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Comparative Study of Induction Motor and Steam Turbine at Kebon Agung Sugar Factory Malang Indonesia

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HIGHLIGHTS

- The average value of induction motor efficiency was found to be 94.6%
- The average value of steam turbine efficiency was found to be 77.2%
- Induction motors in sugarcane milling machines are more efficient than steam turbines

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ABSTRACT

Induction motors and steam turbines are the main components in the sugar cane milling process. This study analyzes the efficiency of induction motors and steam turbines as mill drives at the Kebon Agung Sugar Factory in Malang, Indonesia. This study used experimental methods by observing and testing at the Kebon Agung Sugar Factory. The induction motors analyzed were mills 1, 2, and 5. Meanwhile, the steam turbines analyzed were cane cutter 1, 2, heavy-duty hammer shredder, mill 3, and mill 4. Motor and turbine data were obtained through the control system. Furthermore, the motor and turbine data are processed, and the efficiency comparison is calculated. From the results of the analysis, the average value of the efficiency of an induction motor is more significant when compared to a steam turbine. The average weight of induction motor efficiency is 94.6%, and the average value of steam turbine efficiency is 77.2%. This research recommends that the Kebon Agung Sugar Factory replace the steam turbine with an induction motor in the future. The recommendation given to Kebon Agung Sugar Factory is the use of induction motors on CC 1, CC 2, HDHS, mill 1, and mill 5. An induction motor is a relatively easy install compared to a steam turbine; the construction is robust and highly efficient, requires minimal maintenance, and does not require special equipment during operation.

1. Introduction

Sugar is one of the most important basic needs for people around the world. The sugar industry has been known since the 13th century in Thailand and the 15th century in Brazil, while Indonesia's sugar industry is thought to have existed since the Dutch colonial era using sugar cane as its main ingredient [1]. Apart from being a sweet taste, sugar is also useful in the medical world as a source of glucose and fructose flavors. Increasing sugar production is still a big challenge that must be achieved, in the five years from 2015 to 2019 sugar production in Indonesia tends to decrease, from 2.53 million tons in 2015 and 2.23 million tons in 2019 [2].

Technological developments, especially in the industrial sector, can increase efficiency in a factory. Demand for raw sugar for food and beverages in Indonesia is increasing every year. In 2017, Indonesia consumed 6.32 million tons of sugar, with an increase of 6% in 2018. In addition, Indonesia became the largest sugar importer in the world in 2017-2018 with 4.45 million tons [3]. The Kebon Agung Sugar Factory is a fairly large industry in producing sugar with two types of drive in the mill, namely using an induction motor and a steam turbine. Optimization of the milling process needs to be done to get the efficiency value between induction motors or steam turbines.

Induction motors continue to develop in the industrial world because they have low costs, high power-to-weight ratios, and the ability to adapt to various operating conditions [4]. Besides having the advantages of an induction motor, it also has disadvantages in terms of constraints in its operation, namely the stability of the voltage supplied to the motor. This problem

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affects the performance of the induction motor, so it is necessary to maintain the stability of the voltage that has been set or measured because if left too long it can cause interference with the motor's mechanical and electrical systems [5].

Consideration of the consumption of electrical energy is a serious concern to reduce the economic costs of their exploitation. Sugar mills can save 13,360 kWh of electricity annually, but motors often fail when the windings overheat. The M30 induction motor is used as a mill drive with a power of 800 kW, 6600 Volts, 887 Amperes, 0.82 power factor, and 895 rpm, and produces an efficiency of 96.2% [6].

Induction motors account for about 68% of industrial energy consumption worldwide. The selection of the size or capacity of the motor is very important to ensure the stability of the industry with high loads, but the use of the motor must avoid the negative effects of unbalanced power quality, such as voltage imbalance. Mandatory Energy Performance Standards (MEPS), have been established in various countries to reduce the energy consumption of induction motors. The method used in this study is the nameplate method. The nameplate method assumes that the efficiency of an induction motor remains constant independently of the load factor. The induction motor used is a de lorenzo motor with a power of 1,100 W, 220 Volts, 3.9 Amperes, 0.9 power factor, and produces an efficiency of 82% [7].

