Study on quantitative risk assessment and inspection of offshore pressure vessels

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Abstract: Quantitative risk assessment of pressure vessels for offshore oil and gas production is beneficial for controlling risks, optimizing design, reducing production costs, guiding the implementation of risk mitigation measures and formulating inspection cycles and inspection plans. A quantitative analysis method is used to calculate the damage coefficient, probabilities and consequences of failure of the pressure vessel. The risk grade of the pressure vessel is divided in accordance with the established risk acceptance criteria, and the future inspection cycle and inspection plan are guided. The research results can accurately and quantitatively evaluate the risks of pressure vessels, and formulate inspection cycles and inspection plans for the risks. This method has been successfully applied to offshore and FPSO in China's seas and can be used as a reference for other projects.

Keywords: quantitative risk assessment; damage factor; probability of failure; consequences of failure; risk acceptance criteria; inspection cycles; inspection plans.

1. Introduction

Pressure vessels are widely used in important areas, such as oil and gas production. The safety plays an important role in offshore production culture [1].Risk analysis plays a more and more important role in various production fields [2-4], and it is also of great significance in the maritime field [5]. International Maritime Organizations (IMO) pay more and more attention to maritime safety [6, 7].

In the 1980s, Norwegian authorities issued a code for the assessment of corrosion risk management of pressure vessels and pressure pipelines in offshore oil and gas production facilities, which requires QRA of corrosion for pressure vessels

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and pressure pipelines. In the early 1990s, some offshore oil companies in the United States began to pay attention to the corrosion damage of pressure vessels and pressure pipes on offshore oil and gas production platforms. In order to reduce production costs and improve economic benefits [8], API and DNV implemented quantitative corrosion analysis and assessment technology on the US offshore oil and gas production platform. So in May 2000, API officially issued API RP 581 First Edition 《Risk-Based Inspection Base Resource Document》 on the basis of summarizing vessels inspection, and updated it to API RP 581 Third Edition 《Risk-based Inspection Methodology》, April 2016. Quantitative risk analysis is important to the offshore pressure vessel. This paper refers to this version for research. Risk-based inspection (RBI) technology and other methods [9] are also introduced and applied in engineering. At the same time, risk-based management is becoming more and more important in the engineering field [10 -13].

At present, risk assessment technology is generally used in risk assessment of offshore facilities [14]. This type of analysis method analyzes risk from a qualitative or semi-quantitative perspective, and the results are greatly affected by human, social and corporate factors [15, 16]. However, the current quantitative risk analysis (QRA) method for platform pipelines and equipment does not combine risk criteria [17, 18] for risk ranking, and there is no targeted inspection cycle and inspection plan for the corresponding risk assessment results in the future [19]. Finally there are problems that cannot guide the rational allocation of on-site inspection resources [20-22].

Therefore, this study establishes a quantitative assessment mathematical model for the risk analysis of offshore pressure vessels. Based on the simplified mathematical model, the various corrosion damage factors (DFs), probabilities of failure (POFs) and economic consequences of failure (COFs) about offshore pressure vessels were quantitatively analyzed and calculated. The risk grade of pressure vessel is judged according to the economic risk acceptable criteria. Based on the mathematical model and analysis method above, and combined with the probabilities of failure curve of pressure vessels, the next inspection cycle and corresponding inspection plan of pressure vessels are determined. Finally, the owner can be guided to take corresponding maintenance, risk monitoring and maintenance measures in the future, so as to achieve the reasonable allocation of on-site inspection resources.

2. Quantitative Risk Assessment Process

2.1. Introduction to the Assessment process

Figure 1 shows the quantitative risk assessment process for the offshore platform upper static vessels.

