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RISK-BASED INSPECTION – YANBU GAS PLANT CASE STUDY MODULE #4 BUTANE MEROX & CAUSTIC REGENERATION UNITS

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ABSTRACT

In November 2006, Yanbu Gas Plant Engineering Inspection Unit had conducted RBI study at Module #4 Butane Merox & Caustic Regeneration Units under the supervision of the Inspection Department. Pertaining to the results of the study, it was a successful study for YGP. In fact, implementing the final recommendations of that study will grant for YGP a total saving of 11.277 MM per year. The key factor of that saving is extending the unit's T&I interval from 5 to 10 years under some certain conditions.

INTRODUCTION

This report describes the findings of a Risk-Based Inspection (RBI) study on Module #4 Butane Merox and Caustic Regeneration Units at Yanbu Gas Plant (YGP). This study was performed by a team from NAGO departments under the supervision of the Inspection Department.

1. Objectives

The main objectives of this study are as follows:

- Identify the dominant damage mechanisms within the YGP Module #4 Butane Merox and Caustic Regeneration Units
- Establish relative risk levels for equipment and in-plant piping
- Evaluate the possibility of increasing the T&I cycle and
- Provide recommendations regarding an optimized future inspection and assessment workscope

2. Scope

The scope of work consisted of static equipment and selected in-plant piping. Criteria for the selection of representative piping were established by the RBI Team, as follows:

1. Main process piping containing hydrocarbon, toxic or corrosive fluid.
2. Piping which failure could present a hazard to humans or to the environment, or where such failure could not be repaired without disrupting operation.
3. Piping known to exhibit a high probability of failure, e.g. piping with injection point(s), dead leg(s) or vibrations.

4. Piping known to be susceptible to Corrosion Under Insulation (CUI) and environmental damage such as Stress Corrosion Cracking (SCC) with failure consequences shown in item 2 above.

Important Notes:

- The above criteria were developed for use in conjunction with RBI studies. Piping not meeting the above criteria may not be exempted from being monitored in the OSI program.
- To optimize data gathering for in-plant piping, the following guidelines are also given:

  i. Establish corrosion loops or circuits for the whole unit under study. Each loop shall include all main lines and associated piping/branches attached to these main lines.

  ii. From each corrosion loop, select one or more main (representative) line and include in the RBI study as a record. Include lines before and after equipment.

  iii. Recommendations / inspection guidelines derived for each main line shall also be applicable to the entire corrosion loop piping, i.e. including associated piping/branches.

The main lines and associated piping relevant to this study are listed in Appendix 1.

The analysis shows more records than actual equipment and piping within the plant; this is because some equipment may be fragmented into several records, e.g. column top, column bottom, heat exchanger tube side, heat exchanger shell side, etc.

The workscope items were further divided into 5 inventory groups based on process streams and isolation systems, as follows:

Group Inventory #	Circuit Description
G1	Feed Gas
G2	Liquid Butane
G3	Caustic
G4	Steam
G5	Disulfide oil

These inventories are shown diagrammatically in Appendix 2.

This study does not include rotating equipment, valves, civil structures, electrical, instrumentation, and internals (e.g. trays, demisters).

3. Approach

The following phased approach was used based on the Saudi Aramco Engineering Procedure SAEP-343 “Risk-Based Inspection for Static Equipment and In-Plant Piping”:

- Phase 1: Pre-assessment Preparation – This phase involved the selection of process and inspection engineers, developing the work schedule and initial data gathering.
- Phase 2: Data Collection – This phase included a team kick-off meeting, plant walkthrough, interviews with Plant staff, completing the data gathering, review of PFDs, P&IDs, SISs, T&I inspection records and OSI data and finalizing the data entry in the software.
- Phase 3: Analysis and Inspection Planning – This phase aimed at producing an initial risk assessment, validating the study assumptions and data output and presentation of preliminary findings.
- Phase 4: Final Reporting – This phase involves the issuance of the final report of all findings and recommendations.

