Quantitative Study of Risk Based Inspection (RBI) Using API 581 on Heat Exchanger Tube Bundle

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Abstract. Risk analysis using RBI on the heat exchanger tube bundle begins with calculating the probability of failure (PoF) and then continues with the calculation of the consequence of failure (CoF). PoF and CoF calculations are based on API 581 Addendum 2020. The type of heat exchanger used is fin fancooler heat exchanger. PoF on fin fan-cooler heat exchanger has several types including PoF before inspection, PoF after inspection, PoF during RBI. PoF is calculated based on the Weibull distribution formula and analyzed based on the Weibull curve. The CoF calculation is only in the financial section. The results of the PoF and CoF calculations will produce a risk value and risk level. The risk will be mapped based on the risk target of the company. Based on the risk value and the level of risk obtained, mitigation recommendations can be estimated. The results of the mitigation recommendations will be analyzed again based on the applicable regulations in Indonesia..

Keywords: Risk analysis, Probability of failure, Consequence of failure, Weibull, Risk level

1 Introduction

Heat exchanger has one important function in the oil and gas production process. The basic principle of processing crude oil is sufficient heat, chemicals and retention time for the oil to break away from its bonds with minerals and other elements [1]. As a tool that functions as a heat regulator in the fluid in the oil and gas production process, heat exchangers have a high level of risk such as allowing leakage or explosion. In February 2010, there was a heat exchanger explosion and fire at the Tesoro Refinery in Anacortes, Washington [2]. Not far away, in Indonesia the same thing happened in October 2013 but did not cause an explosion. Leakage of 93 tubes was found in the Gas-Cooling Heat Exchanger at Pertamina Hulu Energi Offshore North West Java (PHE-ONWJ) [3]. As a result of these risks, the heat exchanger equipment itself can be damaged and other equipment around it can be damaged. Not only that, another impact is that it can take the lives of workers.

To prevent hazards and failures in the heat exchanger, risk management is required. One way is by applying the Risk Based Inspection (RBI) method on heat exchanger equipment. Risk Based

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Inspection (RBI) is one of the risk assessment methodologies by optimizing the equipment inspection plan based on the risk category of the equipment. RBI uses API 581 in more detail. There are three types of RBI, namely quantitative RBI, semi-quantitative RBI, and qualitative RBI [4]. API 581 provides an explanation that the calculation of Risk Based Inspection (RBI) quantitatively is easy to do using the formulas available in API 581. Risk analysis is based on PoF and CoF. Risk is defined as a combination of the probability of failure of an equipment with the magnitude of the consequences of the failure [5]. In API 581, the risk of the Heat Exchanger Tube Bundle equipment can be determined by the weibull distribution while the Tube and Side Heat Exchanger equipment is calculated based on the damage factor. PoF and CoF have certain categories that serve to determine the level of risk. Calculations in API 581 are quite long and time-consuming, which requires a methodology so that risk calculations can be fast and accurate.

The purpose of this research is to create a risk calculation methodology for Heat Exchanger Tube Bundles equipment based on API 581. After that, map the risk level on Heat Exchanger Tube Bundles equipment with the created methodology. and the last is to recommend appropriate mitigation plans for the Heat Exchanger Tube Bundle equipment based on the results of the risk analysis that has been carried out.

2 Research Methodology

Risk is defined as the uncertainty of event which bring financial impact. In this case, the uncertainty of the event refers to the frequency of the failure which occur to equipment. On the other hand, financial impact refers to consequence of failure, which can be represent in many forms, such as financial, safety, environment, operation, area, etc. Risk assessment is one of the most widey method applied in high-risk industries, for exampe finance and bank, petoleum engineering, etc due to its ability to provide insight toward the risk posessesd by them industries, and provide measure to propose minitgation action to reduce the risk impact.