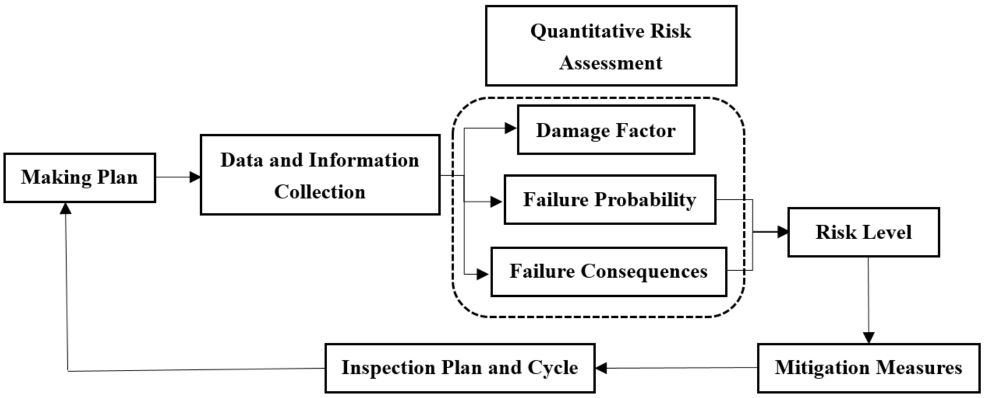


Figure 1. The process of quantitative risk assessment in static vessel

First of all, a rigorous plan should be prepared before the evaluation work is started. This plan can eliminate obstacles or problems that may occur in the process as much as possible, so that each work can be carried out smoothly, orderly and efficiently. The risk-based inspection (RBI) needs to collect data from various aspects. The data collection process should adhere to certain principles and standards, and the data collection should ensure the integrity of the data. Then, based on the theoretical basis of mathematical model, quantitative risk analysis and calculation are performed to obtain the POF and COF. Combined with the established risk acceptance criteria, the risk grade of the analysis object is determined. According to the various damage coefficients calculated by the vessels, the mitigation measures corresponding to the corresponding DF of the vessels are formulated. Finally, according to the POF curve, the next inspection cycle and inspection plan of the vessels are determined.

2.2. Purpose of Quantitative Risk Assessment

Through quantitative risk assessment of pressure vessels, DF that have a large impact on the failure of pressure vessels are screened. At the same time, the specific inspection measures will be formulated for the large DF in the future.

After calculating the POF of the pressure vessel, the curve of POF for the vessel is obtained. Based on the risk acceptance line given by the owner, the paper determine the date and validity of the next inspection in the future, and finally use it to guide the owner to formulate the inspection cycle and inspection plan.

3. Probabilities Of Failure Theory

3.1. Calculation of DFs related to corrosion rate

About the Thinning Damage Factor, calculate is the component wall loss fraction A_{rt} parameter using Equation (1)

$$A_{rt} = \frac{C_{r,bm} \bullet age}{t_{rdi}} \tag{1}$$

Where， $C_{r,bm}$ is the corrosion rate for the base material， mm/y；

t_{rdi} is the last inspection known thickness， mm；

age is the Interval date between of RBI Date and last inspection， y。

$C_{r,bm}$ has there Corrosion Rate Confidence Levels，the paper refer to API 581 Part2 4.5.3 and Part 2 Annex 2.B.

$$FS^{Thin} = \frac{(YS+TS)E \bullet 1.1}{2} \tag{2}$$

$$SR_P^{Thin} = \frac{S \bullet E}{FS^{Thin}} \bullet \frac{Max(t_{\min}, t_c)}{t_{rdi}} \tag{3}$$

$$SR_P^{Thin} = \frac{P \bullet D}{\alpha \bullet FS^{Thin} \bullet t_{rdi}} \tag{4}$$

Where, P is the design pressure;

D is the component inside diameter;

TS is the Tensile Strength at design temperature;

YS is the Yield Strength at design temperature;

E is the weld joint efficiency;

S is the allowable stress at design temperature;

t_c is the minimum structural thickness of the component base material;

t_{min} is the minimum required thickness based on the applicable construction code;

FS^{Thin} is the Flow Stress；

For a cylinder $\alpha = 2$, for a sphere $\alpha = 4$, for a head $\alpha = 1.13$.

SR_P^{Thin} is the strength ratio parameter defined as the ratio of hoop stress to flow stress, take the maximum from Equation (3) and (4).