4. Methodology

RBI is a systematic approach that aims to minimize the risk exposure of plant equipment by optimizing the use of inspection resources. In this study, the API-RBI methodology was used based on API Publication 581, First Edition, May 2000 and API-RBI software version 7.0 (7.00.0012). The quantitative method used in this study prioritizes the process containing equipment, including piping, by calculating likelihood and consequence values for each piece of equipment.

Full details of the RBI methodology are given in Appendix 3.

5. Corrosion Loops

Corrosion loops for the Butane Merox and Caustic Regeneration Units were established based on similarity in process, materials and operating conditions. In total, 7 loops were identified. Selected operating windows affecting mechanical integrity and the damage mechanisms for each loop were also identified in the API RBI software. Detailed descriptions for corrosion loops along with potential damage mechanisms are given in Appendix 4.

6. Assumptions/Comments

It is customary in RBI studies to make certain assumptions and document the basis for the data used. Assumptions and comments relevant to this study are as follows:

1. A population density 1 x 10^{-4} was used based on 2 people being present at any time in the Butane Merox and Caustic Regeneration Units and a calculated process unit area of 20,000 square feet.
2. The production loss after commissioning 3rd Deethanizer system in 2009 is calculated as follows: In case of a shutdown of Mod-4 butane Merox unit, the produced butane (C4) will be diverted to Mod-3 butane Merox unit which can handle up to 50 MBD .This will result in reducing the butane from 80 MBD (based on normal rate of 490 MMBD) to 50 MBD. Reducing the total feed from 490MMBD to 320MMBD to maintain the 50MBD of Mod-3 butane Merox unit will result in a production loss equivalent to $ 4.5 MM/day.
3. Average T&I duration is 25 days per T&I.
4. T&I cost (inspection & maintenance) is $0.27MM per T&I.
5. Equipment cost is $650 per square feet; this is based on the Butane Merox and Caustic Regeneration Units replacement cost of approximately $13 MM over a plot area of 20,000 square feet.
6. A management score of 50 (neutral value) was used in this study. This is to ensure uniformity across Saudi Aramco facilities.
7. $5MM was used for the estimated cost of fatality per individual.
8. The default API BRD piping length of 50’ was used for all piping.
9. For Equipment, a specified T_{min} was used from SIS.
10. For piping, a specified T_{min} was used from SIS and OSI program.
11. Corrosion allowance for piping was calculated as Furnished Thickness – T_{min} . For equipment, corrosion allowance was taken from SIS Sheet.
12. Software default structural T_{min} for piping was overwritten by T_{min} values from SAES-L-310.
13. Localized corrosion was used for all services where caustic is present.
14. For equipment that is internally cladded, the corrosion rate is taken as 1 MPY.
15. Corrosion Rate for external corrosion is taken as 0.5 MPY due to lack of appropriate data.

7. Study Findings

The findings below cover the following:

- Inspection history review
- Risk analysis / Projection results

7.1 Inspection History Review

7.1.1 General Plant Information

- Mod-4 Butane Merox and Caustic Regeneration Units were commissioned in 1982 and thus has experienced approximately 25 years of service.
- All equipment is currently on 5-year EIS. The inspection history was compiled from the last four post T&I reports.
- Detected stress corrosion cracking was found on C-462 (Extractor), D-464 (Caustic pre-wash), D-465 (Butane Water settler), D-466 (Sand filter) and C-463 (Oxidizer).
- All equipment and piping in caustic service was found to be not post weld heat treated.
- One pipe "8" – P – 4704 – 3A1" was replaced in-kind with post weld heat treatment due to detected CSCC.
- Cracking inspection has been performed consistently every two years for all non-stress relieved piping greater than 3'' in caustic service.

7.1.2 Static Equipment

A detailed review of static equipment inspection history was prepared. It is noted that the review centered on the last four inspections carried out to date, i.e. inspection history prior to the reviewed period was not undertaken.

7.1.3 In-Plant Piping

Selected in-plant piping was covered to represent other pipes within the same corrosion loop as describes in the Scope section above. Associated piping related to each representative line are listed in Appendix 1. The piping is monitored via OSI program and full thinning history is documented in this program. Corrosion rates used in this study were partly derived from the OSI program output which is entered as "measured" and partially from expert opinion which is entered as "estimated."

