Volume 3, No. 10 October 2024 - (2344-2357)
p-ISSN 2980-4868 | e-ISSN 2980-4841
https://ajesh.ph/index.php/gp

Failure Pattern and Reliability Analysis of Mobile Biomass Gasifier Engine (Prototype 3) using Weibull Calculation as a Basis for Updating the Preventive Maintenance Activity Schedule

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ABSTRACT
Gasification is a technology that optimistically utilizes biomass to produce syngas (consisting of H2, CO, CO2, CH4) that can be used as an energy source while reducing excess CO2 emissions. However, if there are frequent failures due to unplanned maintenance activities, the engine performance will not be optimal. Therefore, an up-to-date reliability study is needed as a basis for updating preventive maintenance activities to maintain the quality of the engine so that it continues to operate properly and is durable. This research aims to analyze the reliability, unreliability, and availability of the Mobile Biomass Gasifier (Prototype3), as well as study the failure patterns measured using the shape parameter (β) with the Weibull distribution. The focus of this research is on the Suction blower which based on Pareto results is the equipment with the highest failure frequency. The results show that the average reliability is smaller than the failure rate. In addition, the value of the shape parameter (β) > 1, which means that the damage rate increases as the component ages. The implication of this study shows the need to update the preventive maintenance (PM) schedule by considering the addition of new PM activities that are in accordance with the duration of the life of the components that cause machine damage.

Keywords: Biomass Gasifier, Weibull, Preventive Maintenance.

INTRODUCTION

Consuming non-renewable energy can encourage economic development, but excessive use will cause many environmental problems due to excessive CO2 emissions (Rahmandani & Dewi, 2023). Fully utilizing renewable energy has become an important initiative in reducing carbon emissions (Apriliyanti & Rizki, 2023).

Biomass is one of the renewable energy sources that can at least partially replace fossil fuels (Yana et al., 2022). Some countries have policies to encourage the use of biomass as energy for both heat and electricity, especially those in tropical regions that have year-round agriculture

(Radhiana et al., 2023). The potential of biomass in Indonesia that can be used as an energy source is very abundant, Indonesia's biomass potential is 146.7 million tons per year.

Gasification is a technology that optimistically utilizes biomass to produce syngas (consisting mainly of H2, CO, CO2, CH4) that provides heat, power, and valuable chemical products. Biomass gasification is the process of converting cellulosic material in a gasification reactor (gasifier) into fuel (Parinduri & Parinduri, 2020).

Mobile Biomass Gasifier (P3) gasification technology is one of the technologies developed by the University of Indonesia Gasification Laboratory, a machine that is expected to be able to utilize biomass in producing energy and reducing excessive CO2 emissions. However, this machine has a durability that will experience a decrease in function due to use within a certain period of time. Therefore, an appropriate maintenance management is needed so that this machine is able to carry out its functions as expected or has high reliability. The reliability value of a machine or component can be determined using the Weibull distribution calculation (Margana & Suhendar, 2021).

The Weibull distribution is one of the most widely used distributions to analyze equipment life data in reliability engineering (Otaya, 2016). The weibull distribution has been recognized as an appropriate model in the calculation of reliability and failure time problems of a component or machine. In addition, the weibull distribution can be used to process damage data that is symmetrical to data that is not symmetrical. Weibull distribution is a generalization of the exponential distribution (Fitriyati, 2014). The two-parameter Weibull distribution can accommodate more flexible failure rates expressed through model parameters.

In this study, an analysis of the damage characteristics of a machine or component will be carried out using the calculation of the Weibull distribution which will then become the basis for determining the most optimal maintenance management. Weibull distribution calculations that will be carried out include: reliability level (Reliability), damage level (Unreliability) and availability level (Availability) of a component (Yasir & Saputra, 2022).

In maintenance management, there are two maintenance activities, namely tactical and non-tactical. In industrial systems, activities to maintain the reliability and availability of a machine play a very important role in improving operational conditions and the quality of output products. Tactical or commonly called planned maintenance (proactive maintenance) is a maintenance strategy by mapping all possible failures and then determining the most effective maintenance practice to do so that the machine does not fail (Izzati, 2022). Meanwhile, non-tactical is an unplanned maintenance activity due to damage from a machine that is not predicted in advance (Breakdown) so that it will extend downtime (Asyifa Madya, 2023). The planned maintenance techniques used are time-based maintenance, condition-based maintenance, and components left to fail or called run to failure. Each of these maintenance techniques has unique concepts/principles, procedures and challenges for real industrial practice.

