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RCM Analysis of Process Equipment: A Case Study on Heat Exchangers

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Abstract: The traditional approach of maintenance emphasis on individual equipment. This practice has caused a number of problems. Among the problems are the maintenance actions are conservative in nature, thinking failure of parts are equals and performing maintenance actions to become totally reactive. Reliability Centered Maintenance (RCM) was introduced to address these problems. This study focused on RCM analysis applied to process equipment with heat exchangers as a case study. The seven steps of RCM analysis addressing "DEFINE", "ANALYSE" and "ACT" are discussed. Results indicate that RCM could assist in identifying the functional failures, causes of failures and risk ranking which are linked to corrosion rates and remaining life of the heat exchangers. Based on the results of the RCM analysis, the next inspection schedules for the heat exchangers are recommended.

Key words: Reliability centered maintenance, heat exchangers, risk ranking

INTRODUCTION

The traditional goal of maintenance is to preserve equipment. While Reliability Centered Maintenance (RCM) focuses on preservation of system function. It provides a structured framework for analyzing the functions and potential failures of equipment in order to develop a scheduled maintenance plan. The maintenance plan should provide an acceptable level of risk, efficient and cost-effectiveness. RCM was first introduced for application to Boeing 747 maintenance and was then adapted to industrial maintenance (RHW, 2007a). RCM is also known has been applied to aerospace, nuclear industry, shipping and chemical industries (Cotaima *et al*., 2000). For a process to comply with RCM requirements it must answers seven essential questions covering functions, functional failures, functional modes, failure effects, failure consequences, proactive tasks and task intervals and default actions (RHW, 2007a). In (Cotaima *et al*., 2000; RHW, 2007b, c), the steps of applying RCM to address the seven criteria, are grouped into three stages. The first stage is "DEFINE" stage to address the first three criteria. The second is "ANALYSE" stage for addressing the following three criteria. The third stage "ACT", addresses the last criteria. Approaches of applying RCM are also highlighted in (RHW, 2007b-d) covering aircraft industry and process equipment.

In the local industry, the RCM application is mainly confine to big industry such as the oil and gas sector.

Most industry practices preventive maintenance. Among the reasons is lack of understanding of RCM and the approach of adopting it. The objective of this study is to investigate the applicability of RCM in maintenance practice for process equipment. A case study of RCM analysis for heat exchangers (HEX) at a process industry is used. The analysis on the seven steps of RCM categorised under DEFINE, ANALYSE and ACT is discussed in the following sections. The data for the case study was obtained from the historical preventive data.

MATERIALS AND METHODS

Define stage: This stage covers three steps namely:

- Identification of the four HEX.
- Determine the functions of each of the HEX and the main components of the HEX.
- Identify the associated functional failures of the main components of the HEX.

In this case study four HEX from a process plant have been identified for the RCM analysis. Two of the HEX had been in operation for 25 years, while the other two HEX had been in operation for 27 years.

HEX is constructed of a series of individual interrelated component, each performing a specific job.

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Table 1: Information and Functions of the four HEX

HEX	Function	Age (year)	Specifications: Material	Tube: D(mm)	Tube: T(mm)
A	Conversion vapour phase to liquid phase	25	SA516 Gr.60	19.05	2.77
B	Conversion vapour phase to liquid phase	25	SA516 Gr.60	19.05	2.77
C	Heat conversion	27	SA516 Gr.70	25.4(D) 6096 ft.(L)	2.77
D	Heat conversion	27	SA516 Gr.70	25.4(D) 6096 ft.(L)	2.77

Among the main components of the HEX are shell, shell cover, channel head, tube bundle, baffle and nozzle The failure of any component will lead to failure of overall system (API, 2001; Andreone, 1977).

Two fluids of different starting temperatures, flow through HEX. One flows through the tubes (the tube side) and the other flows outside the tubes but inside the shell (the shell side). Heat is transferred from one fluid to the other through the tube walls, either from tube side to shell side or vice versa.

Analyse stage: Three steps are included in this stage, namely:

- Identify functional failures of the main components of the four HEX.
- Identify and evaluate the effects of failure of the main components of the four HEX.
- Identify the causes of failures of the components.