7.2 Risk Analysis (Current Status-2006)

The current risk summary of all equipment and piping (42 components) is given in Appendix 6. The current risk (November 2006) matrix for all components is shown in Figure1. High and medium-high risk components are listed in Tables 1 and 2 respectively.

Current Risk (2006)

Likelihood Category	A	B	C	D	E	
	Consequence Category					
5	0	0	0	0	0	0
4	0	0	0	0	0	0
3	0	0	0	0	3	3
2	0	0	3	1	4	8
1	3	3	12	4	9	31
	3	3	15	5	16	

Total Components = 42

High	3	7.41%
Medium High	13	30.95%
Medium	20	47.62%
Low	6	14.29%

Figure 1 – Current Risk Matrix (March 2007)

Table 1 – High Risk Components

Component (Risk)	**Description**	**Maine Driver**
C- 462 Bottom (3E)	Merox Butane Extractor	Caustic Stress Corrosion Cracking (no PWHT) + Consequence
C- 462 Middle (3E)	Merox Butane Extractor	Caustic Stress Corrosion Cracking (no PWHT) + Consequence
C- 462 Top (3E)	Merox Butane Extractor	Caustic Stress Corrosion Cracking (no PWHT) + Consequence

Table 2 – Medium-High Risk Components (Selected)

Component (Risk)	**Description**	**Maine Driver**
C-464 (2E)	Merox Butane Pre-wash Drum	Caustic Stress Corrosion Cracking (no PWHT) + Consequence
C-466 (2E)	Merox Butane Sand Filter	Caustic Stress Corrosion Cracking (no PWHT) + Consequence
C-465 (2E)	Merox Butane Water Settler	Caustic Stress Corrosion Cracking (no PWHT) + Consequence

The main observations to note from the above figures and tables are as follows:

- The risk distribution for this plant shows 7% of components at high risk and 31% at medium high risk category.
- The Butane Merox Extractor (D-462) exhibited a High Risk category driven by both likelihood and consequence. The main driver of the likelihood is the high susceptibility to caustic stress corrosion cracking (CSCC) resulted from detected caustic cracking and lack of post-weld heat treatment (PWHT) in these vessels. The driver of the consequences is the nature and large volume of the fluid handled by this equipment coupled with the low rating of the isolation system.
- 68% of components are either medium or low risk. Accordingly, some relaxation of the inspection requirements for these components is possible.
- The high and medium- high risk components showing high likelihood of failure are driven by the susceptibility to CSCC coupled with high consequence.
- The concern with CSCC is related to the lack of post-weld heat which resulting in detected caustic cracking. It is noted that this type of cracking has already been detected on some equipment at previous T&Is.

7.3 Risk Projection (Future 2010-2016)

A risk projection was carried out to evaluate future risk for 5 and 10-year T&I cycles. For comparison, the risk matrix for the current risk and a 5-year T&I cycle are shown in Figure 2 below.

Current Risk (2006)

Likelihood Category	Consequence Category					
	A	B	C	D	E	
5	0	0	0	0	0	0
4	0	0	0	0	0	0
3	0	0	0	0	3	3
2	0	0	3	1	4	8
1	3	3	12	4	9	31
	3	3	15	5	16	

Future Risk 2010 (5 year T&I)

Likelihood Category	Consequence Category					
	A	B	C	D	E	
5	0	0	0	0	0	0
4	0	0	0	0	3	3
3	0	0	3	0	3	6
2	0	0	1	1	1	3
1	3	3	11	4	9	30
	3	3	15	5	16	

Figure 2 – Current vs. Future (5-Year or 2010) Risk Projection

By comparing the above matrices, it is apparent that the risk level for ten (10) components has increased, as follows:

- D-466, Merox Butane Sand Filter, from category 2E to 3E
- C-463, Oxidizers bottom , from category 2C to 3C
- C-463, Oxidizers middle, from category 2C to 3C
- C-463, Oxidizers top, from category 2C to 3C
- C-462, Merox Butane Extractor bottom, from category 3E to 4E
- C-462, Merox Butane Extractor middle , from category 3E to 4E
- C-462, Merox Butane Extractor top, from category 3E to 4E
- D-465, Merox Butane Water settler bottom, from category 2E to 3E
- D-465, Merox Butane Pre-wash top, from category 2E to 3E
- D-467, Disulfide Separator, from category 1C to 2C

Further risk projection to a 10-year T&I cycle yielded the following results (Figure 3).