Based on the background description above, the purpose of this study is to analyze the level of reliability, unreliability, and availability of the Suction blower component on the Mobile Biomass Gasifier (P3) using the Weibull distribution. This study also aims to determine the most optimal maintenance strategy to improve machine reliability by reviewing component failure patterns and identifying the right preventive maintenance schedule. The benefits of this research include several aspects. Practically, this research provides recommendations that can be implemented to improve the maintenance management of biomass gasification machines, especially the Mobile Biomass Gasifier (P3). With improved maintenance schedules and strategies, it is expected that the machine can operate with higher reliability and reduce the risk of unplanned failures. Theoretically, this research contributes to the development of knowledge related to reliability analysis using the Weibull distribution, which can be a reference for further research in the field of machine maintenance management.

RESEARCH METHOD

The research was conducted on Mobile Biomass Gasifier (P3) equipment located at PT Melu Bangun Wiweka, Bekasi, Tambun. This machine is the 3rd propotype developed from the 2nd protoype with a design that is considered more efficient.

This machine is a device for converting biomass into gas with a downdraft gasification type that can be utilized into electrical and heat energy through drying, pyrolysis, oxidation and reduction processes. The main components of this machine are: Bucket elevator, vibrating grate, rotary feeder, reactor, primary blower, screw ash removal, cyclone, condenser, filter, suction blower, PLC & engine.

The functions of the main components are:

a. Bucket elevator for continuous supply of biomass
b. The rotary feeder has the function of putting biomass into the reactor continuously and preventing smoke from escaping from the reactor.
c. Vibrating grate serves to flatten the biomass and reduce tar from the gasification results continuously.
d. The reactor serves as a place to carry out the gasification process with a downdraft gasifier type.
e. The primary blower serves to send air to the reactor with a speed of 0-50hz which is controlled through a PLC.
f. The ash removal screw is used to remove the remaining char from the reactor and sent to the ash box.
g. Cyclon serves to filter heavy particles such as ash in syngas. This cyclone contains water at the bottom which functions as an ash container so as not to pollute the environment due to leakage.
h. Condenser serves to reduce Tar on syngas by cooling Tar with radiator.

i. The filter serves to reduce Tar in syngas by absorption method.
j. Suction blower functions to suck or pull syngas produced from the reactor to be put into gas storage.
k. PLC functions to operate all motors in the system at P3 and as an apparatus control and data log when the machine is operating.

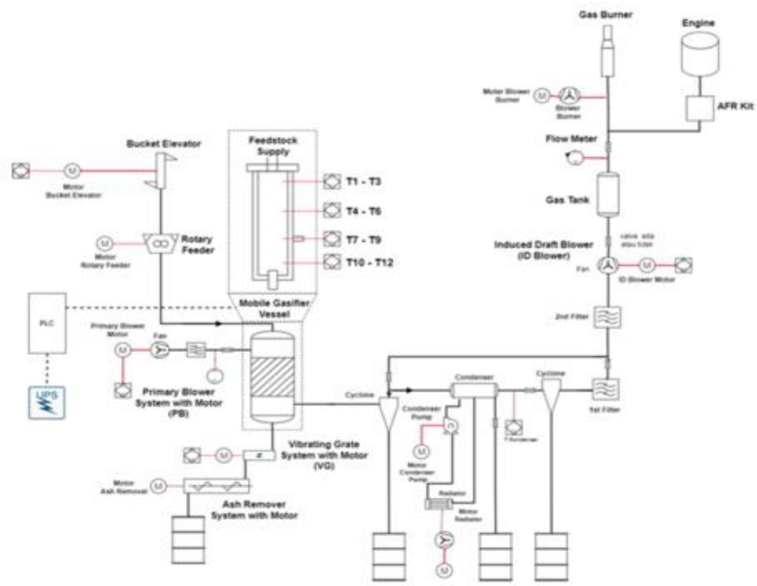


Figure 1. Mobile biomass gasifier (P3)

Weibull distribution

The Weibull distribution is one of the most widely used distributions to analyze reliability data and analyze the maintainability of equipment in reliability engineering. (Yusra et al., 2018). Weibull distribution is recognized as an appropriate model in the study of reliability and failure patterns of a component or product. Therefore, the Weibull distribution is generally used to determine the characteristics of the damage time (life) of a machine or how long the component will last until it fails. The relationship between time and damage distribution can be seen in Figure 2 below:

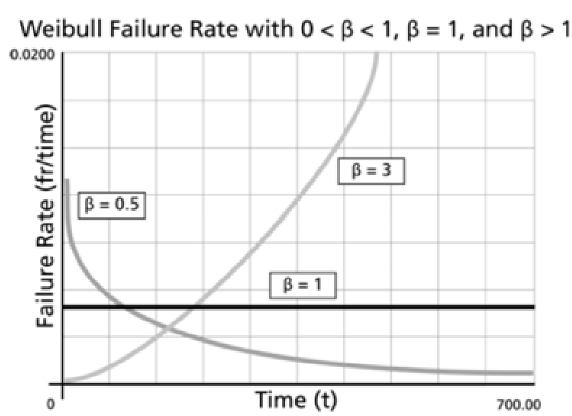


Figure 2. Relationship between time and damage distribution

Basically, the calculation of Weibull distribution parameter values uses the principle of linear regression, which makes the cumulative distribution function into a linear form and is expressed as follows**:**

$$F(ti) = 1 - \exp\left[-\left(\frac{ti}{\alpha}\right)\right]^{\beta}$$

$$1 - F(ti) = \exp\left[-\left(\frac{ti}{\alpha}\right)\right]^{\beta}$$

$$\text{In}\ [[1-F(ti)]^{-1}] = \left(\frac{ti}{\alpha}\right)^{\beta}$$

$$\text{In}\ [\text{In}[[1-F(ti)]^{-1}] = \text{In}\ \left(\frac{ti}{\alpha}\right)^{\beta}$$

$$\text{In}\ [\text{In}[[1-F(ti)]^{-1}] = \beta\text{In}\ \left[\left(\frac{ti}{\alpha}\right)\right]$$

$$\text{In}\ [\text{In}[[1-F(ti)]^{-1}] = \beta[\text{In}(ti) - \text{In}(\alpha)]$$

$$\frac{1}{\beta}\ [In[In[[1 - F(ti)]^{-1}]]] = In(ti) - \ln(\alpha)$$

$$\frac{1}{\beta}\ [In[In[[1 - F(ti)]^{-1}]]] + In(\alpha) - \ln(ti)$$

To simplify the calculation, the final equation is obtained as follows:

$$Yi = a + b\ Xi$$

By:

$$Yi = \text{In}(ti);\ a = \text{In}(\alpha);\ b = 1/\beta$$

Thus the equation is obtained:

$$Xi = \text{In}\ [\text{In}[1-F(ti)]\ ]^{-1}$$

Xi is the independent variable that can be calculated with the cumulative distribution function from the following equation:

$$F(ti) = \frac{i - 0.3}{n + 0.4}$$

For Weibull parameter estimation, there are two methods that will be used to calculate the cumulative distribution function:

a) Median Rank Method Benard's formula
b) Kaplan-Maier Estimation

Since Kaplan-Maier estimation requires a large data size to make a suitable plot, the Median Rank Benard's formula is used in the analysis process. Therefore, F(ti) can be estimated with Benard's formula for median rank estimator with the equation as above.

The constant values of a and b can be obtained using the least square method, the values of a and b are obtained from the following equation:

$$b = \frac{N\sum_{i=1}^{n} XiYi - (\sum_{i=1}^{n} Xi)(\sum_{i=1}^{n} Yi)}{N\sum_{i=1}^{n} Xi^2 - (\sum_{i=1}^{n} Xi)^2}$$

$$a = \frac{\sum_{i=1}^{n} Yi}{N} - b\frac{\sum_{i=1}^{n} Xi}{N}$$

Then the parameters of this Weibull distribution can be obtained from

$$\beta = \frac{1}{b}$$

$$\alpha = \exp^{a}$$

Reliability is a measure of the level of successful performance of a component or machine (Asmoro & Widiasih, 2022). Reliability is the probability that a machine can operate satisfactorily under certain conditions and at a certain time. The level of reliability is calculated using the equation:

$$R(t) = 1 - F(t) = \exp\left[\left(\frac{t}{\alpha}\right)^{\beta}\right]$$

The cumulative distribution function/damage rate (Unreliability), is the probability of a machine failing so that the machine can function as desired. The level of damage or unreliability can be calculated using the equation:

$$F(t) = 1 - R(t)$$

$$F(t) = 1 - \exp\left[-\left(\frac{t}{\alpha}\right)^{\beta}\right]$$

The level of availability (Avilability), is the readiness of a machine or equipment both in quality and quantity to be utilized as desired. The availability value in units of time can be calculated with the following equation:

$$\text{Availability} = \frac{TTF}{TTF+TTR}$$

With:

TTF= time to failure

TTR= time to repair

Failure pattern curve

In 1978, in the report *Relibaility Centered Maintenance*, (Nowlan & Heap, 1978) introduced the first iteration of maintenance techniques with potential failure (PF) curves to manage the reliability of equipment. The pattern of possible failures in the context of the length of operation varies from both electrical and mechanical. Based on Heap & Nolan's research there are six failure pattern curves related to equipment operated in industry as shown in Figure 3. The shape of the failure pattern curve will indicate whether the type of failure is in the early stage or *infant mortality* stage, random failure or wear and tear due to age of use.

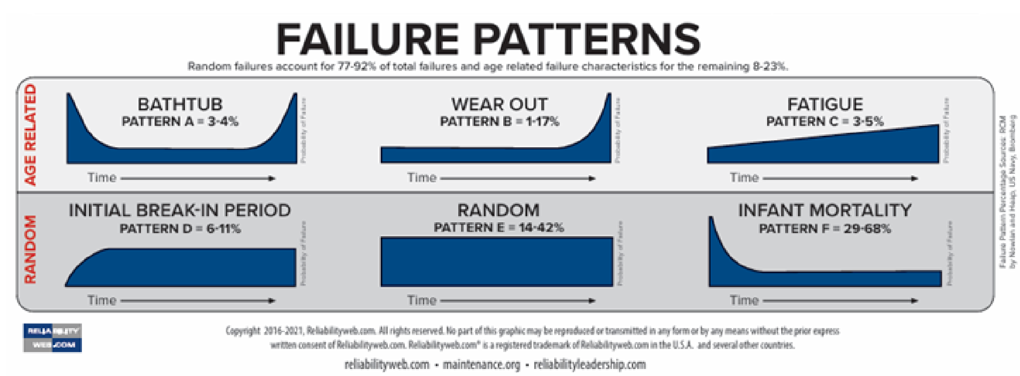


Figure 3. D-I-P-F Curves and Failure Patterns

Source: (Connect, 2014)

In general, the rate of machine failure will change over time and follow a basic curve pattern called a bathtub curve. The following figure 4. bathtub curve:

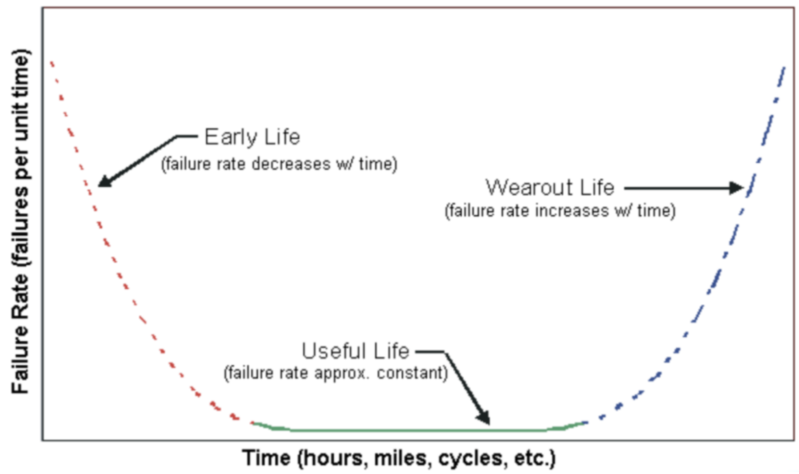


Figure 4. T Curve of Bathtub

Source: (Reliasoft, 2014)

As shown in the plot of Fig. 5 that the Weibull failure function or failure rate depends on the value of β or also called the shape parameter. The following table classifies failures and their possible causes based on the *slope* value:

Table 1. Damage pattern of the bathtub curve

Pattern	Class	Description
Early life (β < 1.0)	High probability of early damage (Infant Mortality)	When β < 1.0, failures are likely due to : a) Selection of spare parts at the time of purchase b) Quality of the components c) Poor quality of installation fabrication or wear and tear d) Problems during refurbishment
Useful life (β =1.0)	Probability of damage is independent of time (Random Failure)	When β = 1.0, failures are likely due to : a) Mechanic error during repair b) Operation process error by operator c) Accident or damage due to environment (Foreign objects, etc.)
Wearout life (β >1.0)	Probability of damage based on design life (Wear out)	When β>1.0, failures are likely due to : a) Low cycle fatigue. b) Bearing failures. c) Corrosion/erosion. d) Manufacturing process.

