

Energy Analysis of Diesel Engine With B30 at PLTD Selat Panjang

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ABSTRACT

Many efforts have been made in energy efficiency in power plants. One way to improve the efficiency of energy consumption is to conduct analysis. The purpose of this study was to analyze the thermal efficiency of a diesel engine with B30 at PLTD Selat Panjang unit 4. The data were collected using a daily operation report log sheet for Caterpillar 3512B diesel with duration 3x24. From the calculation carried out, the average thermal efficiency of diesel engine with B30 as fuel at PLTD Selat Panjang was 47.52%.

KEYWORDS: Diesel Engine, Energy Analysis, Biosolar, B30

NOMENCLATURE

\overline{AFR}	= Air-fuel ratio mole basis
AFR	= Air to fuel ratio
\bar{C}_p	= Specific heat of mole basis (kJ/kmol.K)
c_p	= Specific heat at constant pressure (kJ/kg.K)
c_v	= Specific heat at constant volume (kJ/kg.K)
$c_{p,m}$	= Specific heat of mixture (kJ/kg.K)
$c_{v,m}$	= Specific heat of volume of mixture (kJ/kg.K)
k	= Specific heat ratio
T_0	= Ambient temperature (K)
T_1	= Gas mixture temperature (K)
T_2	= Temperature during compression process (K)
T_3	= Temperature during the combustion process (K)
T_4	= Exhaust temperature (K)
T_m	= Median temperature (middle value) (K)
P_0	= Ambient air pressure (kPa)
P_1	= Pressure of gas mixture (kPa)
P_2	= Pressure during compression process (kPa)

P_3	= Pressure during the combustion process (kPa)
P_4	= Exhaust pressure (kPa)
R	= Gas constant (kJ/kg.K)
R_m	= Constant gas mixture (kJ/kg.K)
\dot{m}_{bb}	= Fuel flow rate (kg/s)
\dot{m}_{ud}	= Air flow rate (kg/s)
\dot{m}_m	= Mass flow rate of mixture (kg/s)
ρ_{bb}	= Density of fuel (kg/m ³)
ρ_{ud}	= Density of air (kg/m ³)
\dot{V}_{ud}	= Combustion air discharge (m ³ /s)
\dot{V}_{bb}	= Fuel discharge (m ³ /s)
\dot{V}_m	= Mixed discharge (m ³ /s)
\dot{W}_c	= Compression work (kW)
\dot{W}_{net}	= Net work (kW)
W_u	= Useful work (kW)
\dot{Q}_{in}	= Heat in (kW)
\dot{Q}_{out}	= Heat out (kW)
$\dot{W}_{net,t}$	= KTotal work (kW)
η_{th}	= Cycle thermal efficiency (%)

1.0 INTRODUCTION

Electrical energy is a very important supporting factor for the overall development of a nation, as industrial activities and population increase, the need for electrical energy also increases. There are several factors that affect the availability of electricity in Indonesia; the availability of primary energy and fuel prices [1]-[3]. Increasing energy demand, harmful emissions and depletion of fossil fuel resources inevitably require optimal utilization of depleted fossil fuels and non-renewable energy resources. Therefore, the use of alternative fuels such as biodiesel is one of the best available sources to meet the world's energy needs [3][4]. The concept of using vegetable oil as a fuel has been around since 1895 in the work of Rudolf Diesel.

Many efforts have been made to increase efficiency in power generation. One of the steps is to perform an exergy analysis. So far, the analysis carried out is only based on the first law of thermodynamics, namely energy can neither be created nor destroyed, in which the degradation of energy quality is not taken into account. So to examine more deeply

about the decline in the quality of the energy can be used exergy analysis. By conducting this exergy analysis in accordance with the relationship in processing resources more efficiently, because this method can identify the location, type and magnitude of losses and can also be used for thermal system design and can reduce energy waste in existing systems [5].

