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by Gunawan Dwi H

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Citation: AIP Conference Proceedings **1725**, 020062 (2016); doi: 10.1063/1.4945516

View online: http://dx.doi.org/10.1063/1.4945516

View Table of Contents: http://aip.scitation.org/toc/apc/1725/1

Published by the American Institute of Physics

Risk Analysis of Heat Recovery Steam Generator with Semi Quantitative Risk Based Inspection API 581

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Abstract. Corrosion is a major problem that most often occurs in the power plant. Heat recovery steam generator (HRSG) is an equipment that has a high risk to the power plant. The impact of corrosion damage causing HRSG power plant stops operating. Furthermore, it could be threaten the safety of employees. The Risk Based Inspection (RBI) guidelines by the American Petroleum Institute (API) 58 has been used to risk analysis in the HRSG 1. By using this methodology, the risk that caused by unexpected failure as a function of the probability and consequence of failure can be estimated. This paper presented a case study relating to the risk analysis in the HRSG, starting with a summary of the basic principles and procedures of risk assessment and applying corrosion RBI for process industries. The risk level of each HRSG equipment were analyzed: HP superheater has a medium high risk (4C), HP evaporator has a medium-high risk (4C), and the HP economizer has a medium risk (3C). The results of the risk assessment using semi-quantitative method of standard API 581 based on the existing equipment at medium risk. In the fact, there is no critical problem in the equipment components. Damage mechanisms were prominent throughout the equipment is thinning mechanism. The evaluation of the risk approach was done with the aim of reducing risk by optimizing the risk assessment activities.

INTRODUCTION

One of the main problems that most often occurs in the power plant industry is corrosion. The impact of corrosion cause the damage of the pipe effect in leakage, loss of product, as further environmental pollution can threaten the safety of employees [1]. Studies conducted by the Electric Power Research Institute (EPRI) states that the cost of damage to the boiler caused by corrosion are the highest costs in the fossil fuel industry. Analysis of the North American Electric Reliability Council Generic Availability Data System (NERC) indicates that coal boilers are among the highest economic risk components in each power plant. The largest number of forced outages in all type of boiler tube failures caused by [2].

A heat recovery steam generator or HRSG is an energy recovery heat exchanger that recovers heat from a hot gas stream. HRSGs consist of four major components: the economizer, evaporator, superheater and water preheater. HRSG equipment used continuously will decrease the value of reliability due to the time of use and various factors in the failure of the equipment. The problem that often occurs is the existence of failures in the HRSG affect the performance of the generation system at the Power Plant [3].

Preventive maintenance is one of the methods that used to prevent damage of the HRSG. Last decade shown a trend where life management programmes are globally moving from prescriptive/time-based towards risk based decision making. Risk analysis finds use/application in decision making, for operation, maintenance and regulatory activities. This methodology has been applied in planning maintenance activities such as testing time, repair time, inspection interval etc. When this is applied to inspection planning, it is termed as Risk based inspection. RBI would be able to establish an effective structural integrity management programme, which reduces plant down time, industry and regulatory burdens, and continue to maintain plant safety.

The 3rd International Conference on Advanced Materials Science and Technology (ICAMST 2015)
AIP Conf. Proc. 1725, 020062-1–020062-7; doi: 10.1063/1.4945516
Published by AIP Publishing. 978-0-7354-1372-6/$30.00

This paper provides HRSG equipment assesment procedure and its risk ranking judgment basen on API 581 semiquantitative method to prioritize future inspection in the plant.

METHODOLOGY

Risk Based Inspection

Risk based inspections are nowadays in a well advanced stage of application and make a well established part of modern practice" [4]. Risk based inspection involves the programming of an inspection on the basis of information obtained from a risk assessment. Risk allows people to view potential hazards that simultaneously accounts for both the likelihood and consequences of an event. Risk Based Inspection (RBI) is a systematic tool that helps users make informed business decisions regarding inspection and maintenance spending.

RBI is a method of planning or testing and inspection programs and maintenance strategies using risk as a fundamental method. Risk is defined as a function of probability of failure (pof) and a function of the consequences of failure (cof) is formulated as follows Equation [5]

$$Risk = CoF \times PoF(t)$$

Probability of Failure

Analysis of probability of failure on equipment with semi-quantitative method RBI through TMSF (Technical Modules Sub-Factor) for any damage suffered mechanisms observed. Mechanism for any damage caused to the equipment can be determined by scanning the operating conditions of the equipment. TSMF used in the damage analysis consists of several mechanisms of damage that can occur by a piece of equipment for the operating conditions and the type of working fluid. The Probability is calculated based on the Equation [6]:

$$PoF = GFF \times FMS \times DF(t)$$

Generic Failure Frequency is a probability of failure developed for specific component types based on a large population of component data that does not include the effects of specific damage mechanisms. FMS (Factor management systems) is derived from the results of an evaluation of a facility or operating unit's management items that affect plant risk. DF is an adjustment factor applied to the generic failure frequency to calculating damage mechanisms that are active in a component [7].