RESULT AND DISCUSSION

Data processing

Failure data for the Mobile Biomass Gasifier (P3) engine, obtained from interviews with the maintenance and operations team. The failure data taken is from 2022-2023. Based on the interview results, the failure data is still based on assumptions because there is no Work order (WO) record data and production is still not carried out routinely continuously because it is still at the development stage. During this period, there were 82 failures that occurred in the Mobile Biomass Gasifier (P3) machine as in the following table:

Table 2. Mobile biomass gasifier (P3) engine failure data

No.	Machine	Number of failures
1	Suction Blower	16
2	Vibrating grate	15
3	Rotary feeder	12
4	Bucket elevator	10
5	Filter	7
6	Screw ash removal	6
7	Condenser	4
8	Cyclone	3
9	PLC	3
10	Primary blower	2
11	Engine	2
12	Reactor	2
	Total	82

Determining the focus of the discussion

The focus of discussion taken in this research is a machine that has a cumulative failure percentage of 20%. Based on Table 2, a Pareto diagram of Mobile Biomass Gasifier (P3) machine failures was made to see which machines have a cumulative failure percentage of 20%. The following is a picture of the Pareto diagram of the Mobile Biomass Gasifier (P3) engine failure:

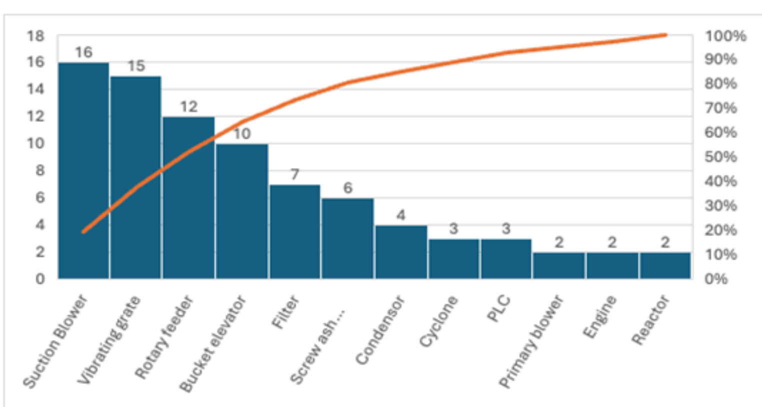


Figure 5. Pareto diagram of Mobile Biomass Gasifier engine failure (P3)

Based on the diagram above, it can be seen that the suction blower component has a cumulative failure percentage of 20%, the focus of the research discussion is directed at this component.

Variable Calculation

From the results of damage and repair records on the Mobile Biomass Gasifier (P3) machine, it is then analyzed by entering two variables to find out two important variables into the Weibull distribution table, namely TTF (Time to failure) and TTR (Time to repair) so that further calculations can be carried out. With these two variables, the variables Yi, f(ti), Xi, Xi2, XiYi, R(ti) or reliability, F(ti) or unreliability, and availability can be calculated.

The following is an example of calculating the Weibull distribution on the first data:

TTF (Time to failure) = 8 hours

TTR (Time to repair) = 1 hour

a. Yi = a + bXi; where Yi - ln(ti)
   Yi = ln (8)
   = 2.08

b. f(ti) = i - 0.3 / n + 0.4
   f(ti) = 1- 0.3 /16 + 0.4
   = 0,04

c. Xi = ln [ln[1-f(ti)$^{-1}$]]
   = ln [ln[1-0.04]]]$^{-1}$
   = -3,13

d. Xi^2 = $(-3.13)^2$
   = 9,81

e. XiYi = (- 3.13) x (6.21)
   = - 6,51

f. $$b = \frac{N\sum_{i=1}^{n} XiYi - (\sum_{i=1}^{n} Xi)(\sum_{i=1}^{n} Yi)}{N\sum_{i=1}^{n} Xi^2 - (\sum_{i=1}^{n} Xi)^2}$$
   b = 16(-10,26)-(-8,62)(30,40)/16(24,67)-(-8,62)^2
   = 0,305

g. β = 1/b
   = 1/ 0,305
   = 3

h. $$a = \frac{\sum_{i=1}^{n} Yi}{N} - b\frac{\sum_{i=1}^{n} Xi}{N}$$
   a = 30,40-(0,305)(-8,62)/16
   a = 2,1
   a = ln(α)
   α = exp^{a}