The order inspection effectiveness factor I_1^{thin} 、 I_2^{thin} 、 I_3^{thin} 、the posterior probability for damage state Po_{p1}^{thin} 、 Po_{p2}^{thin} 、 Po_{p3}^{thin} and the reliability indices for damage state β_1^{thin} β_2^{thin} β_3^{thin} :

Damage state n(n=1、2、3):

$$I_n^{thin} = Pr_{pn}{}^{thin} (Co_{pn}{}^{thin})^{N_A{}^{Thin}} (Co_{pn}{}^{thin})^{N_B{}^{Thin}} (Co_{pn}{}^{thin})^{N_C{}^{Thin}} (Co_{pn}{}^{thin})^{N_D{}^{Thin}} \quad (5)$$

$$Po_{pn}^{thin} = \frac{I_n^{thin}}{I_1^{thin} + I_2^{thin} + I_3^{thin}} \quad (6)$$

$$\beta_n^{thin} = \frac{1 - D_{sn} \bullet A_{rt} - SR_P{}^{Thin}}{\sqrt{D_{sn}{}^2 \bullet A_{rt}{}^2 \bullet COV_{\Delta t}^2 + (1 - D_{sn} \bullet A_{rt})^2 \bullet COV_{sf}^2 + (SR_P{}^{Thin})^2 \bullet \mathrm{cov}_p^2}} \quad (7)$$

where, the number of inspections $N_A{}^{Thin}$, $N_B{}^{Thin}$, $N_C{}^{Thin}$, $N_D{}^{Thin}$ and each inspections effectiveness level refer to Part 2 Section 4.5.6;

$Pr_{p(\mathrm{n})}{}^{thin}$ (n=1、2、3)refer to Part 2 Table 4.5; $Co_{p(\mathrm{n})}{}^{thin}$ (n=1、2、3)refer to Part 2 Table 4.6; $COV_{\Delta t} = 0.2$, $COV_{sf} = 0.2$, $\mathrm{cov}_p = 0.05$; D_{s1}=1, D_{s2}=2, D_{s3}=4, refer to Part 2 Section 4.5.3 [35].

Determine the base value of the DF for thinning D_{fb}^{thin} .

$$D_{fb}^{thin} = \frac{(Po_{p1}^{thin} \phi(-\beta_1^{thin})) + Po_{p2}^{thin} \phi(-\beta_2^{thin}) + Po_{p3}^{thin} \phi(-\beta_3^{thin})}{1.56E-04} \quad (8)$$

Where ϕ is the standard normal cumulative distribution function.

Determine the DF for thinning D_f^{thin} .

$$D_f^{thin} = \max\left[\frac{D_{fb}^{thin} \bullet F_{IP} \bullet F_{DL}}{F_{OM}}, 0.1\right] \quad (9)$$

Where, F_{IP}、F_{DL}、F_{OM} refer to API Part 2.

3.2. External Corrosion and Insulation Corrosion Damage Factor

The base corrosion rate C_{rB} is determined based on the driver and operating temperature using Part 2 Table 15.2. Related calculation process parameters see equation (1)-(7).

Calculate external corrosion DF D_f^{ext} and insulation corrosion DF D_f^{CUIF}

$$D_f^{ext} = \frac{(Po_{p1}^{ext} \phi(-\beta_1^{ext})) + Po_{p2}^{ext} \phi(-\beta_2^{ext}) + Po_{p3}^{ext} \phi(-\beta_3^{ext})}{1.56E-04} \quad (10)$$

$$D_f^{CUIF} = \frac{(Po_{p1}^{CUIF} \phi(-\beta_1^{CUIF})) + Po_{p2}^{CUIF} \phi(-\beta_2^{CUIF}) + Po_{p3}^{CUIF} \phi(-\beta_3^{CUIF})}{1.56E-04} \quad (11)$$

3.3. Other Related Damage Factor Calculations

1. Sulfide Stress Cracking Damage Factor.

Based on the properties of the pressure vessel medium，the paper refer to API Part 2 Table 8.2、Table 8.3、Table 8.4，and determine the severity index, S_{VI}. By using API Part 2 Table 6.3 and based on the number of the highest inspection effectiveness and the severity index, S_{VI}, the base DF for sulfide stress cracking, D_{fB}^{ssc},is determined.