In term of petroleum engineering, API (American, Petrloleum Institute) is one of widely used standard guide in petroleum company eraund the world. API provides a systematical approach in performing risk assessment. Fig. 1 shows the methodology widely used in performing risk based assessment (RBI) as stated in API 681

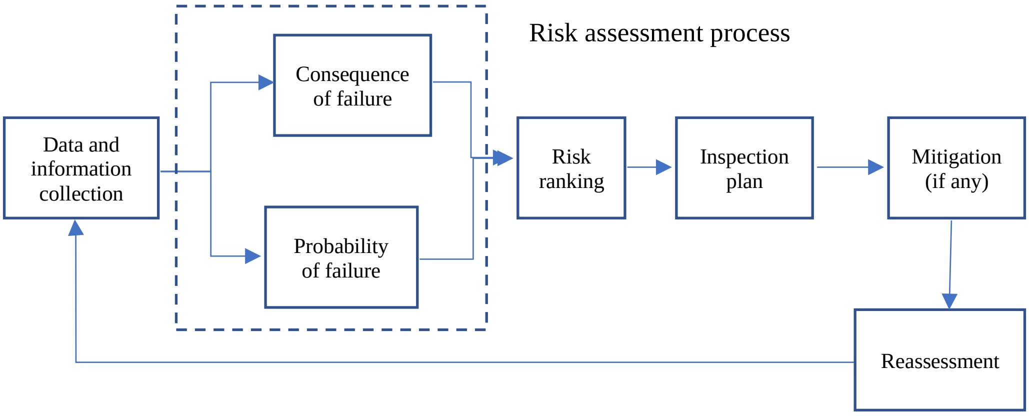

Fig. 1. RBI Planning Process [6]

In API 581 it is explained the procedure to determine the Probability Of Failure (PoF) can be in three ways, namely [5]:

• Calculating the Probability of Failure (PoF) of the heat exchanger using the weibull distribution with the weibull parameters already determined by the company. However, when the weibull parameter is not provided by the company, the weibull parameter can be determined using statistical formulas analyzed through failure data.

• Calculating the Probability of Failure (PoF) using the mean time to failure (MTTF) data that has been known by the company. The MTTF value will be used to determine the weibull parameter and then used to determine the probability of failure of the heat exchanger equipment itself.

• Calculating the Probability of Failure (PoF) using specific data from the heat exchanger during past inspections.

3 Results and Discussion

The heat exchanger tube bundle consists of a shell that encloses the bundle [6]. Heat exchanger tube bundles generally deliver low temperatures outside the bundle and high temperatures in the bundle [7]. Covective transfer is more dominant in the heat exchanger tube bundle [8]. In this study, the heat exchanger used is a fin fan cooler heat exchanger which consists of a tube bundle, header, nozzle, fan, fan ring, drive assembly and fan guard [9].

Table 1. Specifications of Heat Exchanger Tube Bundle

No	Data	Information
1	Heat Exchanger Type	Air-Cooler Heat Exchanger
2	Specific Typer	Fin Fan-Cooler Heat Exchanger
3	Tag Number	L-COMP E-1300A
4	Desain Code	ASME VII Div.1/ API 661
5	Orientation	Horizontal
6	Commissioning Date	1994
7	Pressure Design	950 psi

8	Pressure Operating	650 psi
9	Temperature Design	350 ºF
10	Temperature Operating	350 ºF
11	First Inspection	1 July 2014
12	Weibull Shape Parameter *(β)*	3
13	Weibull Characteristic Life *(η)*	14

2.1 ***PoF Before Inspection***

PoF before inspection is needed to analyze the decrease in PoF value on the Weibull curve caused by inspection was carried out in 2014. The time variable used is 20 years (first time difference installation times with the time of the first inspection).

Table 2. PoF Before Inspection

Data	Value	Unit
Time Variable (t)	20	years
Weibull Shape Factor (β)	3	
Weibull Characteristic Life (η)	14	years
Probability of Failure (P_{before})	0,945820458	
Probability of Failure Categoty	5	

2.2 ***PoF After Inspection***

PoF after inspection is an expression of the decrease in the Weibull curve caused by the inspection. This PoF is still being reviewed in the same year as the PoF before the inspection which is 2014. The Weibull parameters are still the same as given by the original company. The results of the PoF calculation after inspection are in Table 3.

