Determination of risk level, remaining life prediction, and risk based inspection planning based on API 581

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Abstract. Electricity can be produced through several types of plants, one of which is Geothermal Power Plant (PLTP). One company that manages Geothermal Power Plants in Indonesia is PT Indonesia Power. In processing geothermal into electricity, companies need machines that work well in any condition, one of which is a separator machine that functions as a separator of geothermal steam with impurities. To keep the separator machine working properly, proper inspection is needed. Inspections can be done by a variety of methods, but inspections of separators should use a risk-based inspection method. Therefore, the study was conducted by applying a risk-based inspection method based on API 581 Second Edition to determine the level of risk, the remaining life of the machine, and the planning of inspections (intervals and inspection techniques) on the machine. The level of risk for all separator units is medium high with a risk category of 1E, which has a low probability of failure and high failure consequences. The estimated age of the remaining machines working according to their functions based on research for unit I is 25 years, for unit II 13 years, and for unit III 18 years. This affects the inspection intervals in each unit, unit I should be inspected every 6 years, unit II is inspected every 3 years, and unit III is inspected every 4 years with a thorough inspection and thickness measurement as an inspection technique.

Keywords: geothermal power plant, separator machine, risk based inspection, remaining life, inspection intervals and techniques

1. Introduction
Based on the results of projected electricity needs from 2003-2002 carried out by the System Planning Department of PT PLN and the BPPT Energy Team, it can be seen that Indonesia's electricity demand has increased by 6.5% per year in that period [1]. Electricity in Indonesia is generated through several plants, one of which is PLTP (Geothermal Power Plant). One of the geothermal power plants in Indonesia is managed by PT Indonesia Power. PT Indonesia Power is a power generation company that has 133 generating units spread across Java and Bali. PT Indonesia Power UPJP Kamojang is one of the Geothermal Power Plant (PLTP) Generating Services Generation Unit (UPJP). Geothermal power plants are electricity plants that use geothermal energy as their driving energy.

According to Mr. Maman Mulyana Hakim, employee of PT Indonesia Power UPJP Kamojang, all the machines and equipment in PLTP Kamojang were very important to support the production process and the company's revenue. One of the important machines to support the process of
electricity production is a separator because the geothermal separator separates steam from impurities (solids, silica, and water spots) [2]. This causes the separator machine can suffer damage over time because it continues to operate. Based on Figure 1, the machine will suffer damage (such as corrosion, wall thinning, etc) as the operating time increases. Therefore, to ensure that the machines and tools in the company are always in a good condition, an inspection is needed. Inspection activities are carried out to achieve good maintenance activities.

![Figure 1. Operation time and thickness relation](image)

Inspection can be done by several methods, one of which is using the Risk-Based Inspection method. Risk based inspection is a process of risk assessment and management that focuses on loss of containment of pressurized equipment in processing facilities, due to material deterioration [3]. To conduct an inspection, a good inspection plan is needed so that no costs are wasted and operational awareness is increased. Inspection planning is done by determining the inspection interval on the machine based on risk level and remaining life of the machine and determining the inspection technique based on the damage factor that occurs in the machine.

2. Basic theory and research methodology

2.1 Basic theory

2.1.1 Maintenance management

Maintenance is an activity carried out so that a damaged machine or system can be returned or repaired in a certain condition and period [4]. Whereas maintenance management is a collection of management activities needed to (i) determine goals, strategies, raw materials and responsibilities needed for care; (ii) implementing maintenance planning and controlling it; (iii) and carry out direct maintenance activities [5]. A good maintenance program is certainly not only a program that requires low cost, but also a program that can achieve a company's production target [6].

2.1.2 Preventive maintenance

According to the US Department of Energy [7], preventive maintenance is an action or activity carried out on a time-based schedule or machine that detects, prevents, or reduces the degradation of an engine or system with the aim of maintaining or extending the life of the machine through controlling the degradation value to the value that is acceptable.
2.1.3 **Reactive maintenance**  
In reactive maintenance, repairs are performed after the system has already failed [8]. This type of maintenance activity can be applied to new machines and good conditions because there is no need to do maintenance so often that it can save on company maintenance costs.

2.1.4 **Predictive maintenance**  
Predictive maintenance can be defined as a measurement that detects the occurrence of system degradation or when the engine function declines, thus we can find a causal stressor then eliminate or control it before significant damage occurs to the engine [7].

2.1.5 **Risk based inspection**  
Risk based inspection is a method used to plan inspections of an equipment or machine based on the risk factors that occur on the machine, so that each machine has a different inspection schedule due to different risk factors. Risk based inspection involves inspection planning based on information obtained from equipment risk analysis [9].

2.1.5.1 **Probability of failure**  
The probability of failure (POF) is the probability that a machine exceeds the boundary conditions within a specified time [10]. The POF's value is obtained from the multiplication between the value of the frequency of general failures, damage factors, and management system factors. Equation 1 is the equation used to get the probability of failure (POF) value according to the RBI API.

\[ P_f(t) = g_f f . D_f(t) . F_{MS} \]  

2.1.5.2 **Consequence of failure**  
The consequences of failure are events that occur as a result of damage to the machine, this can include all forms of consequences. The consequences of failure are related to the type of asset and include the cost of repairs, reduced income, personnel injury, health impacts, damage to infrastructure or property, and so on [11].

