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# Scheduling Preventive Maintenance Using Age Replacement Method for Test Tube Machine

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***ABSTRACT:*** *PT. X is a company engaged in the manufacturing industry of laboratory equipment and coffee makers. PT X production activities were carried out based on a make to order strategy, PT X experienced quite a large loss, judging from the production data PT X produced more than the number of requests but there were products that were rejected. The most dominant reject is cracked reject, the reject has the most influential factor, namely a damaged machine. When viewed from the frequency of machine breakdowns, the Test Tube engine is the most frequently damaged machine. PT X only has 1 unit of Test Tube machine, with the function of this machine which greatly affects the quality of the products made. Test Tube machine is used in the process of making Test Tube products. The Test Tube machine has 15 components, namely ceramic, wire ram, wire ram clamp retaining plate, fire brick, rocker, conveyor chain, regulator, brander plate, bearing, rubber roll, inventor, drive motor, fan, ven belt, LPG hose. The current policy implemented by PT X is that the maintenance department will repair the machine if the machine is damaged (corrective maintenance), the company must apply a preventive maintenance method using the preventive maintenance method.*

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## I. INTRODUCTION

PT X is a company that operates in the laboratory equipment manufacturing industry, where this company is located West Java Indonesia. PT X was founded in 1991, with its parent company, Pudak Scientific, which was founded in 1979 with the main product being educational demonstration equipment.

Currently PT X produces laboratory equipment made from borosilicate glass, because X is a trusted partner in the field of educational equipment, the products produced are Beakers, Erlenmeyer, Test Tubes and other educational teaching aids, where these types of products are made from heat-resistant glass made from borosilicate.

PT X production is carried out based on a make to order system, this system implements production activities where if there is a product order then PT. X will produce these products according to demand. In carrying out the production process, a product will not always be good, there will be rejects caused by several factors. Likewise at PT. X in every production process there are several product rejects.

Following is percent age rejected product in PT X period January 2022-December 2022:

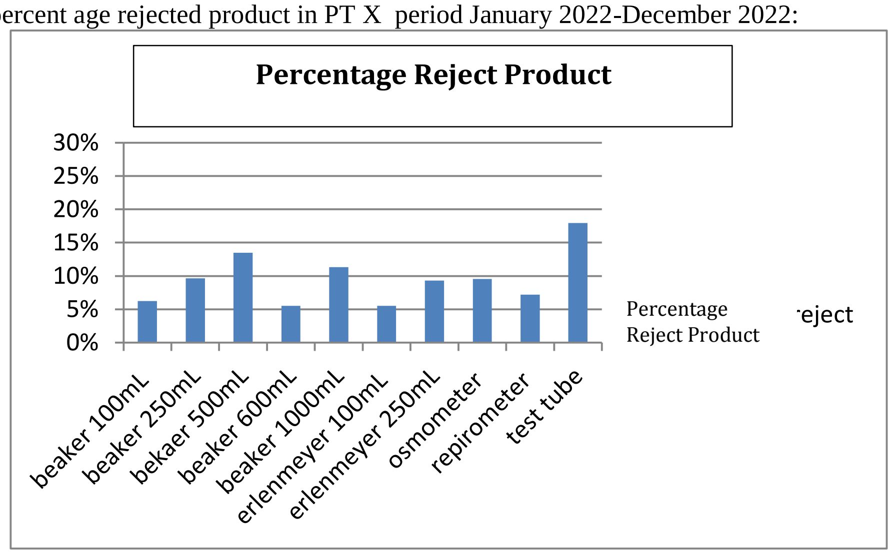


Figure 1. Percentage Reject Product

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From the diagram above, it can be seen that the most rejected products are Test Tube products. So the product that will be discussed is the test tube, this type of product is the type of product that is most in demand by consumers because it is often used in laboratory analysis in various methods. The high demand for this product means that PT X always produces Test Tube products in large quantities compared to other products. The large number of rejected products causes product production costs to increase due to the use of raw materials and wasted work time. The following is data on losses from testube products in the period January 2022 – December 2022:

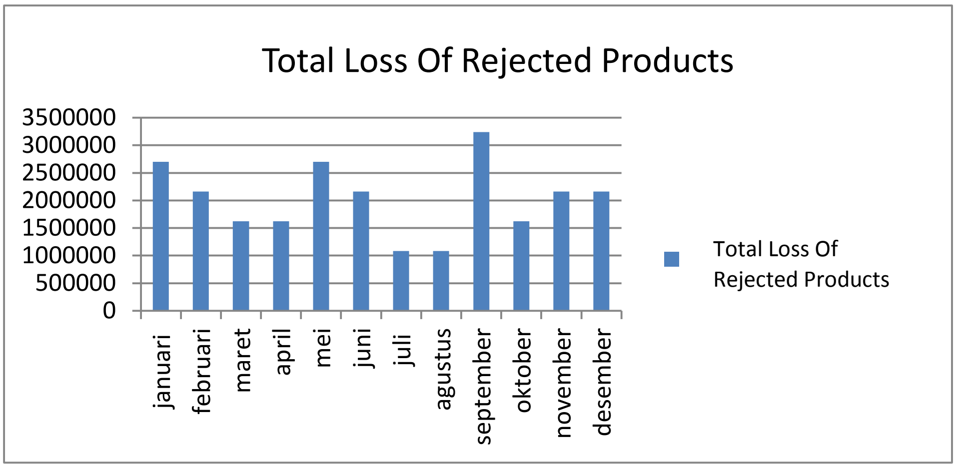


Figure 2. Total Loss of Rejected Products

From data the company must know reason rejected from something product , And How method finish the problem

## II. EXPERIMENTAL SETUP

Maintenance is an activity to maintain or maintain facilities by carrying out maintenance, repairs, adjustments or replacing some of the equipment needed so that the facilities are in the expected condition and are always ready to use.