Calculate the escalation in the DF based on the time in-service since the last inspection, using the age and Equation (12).

$$D_f^{ssc} = D_{fB}^{ssc}\left(Max\left[age,1\right]\right)^{1.1} \quad (12)$$

2. HIC/SOHIC-H2S Cracking Damage Factor.

Determine the severity index, S_{VI} (potential level of hydrogen flux) for cracking based on the H_2S content of the water and its pH using API Part 2 Table 9.2. The sulfur content of the carbon steel, product form and knowledge of whether the component was subject to PWHT refer to API Part 2 Table 9.3 and Table 9.4.

Determine the base DF for HIC/SOHIC-H_2S cracking, $D_{fb}^{\text{HIC/SOHIC-H}_2\text{S}}$, using API Part 2 Table 6.3 based on the number of the highest inspection effectiveness, and the severity index, S_{VI} .

Calculate the final DF accounting for escalation based on the time in-service since the last inspection, using the age and Equation (13).

$$D_f^{\text{HIC/SOHIC-H}_2\text{S}} = \frac{D_{fb}^{\text{HIC/SOHIC-H}_2\text{S}}\left(Max\left[age,1.0\right]\right)^{1.1}}{F_{OM}} \quad (13)$$

Where F_{OM} is the on-line adjustment factor, ,determined from API Part 2 Table 9.5.

3. Chloride Stress Corrosion Cracking Damage Factor.

Determine the severity index, S_{VI}, based on the susceptibility for cracking and the operating temperature, and concentration of the chloride ions using Part 2 Table 12.2 and Table 12.3. Determine the base DF for CLSCC, D_{fB}^{CLSCC}, using Part 2 Table 6.3 based on the number of and highest inspection effectiveness and severity index, S_{VI} .

Calculate the escalation in the DF based on the time in-service since the last inspection, using the age and Equation (14).

$$D_f^{CLSCC} = D_{fB}^{CLSCC}\left(Max\left[age,1\right]\right)^{1.1} \quad (14)$$

4. External Chloride Stress Corrosion Cracking Damage Factor.

Determine the severity index, S_{VI}, based on the susceptibility using Part 2 Table 17.2 and Table 17.3.

Determine the base DF for external CLSCC, $D_{fB}^{ext-CLSCC}$, using Table 6.3 based on the number of the highest inspection effectiveness and the severity index, S_{VI}.

Calculate the escalation in the DF based on the time in-service since the last inspection, using the age and Equation (15).

$$D_f^{ext\text{-}CLSCC} = D_{fB}^{ext\text{-}CLSCC}\left(Max\left[age,1\right]\right)^{1.1} \quad (15)$$

5. External Chloride Stress Corrosion Cracking Under Insulation Damage Factor.

Get the severity index, S_{VI}, based on the susceptibility using Part 2 Table 18.2 and Table 17.3.

Determine the base DF for CUI CLSCC, $D_{fB}^{CUIF\text{-}CLSCC}$, using Part 2 Table 6.3 based on the number of the highest inspection effectiveness and the severity index, S_{VI}.

Calculate the escalation in the DF based on the time in-service since the last inspection, using the age and Equation (16).

$$D_f^{CUIF\text{-}CLSCC} = D_{fB}^{CUIF\text{-}CLSCC}\left(Max\left[age,1\right]\right)^{1.1} \quad (16)$$

3.4. Damage Factor Combination for Multiple Damage Mechanisms.

Governing External DF is D_{f-gov}^{extd}.The governing external DF is determined from Equation (17).

$$D_{f-gov}^{extd} = \max\left[D_f^{ext}, D_f^{CUIF}, D_f^{ext-CLSCC}, D_f^{CUI-CLSCC}\right] \quad (17)$$

Governing SCC DF is D_{f-gov}^{ssc}.The governing SCC DF is determine from Equation (18).

$$D_{f-gov}^{ssc} = \max\left[D_f^{ssc}, D_f^{HIC/SOHIC-H_2S}, D_f^{CLSCC}\right] \quad (18)$$

Total DF is $D_f(t)$, the external and thinning damage are general, and damage is likely to occur at the same location and the total DF is given by Equation (19).

$$D_f(t) = D_f^{thin} + D_{f-gov}^{extd} + D_{f-gov}^{ssc} \quad (19)$$

3.5. Probabilities of Failure

The POF is computed from Equation (20).

$$P_f(t) = gff * D_f(t) * F_{MS} \quad (20)$$

Where: P_f（t）is Probabilities of Failure;

gff is determined as the product of a total generic POF, Obtained from relevant OREDA database query[23];

D_f（t）is a DF;

F_{MS} is a management coefficient, determined according to the actual management situation during the working of the equipment, generally 0.8 ~ 1.5. If the management is perfect during the working of the equipment, it is taken as 0.8. If the management of the equipment is insufficient, it is taken as 1.5.

