Risk Analysis using Corrosion Rate Parameter on Gas Transmission Pipeline

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Abstract. In the oil and gas industry, the pipeline is a major component in the transmission and distribution process of oil and gas. Oil and gas distribution process sometimes performed past the pipeline across the various types of environmental conditions. Therefore, in the transmission and distribution process of oil and gas, a pipeline should operate safely so that it does not harm the surrounding environment. Corrosion is still a major cause of failure in some components of the equipment in a production facility. In pipeline systems, corrosion can cause failures in the wall and damage to the pipeline. Therefore it takes care and periodic inspections or checks on the pipeline system. Every production facility in an industry has a level of risk for damage which is a result of the opportunities and consequences of damage caused. The purpose of this research is to analyze the level of risk of 20-inch Natural Gas Transmission Pipeline using Risk-based inspection semi-quantitative based on API 581 associated with the likelihood of failure and the consequences of the failure of a component of the equipment. Then the result is used to determine the next inspection plans. Nine pipeline components were observed, such as a straight pipes inlet, connection tee, and straight pipes outlet. The risk assessment level of the nine pipeline's components is presented in a risk matrix. The risk level of components is examined at medium risk levels. The failure mechanism that is used in this research is the mechanism of thinning. Based on the results of corrosion rate calculation, remaining pipeline components age can be obtained, so the remaining lifetime of pipeline components are known. The calculation of remaining lifetime obtained and the results vary for each component. Next step is planning the inspection of pipeline components by NDT external methods.

Keywords : Risk analysis, corrosion, gas transmission, pipeline

1. Introduction

Pipe is a major component in the transmission and distribution process of oil and gas [1-2]. Pipeline system that used to distribute oil and gas is a series of pipes that used to transport the fluids with a certain distance. Generally, the fluids have hazardous properties such as flammable and toxic. This condition would lead to increment of the risk if pipeline system experienced failure or leakage [3]. The interaction between walls of pipe in the form of metal with its environment will cause the occurrence of corrosion, the corrosion which can be one of the causes of leakage on pipes. The installation process and the different environmental conditions of the different piping network also affect the occurrence of the corrosion. The corrosion process occurs naturally and can not be prevented entirely, often take

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place suddenly and outside the prediction that has been planned. The presence of corrosion in oil and gas industry led to high impacts from various aspects, such as environmental pollution, disruption of production processes due to the process of the replacement of the affected pipeline corrosion, and increment of the operating costs.

Therefore periodic inspections or checks on the pipeline system are needed. Every production facility in an industry has a level of risk for damage which is a result of probabilities and consequences of damage. The level of risk in the production facility should be at low levels, because when a production facility has a high level of risk, it will be very dangerous and may affect the safety, environment, and operational costs as well. A method that can be used for inspection of pipeline systems is to run a risk assessment [2]. Risk assessment is a systematic method to determine the level of risk. This method is defined as a whole series of identification process and damage estimation of risks such as likelihood, exposure, consequences, and safety level assessment. Risk assessment process was undertaken to identify the adverse likelihood that could possibly endanger human health, environment, production process, as well as equipment due to human activities and technology. The first-step method makes identification of hazards and impacts from such danger as well as anyone and anything that would be affected by such risks. The next step, namely to determine the frequency of the occurrence or likelihood of occurrence of such hazards and how often such events can occur, and the last step is performing risk evaluation. Risk assessment on pipeline system is done to evaluate the damaging impact of the pipeline to the community and to identify how to resolve risks more effectively.

Risk-based inspection is a method which is closely related to the discussion of risk assessment. This method uses risk as the basis to prioritize and manage inspection programs. The methodology of risk-based inspection allows the optimization of inspection and maintenance resources on the areas that have a higher risk. In addition, risk-based Inspection is an optimized combination of equipment inspection method, inspection scope, and frequency. The purpose of the Risk-based inspection is listed below [3-5].

a. Identify the area that is included in the high-risk classification.
b. Estimate the magnitude of the value of risk that exist on any equipment while operating based on a consistent methodology.
c. Prioritizing equipment based on the measurement of the enormity of risks.
d. Plan and design appropriate inspection programs.
e. Overcome risks systematically when a failure occurs.