Table 3. PoF After Inspection

Data	Value	Unit
Time Variable*(t)*	20	year
Weibull Shape Parameter *(β)*	3	
Weibull Characteristic Life *(η)*	14	year
Probability of Failure (P_{after})	0,189164	
Probability of Failure Categoty	2	

After inspection and a decrease in the PoF value, it turns out that there are other factors that can cause PoF, namely tube plugging. Therefore the actual PoF will be the average of the PoF due to tube plugging and general PoF.

The calculation results of the actual PoF are in Table 4. The PoF by the plug will be 0 and then averaged with the PoF value after inspection. The average result is the real PoF. PoF will be the benchmark for starting a new weibull curve used for life analysis..

Table 4. Thin Damage Factor Value

Data	Value	Unit
Tube Plugging	0	
Total Number of Tube *(N)*	156	
Probability of Failure by Plug (P_{Plug})	0	
Real Probability of Failure (P_{Real})	0,094582046	
Probability of Failure Category	1	

2.3 ***PoF Current (PoF RBI)***

PoF RBI is the PoF analyzed in the current year (2022). The PoF RBI will be a benchmark to determine the inspection time interval that has been targeted by the company. The distance is known from the weibull curve. The time parameter used is 8 years (distance from real PoF) [10]. The results of calculations based on the methodology that have been made can be seen in Table 5.

Table 5. PoF Current

Data	Value	Unit
Time Variable (t)	8	year
Weibull Shape Parameter *(β)*	3	
Weibull Characteristic Life *(η)*	14	year
Probability of Failure RBI (Pcurrent)	0,264797273	
Probability of Failure Category	3	

Consequence of Failure in the heat exchanger tube bundle only focuses on finance [5]. The area part is not taken into account because seen from the location of the tube bundle, there isno area impact. CoF in the heat exchanger tube bundle takes into account production costs, environmental costs, bundle replacement costs, and maintenance costs [4]. The results of the CoF calculation can be seen in Table 6

Table 6. Damage Factor Total Value

Part	Data	Symbol	Value	Unit
Production	Unit Production Cost	*UnitProd*	883.679	$/day
	Production Impact	*RateRed*	19,57	%
	Unplanned Shutdown	*Dsd*	12	Day
	Production Cost	$Cost_{Prod}$	2.075.231,76	$
Enviromental	Enviromental Impact	$Cost_{Env}$	0	$
Bundle	Bundle Replacement Cost	$Cost_{Bundle}$	279.215	$
Maintenance	Maintenance Cost	$Cost_{Maint}$	60.000	$
Consequence of Failure			2.414.446,764	$
Consequence of Failure Category			E	

The CoF results obtained have been included in category E, which means that the costs incurred are very large. Although the cost of environmental impact is 0 but the cost of production impact is very large. It is expected that the company can reduce these costs, especially in the cost of the production section.

Risk is a combination of probability of failure and consequence of failure [5]. The risk obtained from the multiplication between PoF and CoF will then be plotted on the risk matrix.

The risk matrix will be a map to determine how big the delta is between the RBI PoF and the target PoF as well as the CoF.

Risk is mathematically defined as the product of PoF with CoF [5]. Risk can be in the form of numbers or categories. Risk has levels ranging from low to high. The results of the calculation of the risk obtained are in Table 7. In this study, the level of risk obtained is medium high with category 3E.

Table 7. Probability of Failure Value

Data	Value	Unit
Probability of Failure	0,264797273	
Consequence of Failure	2.414.446,764	$
Risk	228.363,3	
Risk Category	3E	

The company has set targets in the form of risk categories. Mitigation planning will be analyzed based on the risk targets that have been given by the company. The risk targets are 0.8A, 0.8B, 0.6C, 0.4D, and 0.5E. To analyze the mitigation planning based on the target, it is necessary to map the target on the risk matrix. The target map in the risk matrix can be seen in **Figure 2.**