Induction motors have very wide industrial applications, and it is not surprising to say that they consume a large part of all the power generated in Brazil. In industry, 43.7% of the energy produced is generated by an induction motor, because 68% of the driving force in an industry uses an induction motor. An induction motor that has too much power can cause difficulty to recondition the induction motor itself, therefore it is necessary to carry out an efficiency analysis. The method used in this analysis is the three-phase voltage and current, input power, and power factor, measured at the machine terminals. The induction motor used is a three-phase induction motor with a power of 3 hp, 380 Volts, 4.95 Amperes, 0.85 power factor, and produces an efficiency of 79% [8].

An induction motor is a motor that is widely used in industry. In recent decades rising costs, environmental concerns, and legal requirements have pushed electric motor manufacturers and industry to use energy more efficiently. The method used to find efficiency is the torque estimation method. An induction motor with a power of 15 hp, 380 Volts, 399 Amperes, 0.78 power factor, and1765 rpm, produces an efficiency of 92.7% [9].

Induction motors are the most widely distributed electricity producer throughout the world, more than 300 million electric motors exist in the world, overall in this world, nearly 40% consume induction motors. Induction motors consume almost 80% of the energy in an industry. In a factory, there may be hundreds or even thousands of these induction machines, therefore induction machines have a strong influence on the global efficiency and reliability of the factory. Efficiency in an industry is often neglected, therefore the impact of that is that the economic expenditure of a factory will increase significantly. So to avoid that it is necessary to analyze the efficiency of the induction motor. Induction motor with a power of 1269 kW, 269 Volts, 182 Amperes, 0.86 power factor, 989 rpm, and produces an efficiency of 89% [10].

The optimized harmonic determines the switch angles of the switch device's stepped waveform technique to reduce the output harmonics of the multilevel cascade inverter for the induction motor is proposed. As a result, the efficiency of the system has improved [11].

Meanwhile, steam turbines are very widely used in the industrial world because they have complex components with high power and consist of several cylinders [12]. In addition, steam turbines also often experience a decline due to several factors such as derating, length of maintenance, and errors in operation and maintenance, besides that the size of the load greatly influences the steam that is produced. If the load is high enough, the amount of steam required will also be higher, and vice versa. Setting the amount of steam that enters the turbine in the control valve that works automatically [13].

Cogeneration systems can produce electrical energy and heat energy. Cogeneration systems can be found in several industries such as chemical, paper, and sugar cane. One of the largest industries that use cogeneration systems is the cane sugar industry. The steam extracted from the steam turbine is usually very hot. Superheated steam is not suitable for process heating such as saturated steam because it provides a lower heat transfer rate, and requires a larger heat transfer area. Several suggestions to improve the energy efficiency of sugar industry cogeneration systems can be found in the literature. Therefore, an increase in energy efficiency is expected from a cogeneration system that is integrated with a steam air preheater. Steam turbines in the sugar industry with a mass flow rate of 40 tons/hour, new steam is 180°C, used steam is 120°C, and produce an efficiency of 75% [14].

The sugar factory cogeneration system consists of a boiler, a steam turbine, and a sugar juice evaporation process. Bagasse which is a by-product of the sugar juice extraction process is used as the main fuel for boilers. The cogeneration system consumes the same amount of bagasse and produces the same amount of raw sugar. Therefore, a cogeneration system that produces a higher power output has a higher energy efficiency. A steam turbine with an output power of 29,286 kW, and a new steam temperature of 440°C, produces an efficiency of 85% [14].

Steam turbines have many functions in the world of industry and sea transportation. This time the steam turbine is used to drive the feed water pump (MFP). The main objective of the Main Feedwater Pump Turbine (MFPT) analysis is to present changes in the energy efficiency of steam turbines and power losses during changes in the power developed by the turbine. At each point, the turbine developed varied from a value of 50 kW to 570 kW. The continuous increase in MFPT energy efficiency is caused by a decrease in enthalpy. The MFPT energy loss is most affected by the mass flow of steam through the turbine and by the enthalpy. In this study, a steam turbine with the Mitsubishi MS40-2 type was used, power 570 kW, mass flow rate 4502 kg/hour, new steam temperature 497 °C steam enthalpy 2960.45 kj/kg, and produced an efficiency of 60.30% [15].

The performance of the different schemes is analyzed given the first and second laws. In this analysis, the entropy method (second law), in addition to more conventional energy analysis (first law), is employed to evaluate overall and component efficiencies and fuel consumption and identify the thermodynamic losses. The results show that using the suggested method increases the overall efficiency of the cogeneration plant for all types of back-pressure turbines and can reduce fuel consumption.