Future Risk 2010 (5 year T&I)

Likelihood Category	Consequence Category A	B	C	D	E	
5	0	0	0	0	0	0
4	0	0	0	0	0	0
3	0	0	3	1	7	11
2	0	0	0	0	0	0
1	3	3	12	4	9	31
	3	3	15	5	16	

Future Risk 2016 (10 year T&I)

Likelihood Category	Consequence Category A	B	C	D	E	
5	0	0	0	0	0	0
4	0	0	3	1	7	11
3	0	0	0	0	0	0
2	0	0	2	0	0	2
1	3	3	10	4	9	29
	3	3	15	5	16	

Figure 3 – Future (5-Year or 2010) vs. Future (7-Year or 2016) Risk Projection

With the exception of thirteen (9) components showing an increase in the risk category, the risk level for the rest of components remains unchanged. The thirteen subject components are:

- D-466, Merox Butane Sand Filter, from category 3E to 4E
- C-463, Oxidizers bottom , from category 3C to 4C
- C-463, Oxidizers middle, from category 3C to 4C
- C-463, Oxidizers top, from category 3C to 4C
- D-467, Disulfide Separator from category 2C to 3C
- D-465, Merox Butane Water Settler bottom, from category 2E to 3E
- D-465, Merox Butane Water Settler top, from category 2E to 3E
- D-465, Merox Butane Water Settler Middle, from category 3E to 4E
- D-464, Merox Butane Pre-wash Drum bottom, from category 2D to 3D

Overall, it is apparent that there is an increase in the risk for some components when projecting from a 5 to a 10-year T&I cycle. The risk category for these components which are prone to caustic stress corrosion cracking may be significantly reduced by performing post-weld heat treatment at the next available opportunity. Based on the above, it is concluded that an increase in the T&I cycle to 10 years is permissible provided the following recommendations are implemented:

a. Perform PWHT at the next available opportunity for all none stress relieved equipment in caustic service: C-462 (Extractor), D-464 (Caustic Pre-wash), D-465 (Butane Water Settler), D-466 (Sand filter), and C-463 (Oxidizer).
b. Perform WFMPI on the internal welds for all stress relieved equipment on 2016 utilizing Debutanizer Column T&I opportunity.
c. Replace all non stress relieved piping in caustic service with stress relieved piping. As a minimum, replace the 3" diameter and below piping and perform 100% shear wave inspection on the welds of piping 4" diameter and greater.
d. Incorporate critical parameters that could affect RBI results in the existing Management of Change (MOC) program.

8. Financial Benefits

Based on an increased T&I interval from 5 to 10 years, a saving of approximately $11.28 MM per year over 20 years is derived based on the following information:

- Mod-4 Butane Merox and Caustic Regeneration Unit is shutdown for approx. 25 days every 5 years
- T&I Maintenance/Inspection Cost approx. $0.27MM per T&I
- Business Interruption Cost = $4.5 MM / day x 25 days = $112.5 MM (Based on 490 MMBD)

- Over 20-year timeframe, based on proposed T&I interval of 10 years, Number of T&Is reduced from 4 (5-Y) to 2 (10-Y), i.e. 2 x ($112.5 MM+0.27 MM)
- Total Savings per year (Reduced number of T&Is) = ($225 MM + $.54MM)/20 = $225.54 MM/20 = $11.28 MM / year (over 20 years)

The production loss after commissioning 3rd Deethanizer system in 2009 is calculated as follows: In case of a shutdown of Mod-4 butane Merox unit, the produced butane (C4) will be diverted to Mod-3 butane Merox unit, which can handle up to 50 MBD .This will result in reducing the butane from 80 MBD (based on normal rate of 490 MMBD) to 50 MBD. Reducing the total feed from 490MMBD to 320MMBD to maintain the 50MBD of Mod-3 butane Merox unit will result in a production loss equivalent to $ 4.5 MM/day.