Maintenance plays a very important role in the production activities of a company because it involves the smooth running of the production process, ensuring that there are no idle resources due to damage (downtime) to machines during the production process, thereby minimizing wasted production costs, and production results can be received by consumers on time.

a. Some of the treatment goals are as follows:
b. Production capabilities can meet production needs in accordance with the production plan
c. Overcoming all problems and obstacles that occur during the production process
d. Minimizes idle time (downtime) when the engine is off
e. Increasing the efficiency of production resources
f. Minimize repair costs and costs arising from stopping the production process due to machine problems
g. Extends the life/service life of equipment facilities

In industry there are various types of treatment that can be applied. The following are the types of treatment:

1. Preventive maintenance (Preventive Maintenance)

Preventive maintenance includes all maintenance activities aimed at preventing failures or detecting failures before they develop into damage to production facilities. Preventive care is divided into 2, namely:

a) Immediate preventative care

A preventive maintenance activity that has a direct effect on the condition of equipment, such as routine cleaning and replacement of spare parts. This maintenance is often called Fixed Time Maintenance (FTM) because all of these activities are controlled in units of time.

b) Indirect preventive care

A preventive maintenance activity that does not have a direct effect on the condition of the equipment. Activities usually carried out are damage detection and monitoring or often also called Condition Based Maintenance (CBM).

2. Repair Treatment

Repair maintenance is a maintenance activity that aims to modify equipment. Modification of components of equipment aims to extend the life of components, increase the technological value of components that are already obsolete.

3. Corrective Maintenance (Corrective Maintenance)

Corrective maintenance includes all maintenance aimed at repairing damaged equipment. It is also called Emergency Maintenance or Breakdown Maintenance because it is carried out when there are signs of damage or when the machine has stopped because it is damaged.

Overall Equipment Effectiveness (OEE)is the amount of effectiveness possessed by equipment or machines. OEE is calculated by obtaining the availability of equipment, work efficiency of the process and rate of product quality.

In implementing OEE there are several benefits that can be taken from OEE, including:

a. Can be used to determine the starting point of the company or equipment/machines.
b. Can be used to identify bottleneck events on equipment/machines.
c. Can be used to identify productivity losses (true productivity losses).
d. Can be used to determine priorities in efforts to increase OEE and increase productivity. (Destya Prasetyo, 2020)

According to Nakajima (1988) there are 6 major losses that cause low performance of equipment which causes low performance of equipment. These six losses are called the six big losses which consist of:

a. Startup Loss,categorized as quality loss due to scrap/reject during production startup caused by machine setup errors, insufficient warm-up process and so on.
b. Loss Adjustment Setup,categorized as downtime loss due to "stolen" time due to long setup times caused by product changeovers, lack of material (material shortages), absence of operators (operator shortages), machine adjustments, warm-up time, and so on.
c. Cycle Time Loss (reduce speed), categorized as speed loss due to a decrease in process speed caused by several things, for example: the machine is worn out, below the capacity written on the nameplate-
d. performance, below expected capacity, operator inefficiency, and so on.
e. Chokotei Loss (minor stoppage), is categorized as speed loss because there is a minor stoppage, namely the machine stops quite often for a short duration, usually no more than ten minutes and does not require maintenance personnel. This is because the machine hangs so it has to be reset, there is cleaning/checking, sensors are blocked, delivery is blocked, and so on.
f. Breakdown Loss, categorized as downtime loss due to damage to machinery and equipment, unscheduled maintenance, and so on.
g. Defect Loss is categorized as quality loss due to rejects during production.

Six Big Lossescalculated to determine the OEE of a piece of equipment so that steps can be taken to improve the machine effectively. From the six losses above, it can be concluded that there are three types of losses related to the production process that must be anticipated, namely:

a. Downtime losswhich affects the Availability Rate,
b. Speed losswhich affects Performance Rate, and
c. Quality losswhich affects the Quality Rate or also called FTT (first time through). (Bori, S, 2006)

When carrying out maintenance on a facility system or equipment, there are several elements that must be considered. Maintenance in production activities has various time elements which can be distinguished as follows:

a) Operating Time (Up Time)

Operation time is the time when the machine functions properly and is used by the system to carry out activities.

b) Delay Time

Delay time is the time when the machine is functioning properly but is not used by the system.

c) Obstacle Time (Down Time)

Obstacle time is the time when the system cannot be used due to damage that occurs.

The age replacement model is where the time interval for component replacement takes into account the useful life of the component, so as to avoid replacement of equipment that has just been installed, it will be replaced in a relatively short time, if damage occurs, this model will readjust the schedule after the component replacement is carried out. whether due to damage or simply as preventive maintenance.

This model is suitable to be applied to components whose replacement interval relatively does not affect the life of other components or components which are replaced simultaneously, meaning that this model applies if there is component damage in a set of machines, then only one component that is damaged will be replaced. In the age replacement model, the point is that when a replacement is carried out it depends on the age of the component, so preventive replacement will be carried out by resetting the next replacement time interval according to the predetermined interval.

The age replacement model has two preventive replacement cycles, namely:

a. Cycle 1 or the preventive cycle which ends with preventive replacement activities, is determined by components that have reached their replacement age according to plan.
b. Cycle 2 or the damage cycle which ends with damage activities, is determined by components that have experienced damage before reaching the predetermined replacement time.

The two cycles of the age replacement model can be seen clearly in the following picture:

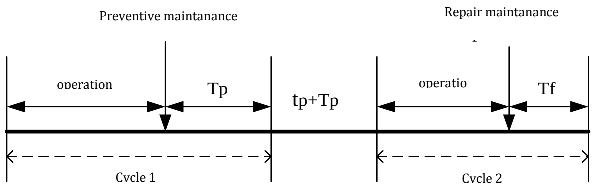


Figure 3. Age Replacement models

tp = Time interval for preventive replacement per unit time.
f = time required for replacement due to damage
Tp = Down time that occurs due to replacement activities.

The total downtime per unit of time for preventive replacement at tp is denoted by D (tp), as follows: (Jardine, 96).

$$C(tp) = \frac{total\ expected\ cycle\ replacement\ cost}{expected\ cycle\ length} \quad \text{……………………. (2.1)}$$

The expected failure condition cycle length is also the sum of the damage repair downtime and the average failure interval or M(tp), where M(tp):

$$M(tp) = \left(\frac{tp}{\alpha}\right)^{\beta} \quad \text{………………………………………………………. (2.2)}$$

So, the model for determining the replacement interval is as follows:

$$C(t_p) = \frac{C_p x R(t_p) + C_f\ [1 - R(t_p)]}{(t_p + T_p)R(t_p) + [M(t_p) + T_f][1 - R(t_p)]} \quad \text{……………………………………………. (2.3)}$$

Information :
C(tp)= Total cost per unit time if replacement is carried out in the interval (tp)
R(tp) = Reliability value at time (tp)
Cp = Cost of preventive replacement
Cf = Cost of replacing damage
M(tp) = Average value of time when damage occurs
Tf = Damage replacement time
Tp = Preventive replacement time
tp = Time interval for preventive replacement

The problem that will be discussed in this research is determining preventive maintenance scheduling on test tube machines to reduce product rejects.The policy currently implemented by PT POI is that the maintenance department will repair the machine if the machine is damaged or apply corrective maintenance methods and not implement inventory control. Meanwhile, the Test Tube machine itself is continuous, so if the machine is damaged in the middle of the production process, semi-finished products that are prone to breaking will experience stress, resulting in the product being rejected because it breaks. Therefore, scheduling preventive maintenance needs to be done.