Consequences of Failure

Analysis of the consequences of failure due to release fluid representative in the semi-quantitative method RBI consists of two parts. The consequences regardless of combustible fluid and the consequences from the release of toxic fluid [8]. Analysis of the consequences of the API RBI assessment performed to aid in establishing ranking items of equipment on the basis of risk. The measures consequences presented are intended to be used to set priorities for the inspection program [9]. The main consequence category are analyzed using different techniques:

a) Flammable and explosive consequences are computed using the tree to determine the probability of event combined with computer modeling to determine the magnitude of the consequences. Area can be determined based on the consequences of a serious injury to personnel and damage to components of the thermal radiation and blast. Financial losses is also determined based on the area affected by the release.
b) Consequences of toxic calculated using a computer model to determine the area consequences as a result of overexposure of personnel to toxic concentrations of the vapor cloud. Where flammable liquids and toxic, toxic event probability assumes that if the release ignited, the consequences of toxic ignored (ie toxins consumed in the fire). Financial losses is also determined based on the area affected by the release.
c) Non-flammable, non-toxic releases are also considered since they can still result in serious consequences. Consequences from chemical splashes and high temperature steam burns are determined based on serious injuries to personnel. Physical explosions and BLEVEs can also cause serious personnel injuries and component damage.

d) Financial Consequences includes losses due to business interruption and costs associated with environmental releases. Business interruption consequences are estimated as a function of the flammable and non-flammable consequence area results. Environmental consequences are determined directly from the mass available for release or from the release rate.

RBI CASE STUDY ON A HEAT RECOVERY STEAM GENERATOR

Risk analysis with the Risk Based Inspection requires data such as: data sheets, design data and operational data, and data inspection reports that have been done. After required data is collected, then analyzed risk refers to the API 581 RBI semi quantitative to find the Probability of Failure (POF) and the Consequence of Failure (COF). Furthermore POF and COF values are combined to obtain the risk [10].

Release Rate Analysis

The first step in analyzing the rate of leakage according to the workbook for semi-quantitative standard API 581 Appendix B is to determine the representative fluid and equipment category (Table 7.2 API 581 BRD). The equipment that is analyzed in this study are as follows:

TABLE 1. Representative Fluid And Equipment Category

invetory	code	Fluida representatif	Inventory value	Invetory category
HP economizer	HP-ECO	water	23717.14 lbs	C
HP evaporator II	HP-EVAP2	steam	29503.41 lbs	C
HP Superheater I	HP-SH1	steam	15862.76 lbs	C

Based on the detection system and insulation systems Table 7.6 API 581, the components are categorized as C for detection systems and insulation systems. Observation of changes or leakage of the fluid in the pipe visually and in case of a leak was isolated by manually operated valve. Based on the detection system and the insulation system which is then adjusted by BRD 581 Table 7.7 API, the estimated duration of leakage shown in Table 2.

TABLE 2. Leak Durations Based on Detection and Isolation Systems

size hole	¼ inch	1 inch	4 inch	16 inch
Leak duration	1 hour	40 minutes	20 minutes	0

Subsequently calculates leakage rate of the fluid phase of steam and water contained in the pipe HRSG. To calculate the rate of fluid leakage by using the equations contained in the API BRD 581. Having in mind the rate of the leak, the next is to calculate the duration of the leak of the amount (capacity) total fluid stored in it. Then analyzed the leak flow types, whether the kind of continuous flow or instantaneous. In accordance with the method of RBI, to determine the type of leakage flow, the mass flow out within 3 minutes can be calculated. If within 3 minutes of outgoing mass flow exceeds 10,000 lbs, then the flow is categorized into instantaneous flow and vice versa. Based on the calculation, the size of the holes ¼ inch and 1 inch is continuous flow while the size of the hole for 4-inch and 16-inch is the instantaneous flow.