The risk-based inspection will not eliminate the risk, the likelihood of the occurrence of an adverse incident (probability) and the impact of the incident (consequences) of equipment will always be there. Risk-based inspection is useful to assist and control the risks to a level that can still be received with prioritizing resources to the equipment that is known to have a higher risk [5-7]. American Petroleum Institute is an international organization that issued the guidelines for conducting the procedure of risk-based inspection. This guideline is in the form of codes and for pipeline system, codes API 570, API 580, and API 581 are used. Based on this codes, risk analysis of 20-inch natural gas transmission pipeline have been performed.

2. Experimental Method

2.1 Risk based inspection

Risk-based inspection , are nowadays in a well-advanced stage of application and make a well-established part of modern practice. Risk-based inspection involves the programming of an inspection on the basis of information obtained from a risk assessment. Risk-based inspection allows people to view potential hazards that simultaneously accounts for both likelihood and consequences of an event. Risk based inspection is a systematic tool that helps users make informed business decisions regarding inspection and maintenance spending [5].

Risk-based inspection is a method of planning or testing and inspection programs and maintenance strategies using risk as a fundamental method. The risk is defined as a function of probability of Failure (PoF), and a function of the Consequences of Failure (CoF) is formulated with the equation below.

$$\text{Risk} = \text{CoF} \times \text{PoF}(t)$$

2.2 Consequences of Failure

Analysis of the consequences of failure due to release fluid representative in the semi-quantitative Risk-based inspection method consists of two parts. The consequences are regardless of combustible fluid and consequences from the release of toxic fluid. Analysis of the consequences of API Risk-based inspection 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 inspection program. The main consequence categories are analyzed using different techniques as described below.

a. Flammable and explosive consequences are computed to determine the probability of event combined with computer modeling to determine the magnitude of consequences. The area can be determined based on consequences of a serious injury to personnel and damage to components of the thermal radiation and blast. Financial losses are also determined based on the area affected by the release.
b. Consequences of toxic calculated using a computer model to determine consequences area as a result of overexposure of personnel to toxic concentrations of a vapor cloud. Where flammable liquids and toxic, toxic event probability assumes that if the release ignited, the consequences of toxic ignored (i.e. toxins consumed in the fire). Financial losses are also determined based on the affected area by the release.
c. Non-flammable, non-toxic releases are also considered since it 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 personal injuries and component damage.
d. Financial consequences include losses due to business interruption and costs associated with environmental releases. Business interruption consequences are estimated as a function of the results of flammable and non-flammable consequence area. Environmental consequences are determined directly from the mass available for release or from the release rate.

3. RBI Case Study on 20 Inch Natural Gas Transmission Pipeline

Risk analysis with Risk-based inspection requires data such as sheets data, design and operational data, and inspection reports that have been done. After required data are collected, then perform risk analysis refers to API 581 Risk-based inspection Semi-Quantitative to find Probability of Failure (PoF) and Consequence of Failure (CoF). Furthermore, PoF and CoF values are combined to obtain the risk level [8-9].

3.1 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) [1,2]. The equipment that is analyzed in this study is described in Table 1.

Table 1. Representative Fluid And Equipment Category

Inventory	Representative Fluid	Inventory Value	
		Detection	Isolation
Automatic Shutdown Valve Straight Pipe KP-0 Ø 20"	C1 – C2	A	B
Automatic Shutdown Valve Straight Pipe KP-20 Ø 20"	C1 – C2	A	B
Manual Shutdown Valve Straight Pipe KP-40 Ø 20"	C1 – C2	A	C

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Based on the detection system and isolation systems Table 7.6 API 581, the components are categorized as A for detection systems, B, and C for insulation systems. Observation of changes or leakage of the fluid in the pipe visually and in the case of a leak was isolated by automatically and 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