This is very profitable for the company because it uses this methodpreventive maintenance,Companies can optimally schedule routine maintenance for existing machines and components. This aims to reduce the possibility of machine damage and minimize downtime and maintenance costs. The method used in scheduling preventive maintenance is a quantitative method, namely the Age Replacement method.

## III. RESULTS AND DISCUSSION

Test Tube is one of the products produced by PT. Indonesian Oriental Pudak. This test tube product has a fairly high level of demand compared to other products. However, in the production process there are quite a lot of product rejects. A product is said to be rejected if there is one type of defect, as follows:

a. RejectCracked
b. RejectIncorrect Size

c. RejectSimple

From the 5W analysis, it was found that the factors causing test tube product rejection were as follows:

a. Reject cracks were caused by damaged test tube machine components, namely, ceramic, flint, rocker, and drive motor, fan, vent belt, retaining plate and wire ram clamp.
b. Rejects of inappropriate sizes are caused by damaged test tube machine components, namely, regulator, brander plate, LPG hose, inventor, vent belt and bearing.
c. The reject sample was caused by damaged test tube machine components, namely the rubber roll and bearing.

The OEE value on the test tube machine is 57.62% which is obtained from the calculation results in table 4.9. From the calculation results, the test tube machine has a low OEE value. Apart from the comparison with other machines, the test tube machine has an OEE value below the OEE value limit, namely 85%.

To increase the OEE on the gtest tube machine so that it can reach a value of 85%, preventive maintenance scheduling efforts need to be made. To determine the preventive maintenance schedule for each component, an analysis of the level of component damage is required. In the damage level analysis there is an analysis of the reliability function and damage rate. The reliability function shows the ability of a component to operate continuously without damage. The damage rate function is the rate of damage that occurs within a certain time interval. The following is the reliability function curve and damage rate for ceramic components:

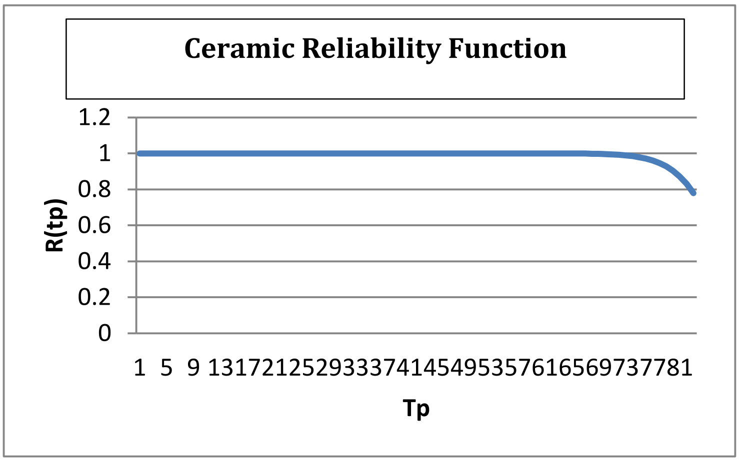


Figure 4. Ceramic Reliability Function

The reliability experienced by these components decreases over time, often increasing the time of use (Tp) where the component has reached its useful life limit so that the component experiences damage.

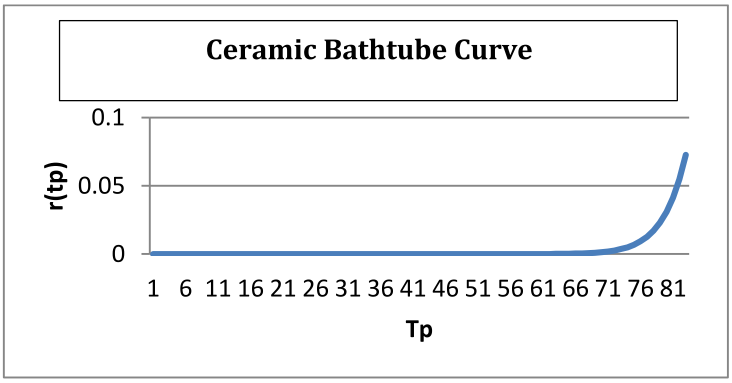


Figure 5. Ceramic Curve Bathtube

The rate of damage experienced by these components increases over time with increasing usage time (Tp). The bathtube curve is in the 3rd phase position or wear out period, in that phasethis increase occurred due to worseningthe condition of equipment that has reached its useful life limit. If the component has entered this phase, preventive maintenance should be carried out to reduce more fatal consequences. Analysis of damage to other components is in Appendix E.

Analysis of Distribution and Parameter Testing

In testing the distribution, the Index of Fit is calculated. The Index of Fit calculation is carried out with the aim of determining what distribution represents or is closest to the distribution of data on test tube machine components. The Index of Fit calculation is carried out for data on the time between failures, by calculating the Index of Fit from the Weibull, Exponential, Normal and Lognormal distributions using the Anderson-Darling method. The following are the recap results of the test tube machine distribution calculations:

Table 1. Recap of Test Tube Machine Distribution Calculations

| No | Component | distribution type | | | | Selected Distributions |
|---|---|---|---|---|---|---|
| | | Weibull | normal logs | exponential | normal | |
| 1 | Wire ram | 2,099 | 2,134 | 3,908 | 2,126 | Weibull |
| 2 | fire brick | 2,148 | 2,185 | 3,727 | 2,159 | Weibull |
| 3 | Regulators | 2,148 | 2,185 | 3,727 | 2,159 | Weibull |
| 4 | Ceramics | 1,829 | 1,845 | 4,363 | 1,833 | Weibull |
| 5 | Wire ram clamp retaining plate | 2,080 | 2,116 | 3,647 | 2,097 | Weibull |
| 6 | Conveyor Chain | 2,608 | 2,713 | 3,679 | 2,655 | Weibull |
| 7 | Rokul | 2,454 | 2,523 | 3,801 | 2,503 | Weibull |
| 8 | Rubber Roll | 2,631 | 2,642 | 3,523 | 2,624 | Weibull |
| 9 | Brander Plate | 2,658 | 2,679 | 3,588 | 2,667 | Weibull |
| 10 | Bearings | 2,847 | 2,856 | 3,837 | 2,850 | Weibull |
| 11 | Inventor | 3,100 | 3,108 | 3,817 | 3,129 | Weibull |
| 12 | Drive Motor | 3,765 | 3,807 | 4,194 | 3,810 | Weibull |
| 13 | Fan | 3,813 | 3,879 | 4,158 | 3,879 | Weibull |
| 14 | Ven Belt | 3,677 | 3,706 | 4,172 | 3,697 | Weibull |
| 15 | LPG Hose | 3,652 | 3,656 | 4,208 | 3,657 | Weibull |