Finally, the results show that increasing back pressure improves the performance of the cogeneration plant regardless of the method used [16].

The energy analysis of the steam turbine includes all the main steam turbines and their two cylinders (high-pressure and low-pressure cylinders). The main turbine and the two turbine cylinders at three different loads experience losses. The high-load steam turbine has a power of 6422.52 kW, a new steam temperature of 500°C, a mass flow rate of 96474 kg/h, a steam enthalpy of 3424.3 kJ/kg, and produces an efficiency of 79.45% [17].

In marine applications, steam turbines can be used in various combinations and various systems. The most common use of steam turbines in marine applications is in the engine room of LNG (Liquefied Natural Gas) carriers. The analyzed steam turbine is divided into two sections - The High Pressure (HP) section before steam extraction and the Low Pressure (LP) section after steam extraction. Analysis shows that the HP turbine section generates the majority of the cumulative turbine power and consequently has higher mechanical, energy, and activity losses when compared to the LP turbine section. The steam turbine has a power of 1178.40 kW, a new steam temperature of 379°C, a mass flow rate of 8.80 t/h, a steam enthalpy of 3172.9 kJ/kg, and produces an efficiency of 65.58% [18].

From previous research, the efficiency value of an induction motor is greater when compared to a steam turbine, therefore this study wants to prove the efficiency between an induction motor and a steam turbine as a mill drive at the Kebon Agung Sugar Factory. The positive impact of this analysis on the Kebon Agung Sugar Factory is that it can increase the quantity and quality of the sugar productionTheoretical section.

2. Experimental

2.1 Methods

This study used an experimental method with observation and testing at the Kebon Agung Sugar Factory, Malang, Indonesia. The induction motors analyzed are in mills 1, 2, and 5 (see Figure 1). At the same time, the turbines analyzed were cane cutter 1, cane cutter 2, heavy-duty hammer shredder, mill 3, and mill 4 (see Figure 2). Motor and turbine data are obtained through the control system, and all measuring instruments connected to the control system have been calibrated to produce valid data. Furthermore, the motor and turbine data are processed, and the efficiency ratio is calculated, as shown in Figure 3.

Induction motor data obtained through the control system is processed using the following Equation 1.

$$\eta = \frac{P_{OUT}}{P_{IN}} \times 100\% \quad (1)$$

where: η = Efficiency of induction motor P_{OUT} = Power out of indution motor, P_{IN} = Input power of induction motor.

Steam turbine data obtained through the control system is processed using the following Equation 2.

$$\eta_{Turbine} = \frac{Heat\ energy\ in\ kwH}{HRT} \times 100\% \quad (2)$$

where: $\eta_{Turbine}$ = Turbine efficiency %,1 kWh = 860 kcal, HRT = Turbine heat rate, $Wt = h_1 - h_2$, $Wt = \dot{m} \times w_{Turbine}$, $Wta = Wt \times \eta_{Turbine}$,

where: Wt = The power generated by the turbine (kW), Wta = Turbine actual power (kW).

Figure 1: Induction motor in mills 1,2, and 5

Figure 2: Steam turbines at mills 3 and 4

Figure 3: Retrieval of motor and turbine data in the control system

3. Results and Discussion

3.1 Data

3.1.1 Induction motor data

The object of this study is a three-phase induction motor at mill 1, mill 2, and mi,ll 3 and the specifications for a three-phase induction motor can be seen in Table 1 to Table 3.

Table 1: Induction motor data at mill 1

Parameter	Data	Unit
Type	Weg W50	
Speed	988	rpm
Voltage	380	volts (V)
Frequency	50	hz
Current	1005	ampere (A)
Input Power	676	kW
Power factor	0.94	

Table 2: Induction motor data at mill 2

Parameter	Data	Unit
type	Weg W50	
Speed	988	rpm
Voltage	380	volts (V)
Frequency	50	hz
Current	760	ampere (A)
Input Power	492	kW
Power factor	0.94	

Table 3: Induction motor data at mill 5

Parameter	Data	Unit
type	Weg W50	
Speed	988	rpm
Voltage	380	volts (V)
Frequency	50	hz
Current	1018	ampere (A)
Input Power	685	kW
Power factor	0.98	

3.1.2 Steam turbine data

Data collection on this steam turbine by a direct survey of Kebon Agung Sugar Factory can be seen in the Table 4 to Table 8.