The main components of the HEX were fabricated from steel and were designed to specific thickness requirements. Due to nature of the function of the HEX, corrosion was the main cause which affected the components. Ultrasonic Thickness (UT) measurement approach was used to measure the wall thickness of the components at periodic intervals of five years. API 510 (API, 1997) was used to evaluate the corrosion rate and remaining life of the respective components.

Risk ranking: The guideline as provided (API, 2002) was used as the basis for risk ranking. The probabilities categories vary from 1 to 5 as mentioned in Table 3, while the consequence categories are C1, C2, C3, C4 and C5 as in Table 4. The risk ranking of the components of the HEX, were determined based on the outcomes of the combination of the probability and consequence categories.

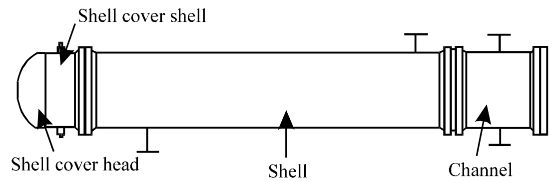

Fig. 1: The main components of the HEX and the locations the UTTM were recorded

Act stage: The final stage is select maintenance tasks step. This step deals with the sixth and seventh questions in the SAE JA1011 standard (SAE JA1012, 2002). The standard stipulates the following two criteria that must be adhered to:

- Action required to predict or to prevent each failure.
- Action required if a suitable proactive task could not be identified.

Four management strategies are considered namely; scheduled inspection, scheduled preventive maintenance, run to failure and design change (RHW, 2007d). Based on the maintenance practices for the understudied HEX, the company could opt any one of the first three strategies.

RESULTS AND DISCUSSION

Define stage: Four HEX of shell and tube types had been identified. The functions, age and the main specifications of the four HEX are shown in Table 1.

HEX A and B are of same age and having similar specifications and were used for same fluid. HEX C and D are of similar age and also having similar specifications.

Both HEX A and B were used for the same function namely to convert vapour phase to liquid phase. The design pressure for the shell side and tube were 100 psig and 660 psig, respectively. While the design temperature for the shell and tube were 680 and 650 °F, respectively.

The HEX C and D were used for heat conversion. The design pressure of the shell and the tube were 375 psig and 575 psig, respectively. The shell and the tube were designed to withstand temperature of 650 °F.

Analyse stage: Each of the HEX has five main components. The five components are channel, shell, shell cover shell, shell cover head and tubes as dipict in Fig. 1. These components influenced the functions of the HEX. Since the components were fabricated from steel and exposed to corrosive atmosphere, corrosion had been identified as the main cause which could lead to

Table 2: Failure modes and causes of failures of the components for the HEX

HEX	Component	Failure modes	Causes of failures
A	Channel	GC	ACC
	Shell	GC	WHSD, HClC
	Shell Cover Shell	LC	S
	Shell Cover Head	LC	SC
	Tubes	GC	E, EC, S
B	Channel	GC	ACC
	Shell	LC	S
	Shell Cover Shell	GC	S
	Shell Cover Head	LC	S
	Tubes	LC	E, EC, S
C	Channel	LC	S
	Shell	GC	S
	Shell Cover Shell	GC	S
	Shell Cover Head	GC	S
	Tubes	LC	E. EC, S
D	Channel	LC	S
	Shell	GC	S
	Shell Cover Shell	GC	S
	Shell Cover Head	GC	S
	Tubes	LC / GC	E. EC, S

functional failures of the HEX. As shown in Table 2, generalized corrosion (GC) and localized corrosion (LC) are two main failure modes of the five main components of the four HEX.

The ability of the EX to function depends on the four components. The failure modes of the components were either due to GL or LC or due to both occurrences. While the causes of failures were due to either one or combination of the following: Ammonia chloride corrosion (ACC), Wet H_2S Damage (WHSD), HCl corrosion (HClC), Sulfidation (S), Erosion (E) and /Erosion-Corrosion (EC). The failure modes and the causes of failures of the components for the respective HEX are tabulated Table 2.