From several of these distributions, the distribution that has the smallest Index of Fit value is selected. In the Test Tube machine component, the distribution selected is the Weibull distribution.

To validate the Weibull distribution data distribution pattern, Mann's Test was carried out. with a p-value of 0.25, the result of the test is P-Value > 0.05, so the data is Weibull distributed.

After obtaining the Weibull distribution data pattern, parameter calculations are carried out which will determine when the tool must be replaced. There are 2 parameters calculated for the Weibull distribution, namely the scale parameter ($\alpha$)which indicates the maximum life of the componentand shape parameters ($\beta$)which shows the shape of the parameters. The resulting value of the estimated distribution parameters will provide information regarding the condition of component damage and the value of the statistical distribution model. Both Weibull distribution parameters are calculated using simple linear regression.

Treatment Time Interval Analysis

Calculation of maintenance time intervals for components is carried out by selecting the maintenance time interval that provides the smallest costs. The amount of this cost depends on the time needed to carry out preventive maintenance and repair maintenance, the number of workers directly involved such as technicians and machine operators who are unemployed due to maintenance actions, component costs, costs borne by the company due to the machine not working. The following is a recap of the maintenance time intervals for Test Tube machines using the Age Replacement method:

Table 2. Recap of Test Tube Machine Maintenance Time Intervals

| No | Component Name | Maintenance Fee (Rp) | Treatment Time Interval (Days) |
|---|---|---|---|
| 1 | Wire ram | 7,625 | 86 |
| 2 | fire brick | 20,720 | 91 |
| 3 | Regulators | 21,807 | 99 |
| 4 | Ceramics | 25,144 | 76 |
| 5 | Wire ram clamp retaining plate | 10,475 | 76 |
| 6 | Conveyor Chain | 9,235 | 90 |
| 7 | Rokul | 12,820 | 94 |
| 8 | Rubber Roll | 19,099 | 85 |
| 9 | Brander Plate | 32,269 | 85 |
| 10 | Bearings | 9,922 | 110 |
| 11 | Inventor | 30,362 | 132 |
| 12 | Drive motor | 6,754 | 168 |
| 13 | Fan | 7,470 | 163 |
| 14 | Ven belt | 3,335 | 191 |
| 15 | LPG Hose | 4,643 | 159 |

From this table, a graph of maintenance costs is created. The following is a graph of maintenance costs for ceramic components:

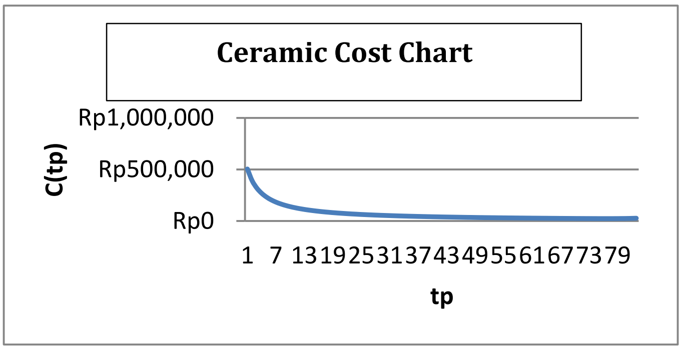


Figure 5. Ceramic Cost Graph

From this graph it can be seen that the higher the tp value, the lower the C (tp) value. After knowing the useful life of each component using the Age Replacement methodt. Damage Time Interval Calculation. The following is the time interval for damage to ceramic components:

Table 3. Time Interval for Ceramic Component Damage

| No | Damage Date | Intervals |
|---|---|---|
| 1 | 08/08/2015 | |
| 2 | 10/26/2015 | 79 |
| 3 | 1/19/2016 | 85 |
| 4 | 4/18/2016 | 90 |
| 5 | 07/04/2016 | 87 |
| 6 | 01/10/2016 | 89 |
| 7 | 12/30/2017 | 90 |

| No | Damage Date | Intervals |
|---|---|---|
| 8 | 4/25/2017 | 84 |
| 9 | 7/21/2017 | 85 |

On August 8 2021 the ceramics were damaged and on October 26 2021 the ceramics were damaged again. The bearing damage interval is from August 8 2021 to October 26 2021, which is 79 days.

Damage Distribution Testing (Index Of Fit)

To identify damage data that follows a certain distribution pattern, an index comparison is carried out. The smallest index value will be selected as the appropriate distribution. Determining the Distribution Type is carried out with the help of Minitab18 software. The distributions tested include normal, lognormal, Weibull, and exponential. The following are the results of testing the distribution of ceramic components:

Table 4. Recap value
Anderson darling ceramic component

| Distribution | Anderson-Darling (adj) |
|---|---|
| Weibull | 1,829 |
| Lognormal | 1,845 |
| Exponential | 4,363 |
| Normal | 1,833 |

The selected distribution pattern can be seen from the smallest index value, so that the distribution pattern chosen is forceramicis the Weibull distribution. For other distribution results, see Appendix A.