Hole Size	¼ inch	1 inch	4 inch	16 inch
Leak Duration	30 minutes	20 minutes	10 minutes	0
	40 minutes	30 minutes	20 minutes	0

Subsequently, calculates leakage rate of the fluid phase of natural gas contained in the pipe. To calculate the rate of fluid leakage by using the equations contained in the API BRD 581. Having 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 Risk-based inspection , 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 the 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 isolation 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 for 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's 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

Inventory	Fluid Phase	Hole Size	Release Rate	Release Type
Inlet Automatic Shutdown Valve Straight Pipe KP-0 Ø 20"	Gas	¼ inch	366.403197	Continuous
		1 inch	5862.451152	Continuous
		4 inch	93799.21844	Instantaneous
		16 inch	844192.9659	Instantaneous
Inlet Automatic Shutdown Valve Straight Pipe KP-20 Ø 20"	Gas	¼ inch	385.3093463	Continuous
		1 inch	6164.94954	Continuous
		4 inch	98639.19264	Instantaneous
		16 inch	887752.7338	Instantaneous
Inlet Manual Shutdown Valve Straight Pipe KP-40 Ø 20"	Gas	¼ inch	373.4385391	Continuous
		1 inch	5975.016626	Continuous
		4 inch	95600.26602	Instantaneous
		16 inch	860402.3942	Instantaneous

3.2 Likelihood Analysis

Analysis of Probability of Failure on the equipment was observed, with a semi-quantitative method Risk-based inspection is done through a process of TMSF (Technical Modules Sub-Factor) for each mechanism of the damage suffered. The mechanism for each damage caused to the equipment can be

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determined by scanning the operating conditions of the equipment. TSMF used in the damage analysis consists of several mechanisms of damage that can occur from a piece of equipment for the operating conditions and the type of working fluid. In this pipeline equipment only thinning factor that has probably caused by fluid services that are in it in the form of gas.

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 in various 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 any reliable data from inspections. In this research, enough data are available from thickness measurements of the pipeline. Here, the data 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. The fraction of wall loss due to thinning is calculated by the formula cited below (see page 9-9 API 581):

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

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 shown in Table 4.

Table 4. TMSF Thinning

Inventory	ar/t	Likelihood Category
Automatic Shutdown Valve Straight Pipe KP-0 Ø 20"	0.04	2
Automatic Shutdown Valve Straight Pipe KP-20 Ø 20"	0.07	1
Manual Shutdown Valve Straight Pipe KP-40 Ø 20"	0.03	2

3.3 Consequence Analysis

There are two analyses of the consequences of failure due to the 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 the release of toxic fluid representative.

3.3.1 Detection and Isolation System. Type of detection system for cases observed is the type A. Detection systems according to API 581 type *A* 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 are type B and C isolation systems according to API 581 type B, and C of this system depends on the isolation valves are operated manually or automatically if there is a leak material. According to API 581 BRD isolation and detection systems are 20% for KP-0 and KP-20 and 10% for a KP-40 reduction in the rate adjustment due to leak fluid.

3.3.2 Mitigation System. The next area has been determined as a result of leakage is reduced by mitigation system. Mitigation system conditions on a case observed in the case of leaks is inventory blow down system. The condition of the system is the area due to leakage can be reduced by 25%.
The consequence of failure is determined based on the area of damage or hazard due to 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 by the analysis of the consequences of failure. The consequences of the fire are determined by the value of the area due to leakage of the area which

consists of extensive fire and hazardous areas. Value consequences of fires and the area of the consequences of the failure of each piece of equipment at Table 6.