4. Consequences of Failure

There are many costs associated with any failure of vessels in a process plant. These include, but are not limited to:

1. Cost of vessels repair and replacement, FC_{cmd}
2. Cost of damage to surrounding vessels in affected areas, FC_{affa}.
3. Costs associated with production losses and business interruption as a result of downtime to repair or replace damaged vessels, FC_{prod}.
4. Costs due to potential injuries associated with a failure, FC_{inj}.
5. Environmental cleanup costs$FC_{environ}$.

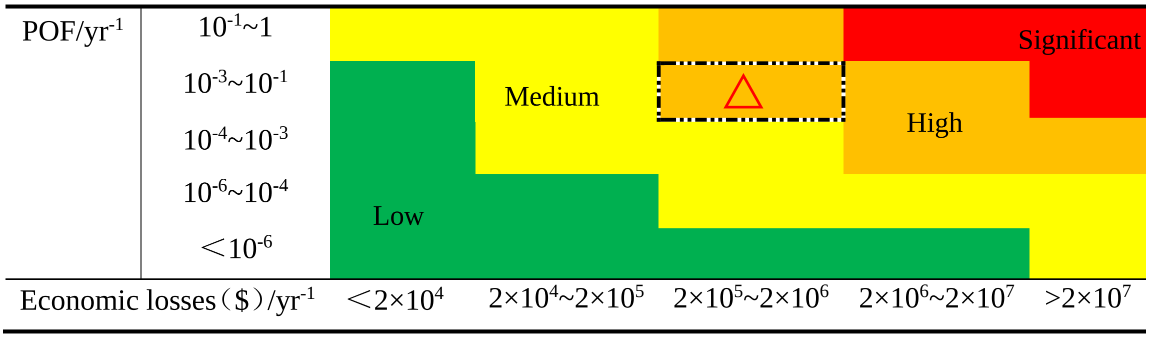
The economic consequence of a loss of containment and subsequent release of hazardous materials can be determined by adding up the individual costs discussed above, see Equation (21):

$$FC = FC_{cmd} + FC_{affa} + FC_{prod} + FC_{inj} + FC_{environ} \quad (21)$$

5. Risk Acceptance Criteria

Based on the current status of China's offshore oil and gas industry, a risk acceptance criteria was formulated to determine the risk grade [24]. This risk acceptance criteria is based on the acceptance criteria of CNOOC's economic risk, as shown in Table 1.

Table 1 The Criteria for Acceptable Risk of Economic Loss



The risk was divided into 4 risk grade areas according to probabilities of failure and corresponding failure consequence, which were Low, Medium, High and Significant respectively.

According to the platform manager's ability of accepting risks, different risk management methods and measures are adopted for each risk grade area in the risk acceptance criteria, as shown in Table 2.

Table 2. Risk management methods and measures of different risk grade

Risk grade	Risk Management Methods	Risk Management Measures
Low	Minimum monitoring	Minimum monitoring is applicable to risk projects with low f probabilities of failure and low consequences of failure. This kind of risk belongs to unexpected failure and failure has no serious impact on safety and production and environment. General visual inspection or return or replacement after failure can be selected for risk management.
Medium	Preventive maintenance	Preventive maintenance applies to projects with low probabilities of failure and high consequences of failure. These risks are unexpected failures that may result in serious consequences. Preventive maintenance should be used to keep the probabilities of failure low. It is generally recommended to increase the scope and intensity of monitoring to ensure the normal operation of equipment during the use and inspection period.
High	Corrective maintenance	Corrective maintenance applies to projects with a high probabilities of failure and low consequences of failure. Such risks can be expected to fail without serious consequences. You can use routine monitoring and maintenance to keep the probabilities of failure of devices and pipelines low. It is generally recommended to increase the monitoring frequency of equipment.
Significant	detailed assessment	For high-risk projects with high probabilities of failure and high consequences of failure, it is necessary to carry out a detailed assessment, determine the detailed information of risk projects by the method of close inspection and nondestructive testing technology, and take measures to mitigate or

	eliminate risks in time according to the inspection results.