The recap results of calculating the index of fit for Test Tube machine components can be seen in the following table:

Table 5. Recap of Index of Fit Calculation for Test Tube Machine Components

| No | Component | distribution type | | | | Selected Distributions |
|---|---|---|---|---|---|---|
| | | Weibull | normal logs | exponential | normal | |
| 1 | Wire ram | 2,099 | 2,134 | 3,908 | 2,126 | Weibull |
| 2 | fire brick | 2,148 | 2,185 | 3,727 | 2,159 | Weibull |
| 3 | Regulators | 2,148 | 2,185 | 3,727 | 2,159 | Weibull |
| 4 | Ceramics | 1,829 | 1,845 | 4,363 | 1,833 | Weibull |
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| 8 | Rubber Roll | 2,631 | 2,642 | 3,523 | 2,624 | Weibull |
| 9 | Brander Plate | 2,658 | 2,679 | 3,588 | 2,667 | Weibull |
| 10 | Bearings | 2,847 | 2,856 | 3,837 | 2,850 | Weibull |
| 11 | Inventor | 3,100 | 3,108 | 3,817 | 3,129 | Weibull |
| 12 | Drive Motor | 3,765 | 3,807 | 4,194 | 3,810 | Weibull |
| 13 | Fan | 3,813 | 3,879 | 4,158 | 3,879 | Weibull |
| 14 | Ven Belt | 3,677 | 3,706 | 4,172 | 3,697 | Weibull |

| No | Component | distribution type | | | | Selected Distributions |
|---|---|---|---|---|---|---|
| | | Weibull | normal logs | exponential | normal | |
| 15 | LPG Hose | 3,652 | 3,656 | 4,208 | 3,657 | Weibull |

- Distribution Suitability Test(Goodness Of Fit)

After calculating the index of fit and obtaining the hypothesis that all components have a Weibull distribution, to prove that this hypothesis is correct it is necessary to carry out a test, namely the Mann test for the Weibull distribution.

The following is an example of a calculation using Minitab18 software to test distribution suitability forceramic components. H0 states that the component is ceramic Weibull distribution and H1 states that the ceramic component does not have a Weibull distribution, if Calc < Stable then H0 is accepted. The following are the results of distribution suitability testing:

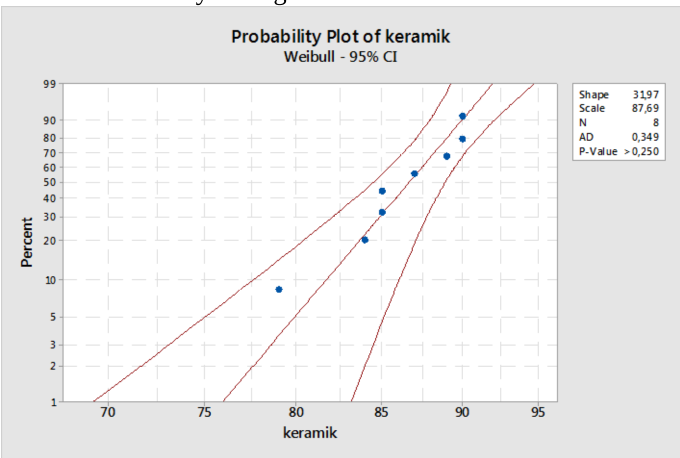


Figure 6. Goodness of fit test of ceramic components

From Figure 4.6 it can be concluded that:
A P-Value value of 0.250 was obtained

The hypothesis for conducting the test is:
Ho = Time to Failure data has a Weibull distribution
H1 = Time to Failure data does not have a Weibull distribution
A = 0.05 (90% confidence level)
Critical region: P-Value > Dcrit, then Ho is accepted.

This means that P-Value > 0.05, = 0.250 > 0.05, so Ho is Weibull distributed.For other distribution results, see Appendix B.

Determination of Parameter Values (α and β)

The parameters of the Weibull distribution consist of α and β, so these two parameters must first be found for their values to determine the component replacement time. The following is the determination of parameter values for ceramic components:

Table 6. Determination of Parameter Values

| i | ti | F(ti) | R(ti) | Yi=lnln(1/R(ti) | Xi=lnTi | xi. yi | x2 | y2 |
|---|---|---|---|---|---|---|---|---|
| 1 | 79 | 0.083333 | 0.916667 | -2.441716399 | 4.36944785 | -10.6689525 | 19.09207454 | 5.961979 |
| 2 | 84 | 0.202381 | 0.797619 | -1.486670964 | 4.4308168 | -6.58716668 | 19.6321375 | 2.2101906 |
| 3 | 85 | 0.321429 | 0.678571 | -0.947354424 | 4.44265126 | -4.20876532 | 19.73715019 | 0.8974804 |
| 4 | 85 | 0.440476 | 0.559524 | -0.543574052 | 4.44265126 | -2.41490995 | 19.73715019 | 0.2954728 |
| 5 | 87 | 0.559524 | 0.440476 | -0.198574256 | 4.46590812 | -0.88681438 | 19.94433532 | 0.0394317 |
| 6 | 89 | 0.678571 | 0.321429 | 0.12661497 | 4.48863637 | 0.568328561 | 20.14785646 | 0.0160314 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 7 | 90 | 0.797619 | 0.202381 | 0.468504666 | 4.49980967 | 2.108181825 | 20.24828707 | 0.2194966 |
| 8 | 90 | 0.916667 | 0.083333 | 0.910235093 | 4.49980967 | 4.095884675 | 20.24828707 | 0.8285279 |
| amount | 689 | 4 | 4 | -4.112535365 | 35.639731 | -17.9942137 | 158.7872783 | 10.46861 |

Explanation of calculations:

$$B = \frac{n\sum_{i=1}^{n} x_i y_i - (\sum_{i=1}^{n} x_i)(\sum_{i=1}^{n} y_i)}{\left[n\sum_{i=1}^{n} x_i{}^2 - (\sum_{i=1}^{n} x_i)^2\right]}$$

$$= \frac{8(-11.7170) - (24.3156) - 2.4544)}{[5(118.2630) - (24.3156)^2]}$$

24.2663=

$\beta = B = 24.2663$

$a = y - Bx$

$$a = \frac{-2.4544}{8} - 16.2814(\frac{24.3156}{8})$$

=-79.6693

$\alpha = e^{-\frac{a}{b}}$

$\alpha$ 87.8956

Calculations for other components can be seen in full in Appendix C.