$= exp^{a}2,1$

$= 7,88$

i. R(ti) = exp [-(ti/α)β]

= exp [- 8/7,88)3]

= 0,366

j. F(ti) = 1- R (ti)

= 1- 366

= 0,633

Figure 6 Weibull distribution calculation results for data of all suction blowers that experienced damage and repair for all types of failures:

No	ipment descript	Failure description	Failure mode	TTF (Hrs)	TTR (Hrs)	Yi	f(ti)	Xi	Xi2	Xi.Yi	R(ti)	F(ti)	Availability
1	Suction Blower	Performance decreases due to deposit tar on suction pipe	Pipe clog	8,0	1,0	2,08	0,04	-3,13	9,81	-6,51	0,366162902	0,633837098	0,88888889
2	Suction Blower	Performance decreases due to deposit tar on blade and cause unbalan	Blade unbalance	4,0	0,5	1,39	0,10	-2,21	4,89	-3,07	0,443401965	0,556598035	0,88888889
3	Suction Blower	Performance decreases due to deposit tar on suction pipe	Pipe clog	3,0	0,5	1,10	0,16	-1,72	2,94	-1,88	0,474744116	0,525255884	0,85714286
4	Suction Blower	Performance decreases due to deposit tar on blade and cause unbalan	Blade unbalance	6,5	0,5	1,87	0,23	-1,36	1,86	-2,55	0,389441664	0,610558336	0,92857143
5	Suction Blower	Performance decreases due to deposit tar on suction pipe	Pipe clog	5,0	0,5	1,61	0,29	-1,09	1,18	-1,75	0,418725846	0,581274154	0,90909091
6	Suction Blower	Performance decreases due to deposit tar on suction pipe	Pipe clog	6,0	0,5	1,79	0,35	-0,85	0,72	-1,52	0,398397881	0,601602119	0,92307692
7	Suction Blower	Performance decreases due to deposit tar on blade and cause unbalan	Blade unbalance	7,5	0,5	2,01	0,41	-0,64	0,41	-1,30	0,373401988	0,626598012	0,9375
8	Suction Blower	Performance decreases due to deposit tar on suction pipe	Pipe clog	4,0	1,5	1,39	0,47	-0,46	0,21	-0,63	0,443401965	0,556598035	0,72727273
9	Suction Blower	Performance decreases due to deposit tar on suction pipe	Pipe clog	5,0	0,5	1,61	0,53	-0,28	0,08	-0,45	0,418725846	0,581274154	0,90909091
10	Suction Blower	Performance decreases due to deposit tar on suction pipe	Pipe clog	6,0	1,0	1,79	0,59	-0,11	0,01	-0,20	0,398397881	0,601602119	0,85714286
11	Suction Blower	Performance decreases due to deposit tar on suction pipe	Pipe clog	5,0	0,5	1,61	0,65	0,06	0,00	0,09	0,418725846	0,581274154	0,90909091
12	Suction Blower	Performance decreases due to deposit tar on suction pipe	Pipe clog	7,0	0,5	1,95	0,71	0,22	0,05	0,43	0,381138293	0,618861707	0,93333333
13	Suction Blower	Performance decreases due to deposit tar on blade and cause unbalan	Blade unbalance	5,0	0,5	1,61	0,77	0,40	0,16	0,64	0,418725846	0,581274154	0,90909091
14	Suction Blower	Performance decreases due to deposit tar on suction pipe	Pipe clog	4,5	0,5	1,50	0,84	0,59	0,35	0,89	0,430410089	0,569589911	0,9
15	Suction Blower	Performance decreases due to deposit tar on suction pipe	Pipe clog	6,0	1,0	1,79	0,90	0,82	0,67	1,47	0,398397881	0,601602119	0,85714286
16	Suction Blower	Bearing wear	Bearing wear	200,0	0,5	5,30	0,96	1,15	1,32	6,09	0,068504844	0,931495156	0,99750623
						30,40	8,00	-8,62	24,67	-10,26			

Figure 6. Weibull Distribution Calculation Results for Suction Blower Components Experiencing Damage and Repair for Various Failure Types

Failure curve

Based on the calculation results, the shape parameter value (β) is 3 or β> 1. In accordance with the Weibull curve or bathtub in Figure 6 shows the value of the shape parameter (β) in accordance with the damage pattern, namely wearout life, where the potential possibility of damage is getting bigger along with the operating time.