By using the exergy analysis method, it can be used as an alternative to increase the efficiency of fuel which is used in a power plant. A large amount of exergy loss in a diesel engine can occur in one or more components of a diesel engine. To find out these components. Therefore, it is necessary to analyze each component of the diesel engine. This method has been widely used by researchers and system designers to increase the efficiency of the generator. Such as the exergy analysis of the gas engine at the PLTMG Duri power plant with a capacity of 7 x 15 MW with HSD fuel and natural gas. The results of the exergy analysis show that the largest exergy destroyed occurred in the combustion process, where the previous period before the overhaul exergy destroyed was 9,879.6 kW and after the overhaul was 10,665.4 kW. Exergy analysis showed the location where the largest exergy loss occurred in cylinder number 3 by 31.4% [6].

Conducting experiments on a single cylinder four stroke diesel engine fueled by a mixture of Mahua Oil Methyl Ester (MOME). Emissions performance, energy, and exergy analyzes have been carried out in B20 (80% diesel by volume mix with 20% MOME). From the exergy analysis, it is known that the input of fuel energy and the energy carried by exhaust gas is 6.25% and 11.86% more for diesel compared to B20 [7].

In this study, the analysis was carried out on the Selat Panjang PLTD on one of the main components of the diesel engine. This component will be analyzed to find out how much energy and exergy losses are caused by the turbocharger, engine, radiator and exhaust gas components as well as the location of the exergy loss in the diesel engine.

The benefits of this research are expected to provide convenience in determining the occurrence of a decrease in energy quality in diesel engines with biodiesel fuel and provide references in efforts to improve the system on diesel engines at the Diesel Power Plant in Selat Panjang.

2.0 LITERATURE REVIEW

2.1 Diesel Power Plant (PLTD)

Diesel Power Plant (PLTD) is a power plant that uses a diesel engine as the prime mover. Prime mover is equipment that has the function of producing the mechanical energy needed to rotate the generator rotor. Diesel motors are also called compression ignition motors (compression ignition engine) due to ignition method the fuel is done by spraying the material the baker into compressed air and high temperature, as a result of the process in the combustion chamber head cylinder.

The PLTD is a power plant installation consisting of a generating unit and generating facilities. In diesel engines, fuel energy is converted into mechanical energy by the combustion process in the engine itself. This type of generator is usually used to meet the electricity needs of small loads, especially for remote or rural areas and to supply the electricity needs of a factory. An example of a Caterpillar 3512B diesel engine can be seen in Figure 1.



Figure 1: Engine caterpillar 3512B

2.2 Biodiesel Fuel

Biodiesel is produced from vegetable oil through a transesterification reaction process between vegetable oil, methanol and a catalyst. The transesterification reaction is shown in Figure 2. Transesterification is a transformation process from one type of ester to another type of ester. Esters are hydrocarbon chains that form bonds with other molecules. From Figure 2 it is shown that there is an excess of oxygen atoms in biodiesel, so biodiesel can be said to be a fuel that has oxygenate properties, and because of these properties, biodiesel has the ability to bind carbon monoxide (CO) molecules to carbon dioxide (CO₂). Methanol which is used as a mixture of vegetable oils produces a biodiesel reaction that is more stable than other types of alcohol [8].

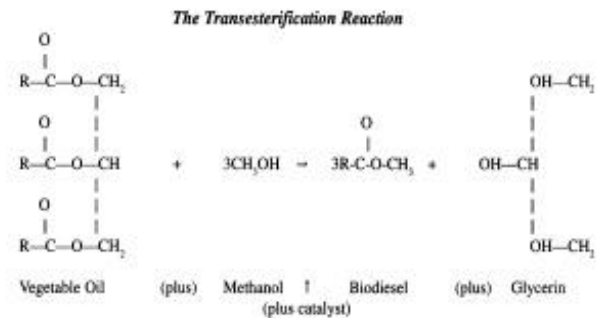


Figure 2: Transesterification reaction [8]