The calculation results can be seen in the following table:

Table 7. Recap of Test Tube Machine Component Parameter Values

| No | Component | α | β |
|---|---|---|---|
| 1 | Wire ram | 102.918 | 18.70978 |
| 2 | fire brick | 119.9708 | 8.537368 |
| 3 | Regulators | 128.9326 | 7.551509 |
| 4 | Ceramics | 87.89569 | 24.26633 |
| 5 | Wire ram clamp retaining plate | 106.2147 | 7.492786 |
| 6 | Conveyor Chain | 129.1212 | 6.343214 |
| 7 | Rokul | 116.7014 | 13.53681 |
| 8 | Rubber Roll | 123.8927 | 4.825773 |
| 9 | Brander Plate | 116.3639 | 6.044011 |
| 10 | Bearings | 133.3886 | 16.28141 |
| 11 | inventor | 172.8273 | 7.945215 |
| 12 | driving motto | 226.1169 | 7.710001 |
| 13 | fan | 222.3973 | 6.966964 |
| 14 | vein belt | 210.6556 | 9.073619 |
| 15 | LPG hose | 220.3884 | 18.38329 |

Component Replacement Calculations Using Age Replacement

Calculation of component replacement with age replacement:

$$C(t_p) = \frac{C_p xRtp + C_f\ [1 - R(t_p)]}{(t_p + T_p)R(t_p) + [M(t_p) + T_f][1 - R(t_p)]}$$

Information :

tp = preventive replacement time interval.

Cf = Cost required to replace damage.

Cp = Cost required for preventive replacement.

F(t) = distribution function of the interval between damages that occur.

R(tp) = probability of preventive replacement occurring at time tp.

M(tp) = average time when damage occurs if preventive replacement is carried out on tp.

C(tp) = cost of carrying out maintenance

The following is a table for calculating replacement of ceramic components using age replacement:

Table 8. Calculation of replacement of ceramic components using age replacement
Explanation of calculations for tp = 83:

| but | Cp | Cf | α | β | F(tp) | R(tp) | M(tp) | 1 - R(tp) | C(tp) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0 | 1 | 6.72E-48 | 0 | Rp. 503,330 |
| 2 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0 | 1 | 1.36E-40 | 0 | Rp. 389,454 |
| 3 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0 | 1 | 2.54E-36 | 0 | Rp. 317,599 |
| 4 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0 | 1 | 2.73E-33 | 0 | Rp. 268,129 |
| 5 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0 | 1 | 6.14E-31 | 0 | Rp. 231,993 |
| 6 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0 | 1 | 5.13E-29 | 0 | Rp. 204,440 |
| 7 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0 | 1 | 2.16E-27 | 0 | Rp. 182,738 |
| 8 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0 | 1 | 5.52E-26 | 0 | Rp. 165,200 |
| 9 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0 | 1 | 9.62E-25 | 0 | Rp. 150,734 |
| 10 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0 | 1 | 1.24E-23 | 0 | Rp. 138,598 |
| 11 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0 | 1 | 1.25E-22 | 0 | Rp. 128,270 |
| 12 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0 | 1 | 1.03E-21 | 0 | Rp. 119,375 |
| 13 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0 | 1 | 7.22E-21 | 0 | Rp. 111,633 |
| 14 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0 | 1 | 4.36E-20 | 0 | Rp. 104,835 |
| 15 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0 | 1 | 2.33E-19 | 0 | Rp. 98,817 |
| 16 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0 | 1 | 1.11E-18 | 0 | IDR 93,452 |
| 17 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0 | 1 | 4.85E-18 | 0 | Rp. 88,640 |
| 18 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0 | 1 | 1.94E-17 | 0 | Rp. 84,299 |
| 19 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0 | 1 | 7.21E-17 | 0 | Rp. 80,364 |
| 20 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0 | 1 | 2.5E-16 | 0 | Rp. 76,779 |
| 21 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0 | 1 | 8.17E-16 | 0 | Rp. 73,501 |
| 22 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 2.55E-15 | 1 | 2.53E-15 | 2.55E-15 | Rp. 70,491 |
| 23 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 7.44E-15 | 1 | 7.43E-15 | 7.44E-15 | Rp. 67,718 |
| 24 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 2.09E-14 | 1 | 2.09E-14 | 2.09E-14 | Rp. 65,155 |
| 25 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 5.62E-14 | 1 | 5.62E-14 | 5.62E-14 | Rp. 62,779 |
| 26 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 1.46E-13 | 1 | 1.46E-13 | 1.46E-13 | Rp. 60,570 |
| 27 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 3.64E-13 | 1 | 3.64E-13 | 3.64E-13 | Rp. 58,511 |
| 28 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 8.8E-13 | 1 | 8.8E-13 | 8.8E-13 | Rp. 56,587 |
| 29 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 2.06E-12 | 1 | 2.06E-12 | 2.06E-12 | Rp. 54,786 |
| 30 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 4.69E-12 | 1 | 4.69E-12 | 4.69E-12 | Rp. 53,096 |
| 31 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 1.04E-11 | 1 | 1.04E-11 | 1.04E-11 | Rp. 51,508 |
| 32 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 2.25E-11 | 1 | 2.25E-11 | 2.25E-11 | Rp. 50,011 |
| 33 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 4.74E-11 | 1 | 4.74E-11 | 4.74E-11 | Rp. 48,599 |
| 34 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 9.78E-11 | 1 | 9.78E-11 | 9.78E-11 | Rp. 47,265 |
| 35 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 1.98E-10 | 1 | 1.98E-10 | 1.98E-10 | Rp. 46,002 |
| 36 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 3.92E-10 | 1 | 3.92E-10 | 3.92E-10 | Rp. 44,804 |
| 37 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 7.61E-10 | 1 | 7.61E-10 | 7.61E-10 | Rp. 43,668 |
| 38 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 1.45E-09 | 1 | 1.45E-09 | 1.45E-09 | Rp. 42,588 |