The last stage of this step is a comparison between the estimated duration of the leak detection system accordingly and insulation systems with a real leak. For instantaneous flow is considered 0 minutes, whereas for continuous flow compared and determined the smallest, which is then used as the duration of the leak. Determining the size of the leak hole that has been determined by API, the mass flow rate out of any hole state can be determined. The rate of fluid flow out due to leakage for each hole is presented in the following Table 3.

TABLE 3. Rate of fluid flow out due to leakage for each hole

invetory	Fluid phase	Hole size	Release rate	Leak duration	Release type
HP economizer	water	¼ inch	0.314 lb/s	217.208 min	continuous
		1 inch	5.03747 lb/s	13.575 min	continuous
		4 inch	80.599 lb/s	0.848 min	instantaneous
		16 inch	1289.592 lb/s	0.053 min	instantaneous
HP evaporator II	steam	¼ inch	1.217 lb/s	403.989 min	continuous
		1 inch	19.474 lb/s	25.249 min	continuous
		4 inch	311.595 lb/s	1.578 min	instantaneous
		16 inch	4985.522 lb/s	0.0986 min	instantaneous
HP Superheater I	steam	¼ inch	0.891 lb/s	296.65242	continuous
		1 inch	14.259 lb/s	18.54 min	continuous
		4 inch	228.149 lb/s	1.15879 min	instantaneous
		16 inch	3650.393 lb/s	0.0724 min	instantaneous

Likelihood analysis

Analysis of probability of failure on the equipment was observed, with a semi-quantitative method RBI is done through a process of TMSF (Technical Modules Sub-Factor) for each mechanism of the damage suffered. Mechanism for each damage caused to the equipment can be determined by scanning the operating conditions of the equipment. TSMF used in the damage analysis consists of several mechanisms of damage that can occur by a piece of equipment for the operating conditions and the type of working fluid. In this HRSG equipment only thinning factor that has probably caused by fluid services that are in it in the form of steam and water.

TMSF Thinning

The thinning rate can be determined from available thickness data (which so far has shown that it contains different kinds of errors and human mistakes) or an alternative technique based upon estimated rates can be used from the API 581 Appendix G. Thinning technical module (Appendix G) includes 'Estimated Corrosion Rate Tables' for different kind of steels and alloys invarious acidic and basic environments. API 581 suggests that this information can be used for RBI analysis whenever the potential thinning mechanism is known and there is not anyreliable data from inspections. In this research, enough data are available from thickness measurements of the power station. Here, the PN data (the thinning rates derived from the PN method) is compared with the API 581 thinning rates for RBI analysis. After finding the thinning rate, the fraction of wall loss due to thinning and the number of 'highest effective' inspections will be used to determine the thinning technical module sub-factor. Fraction of wall loss due to thinning is calculated by the formula cited below (see page 9-9 API 581):

$$\text{Fraction ofwall loss} = ar/t,$$

where a is the time (years) equipment age; r the corrosion rate; t the thickness. Based on the analysis, the result of TMSF thinning of inventory show in Table 4:

TABLE 4. TMSF Thinning

inventory	Ar/t	Inspection Category	Effectiveness Category	Thinning damage factor	Overdesign factors	Likehood category
HP economizer	0.42	1	B	220	1	4
HP evaporator II	0.34	1	B	140	1	4
HP Superheater I	0.28	1	B	90	1	3

Consequence Analysis

There are two analysis of the consequences of failure due to release of a representative fluid in the semi-quantitative method API 581: the consequences of the release of flammable fluid representative and the consequences due to release of of toxic fluid representative. Representative fluid used for the analysis are the determination of the consequences of steam

Detection and Isolation System

Type of detection system for cases observed is the type C. Detection systems according to API 581 type C system is only performed visual observation to detect leakage of material out if the system exceeds the operating pressure. In the case of the observed type of isolation system there is a type C insulation system according to API 581 type C of this system depends on the isolation valves are operated manually if there is a leak material. According to API 581 BRD isolation and detection system is no reduction in the rate adjustment due to leak fluid.

Mitigation System

The next area has been determined as a result of leakage are reduced by mitigation system. Mitigation system conditions on a case observed in case of leaks is to spray foam system. The condition of the system is the area due to leakage can be reduced by 5%.