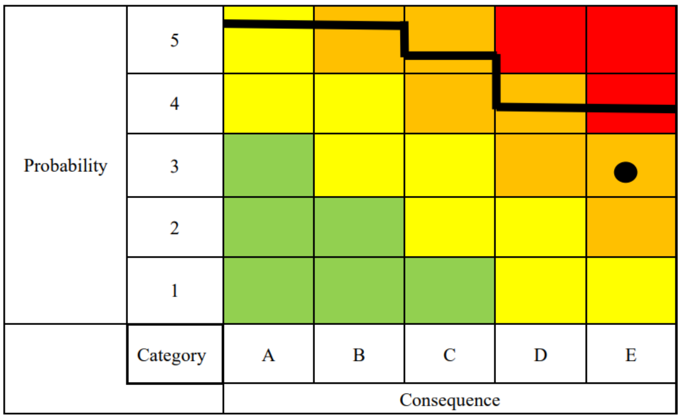

Fig. 2. Risk Target Map

It is clear that there is a delta between the risk target and the current risk value. The risk delta will be known through the weibull curve which has previously been analyzed based on PoF before inspection, PoF after inspection, real PoF, and RBI PoF. The weibull curve can be seen in **Figure 3**.

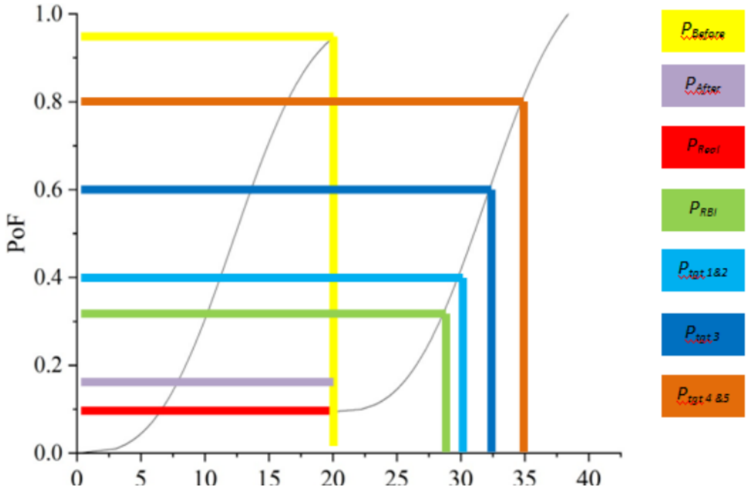

Fig. 3. Weibull Curve Analysis

Based on the risk map and weibull curve above, a mitigation plan in the form of optimizing the inspection plan time can be written. Weibull curve analysis will provide the distance between the current time and the time based on the given risk target. The risk matrix can provide an overview of the recommended cost reductions. The results obtained from the second analysis can be seen in Table 8.

Table 8. Result Of Analysis Of Weibull Curve And Risk Map

No	PoF Target	Inspection Schedule	CoF Target	Cost Reduction Required	Recommend/NotRecommend
1	0,8	28 June 2029	A	2.404.448 $	Not Recommend
2	0,8	28 June 2029	B	2.364.448 $	Not Recommend
3	0,6	12 December 206	C	2.264.448 $	Not Recommend
4	0,4	29 June 2024	D	1.444.448 $	Not Recommend
5	0,4	29 June 2024	E	-	Recommend

From the results of the analysis, it can be concluded that the appropriate mitigation plan is to carry out inspections on June 29, 2024

4 Conclusion

Based on the analysis that has been carried out, the following conclusions are obtained:

1. The probability of failure before inspection was reported to be 0. 95. the probability of failure after inspection was obtained to be 0.9 The real probability after inspection was performed was 0.09. The current probability of a failure was
2. 0.23 which will be used to determine the next inspection schedule.
3. The consequence of failure was reported to be USD $ 2,414,446.76, which faal under category E.
4. The risk was calculated to be 228,363.3, which falls under category medium high (3E)
5. The appropriate mitigation plan for the heat exchanger tube bundle based on the risk assessment is to conduct an inspection on June 29, 2024.

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