2.3 Air Fuel Ratio (AFR)

Air Fuel Ratio (AFR) is the ratio of the amount of air to the amount of fuel in a reaction [9].

$$AFR = \frac{\text{air mole} \times M_{air}}{\text{moles of fuel} \times M_{fuel}} \quad (1)$$

$$AFR = \overline{AFR} \left(\frac{M_{air}}{M_{fuel}} \right) \quad (2)$$

- Excess air (λ)

The process of complete combustion of fuel with theoretical air is called stoichiometric combustion. However, in fact the combustion process uses excess air to increase the chances of complete combustion or to control the temperature of the combustion chamber. The amount of excess air is called excess air [10] The equation of excess air (λ) is,

$$\lambda = \frac{\text{actual air quantity}}{\text{theoretical air quantity}} \quad (3)$$

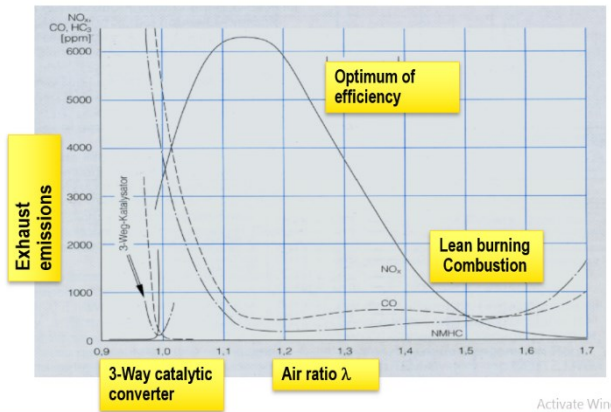


Figure 3: Caterpillar Engine AFR

Based on the exhaust emission monitoring results for the NO_x was 895.9 mg/Nm³ (437 ppm), and the excess air factor value for the Caterpillar engine is 1.5 or 150% (Figure 3).

2.4 Thermodynamic Analysis

Fuel input energy is affected by energy loss depending on incomplete combustion, friction loss, heat transfer loss and exhaust gas output loss [11]. For practical cycling on engine performance, it is important to evaluate the effect of the variable specific heat of the operating fluid on the actual cycle performance [12]. In Figure 4 is illustrated the thermodynamics for the diesel cycle using a turbocharger [9].

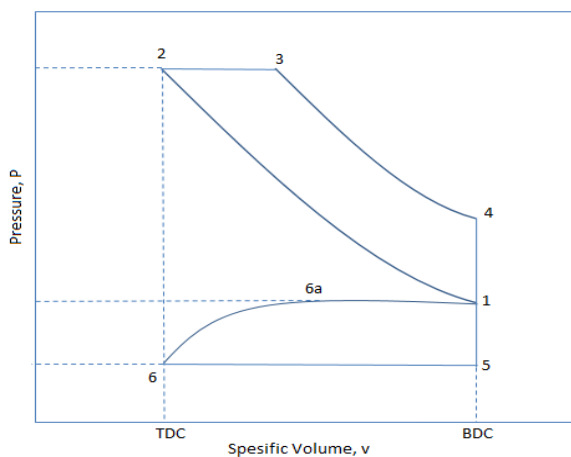


Figure 4: Diagram on the diesel cycle [9]

The work (W) and heat (Q) in each state of the diesel engine are as follows:

- Process 6-6a : Compressor

Process air enters the compressor to increase its pressure before entering the engine. According to [9], the relationship between temperature and pressure is expressed in Equation 10.

$$\frac{T_{6a}}{T_6} = \left(\frac{P_{6a}}{P_6}\right)^{\left(\frac{k-1}{k}\right)} \quad (10)$$