TABLE 5. Area of Equipment Damage and Fatalities

Equipment	Hole size (inch)	Area of Equipment Damage (ft^2)	Area of Fatalities (ft^2)
HP economizer	¼	3.286	113.352
	1	49.747	1336.893
	4	109.359	226.963
	16	681.672	1866.751
HP evaporator II	¼	12.366	29.768
	1	187.189	426.293
	4	266.960	488.801
	16	1664.049	3046.851
HP Superheater I	¼	9.111	22.0697
	1	137.917	137.917
	4	217.321	397.912
	16	1354.632	2480.312

The consequence of failure is determined based on area of damage or hazard due toxicity. In this study analyzed the equipment is not toxic in its flow, the area the consequences of failure can use the value of the consequences of the damage. the consequences of the damage value equal to the value consequences of the fires which have been calculated on the analysis of the consequences of failure. The consequences of the fire is determined by the value of the area due to leakage of the area which consists of extensive fire and hazardous areas. The area of the consequences of flammable multiplication value with a generic fraction failure of equipment. Value consequences of fires and the area of the consequences of the failure of each piece of equipment are:

TABLE 6. Consequences of Area of Equipment Damage and Fatalities

invetory	Hole Size (inch)	Flammable Consequence (ft²)	Area Consequences of Failure (ft²)	total area of failure (ft²)	failure consequence category
HP economizer	¼	113.35	103.721		
	1	1336.89	0	262.333	C
	4	226.96	0		
	16	1866.75	158.612		
HP evaporator II	¼	29.76	27.238		
	1	426.29	0	286.121	C
	4	488.80	0		
	16	3046.85	258.88		
HP Superheater I	¼	22.069	20.194		
	1	137.91	0	230.94	C
	4	397.91	0		
	16	2480.31	210.745		

Risk Level

The level of risk on a semi-quantitative method API 581 are a combination of categories the possibility of failure and the consequences of failure categories. Based on the analysis that has been done, then the value of the category of possible failures obtained from the calculation of the value category TMSF and the consequences of failure for each equipment are are analyzed:

TABLE 7. Risk Level

Equipment	Likehood Category	Failure Consequence Category	Risk Level
HP economizer	4	C	Medium High Risk
HP evaporator II	4	C	Medium High Risk
HP Superheater I	3	C	Medium Risk

The final Risk Ranking is Obtained by considering the probability of failure rating (1 to 5) on the Y-axis and the consequence rating (A to E) on the X axis of the Risk Matrix. Risk rating is shown below in Figure 1.

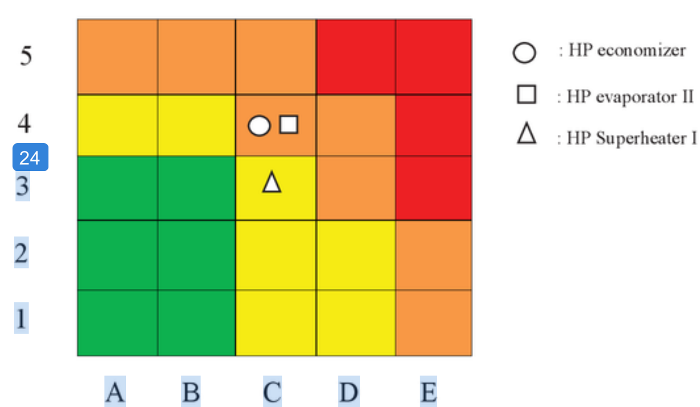

FIGURE 1. Risk Matrix

Risk Evaluation

Risk evaluation carried out aimed at reducing the risk to the optimization of the risk assessment events. in this context, it is also necessary that the optimal inspection program to be performed are:

a) risk ranking
b) risk reduction
c) optimization of inspection activities

From the analysis that has been done, recommendations for lowering the risk is:

a) Necessary maintenance and periodic inspections at intervals that are not too long.
b) need to be re-evaluated equipment operating conditions, the material conditions of the equipment, mitigation system, and still consider economic factors.
c) to support the risk assessment, the necessary inspection activities more effectively using a risk based approach to the equipment being analyzed.

SUMMARY

Based on the results of analysis using semi-quantitative method of API 581, based on the results of the analysis using semi-quantitative API 581, the risk level of each HRSG equipment are analyzed: HP superheater has a medium high risk (4C), HP evaporator has a medium-high risk (4C), and the HP economizer has a medium risk (3C). The results of the risk assessment using semi-quantitative method of standard API 581 based on the existing equipment at medium risk. Facts on the ground there is no critical problem in the equipment components. Damage mechanisms were prominent throughout the equipment is thinning mechanism. Evaluation of the risk approach is done with the aim of reducing risk by optimizing the risk assessment activities.

ACKNOWLEDGMENTS

The author would like to acknowledge input and support from colleagues in EAEM reliability Analysis, Department of Mechanical Engineering, Diponegoro University, Semarang and Department of Mechanical & Automotive Engineering of Pukyong National University.

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