CONCLUSION

1. The risk distribution for this plant shows 7% of the components at high risk and 31% at Medium-High risk category.
2. The Butane Merox Extractor (D-462) exhibited a High Risk category driven by both likelihood and consequence. The main driver of the likelihood is the high susceptibility to caustic stress corrosion cracking (CSCC) resulted from detected caustic cracking and lack of post-weld heat treatment (PWHT) in this drum. The driver of the consequences is the nature and large volume of the fluid handled by this equipment coupled with the low rating of the isolation system.
3. 62% of components are either medium or low risk. Accordingly, some relaxation of the inspection requirements for these components is possible.
4. The Medium- High risk components showing high likelihood of failure are driven by the susceptibility to CSCC coupled with high consequence.
5. The susceptibility for (CSCC) is driven by the lack of post-weld heat treatment of components.
6. Risk projection to 2016 (10-year T&I cycle) showed that risk level has increased in comparison with the 2010 (5-year T&I cycle) due to the susceptibility of (CSCC).
7. Based on the results of this study, it is concluded that an increase in the T&I cycle from 5 to 10 years is permissible provided the following recommendations are implemented:
   - Perform PWHT at the next available opportunity for all none stress relieved equipment in caustic service: C-462 (Extractor), D-464 (Caustic pre-wash), D-465 (Butane Water settler), D-466 (Sand filter), and C-463 (Oxidizer).
   - Perform Wet Fluorescent Magnetic Particle Inspection (WFMPI) on the internal welds for all stress relieved equipment on 2016 utilizing Debutanizer column T&I opportunity.
   - Replace all non stress relieved piping in caustic service with stress relieved piping. As a minimum, replace the 3” diameter and below piping and perform 100% shear wave inspection on the welds of piping 4” diameter and greater.
   - Incorporate critical parameters that could affect RBI results in the existing Management of Change (MOC) program.
8. Based on initial estimates, the anticipated savings derived from an increase in the T&I cycle from 5 to 10 years is $11.28 MM per year.

APPENDIX 1
REPRESENTATIVE AND ASSOCIATED PIPING

Representative Piping	Corrosion Loops	Associated Piping
10-P-4312-1A1	2	
10-P-4701-1A1		2-S-4701-1A1C
3-C-4701-3L1		4/6-C-4702-3A1
6-P-4702-1A1		6-BD-4701-1A1
10-P-4703-1A1		2-S-4702-1A1C
2-C-4706-1A1		2-BD-4702-1L1
6-BD-4703-1A1		3-C-4705-1A1
4-C-4705-1A1		
10-P-4704-1A1		8-P-4707-1A1
		3-P-4712-1A1
3-P-4706-1A1		2-BD-4705-1L1
4-P-4705-1A1		6-BD-4704-1A1
2-C-4707-1A1		2-C-4706-1A1
		3-C-4658-1A1
10-P-4707-1A1		2-P-4708-1A1
2-BD-4705-1L1		
4-P-4709-1A1		6-BD-4701-1A1
3-C-4658-1A1		
2-P-4709-1A1		6-BD-4701-1A1
2-C-4709-3L1		
4-C-4754-1A1		2-BD-4753-1L1
		2-C-4753-1A1
3-S-4751-1A1C	3	
2-SC-4751-1A1C		1-SC-4753-3L1
4-C-4751-1A1	5	1/1/2-A-4751-2D3
4-C-4755-1A1		
2-C-4769-1A1	7	
6-C-4764-1A1		2-C-4763-1A1
		2-C-4763-1A1
		6-C-4765-1A1
		2-C-4767-1A1
1-C-4766-1A1		
6-RL-4751-1A1		1/1/2-S-4755-1A1C