Cane cutter 1 (CC 1)

Table 4: Turbine data on cane cutter 1

Parameter	Data	Unit
New steam pressure (P_1)	19	kg/cm^2
Used steam pressure (P_2)	1	kg/cm^2
New steam temperature (T_1)	325	celsius
Used steam temperature (T_2)	170	celsius
Mass flow rate($\dot{m}$)	6,1	kg/s
Torque	0.2873	n m
New steam enthalpy(h_1)	3083,1	j/kg
Used steam enthalpy(h_2)	2815,5	j/kg

Cane cutter 2 (CC 2)

Table 5: Turbine data on cane cutter 2

Parameter	Data	Unit
New steam pressure (P_1)	19	kg/cm^2
Used steam pressure (P_2)	1	kg/cm^2
New steam temperature (T_1)	326	celsius
Used steam temperature (T_2)	170	celsius
Mass flow rate($\dot{m}$)	8.05	kg/s
Torque	0.4867	n m
New steam enthalpy(h_1)	3085,4	j/kg
Used steam enthalpy(h_2)	2815,5	j/kg

Heavy-duty hammer shredder (HDHS)

Table 6: Turbine data in heavy-duty hammer shredder (HDHS)

Parameter	Data	Unit
New steam pressure (P_1)	17	kg/cm^2
Used steam pressure (P_2)	1	kg/cm^2
New steam temperature (T_1)	328	celsius
Used steam temperature (T_2)	169	celsius
Mass flow rate($\dot{m}$)	10.55	kg/s
Torque	0.6967	n m
New steam enthalpy(h_1)	3094,5	j/kg
Used steam enthalpy(h_2)	2813,5	j/kg

Mill 3

Table 7: Turbine data on mill 3

Parameter	Data	Unit
New steam pressure (P_1)	19	kg/cm^2
Used steam pressure (P_2)	1	kg/cm^2
New steam temperature (T_1)	326	celsius
Used steam temperature (T_2)	172	celsius
Mass flow rate($\dot{m}$)	4.72	kg/s
Torque	0.2753	n m
New steam enthalpy(h_1)	3085,4	j/kg
Used steam enthalpy(h_2)	2819,5	j/kg

Mill 4

Table 8: Turbine data on mill 4

Parameter	Data	Unit
New steam pressure (P_1)	18	kg/cm^2
Used steam pressure (P_2)	1	kg/cm^2
New steam temperature (T_1)	324	celsius
Used steam temperature (T_2)	170	celsius
Mass flow rate($\dot{m}$)	4.72	kg/s
Torque	0.2753	n m
New steam enthalpy(h_1)	3083,3	j/kg
Used steam enthalpy(h_2)	2815,5	j/kg

3.2 Comparison of Induction Motor Efficiency

Figure 4 and Table 9 explain that mill 1, with an input power of 676 kW and an output power of 621 kW, produces an efficiency of 91.97%. In contrast, mill 2, with an input power of 492 kW and an output power of 470 kW, has an efficiency of 95.56%. Mill 5, with an input power of 685 kW and an output power of 656 kW, produces an efficiency of 95.85%. In mill 1, it gets the lowest efficiency compared to mill 5, which has the highest efficiency. The reason is that the current that comes out of mill 5 is higher than that of mill 1. The input power issued by mill 5 is also higher than mill 1. The power factor in mill 5 is larger than mill 1, and in addition to other causal factors, the age factor of the induction motor in mill 1 is older than the age factor in mill 5.

Table 9: Comparison of induction motor efficiency

Parameter	Mill 1	Mill 2	Mill 5	Average	Unit
Pout	621	470	656	582.3	kW
Pin	676	492	685	617,7	kW
η	92	96	96	94.7	%