2.1.5.3 **Risk level**

![Risk matrix](image)

**Figure 2.** Risk matrix [3]

POF and COF categories are presented in the risk matrix to indicate the risk level (high, medium and low) on a machine. So that the inspection plan can be done well because it follows the risk level of each machine. The risk matrix used by the API 581 [3] is shown in **Figure 2**.
2.1.5.4 Remaining life prediction
Remaining Life (RL) is the remaining life of a machine to operate properly without failure. The prediction of remaining life for subsystems or components is described as an effective strategy to establish the maximum duration of time that they could operate beyond their original design life [12]. Equation 2 shows the remaining life calculation used by the American Petroleum Institute [3].

$$RL = \frac{t_{actual} - t_{minimum}}{corrosion\ rate}$$  \hspace{1cm} (2)

2.1.5.5 Inspection intervals
Inspection interval is determined based on the results of the calculation of remaining life and the risk level of the machine. This is because the planned inspection interval is an inspection interval based on risk. The planned inspection interval provides operational risk reduction [13]. Equation 3 is the equation used to calculate inspection interval based on American Petroleum Institute [3].

$$Inspection\ Interval = \frac{Remaining\ Life}{d}$$ \hspace{1cm} (3)

2.2 Research Methodology
Figure 3 shows the conceptual model used by the author for this research. The study began with the data collection stage. The data collected is the data needed to calculate or determine the value of the corrosion rate, remaining life, probability of failure, consequence of failure, inspection intervals, and inspection techniques. After all the necessary data has been collected, the initial calculation phase will be carried out by determining the value of generic failure frequency, damage factor, and management systems factor on the machine. Then the probability of failure value is obtained by multiplying these values. The next stage is processing data of the fluid, the mass of the fluid, and the size of the engine leakage hole to determine the consequences of failure. Categories of probability of failure and consequence of failure are then mapped into the risk matrix to determine the risk level and determine the inspection interval.

Data on operating time and wall thickness of the machine are used to calculate the value of corrosion rate during operating time. Corrosion rate and minimum allowable thickness on the machine will then be needed in calculating the remaining life of the machine. The remaining life and risk level of the machine are used to determine the inspection interval, so that inspections can be carried out optimally and efficiently. Furthermore, inspection techniques performed on the machine are determined based on the damage factor that occurs in the engine. After knowing the inspection intervals and inspection techniques that are appropriate for the machine, the inspection planning can be known.
3. Discussion

3.1 Risk Level

3.1.1 Probability of Failure

The value of probability of failure is determined based on the value of generic failure frequency, damage factor, and management systems factor. The value of generic failure frequency on separator machines based on API RBI 581 is 0.0000306 failures/year [3]. The damage factor that occurs in Separator Machine at PT Indonesia Power UPJP Kamojang is a thinning mechanism, so that the calculation of the damage factor value is carried out using the concept of calculating the thinning damage factor on API RBI 581. So, based on the stages that have been done and calculations using equation 4, the value obtained $D_{thin}^f$ for Separator Machine at PT Indonesia Power UPJP Kamojang is 1. Management system factor assessment is based on expert judgement using a list of questions provided by API RBI 581 2nd Edition. Table 1 shows the value of management system factors obtained from interviews with Mr. Moch Alam B as expert judge PT Indonesia Power UPJP Kamojang on June 6th, 2020. The probability of failure based on research is 0.00002802 with the category of probability of failure is 1.
\[ D_{f}^{thi} = \frac{D_{fb}^{thi} \cdot F_{IP} \cdot F_{DL} \cdot F_{WD} \cdot F_{AM} \cdot F_{SM}}{F_{OM}} \] (4)

**Table 1. Management system factor**

| Title                          | Score |
|-------------------------------|-------|
| Leadership and Administration | 70    |
| Process Safety Information    | 80    |
| Process Hazard Analysis       | 84    |
| Management of Change          | 72    |
| Operating Procedures          | 80    |
| Safe Work Practices           | 75    |
| Training                      | 85    |
| Mechanical Integrity          | 100   |
| Pre-Startup Safety Review     | 60    |
| Emergency Response            | 57    |
| Incident Investigation        | 69    |
| Contractors                   | 38    |
| Audits                        | 40    |
| TOTAL                         | 910   |
| pscore                        | 91.0% |
| \( F_{MS} \)                  | 0.915798652 |

3.1.2 Consequence of failure

Determination of consequence of failure is done by determining the value of the consequences of areas for flammable and explosion consequences, toxic consequences, and non-flammable and non-toxic consequences. The area consequences is very dependent on the fluid contained, geothermal steam. Kamojang Geothermal Steam is included in the type of dry steam which contains 90% CO₂, 9.7% H₂S, 0.05% H₂, 0.0065% N₂, 0.123% Ar, dan 0.08% CH₄ [14]. The representative fluid used in calculating the value of flammable and toxic consequences is H₂S fluid, while the fluid used in calculating the value of non-toxic and non-flammable consequences is steam. After determining the representative fluid, the calculation of the consequence area is then performed based on the API RP 581 2nd Edition. The value of the flammable consequences for component damage is 33800 ft², the value flammable consequences for personnel injury is 33800 ft², the value of the toxic consequences for personnel injury is 83100 ft², and non-toxic and non-flammable consequences for personnel injury is 2480 ft².