Compression work on the compressor as follows:

$$W_{k_{6-1}} = \dot{m}_{udara} \times P_6 \times (V_1 - V_6) \quad (11)$$

- Process 6a-1 : Intercooler

This process starts from the position of the piston at TDC, the piston will move down. At the same time the intake valve opens and the exhaust valve closes. When the piston is at BDC, the cylinder volume is at its maximum so that air will enter through the intake valve at a constant pressure.

$$w_{6-1} = P_0(v_1 - v_6) \quad (12)$$

- Process 1-2 : Compression

In this process the piston will move up and compress the air.

$$W_{k_{1-2}} = (\dot{m}_u) \times ((c_{v1} \times T_1) - (c_{v2} \times T_2)) \quad (13)$$

- Process 2-3 : Combustion

In the final compression stroke, the high-pressure fuel pump will inject fuel into the combustion chamber containing compressed air. The fuel will mix with the air and there will be combustion.

$$Q_{in} = \left(\frac{\dot{m}_u + \dot{m}_{fuel}}{\text{cylinders}}\right) \times ((c_{p3} \times T_3) - (c_{p2} \times T_2)) \quad (14)$$

- Process 3-4 : Expansion Step

When combustion occurs, the pressure in the combustion chamber rises and the piston moves from TDC to BDC.

$$W_k = \left(\frac{\dot{m}_u + \dot{m}_{fuel}}{\text{cylinders}}\right) \times ((c_{v3} \times T_3) - (c_{v4} \times T_4)) \quad (15)$$

- Process 4-1 : Dispose process

Before the piston is at BDC, the exhaust valve opens so that heat and combustion gases exit the cylinder.

$$Q_{out} = (\dot{m}_u + \dot{m}_{fuel}) \times ((c_{p1} \times T_1) - (c_{p4} \times T_4)) \quad (16)$$

- Process 1-5 Exhaust gas

Process exhaust gases into the Turbocharger. Therefore, the pressure and temperature of the exhaust gas decreases because the heat is used to heat the air entering the compressor.

$$W_t = (\dot{m}_{air} + \dot{m}_{fuel}) \times ((c_{p1} \times T_1) - (c_{p5} \times T_5)) \quad (17)$$

The thermal efficiency of a diesel engine is the following equation:

$$(\eta_t)_{Diesel} = \frac{|w_{net}|}{|q_{in}|} \times 100\% \quad (18)$$

3.0 RESULTS AND DISCUSSION

3.1 Research Result Data

Observational data is actual data obtained from the data record (log sheet) of unit 4 PLTD Selat Panjang, on September 25-27 2021. As an example of the calculation used data on September 25, 2021 at 11.00 which is shown in Table 1.

Table 1: Machine data for unit 1 PLTD Selat Panjang

Parameter	Notasi	Value	Unit
Compressor intake air temperature	T ₆	306.35	K
Engine intake air temperature	T ₁	309.15	K
Environmental air temperature	T ₀	304.15	K
Engine intake air pressure	P ₆	144.00	kPa
Environmental air pressure	P ₀	101.325	kPa
Mass flow rate of fuel	\dot{m}_{bb}	0.2226	m ³ /h
Compression ratio	r	14:1	
Expansion ratio	r _e	7	
Exhaust gas temperature	T ₄ Blok A1	795.15	K

Table 2 : Biodiesel and solar fuel specifications

Parameter	Biodiesel (B100)	Solar (B0)
Heat value (MJ/kg)	Min. 37	Min. 42.7
Density (kg/m ³)	890	870

The work (W) and heat (Q) in each state of the diesel engine are as follows:

• Process 6-6a : Compressor

The temperature of the air entering the compressor (T₆) is 306.35 K and the air leaving the compressor (T_{6a}) is 338.71 K. Compressor work (W_k) is formulated by Equation 11.