Corrosion rates and remaining thickness before retirement: The measurements of UT were undertaken every five years. Using UT measurement data, the corrosion rate (CR) and the remaining thickness before retirement of the components of the respective HEX were calculated as per Eq. 1-3 from API 510 (API, 1997). The calculated corrosion rates and remaining thickness before retirement of the components for the respective HEX are as illustrates in Fig. 2 and 3.

Long term corrosion rate, CR (LT) in mm:

$$CR\,(LT) = \frac{(TI)-(TA)}{\text{Time (years) between TI and TA}} \quad (1)$$

Short term corrosion rate, CR(ST) in mm,

$$CR\,(ST) = \frac{(TP)-(TA)}{\text{Time (years) between TP and TA}} \quad (2)$$

Remaining life, RL in years,

$$RL = \frac{(TA)-(TR)}{CR} \quad (3)$$

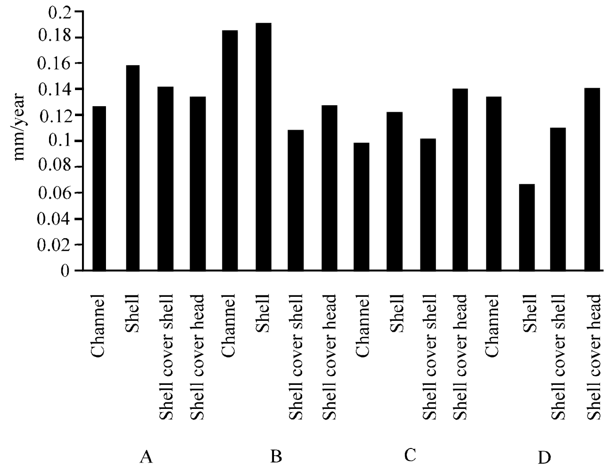

Fig. 2: Corrosion rate (LT) of the components for HEX

TI = Thickness in mm, measured at initial installation.
TA = Actual thickness in mm, measured at the time of inspection.
TR = Required thickness in mm, computed by design formulas before corrosion allowance and manufacturer's tolerance are added.
TP = Thickness in mm, measured during a previous inspection.

It is noted that generally the corrosion rates for the components for the HEX A and B are higher than that of HEX C and D. This trend is also noticeable for the case of the remaining thickness before retirement for some of the components, Differences in corrosion rates occurred due to different functions of the HEX A and B. Both HEX A and B functioned as conversion equipment, while HEX C and D functioned only as heat conversion. The existence of vapour phase in the HEX A and B was the main cause of higher corrosion rates.

Remaining life evaluation: The remaining life of the components for the respective HEX, were calculated based on API 510 (API 510, 1997). Figure 4 explain the plot of the calculated remaining life of the components for the respective HEX.

It is noted that HEX B had the least remaining life of 10.99 years, while HEX A, C and D had more than 15 years of remaining life. This might be due to the effect of ammonium chloride corrosion.

Risk ranking: For risk ranking, probability and consequence categories as dipict in Table 3 and 4 are used as the basis. Results of the risk ranking of the components of the four HEX are listed in Table 5. Risk