6. Engineering Example

The production separator (V-2001) of offshore upper facility in China's sea area was put into use in February 2014. The inspections of the production separator were performed on the offshore platform inspection cycle day in March 2018. The inspection method of the production separator was Non-intrusive Inspection，and 80% spot UT for the total surface area.

Based on the inspection records, a large area of the vessel's outer coating had been completely corroded. The corrosion of the left head was more severe than the right head. Figure 2 is the on-site state of vessel. Considering the overall risk of vessel, the maximum vessel component risk is taken as the vessel risk. Therefore, this paper mainly studies the risk situation of cylinder and left head of the production separator.

Figure 2. Corrosion state inspected on site

Considering the environmental conditions of the sea area and the state of medium of vessel, we speculate that inside of vessel had been corroded, and there was an area where the internal coating had been completely corroded.

Based on the inspection effectiveness categories (A, B, C, D, E) in API 581 Part 2 Annex 2C, we believe that the effectiveness of the on-site inspection in March 2018 was B category. The risk assessment of vessel (RBI Date) was carried out in September 2019, and $age = 1.5$.

6.1. Data Collection and Screening

Based on the collection, analysis and screening of the design data and on-site inspection record data of the production separator, the basic design data related to this assessment is shown in Table 3, and the detailed inspection data is shown in Table 4.

Table 3. Design Basic Date Sheet of Production Separator Vessel

vessels ID	Vessel Name	Inner diameter	Design Pressure	Design Temperature	volume	As-Welded Max Brinnell Hardness
V-2001A	Production Separator Vessel	3400mm	1.55 MPa	90（℃）	134（m^3）	＜200MPa
Design thickness（Cylinder /Head）	Corrosion allowance	Vessel materials	Sulfur Content of vessel materials	E	t_{min}（Cylinder /Head）	TS 、 YS and S at
20/18（mm）	3（mm）	Q345R	0.004%	1.0	14.30/14.27 mm	185/490/315 MPa

Table 4. On-site Inspection Date Sheet of Production Separator Vessel

Medium	Operating Pressure	Operating Temperature	Medium PH	Medium H_2S concentration	Medium CL^-concentration
Oil,Gas,Water	1.0MPa	38~60℃	6.7~7.2	72ppm	768ppm
Insulation Type	OnLine Corrosion Monitoring	corrosion rate adjustment factor for insulation complexity	corrosion rate adjustment factor for insulation condition	Vessel environment	inside and outside coating condition
Mineral Wool	Corrosion Coupons	average	average	Marine / Cooling Tower Drift Area	Large area coating is no longer effective
t_{rd} (Cylinder / Left head / Right head）	$F_{IP}/F_{DL}/F_{OM}/F_{EQ}/F_{IF}$	Whether has experienced vibration failure	Level of vibration or noise around the Vessel	$C_{r,bm}$（Cylinder / Left head）	Method of the last inspection (simple description)
18.76/17.22/17.52 mm	3/3/2/2/1	NO	NO	0.3/0.2 mm/y	100%visual inspection, ＞75% non-destructive inspection

6.2. POF Result

The assessment interval age = 1.5 years. The calculation results of various damage factors (DFs) and total damage factors of production separator cylinder and left head are shown in Table 5 and table 6 respectively.