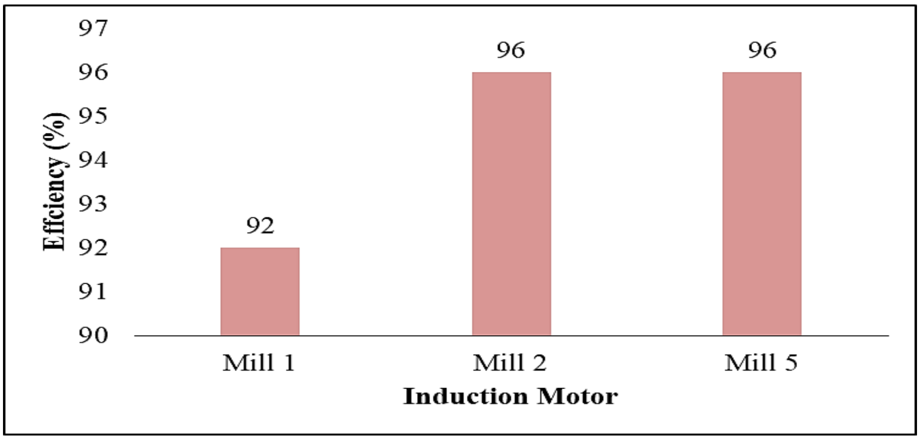

Figure 4: Comparison of induction motor efficiency

3.3 Comparison of Power and Efficiency of Steam Turbine

Figure 5 and Table 10 explain that CC 1 with an internal energy of 1 kWh equals 860 kcal, HRT 1358 kcal, with a torque of 0.2873 Nm, produces an efficiency of 63%, produces 1632 kW of power, and produces an actual power of 1034 kW. In CC 2, with an internal energy of 1 kWh equal to 860 kcal, HRT 1066 kcal, with a torque of 0.4867 Nm, produces an efficiency of 81%, produces 2173 kW of power, and produces an actual power of 1753 kW. In HDHS with an internal energy of 1 kWh equal to 860 kcal, HRT 1016 kcal, with a torque of 0.6967 Nm, produces an efficiency of 85%, produces 2965 kW of power, and produces an actual power of 2509 kW. In Mill 3, with an internal energy of 1 kWh equal to 860 kcal, HRT 1089 kcal, with a torque of 0.2753 Nm, it produces an efficiency of 79%, produces 1255 kW of power, and creates an actual power of 991 kW. In Mill 4, with an internal energy of 1 kWh equal to 860 kcal, HRT 1096 kcal, with a torque of 0.2753 Nm, produces an efficiency of 78 %, produces 1264 kW of power, and produces an actual power of 992 kW. CC 1 gets the lowest efficiency compared to HDHS, which has the highest efficiency. The reason is that the torque from HDHS is higher than the torque from CC 1, and the mass flow rate in HDHS is also greater than the mass flow rate in CC 1. Furthermore, HDHS is indeed made higher than the others because HDHS requires the most power compared to the others.

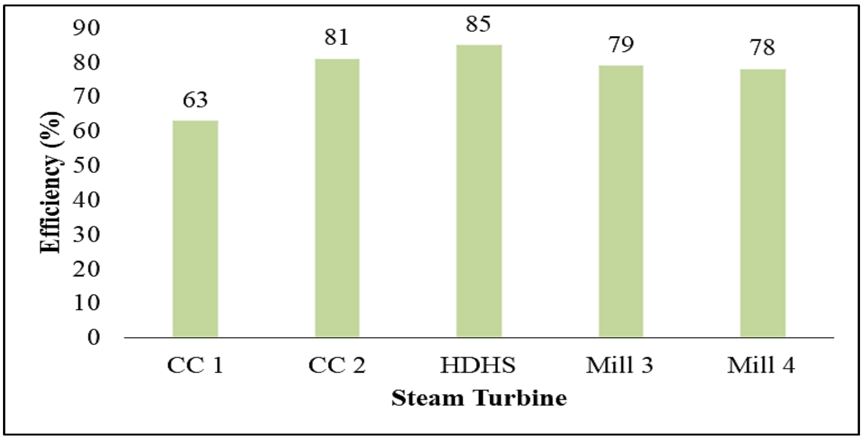

Figure 5: Comparison of steam turbine efficiency

Table 10: Comparison of turbine power and efficiency

Parameter	CC 1	CC 2	HDHS	Mill 3	Mill 4	Average	Unit
Power	1632	2173	2965	1255	1264	1857,8	kW
Actual Power	1034	1753	2509	991	992	1455.8	kW
Efficiency	63	81	85	79	78	77,2	%

3.4 Comparison of Induction Motor and Steam Turbine Efficiency

Figure 6 shows the comparison of induction motor and steam turbine efficiency. In the process, cane cutter 1 functions to cut cane which is still a protrusion into a size of about 10-15cm. To support the performance of the sugar cane cutting machine 1, it is better to use an induction motor to drive it, because an induction motor has a higher efficiency compared to a steam turbine and is easier to maintain than a steam turbine.