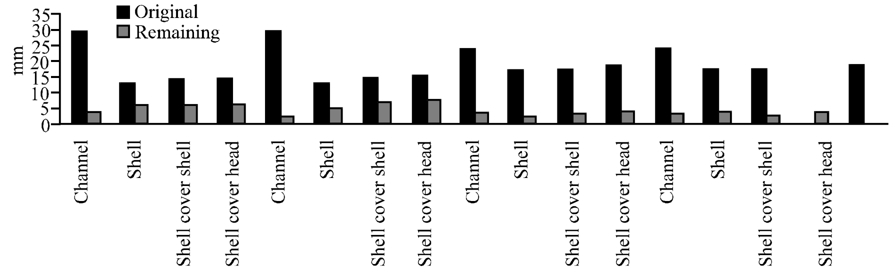

Fig. 3: Original and remaining thickness for the component

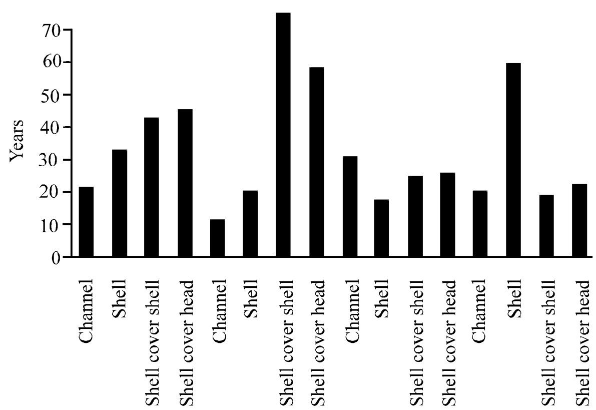

Fig. 4: Remaining life (years) of the components for HEX

Table 3: Probability category

Probability category	Definition	Remaining life (years)
1	Possibility of repeated incidents	<10
2	Possibility of isolated incidents	10 - 20
3	Possibility of occurring sometimes	20 - 30
4	Not likely to occur	30 - 40
5	Practically impossible	>40

Table 4: Consequence category

	Considerations	
Consequence category	Health and Safety	Economic
C1	Fatalities / serious impact on public shutdown)	Corporate (> 2 weeks (~ 10 M, RM)
C2	Serious injury to personnel / limited impact on public	Regional (3-14 days shutdown) (1 – 10 M, RM)
C3	Medical impact on personal / No impact on public	Site (Slow down of critical units) (100 K–1 M, RM)
C4	Minor impact on personnel	Other
C5	None	Other

Table 5: Risk ranking of the components for the FOUR HEX

			Failure consequence		
HEX	Component	Prob	HSE	Economic	Risk
A	Channel	3	C2	C2	Med
	Shell	4	C3	C2	Med
	Shell Cover Shell	5	C4	C2	Med
	Shell Cover Head	5	C4	C2	Med
B	Channel	2	C2	C2	High
	Shell	2	C3	C2	Med
	Shell Cover Shell	5	C3	C2	Med
	Shell Cover Head	5	C3	C2	Med
C	Channel	4	C3	C3	Med
	Shell	2	C3	C3	Med
	Shell Cover Shell	3	C2	C2	Med
	Shell Cover Head	3	C3	C3	Med
D	Channel	2	C3	C3	Med
	Shell	5	C3	C3	Med
	Shell Cover Shell	2	C2	C2	High
	Shell Cover Head	3	C3	C3	Med

Table 6: The recommended inspection schedules for the four HEX

HEX	Recommended Inspection Schedules for the HEX
A	Next inspection should be 10 years from the date of the last inspection. The follow up inspection should to be determined based on the results of the proposed scheduled inspection.
B	Next inspection should be 5 years from the date of the last inspection. The basis is due to remaining life of 10.99 years. The follow up inspection to be determined based on the results of the proposed scheduled inspection.
C	Next inspection should be 10 years from the date of the last inspection. The follow up inspection should to be determined based on the results of the proposed scheduled inspection.
D	Next inspection should be 10 years from the date of the last inspection. The follow up inspection should to be determined based on the results of the proposed scheduled inspection.

ranking indicate that two out of the total sixteen components of the HEX are high risk while others are medium risk.

"ACT" stage: From the analysis, the high risk components and the remaining life, the next inspection schedule of the respective HEX are recommended. These are listed in Table 6. The recommended inspection schedule for HEX B is 5 years from the date of last inspection. The basis is based on the calculated remaining life of 10.99 years. While the recommended schedules for

HEX A, HEX C and HEX D are 10 years from the date of last inspections since the calculated remaining life of these HEX A, HEX C and HEX D are more than 15 years. The follow up inspection schedules should then be determined based on the results obtained from the proposed scheduled inspections.

CONCLUSION

Adoption of RCM analysis for the four HEX led to the following findings:

- The difference in the functions of the HEX led to differences in corrosion rates of the components of HEX. For this case HEX used for conversion functions showing higher corrosion rates.
- The approach has identified that different causes of failures led to different remaining life of the HEX. HEX B had the least remaining life of 10.99 years, while the other three HEX had more than 15 years of remaining life.
- Based on the risk ranking and the remaining life of the components, the proposed next inspection schedule for HEX B is 5 years, while the next inspection schedules for HEX A, HEX C and HEX D are 10 years respectively. The follow up inspection schedules for the four HEX to be determined based on the results obtained from the proposed inspection schedules.

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