar B30 requires the highest total of fuel consumption compared to other fuels. while natural gas requires the least fuel consumption so that the most economical fuel is natural gas. MFO fuel requires the secong highest total consumption. This means that the most wasteful use of fuel is Biosolar B30.

The heating value of the fuel influences the fuel mass flow rate. A high fuel mass flow rate will be produced when the heating value of the fuel is low. The total fuel used for combustion in the boiler for one hour is understanding the fuel mass flow rate. Fuels with high mass flow rates will require high fuel consumption.

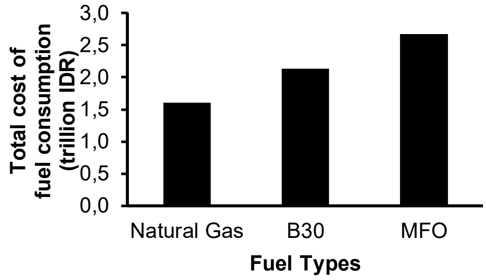

Fig. 7 Total cost of fuel consumption on each type of fuel for one year

Figure 7 shows a comparison of total fuel consumption costs generated in one year. The cost of natural gas fuel consumption for one year is IDR1,60 trillion. Furthermore, MFO fuel consumption cost for one year is IDR2,67 trillion. The cost of consuming Biosolar B30 fuel for one year is IDR2,13 trillion. MFO fuel generates the highest costs of fuel consumption while natural gas fuel generates the lowest fuel consumption costs.

Table 5 shows that MFO fuel has the highest price, while Biosolar B30 has the lowest price compared to other fuels. This resulted in a high one-year MFO fuel consumption cost. However, it turns out that the fuel with the lowest fuel consumption costs is not Biosolar B30 but natural gas. This is due to the fuel required. The total cost of each type fuel consumption is affected not only by the price of fuel, but also by the value of the fuel mass flow rate or the total of fuel required [4]. Natural gas fuel produces the lowest consumption value while Biosolar B30 fuel produces the highest consumption.

Syukran's research, shows that fuel with the highest mass flow rate value results in low fuel costs due to low fuel prices [4]. Fuels with low mass flow rate values result in high consumption costs because of their high prices. The difference in fuel prices in that research is too great, so the comparison of the results obtained is clear. Meanwhile, the price of biosolar B30 and natural gas in this study is not much different from the price of MFO.

This research shows that natural gas required the lowest of fuel consumption for one year. Meanwhile, the highest cost of fuel required by MFO and the lowest cost of fuel required by natural gas. This shows that, natural gas is the most economical fuel.

IV. Conclusion

The power plant cycle simulation results have been validated with an error that does not exceed 10%. This shows that the simulation results are good so that they can be used as calculation and analysis data. Natural gas fuel produces a thermal efficiency of 30.68%, MFO fuel 31.66%, and Biosolar B30 fuel 31.78%. Biosolar B30 is generated the highest thermal efficiency. Fuel produced by each fuel type are 277 million liters of natural gas, 371 million liters of MFO and 414 million liters of biosolar B30 during one year of operation. Natural gas is the lowest of fuel consumption than the other fuel.

Nomenclature

h	Entalphy	kJ/kg
HHV	High Heating Value	kJ/kg
HR_G	Gross Plant Heat Rate (GPHR)	kJ/kWh
HR_N	Net Plant Heat Rate (NPHR)	kJ/kWh
LHV	Low Heating Value	kJ/kg
$\dot{m}$	Mass flow rate	kg/s
P	Pressure	bar
P_{gross}	Gross generator output power	Watt (W)
P_{net}	Net generator output power	Watt (W)
T	Temperature	^oC
Wnett	Net ouput power	Watt (W)
Wp	Pump ouput power	Watt (W)
Wt	Turbine ouput power	Watt (W)
$\dot{Q}_{boiler}$	Heat energy from fuel combustion	Watt (W)
η_{th}	Eficiency	%

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