Table 5. Calculation results of POF for cylinder

Time			Damage Factor								
			D_f^{thin}	D_f^{ssc}	$D_f^{HIC/SOHIC-H_2S}$	D_f^{CLSCC}	D_f^{ext}	D_f^{CUIF}	$D_f^{ext-CLSCC}$	$D_f^{CUI-CLSCC}$	$D_f(t)$
$t=0$			8.65	1	0.5	50	1.92	1.92	1	5	63.65
RBI Date			11.93	1.56	0.78	78	2.58	2.63	1.56	7.8	$11.93+55\times t^{1.1}$
$t=2.5$	A	$[1,2.36]$	14.45	2.74	1.37	21.92	2.56	2.57	2.74	2.74	$17.02+8\times t^{1.1}$
		$t\geq 2.36$									$14.45+9\times t^{1.1}$
	B	$[1,1.26]$	14.55	2.74	1.37	54.8	2.57	2.59	2.74	5.48	$17.14+20\times t^{1.1}$
		$t\geq 1.26$									$14.55+22\times t^{1.1}$
	C		14.72	2.74	1.37	137	2.57	2.62	2.74	13.7	$14.72+55\times t^{1.1}$

Table 6. Calculation results of POF for Left Head

Time			Damage Factor								
			D_f^{thin}	D_f^{ssc}	$D_f^{HIC/SOHIC-H_2S}$	D_f^{CLSCC}	D_f^{ext}	D_f^{CUIF}	$D_f^{ext-CLSCC}$	$D_f^{CUI-CLSCC}$	$D_f(t)$
$t=0$			17.31	1	0.5	50	3.85	3.85	1	5	72.31
RBI Date			20.3	1.56	0.78	78	3.92	4.58	1.56	7.8	$20.3+55\times t^{1.1}$
$t=2.36$	A	$[1,4.43]$	20.2	2.57	1.29	20.56	4.5	5.14	2.57	2.57	$25.34+8\times t^{1.1}$
		$t\geq 4.43$									$20.2+9\times t^{1.1}$
	B	$[1,2.38]$	20.4	2.57	1.29	51.4	4.51	5.18	2.57	5.14	$25.58+20\times t^{1.1}$
		$t\geq 2.38$									$20.4+22\times t^{1.1}$
	C		20.62	2.57	1.29	128.5	4.53	5.24	2.57	12.85	$20.62+55\times t^{1.1}$

6.3. COF Result

a) When the production separator failed, the owner and operator indicated that the maximum cost of repair or replacement was $ 300,000;

b) The production separator is isolated from external vessel, which will not affect other vessel;

c) The owner and operator stated that the failure of production separator V-2001 would only cause part wells to shut down in the oil field, and would not cause the entire oil field to stop production. The production separator was repaired for 5 days, and the daily output lost 800 cubic meters. A barrel of oil was calculated at $ 58 (floatable). The final shutdown loss was $ 1.46 million.

d) It was hard to estimate the personal injury caused by the failure of production separator, and the owner and operator did not consider the cost of personal injury.

e) The failure of production separator would not cause sea area pollution. Only the offshore platform cleaning cost caused by the failure of production separator needed to be considered. The owner and operator only considered that the offshore platform cleaning cost was $100000.

According to equation (21), the total economic loss was $ 1.86 million.

6.4. Probabilities of Failure Curve

In the probabilities of failure calculation formula (20), the management coefficient F_{MS} in this paper is taken as 1.0, and the total probabilities of failure *gff* of pressure vessel is taken as 3.0E-05.

According to the analysis and calculation results in sections 6.1 and 6.2 of this paper, The POF curves of the left head and cylinder are respectively shown in Figure 3 and Figure 4. The probability acceptance value determined by the owner is 5E-03.