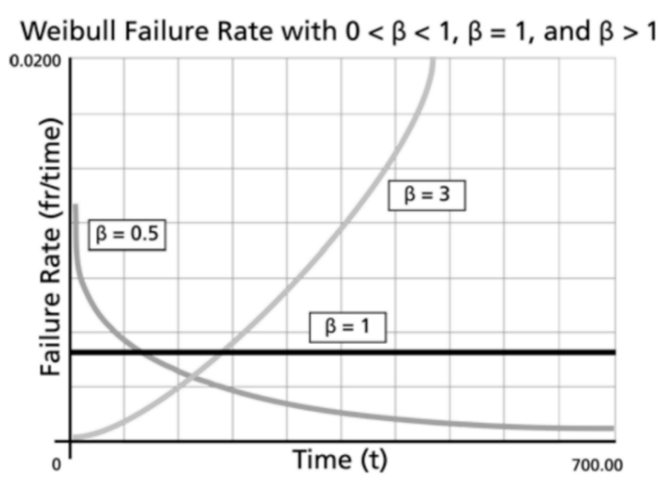
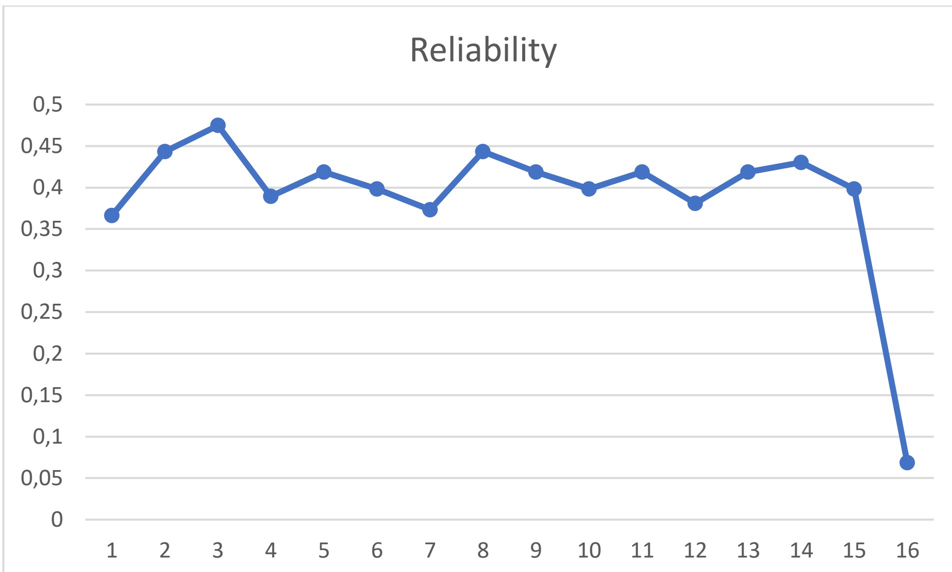


Figure 7. Curves in the early life condition due to the value of β<1.

Because the pattern of damage or failure in the suction blower tends to be in line with the age of operation, the possible causes are life cycle fatigue, bearing failure etc. From the results of interviews, this damage pattern is mostly caused by operating patterns that are still not optimal so that blockages often occur in the gas flow channel due to the tar contained in the syngas, besides that the tar residue can cause buildup on the blade of the blower and cause unbalance and damage to other parts such as bearings. This condition will cause a decrease in suction performance. Conditions like this need an optimal maintenance plan to prevent a decrease in performance or catastrophic failure and disruption of the production process if operated continuously.