| but | Cp | Cf | α | β | F(tp) | R(tp) | M(tp) | 1 - R(tp) | C(tp) |
|---|---|---|---|---|---|---|---|---|---|
| 39 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 2.73E-09 | 1 | 2.73E-09 | 2.73E-09 | Rp. 41,559 |
| 40 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 5.05E-09 | 1 | 5.05E-09 | 5.05E-09 | Rp. 40,580 |
| 41 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 9.19E-09 | 1 | 9.19E-09 | 9.19E-09 | Rp. 39,645 |
| 42 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 1.65E-08 | 1 | 1.65E-08 | 1.65E-08 | Rp. 38,753 |
| 43 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 2.92E-08 | 1 | 2.92E-08 | 2.92E-08 | Rp. 37,899 |
| 44 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 5.1E-08 | 1 | 5.1E-08 | 5.1E-08 | Rp. 37,083 |
| 45 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 8.8E-08 | 1 | 8.8E-08 | 8.8E-08 | Rp. 36,301 |
| 46 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 1.5E-07 | 1 | 1.5E-07 | 1.5E-07 | Rp. 35,551 |
| 47 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 2.53E-07 | 1 | 2.53E-07 | 2.53E-07 | Rp. 34,832 |
| 48 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 4.21E-07 | 1 | 4.21E-07 | 4.21E-07 | Rp. 34,141 |
| 49 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 6.95E-07 | 0.999999 | 6.95E-07 | 6.95E-07 | Rp. 33,477 |
| 50 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 1.13E-06 | 0.999999 | 1.13E-06 | 1.13E-06 | Rp. 32,838 |
| 51 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 1.83E-06 | 0.999998 | 1.83E-06 | 1.83E-06 | Rp. 32,224 |
| 52 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 2.94E-06 | 0.999997 | 2.94E-06 | 2.94E-06 | Rp. 31,632 |
| 53 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 4.67E-06 | 0.999995 | 4.67E-06 | 4.67E-06 | Rp. 31,061 |
| 54 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 7.34E-06 | 0.999993 | 7.34E-06 | 7.34E-06 | Rp. 30,510 |
| 55 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 1.15E-05 | 0.999989 | 1.15E-05 | 1.15E-05 | Rp. 29,979 |
| 56 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 1.77E-05 | 0.999982 | 1.77E-05 | 1.77E-05 | Rp. 29,466 |
| 57 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 2.73E-05 | 0.999973 | 2.73E-05 | 2.73E-05 | Rp. 28,971 |
| 58 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 4.16E-05 | 0.999958 | 4.16E-05 | 4.16E-05 | Rp. 28,492 |
| 59 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 6.3E-05 | 0.999937 | 6.3E-05 | 6.3E-05 | Rp. 28,028 |
| 60 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 9.47E-05 | 0.999905 | 9.47E-05 | 9.47E-05 | Rp. 27,580 |
| 61 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0.000141 | 0.999859 | 0.000141 | 0.000141 | Rp. 27,147 |
| 62 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0.00021 | 0.99979 | 0.00021 | 0.00021 | Rp. 26,727 |
| 63 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0.000309 | 0.999691 | 0.000309 | 0.000309 | Rp. 26,322 |
| 64 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0.000453 | 0.999547 | 0.000453 | 0.000453 | Rp. 25,929 |
| 65 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0.00066 | 0.99934 | 0.00066 | 0.00066 | Rp. 25,551 |
| 66 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0.000956 | 0.999044 | 0.000957 | 0.000956 | Rp. 25,185 |
| 67 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0.001377 | 0.998623 | 0.001378 | 0.001377 | Rp. 24,834 |
| 68 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0.001972 | 0.998028 | 0.001974 | 0.001972 | Rp. 24,497 |
| 69 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0.002809 | 0.997191 | 0.002813 | 0.002809 | Rp. 24,176 |
| 70 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0.00398 | 0.99602 | 0.003988 | 0.00398 | Rp. 23,873 |
| 71 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0.005611 | 0.994389 | 0.005627 | 0.005611 | Rp. 23,590 |
| 72 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0.00787 | 0.99213 | 0.007901 | 0.00787 | Rp. 23,331 |
| 73 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0.010981 | 0.989019 | 0.011042 | 0.010981 | Rp. 23,101 |
| 74 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0.015244 | 0.984756 | 0.015362 | 0.015244 | Rp. 22,907 |
| 75 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0.021052 | 0.978948 | 0.021276 | 0.021052 | Rp. 22,758 |
| 76 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0.028915 | 0.971085 | 0.029342 | 0.028915 | Rp. 22,667 |
| 77 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0.039494 | 0.960506 | 0.040295 | 0.039494 | Rp. 22,650 |
| 78 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0.053619 | 0.946381 | 0.05511 | 0.053619 | Rp. 22,733 |
| 79 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0.072325 | 0.927675 | 0.075074 | 0.072325 | Rp. 22,945 |
| 80 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0.096854 | 0.903146 | 0.101871 | 0.096854 | Rp. 23,332 |
| 81 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0.12865 | 0.87135 | 0.137711 | 0.12865 | Rp. 23,955 |

| but | Cp | Cf | α | β | F(tp) | R(tp) | M(tp) | 1 - R(tp) | C(tp) |
|---|---|---|---|---|---|---|---|---|---|
| 82 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0.169289 | 0.830711 | 0.185473 | 0.169289 | Rp. 24,904 |
| 83 | IDR 1,721,388 | Rp. 2,021,380 | 87,896 | 24,266 | 0.220342 | 0.779658 | 0.248899 | 0.220342 | Rp. 26,306 |

$$M(83) = \left(\frac{tp}{\alpha}\right)^{\beta} \bullet$$

$$=(87896)^{24266}$$
$$= 0.039$$

$$R(83) = \exp\left(-\frac{tp}{\alpha}\right)^{\beta}$$
$$=0.9605$$

$$F(83) = 1 - R(87)$$
$$= 1 - 0.9605$$
$$= 0.04$$

$$C(110) = \frac{C_p xRtp + C_f\ [1-R(t_p)]}{(t_p + T_p)R(t_p) + [M(t_p) + T_f][1- R(t_p)]}$$
$$= Rp.\ 22,650$$

The following is a graph of C(tp) for Ceramic components:

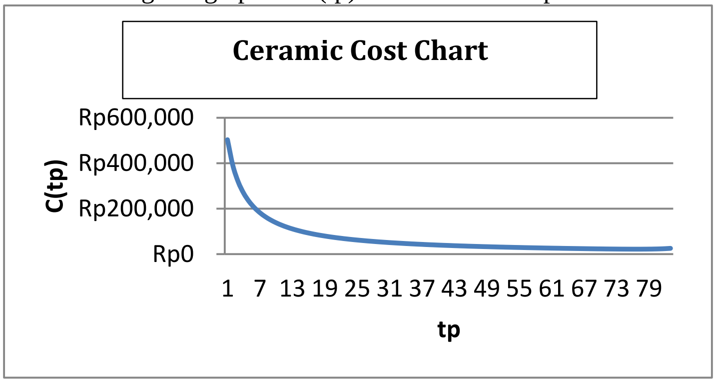


Figure 7. Graph of Age Replacement Treatment Costs

Age replacement calculations for other spare parts can be seen in Appendix D.