Table 5. Area of Equipment Damage and Fatalities

Inventory	Hole Size	Area of Equipment Damage (ft^2)	Area of Fatalities (ft^2)
Automatic Shutdown Valve Straight Pipe KP-0 Ø 20”	¼ inch	5.230.818.235	1.332.775.805
	1 inch	791.784.942	1.908.588.527
	4 inch	1.198.518.899	2.733.175.734
	16 inch	1.032.291.919	2.252.891.869
Automatic Shutdown Valve Straight Pipe KP-20 Ø 20”	¼ inch	5.495.192.156	1.398.728.259
	1 inch	8.318.031.598	2.003.035.424
	4 inch	1.259.093.939	2.868.426.975
	16 inch	1.084.465.738	2.364.376.583
Manual Shutdown Valve Straight Pipe KP-40 Ø 20”	¼ inch	5.981.277.376	1.519.823.525
	1 inch	9.053.812.048	2.176.448.001
	4 inch	1.370.468.398	3.116.760.617
	16 inch	1.180.393.065	256.907.168

Table 6. Consequences of Area of Equipment Damage and Fatalities

Inventory	Hole Size	Flammable Consequences (ft^2)	Area of Consequences of Failure (ft^2)	Total Area of Failure (ft^2)	Failure Consequence Category
Automatic Shutdown Valve Straight Pipe KP-0 Ø 20”	¼ inch	5,230,818.235	1,332,775,805	7,740,259,148	D
	1 inch	791,784,942	1,908,588,527		
	4 inch	1,198,518,899	2,733,175,734		
	16 inch	1,032,291,919	2,252,891,869		
Automatic Shutdown Valve Straight Pipe KP-20 Ø 20”	¼ inch	5,495,192,156	1,398,728,259	7,740,259,148	D
	1 inch	8,318,031,598	2,003,035,424		
	4 inch	1,259,093,939	2,868,426,975		
	16 inch	1,084,465,738	2,364,376,583		
Manual Shutdown Valve Straight Pipe KP-40 Ø 20”	¼ inch	5,981,277,376	1,519,823,525	7,740,259,148	D
	1 inch	9,053,812,048	2,176,448,001		
	4 inch	1,370,468,398	3,116,760,617		
	16 inch	1,180,393,065	256,907,168		

3.3.3 Risk Level

The level of risk on a semi-quantitative method API 581 is 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 analyzed at Table 7.

Table 7. Risk Level

Equipment	Likelihood Category	Failure Consequence Category	Risk Level
Automatic Shutdown Valve Straight Pipe KP-0 Ø 20"	2	D	Medium Risk
Automatic Shutdown Valve Straight Pipe KP-20 Ø 20"	1	D	Medium Risk
Manual Shutdown Valve Straight Pipe KP-40 Ø 20"	2	D	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. The risk rating is shown below in Figure 1.

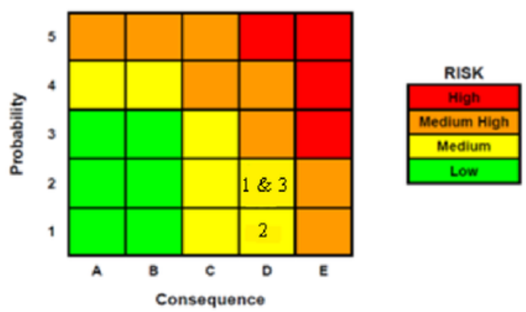

Figure 1. Risk Matrix

1. Automatic Shutdown Valve Straight Pipe KP-0 Ø 20"
2. Automatic Shutdown Valve Straight Pipe KP-20 Ø 20"
3. Inlet Manual Shutdown Valve Straight Pipe KP-40 Ø 20"

3.4 Remaining Life Analysis

Pipes are designed to flow the fluid with a certain pressure, the wall thickness of the pipe is determined based the pressure of working fluid therein. Besides the stress factors work in it, the pipe wall is also designed to accommodate the corrosion process when the pipeline is operated. Corrosion can cause thinning of the pipe wall, thinning process on the pipe will be directly proportional to the time. Therefore it needs to be regularly monitored in order to keep the pipeline wall thickness was observed. The wall thickness of the pipe which has thinning process can not be tolerated anymore if it has reached the minimum thickness of the pipe according to the calculation based on the otherwise require a minimum thickness of the pipe to be able to withstand the working pressure.