Next, determine the value of the component damage consequences, \( CA_{cmd} \), and the value of the personnel injury consequences, \( CA_{inj} \). The value of area consequence for component damage is the same as the value of flammable consequences for component damage, \( CA_{cmd} = CA_{cmd}^{flam} = 33800 \) ft², because the value of \( CA_{cmd}^{tox}, CA_{cmd}^{nft} = 0 \). It is because leakage due to toxic substances and non-toxic and non-flammable substances do not cause damage to the component. The area consequence value is determined based on equation 5, which is 831000 ft². The stage of determining the final consequence area, \( CA \), done by selecting the largest value between the value of the component damage consequences, \( CA_{cmd} \) and the value of the

\[ CA_{inj} = \max\{CA_{inj}^{lam}, CA_{inj}^{tox}, CA_{inj}^{nft}\} \] (5)
personnel injury consequences, \(CA_{\text{inj}}\). Then the final consequence area, \(CA\) is 831000 ft\(^2\) with the category E because \(CA \geq 10000 \text{ ft}^2\).

### 3.1.3 Risk Level Determination

After determining the Probability of Failure category and the Consequence of Failure category, these categories can then be mapped into the risk matrix. Figure 4 shows a risk matrix in accordance with predetermined categories. Figure 4 shows that PT Indonesia Power UPJP Kamojang Separator Machine is at medium high risk level with risk category 1E.

![Risk Matrix](image)

**Figure 4.** Separator PT Indonesia Power UPJP Kamojang’s Risk Matrix

### 3.2 Remaining Life Prediction

The calculation of the remaining life of separator machine is done using equation 2. The actual thickness and corrosion rate selected for each unit are determined from the minimum wall thickness in 2015 (the last year the inspection was carried out). The estimated remaining life of each unit is shown in Table 2.

| Unit            | Wall Thickness 2010 (mm) | Wall Thickness 2015 (mm) | CR  | MAT  | RLP (2015) | RLP (2020) |
|-----------------|-------------------------|--------------------------|-----|------|------------|------------|
| Separator Unit I | 15.1                    | 14.28                    | 0.164 | 9.222 | 30.844     | 25.844     |
| Separator Unit II | 14.5                   | 13.36                    | 0.228 | 9.222 | 18.151     | 13.151     |
| Separator Unit III | 14.2               | 13.34                    | 0.172 | 9.222 | 23.944     | 18.944     |

### 3.3 Inspection Interval

Determination of the inspection interval for each machine unit is done by calculating inspection interval using equation 3 with the value of the risk level is 4. The inspection interval for each unit based on the calculation is shown in Table 3.

| Unit            | RLP (2020) | Risk Level | Inspection Interval (yr) |
|-----------------|------------|------------|--------------------------|
| Separator Unit I | 25.844     | 4          | 6.461                    |
| Separator Unit II | 13.151    |            | 3.288                    |
| Separator Unit III | 18.944    |            | 4.736                    |
3.4 Inspection Techniques
The inspection technique is determined based on the damage factor that occurs in the machine, local thinning, it is because the thinning that occurs in the engine wall is not uniform (the thickness of the engine wall varies at each point). Inspection techniques that can be performed on the separator machine with a local thinning damage factor based on API 581 [3] is a thorough visual examination and thickness measurements. Inspections are carried out by scanning 50 to 100% of the machine parts using automated ultrasonic scanning tools, or profile radiography in areas determined by corrosion specialists (people who have more knowledge about corrosion).

4. Conclusion
The following are the research conclusions.
• Based on the research that has been done, the risk separator machine level obtained at PT Indonesia Power UPJP Kamojang is at medium high level with risk category 1E. This shows the Separator Machine at PT Indonesia Power UPJP Kamojang has a relatively high risk because it has a high failure consequence value and a low probability of failure.
• Estimated remaining machine life based on research that has been conducted, 25 years for unit I separator, 13 years for unit II separator, and 18 years for unit III separator.
• Proposed inspection intervals on separator machines based on research are every six years for unit I separator, every three years for unit II separator, and every four years for unit III separator. This is because each unit has a different estimated remaining life.
• Proposed inspection techniques performed on machines based on API RBI 581 for local thinning damage factors are to do a thorough inspection and thickness measurement using automated ultrasonic scanning tools, or profile radiography in areas determined by corrosion specialists (people who have more knowledge about corrosion).

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