The following is a recap of the age replacement calculation results for all Test Tube Machine components:

Table 9. Recap of Age Replacement of Test Tube Machine Components

| Component Name | i | Cpi | Cfi | α | β | Ti* |
|---|---|---|---|---|---|---|
| Wire ram | 1 | 437621 | 737613.1 | 102.918 | 18.70978 | 86 |
| fire brick | 2 | 1561854 | 1863009 | 119.9708 | 8.537368 | 91 |
| Regulators | 3 | 1761621 | 1781388 | 128.9326 | 7.551509 | 99 |
| Ceramics | 4 | 1721388 | 2021380 | 87.89569 | 24.26633 | 76 |
| Wire ram clamp retaining plate | 5 | 556318.9 | 856311 | 106.2147 | 7.492786 | 76 |
| Conveyor Chain | 6 | 566854.1 | 868008.9 | 129.1212 | 6.343214 | 90 |
| Rokul | 7 | 970923.1 | 1272078 | 116.7014 | 13.53681 | 94 |
| Rubber Roll | 8 | 1173621 | 1473613 | 123.8927 | 4.825773 | 85 |
| Brander Plate | 9 | 2138483 | 2419871 | 116.3639 | 6.044011 | 85 |
| Bearings | 10 | 783716.1 | 1103475 | 133.3886 | 16.28141 | 110 |
| Inventor | 11 | 822862.3 | 1152311 | 172.8273 | 7.945215 | 132 |
| Drive Motor | 12 | 861621 | 1162001 | 226.1169 | 7.710001 | 168 |
| Fan | 13 | 774414 | 1074794 | 222.3973 | 6.966964 | 163 |
| Ven Belt | 14 | 793793.3 | 1123242 | 210.6556 | 9.073619 | 191 |
| LPG Hose | 15 | 813172.7 | 1103863 | 220.3884 | 18.38329 | 159 |

Replacement of engine components is made into 2 parts, with a consecutive replacement interval of 76 days. Replacement is carried out sequentially by grouping components. The following are the types of components that are replaced according to the Age Replacement time interval

Table 10. Group Component Replacement Schedule

| intervals | Group | Component Name |
|---|---|---|
| 76 days | 1 | Wire ram |
| | | fire brick |
| | | Regulators |
| | | Ceramics |
| | | Wire ram clamp retaining plate |
| | | Conveyor Chain |
| | | Rokul |
| | | Rubber Roll |
| | | Brander Plate |
| 154 days | 2 | Wire ram |
| | | fire brick |
| | | Regulators |
| | | Ceramics |
| | | Wire ram clamp retaining plate |
| | | Conveyor Chain |
| | | Rokul |
| | | Rubber Roll |
| | | Brander Plate |
| | | Bearings |
| | | Inventor |
| | | Drive motor |
| | | Fan |
| | | Ven belt |
| | | LPG Hose |

The following are the replacement intervals for the Test Tube machine:

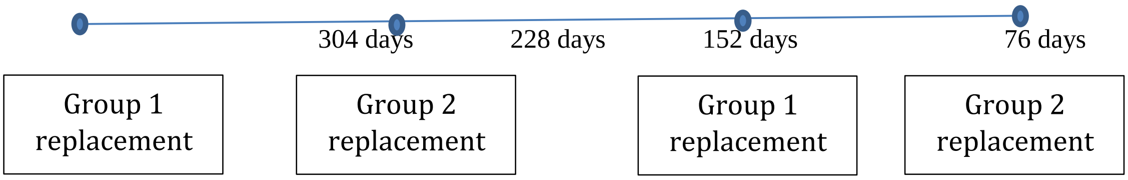


Figure 8. Test Tube Machine Component Replacement Intervals

## IV. CONCLUSION

Based on the results of data processing and analysis in the previous chapter, it can be concluded:

1. Factors causing test tube product rejection are as follows:
   a. Reject cracks were caused by damaged test tube machine components, namely, ceramic, flint, rocker, and drive motor, fan, vent belt, retaining plate and wire ram clamp.
   b. Rejects of inappropriate sizes are caused by damaged test tube machine components, namely, regulator, brander plate, LPG hose, inventor, vent belt and bearing.
   c. The reject sample was caused by damaged test tube machine components, namely the rubber roll and bearing.
2. The OEE value of the Test Tube machine is 57.62%. This requires that the machine's OEE value be increased by scheduling preventive maintenance to reduce down time on the machine.
3. The results of calculating the optimal replacement time interval for test tube components using the age replacement method are as follows:
   a. The wire ram has an optimum replacement time of 86 days and a total annual maintenance cost of Rp. 5,242,-.
   b. The optimum replacement time for fire bricks is 91 days and the total annual maintenance cost is

IDR.18,649,-.

c. The regulator has an optimum replacement time of 99 days and a total annual maintenance cost of Rp.19,863,-.
d. Ceramics has an optimum replacement time of 76 days and a total annual maintenance cost of Rp.22,667,-.
e. The wire ram clamp retaining plate has an optimum replacement time of 76 days and a total annual maintenance cost of Rp.7,996,-.
f. The conveyor chain has an optimum replacement time of 90 days and a total annual maintenance cost of Rp.7,114,-.
g. Rokul has an optimum replacement time of 94 days and a total annual maintenance cost of Rp.10,768,-.
h. Rubber rolls have an optimum replacement time of 85 days and total annual maintenance costs of Rp.16,216,-.
i. Brander plates have an optimum replacement time of 85 days and total annual maintenance costs of Rp.28,648,-.
j. Bearings have an optimum replacement time of 110 days and total annual maintenance costs of Rp.7,395,-.
k. The inventor has an optimum replacement time of 132 days and a total annual maintenance cost of Rp.30,362,-.
l. The driving motor has an optimum replacement time of 168 days and a total annual maintenance cost of Rp.6,754,-.
m. The fan has an optimum replacement time of 163 days and a total annual maintenance cost of Rp.7,470,-.
n. Ven Belt has an optimum replacement time of 191 days and a total annual maintenance cost of Rp.3,335,-.
o. LPG hoses have an optimum replacement time of 159 days and total annual maintenance costs of Rp.4,643,-.

The preventive maintenance replacement schedule is consecutive with an interval of 76 days, the component replacement is divided into 2 groups respectively for group 1 and 152 for group 2. With the following groups:

a) Group 1: wire ram, fire brick, regulator, ceramic, retaining plate, conveyor chain, rocker, rubber roll, and brand plate.
b) Group 2: wire ram, fire brick, regulator, ceramic, retaining plate, conveyor chain, rocker, rubber roll, brand plate, beak ring, inventor, drive motor, fan, vent belt and LPG hose.

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