$$W_{k_{6-6a}} = (\dot{m}_u) \times \left((c_{p_{6a}} \times T_{6a}) - (c_{p_6} \times T_6) \right)$$

$$W_{k_{6-6a}} = \left(0.899 \frac{\text{kg}}{\text{s}} \right) \times \left(\left(1.014 \frac{\text{kJ}}{\text{kg.K}} \times 338.71 \text{ K} \right) - \left(1.0087 \frac{\text{kJ}}{\text{kg.K}} \times 306.35 \text{ K} \right) \right)$$

$$W_{k_{6-6a}} = 30.958 \text{ kW}$$

• Process 6-1 : Intercooler

$$Q_{out} = (\dot{m}_u) \times \left((c_{p_1} \times T_1) - (c_{p_{6a}} \times T_{6a}) \right)$$

$$Q_{out} = \left(0.899 \frac{\text{kg}}{\text{s}} \right) \times \left(\left(1.005 \frac{\text{kJ}}{\text{kg.K}} \times 309.15 \text{ K} \right) - \left(1.014 \frac{\text{kJ}}{\text{kg.K}} \times 338.71 \text{ K} \right) \right)$$

$$Q_{out} = -30.281 \text{ kW}$$

• Process 1-2 : Compression

The temperature of the air entering the engine (T₁) is 309.15 K and after the compression process (T₂) is 634.79 K. The work of compression (W_k) is formulated by Equation 13.

$$W_{k_{1-2}} = (\dot{m}_u) \times \left((c_{v_1} \times T_1) - (c_{v_2} \times T_2) \right)$$

$$W_{k_{1-2}} = \left(\frac{0.899 \frac{\text{kg}}{\text{s}}}{12} \right) \times \left(\left(0.718 \frac{\text{kJ}}{\text{kg.K}} \times 309.15 \text{ K} \right) - \left(1.053 \frac{\text{kJ}}{\text{kg.K}} \times 634.79 \text{ K} \right) \right)$$

$$W_{k_{1-2}} = -35.460 \text{ kW}$$

• Process 2-3 : Combustion

After mixing of fuel and air ($\dot{m}_u + \dot{m}_{fuel}$) the combustion process is considered as heat input at constant pressure, the calorific value entering the engine (Q_{in}) is obtained by Equation 14.

$$Q_{in} = \left(\frac{\dot{m}_u + \dot{m}_{fuel}}{\text{cylinders}} \right) \times \left((c_{p_3} \times T_3) - (c_{p_2} \times T_2) \right)$$

$$Q_{in} = \left(\frac{0.899 \frac{\text{kg}}{\text{s}} + 0.0541 \frac{\text{kg}}{\text{s}}}{12} \right) \times \left(\left(1.260 \frac{\text{kJ}}{\text{kg.K}} \times 1482.11 \text{ K} \right) - \left(1.340 \frac{\text{kJ}}{\text{kg.K}} \times 634.79 \text{ K} \right) \right)$$

$$Q_{in} = 73.212 \text{ kW}$$

• Process 3-4 : Expansion

In the expansion process there is no heat (Q) entering and leaving, but it produces work, so:

$$W_{k(\text{silinder A1})} = \left(\frac{\dot{m}_u + \dot{m}_{bb}}{\text{silinder}} \right) \times \left((c_{v_3} \times T_3) - (c_{v_4} \times T_4) \right)$$

$$W_{k(\text{silinder A1})} = \left(\frac{0.899 \frac{\text{kg}}{\text{s}} + 0.0541 \frac{\text{kg}}{\text{s}}}{12} \right) \times \left(\left(0.976 \frac{\text{kJ}}{\text{kg.K}} \times 1482.11 \text{ K} \right) - \left(0.888 \frac{\text{kJ}}{\text{kg.K}} \times 795.15 \text{ K} \right) \right)$$

$$W_{k(\text{silinder A1})} = 52.294 \text{ kW}$$

• Process 4-1 : Dispose process

The calorific value coming out of the diesel engine (Q_{out}) is obtained by Equation 16.