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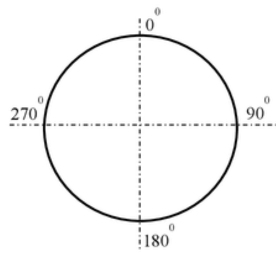

Figure 2. Position of Wall Thickness Inspection

Table 8. Wall Thickness of Pipe

Location	Point	Thickness (inch)				
		Position (°)				average
		0	90	180	270	
Pipe on Automatic Shutdown Valve KP-0 Ø 20 Inch	1	0.52	0.52	0.54	0.53	0.5275
	2	0.51	0.53	0.52	0.51	0.5175
	3	0.52	0.53	0.51	0.55	0.5275
	4	0.53	0.55	0.57	0.58	0.5425
Pipe on Automatic Shutdown Valve KP-20 Ø 20 Inch	1	0.54	0.53	0.56	0.52	0.5375
	2	0.52	0.51	0.59	0.52	0.5350
	3	0.54	0.52	0.55	0.51	0.5300
	4	0.53	0.52	0.55	0.52	0.5300
Pipe on Manual Shutdown Valve KP-40 Ø 20 Inch	1	0.55	0.54	0.55	0.56	0.5500
	2	0.52	0.53	0.53	0.51	0.5225
	3	0.56	0.57	0.56	0.56	0.5625
	4	0.54	0.52	0.52	0.53	0.5275

Periodic monitoring is performed to determine the thickness of the pipe at a certain time and also to determine the projected thickness of the pipe in the future. Projection thickness of the pipe can be use for predicting remaining life of the pipe.

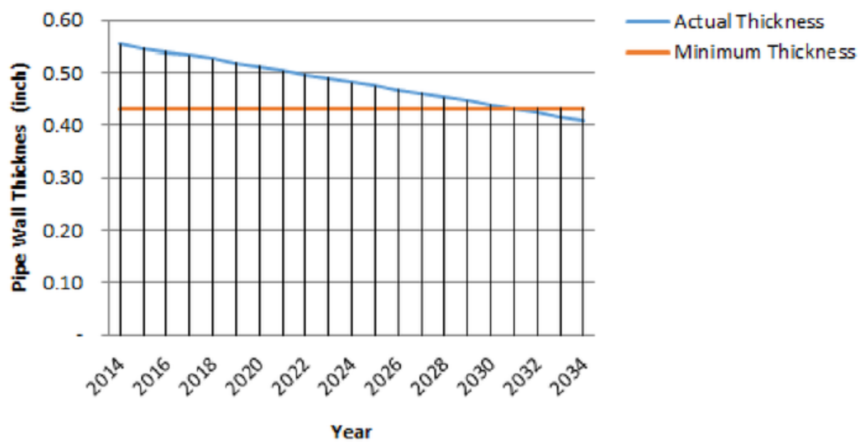

Figure 3. Remaining Life Prediction Charts

The minimum thickness of the pipe is calculated base on the requirement of thickness pipe to resist working pressure of the fluid. Refer to the basic design of this pipe; minimum thickness requirement is 0.432 inch. Base on the data inspection of actual pipe wall thickness, prediction of remaining life the pipe until 2032.

3.5 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 programs to be performed are: Risk ranking, Risk reduction, and Optimization of inspection activities [8-10].

From the analysis that has been done, recommendations for lowering the risk are described as follow. Necessary maintenance and periodic inspections at intervals that are not too long. Need to be re-evaluated equipment operating conditions, the material conditions of the equipment, mitigation system, and still consider economic factors. Need inspection activities more effectively using a risk-based approach to the equipment being analyzed.

4. Conclusion

Based on the results of analysis using semi-quantitative method of API 581, the risk level of each pipeline equipment are analyzed: pipeline at KP-0 has a medium-high risk (2D), pipeline at gas station KP-20 has a medium risk (1D), and pipeline at gas station KP-40 has a medium risk (2D). The results of the risk assessment using the 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.

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