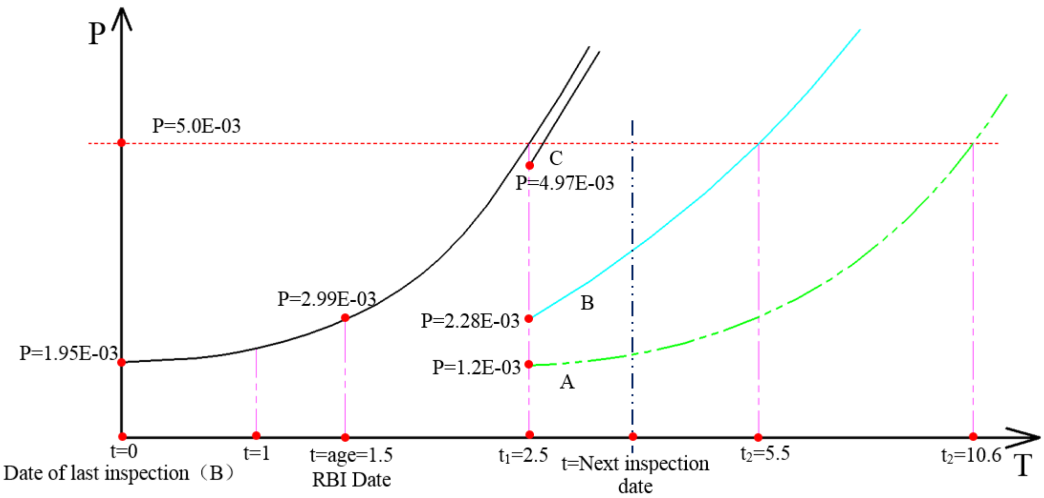


Figure 3. Cylinder POF curve

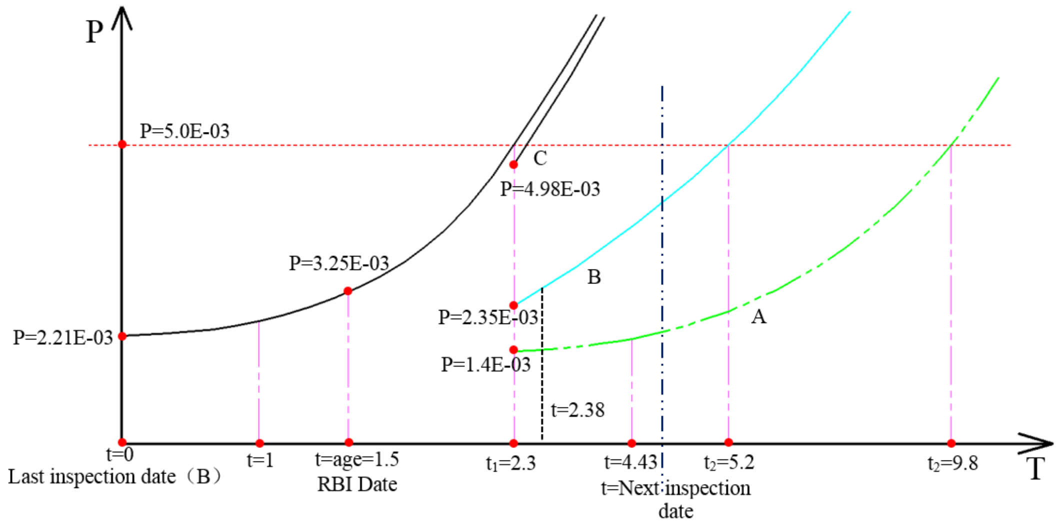


Figure 4. Left head POF curve

The next inspection date is uncertain and it is required to deduce the next inspection date: according to the POF curve of left head, it is recommended to inspect the production separator at the time interval t= 2.36 (around August 2020). According to the type of validity of this inspection (A, B, C) at t_1, the future inspection time should be before the t_2.

The next inspection day already exists: if the time t_1 (POF reaching 5E-03 for the first time) is before the next inspection day, it is recommended to inspect the vessel before the time t_1, and after the inspection, we should ensure that the time t_2 (POF reaching 5E-03 for the second time in the future) is longer than the inspection date.

7 Conclusion

1. About the offshore engineering static vessels, the method of quantitative risk assessment based mathematical model is simple and easy for engineering application, and it can realize the accurate assessment of the risk. According to the risk acceptance matrix in this paper, the current risk level of offshore production separator is determined as high risk.

2. According to the assessment of offshore production separator, thinning DF, chloride stress corrosion cracking DF, and external chloride stress corrosion cracking under insulation DF is the main cause of vessel failure in the future.

3. The risk of the left head is regarded as the risk of production separator. According to the POF curve, the inspection cycle is established. At the same time, according to the calculated DF, the special inspection plan is formulated for the DF

that has the greatest impact on the vessel failure.

4. Through the risk assessment of all static vessels on the offshore platform, the vessel risk ranking is obtained to guide the reasonable allocation of inspection resources in the next inspection. This will be the next key research work.

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