$$Q_{out} = \left(\frac{\dot{m}_u + \dot{m}_{bb}}{\text{silinder}} \right) \times \left((c_{v_1} \times T_1) - (c_{v_4} \times T_4) \right)$$

$$Q_{out} = \left(\frac{0.899 \frac{\text{kg}}{\text{s}} + 0.0541 \frac{\text{kg}}{\text{s}}}{12} \right) \times \left(\left(0.877 \frac{\text{kJ}}{\text{kg.K}} \times 685.23 \text{ K} \right) - \left(0.888 \frac{\text{kJ}}{\text{kg.K}} \times 795.15 \text{ K} \right) \right)$$

$$Q_{out} = -38.451 \text{ kW}$$

- Process 1-5 Exhaust gas

Turbine work is obtained as follows:

$$W_t = (\dot{m}_u + \dot{m}_{bb})x \left((c_{p1} \times T_1) - (c_{p5} \times T_5) \right)$$

$$W_t = \left(0.899 \frac{\text{kg}}{\text{s}} + 0.0541 \frac{\text{kg}}{\text{s}} \right) x \left(\left(1.172 \frac{\text{kJ}}{\text{kg} \cdot \text{K}} \times T_1, \text{K} \right) - \left(1.172 \frac{\text{kJ}}{\text{kg} \cdot \text{K}} \times 665.30 \text{K} \right) \right)$$

Where the work of the turbine is as large as the work of the compressor

$$W_t = -W_k = 38.293 \text{ kW}$$

So:

$$38.293 \text{ kW} = \left(0.899 \frac{\text{kg}}{\text{s}} + 0.0541 \frac{\text{kg}}{\text{s}} \right) x \left(\left(1.172 \frac{\text{kJ}}{\text{kg} \cdot \text{K}} \times T_1, \text{K} \right) - \left(1.072 \frac{\text{kJ}}{\text{kg} \cdot \text{K}} \times 665.30 \text{K} \right) \right)$$

$$T_1 = 685.23 \text{ K}$$

The thermal efficiency of a diesel engine is the following equation:

$$(\eta_t)_{\text{Diesel}} = \frac{|w_{\text{net}}|}{|q_{\text{in}}|} \times 100\%$$

$$(\eta_t)_{\text{Diesel}} = \frac{|420.16 \text{ kW}|}{|883.76 \text{ kW}|} \times 100\% = 47.52 \%$$

Using the same calculation for cylinder (A1), the heat in (Q_{in}), heat out (Q_{out}) and thermal energy efficiency (η) of the 12 cylinder diesel engines are obtained as shown in Table 3.

Table 3. Thermal efficiency of each cylinder

Cylinder	Q_{in} (kW)	Q_{out} (kW)	W_{net} (kW)	η_{th} (%)
A1	73.212	38.451	34.760	47.48
A2	72.370	38.098	34.271	47.36
A3	71.865	37.887	33.977	47.28
A4	71.696	37.816	33.879	47.25
A5	69.507	36.899	32.607	46.91
A6	73.886	38.733	35.152	47.58
B1	74.054	38.804	35.250	47.60
B2	76.917	40.003	36.914	47.99
B3	81.464	41.907	39.557	48.56
B4	73.886	38.733	35.152	47.58
B5	69.338	36.829	32.509	46.88
B6	75.570	39.438	36.131	47.81
Average				47.52

4.0 CONCLUSION

This paper was carried out the analysis of value of thermal efficiency on diesel engines. A case study was conducted in power plant of the PLTD Selat Panjang, Indonesia using B30 as fuel. The study result revealed the average of thermal energy efficiency (η) of the 12 cylinder diesel engines of 47.52%. The value of total work of turbine (\dot{W}_{net}) maximum was occurred

in the cylinder B3, which the value of 39.557 kW. This study result may determine the occurrence of a decrease in energy quality in diesel engines with biodiesel fuel and provide references in efforts to improve the system on diesel engines at the Diesel Power Plant in Selat Panjang.

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