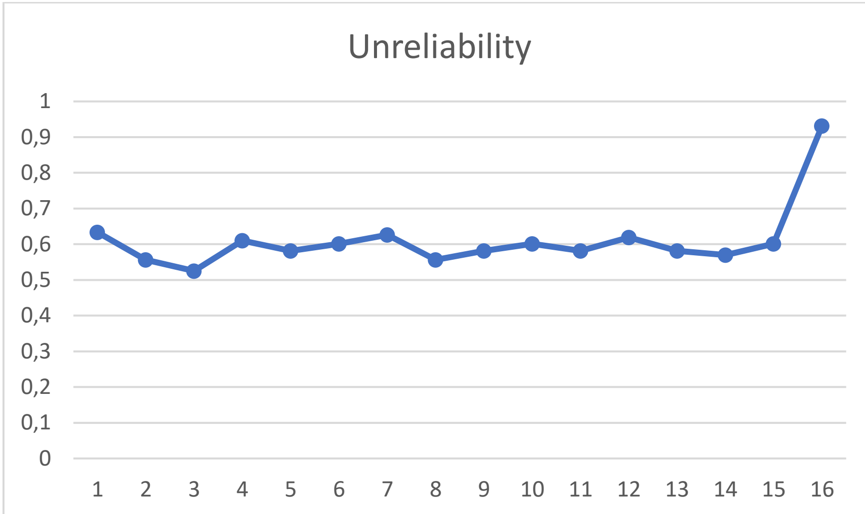
Reliability rate



Graphic 1. Reliability rate

Based on graph 1, it shows that the highest reliability rate R (ti) is in the 3rd data, namely 0.47 which has the lowest TTF (Time to failure) value compared to the others, namely 3 hours. Meanwhile, the lowest reliability rate is shown in the 16th data, which is 0.06 and has the highest TTF (Time to failure) of 200 hours. From these data it can be concluded that the reliability rate will be inversely proportional to the damage time (TTF). Where the longer the component is damaged, the reliability value decreases. From the reliability value data it can also be concluded that a better maintenance plan or operating pattern is needed to increase the reliability of a machine so that it can be operated according to wants and needs.

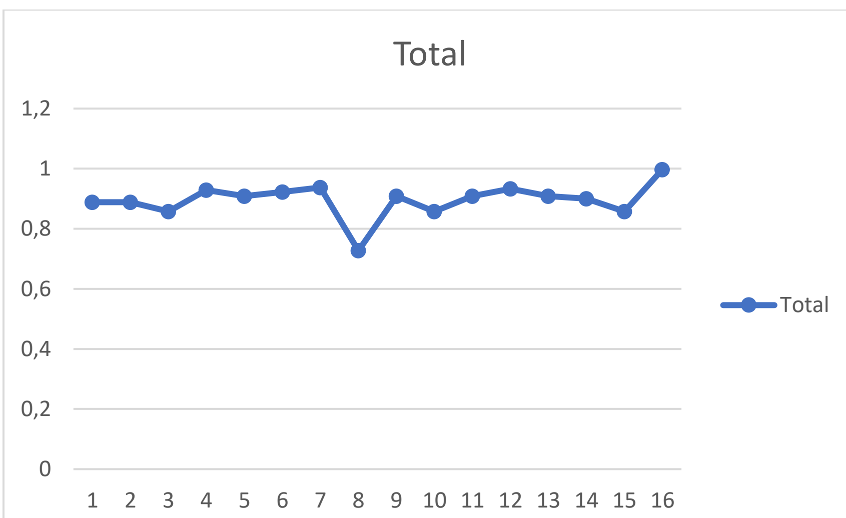
Failure Rate (Unreliability)



Graphic 2. Failure rate (Unreliability)

Graph 2 shows that the highest failure rate F(ti) is achieved by the 16th data which has the highest TTF of 200 hours, and the lowest damage rate is shown by the 3rd data which has the lowest TTF of 3 hours. It can be concluded that if the tar content of the production is excessive, it will cause tar residue to accumulate on the suction blower and result in accelerated production decline and a more severe damage rate.

Availability Rate



Graphic 3. Availability rate

Based on graph 3, the highest level of availability is in the 16th data, where the TTR (Time to repair) in that data is 0.5 hours. The TTR value is relatively short because the work only does lubrication and cleaning, so the highest level of machine availability is 0.997. However, this will take longer if the damage becomes larger such as damage to the bearing due to contamination from syngas which has a lot of Tar residue.

CONCLUSION

The conclusion of this study clearly answers the stated objectives. Based on the analysis conducted, it can be concluded that the reliability of the Suction Blower on the Mobile Biomass Gasifier (P3) is lower than the unreliability, indicating an urgent need to update the maintenance strategy. The Weibull distribution shows that the component experiences increasing failure rates as it ages, so the preventive maintenance schedule needs to be optimized with the addition of new maintenance activities that extend the life of the component. The implications of this research support the reduction of unplanned downtime and improve machine operational efficiency, which in turn can support the sustainable use of renewable energy.

The future contribution of this research lies in the development of a reliability-based maintenance methodology that can be applied to biomass gasification engines and other renewable energy-based technologies. In addition, this research can serve as a basis for further research that explores the influence of other factors on engine reliability, such as the operational environment, raw material quality, and technological improvements. This research is also expected to encourage innovation in the design of more durable and more efficient engines, and support the achievement of future energy sustainability targets..

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Asian Journal of Engineering, Social and Health (AJESH)

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