In the process of cutting sugar cane 2 it also functions to cut cane after cutting cane 1 so that the cane logger 1 has cut the cane even finer. To support the performance of the sugar cane cutting machine 2, it is better to use an induction motor to drive it. An induction motor has a higher efficiency compared to a steam turbine and is easier to maintain than a steam turbine.

HDHS (Heavy Duty Hammer Shredder) The HDHS process consists of a Hammer Holder and at the end, there is a hammer (hammer migrator) strung on a rotating drive shaft, the function of HDHS is to hit rattan that has been cut in cane cutter 1 and cane cutter 2, then sliced according to cane structure. crushed and destroyed. In HDHS this is a process that requires more energy compared to other processes. To support HDHS performance, it is better to use an induction motor as an induction motor. Induction motors have higher efficiency than steam turbines and are easier to maintain than steam turbines.

In milling processes 1-5 the work function is more or less the same, namely with three rollers for milking sap, where the front rollers, top rollers, and rear rollers have different rotation directions. To get maximum results, the Kebon Agung Sugar Factory supplies water pulp to become bagasse. To support the performance of the wheel, it is better to use an induction motor to drive it. An induction motor has a higher efficiency compared to a steam turbine and is easier to maintain than a steam turbine.

Induction motors can be designed for a specific torque, rotation speed, and current parameters drawn according to their use. Therefore, these different designs produce different efficiency percentages at the motor output. When the motor power is increased, the efficiency must also be expanded to avoid unwanted power loss [19].

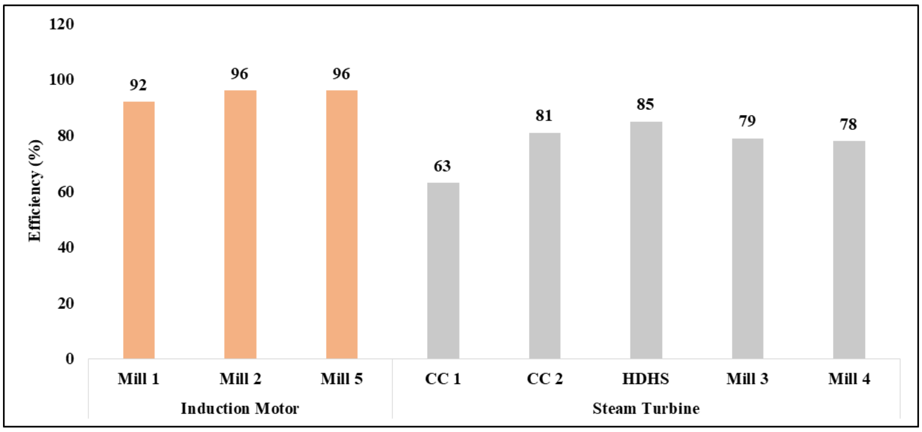

Figure 6: Comparison of induction motor and steam turbine efficiency

4. Conclusion

From the results of the analysis that has been carried out, the use of induction motors on mills 1, 2, and 5 gives an average efficiency of 94.7%. While the use of steam turbines at CC1, CC2, HDHS, Mill 3, and 4 provides an average efficiency of 77.2%. The recommendation given to Kebon Agung Sugar Factory is the use of induction motors on CC 1, CC 2, HDHS, mill 1, and mill 5. An induction motor is a relatively easy installation compared to a steam turbine. The construction is robust, high efficiency, minimal maintenance, and does not require special equipment during operation.

Author contributions

Conceptualization, R. Heni Hendaryati, Sudarman, D. Indra Baskoro, N. Susilo, C. Hendra Pamungkas, W. Satrio Nugroho, and Y. Komaril Sofi'i; formal analysis, R. Heni Hendaryati and Sudarman; resources, Willy Satrio Nugroho; data curation, N. Susilo and W. Satrio Nugroho ; writing—original draft preparation, Yepy Komaril Sofi'i; writing—review and editing, Damario Indra Baskoro; supervision, Yepy Komaril Sofi'i; project administration, Yepy Komaril Sofi'i. All authors have read and agreed to the published version of the manuscript.

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Data availability statement

Not applicable

Conflicts of interest

The authors of the current work do not have a conflict of interest

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