Application of Lean Six-Sigma Methodology to Reduce the Failure Rate of Valves at Oil Field

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Abstract— there are mainly two types of valves used in oil fields: isolation and control valves. Choke valve is an example of control valves. A choke valve is used mainly to adjust the production rates for every individual oil or water well. There are 240 choke valves at the Field under study. Several failures have been reported for these choke valves including: cage damage, seat damage, plug damage or actuator failure. A total of 37 failed choke valves have been reported that affect the availability of the production wells and causing deviation from the production targets. The objective of this study is to make recommendations to reduce the failure rate of choke valves by applying lean six sigma approach aiming to increase availability of production wells as well as meeting production targets for producing wells. The procedure follows the framework: define, measure, analyze, improve and control DMAIC phases. The project started with problem definition through statistical analysis of the current performance and quantification of failed choke valves for certain period of time. This involves using the supplier-input-process-output-customer SIPOC diagram. The process also involved brainstorming session to identify potential root causes of the problem. Classifying and rating these causes were achieved by use of the several tools: a "fishbone" diagram, cause-and-effect matrix, and failure mode and effect analysis (FMEA). This was followed by the root cause analysis technique using five (5) whys concept. Finally implementation plan was generated that's incorporating all of the process improvement recommendations including: approach material specialists and check for proper material selection, upgrade the choke valve material based on feedback received from specialists, ensure availability of spare parts for choke valves, emphasize on proper rig cleaning activities, study the feasibility of installing strainer upstream the choke valve to avoid foreign particles, review existing preventive maintenance procedure and update accordingly and review the design pressure for the choke valve.

Index Terms— Lean six-sigma, oil valves, process improvement, oil and gas industry

I. Introduction

In an oil field, there are mainly two types of valves: isolation and control valves. Sub-service safety valve, service safety valve, crown valve and wing valve are examples of isolation valves. Choke valve is an example of control valves. On each well there is a choke valve mainly used to adjust the production rates for every individual oil or water well. There were 240 choke valves at the Field under study. Several failures have been reported for these choke valves including: cage damage, seat damage, plug damage or actuator failure. A total of 37 failed choke valves have been reported from January 2011 till October 2012 affecting the availability of the production wells and causing deviation from the production targets. Figure 1 illustrates a choke valve with its associated components.

The objective of this study is to make recommendations to reduce the failure rate of choke valves at the field understudy by applying lean six sigma approach aiming to increase availability of production wells as well as meeting production targets for producing wells. A combination of Lean and six sigma tools were utilized and applied in this study. The methodology follows the framework: define, measure, analyze, improve and control (DMAIC) phases. A team was formed for that project, as lean six- sigma is a team-based technique. The selection was based on contribution that each member could bring to the process. The team began to identify the critical parts of the current process by developing a SIPOC diagram. Historical data was collected and reviewed. In the analyze phase of DMAIC, the goal is to develop theories of root causes, confirm the theories with data and finally identify the root causes of the problem. The solution evolved from in-depth analysis of the data including input from customers and stakeholders. The analysis identified four main causes of choke valves failures: design of choke valves, existence of foreign particles coming out of the well, inadequate preventive maintenance program and incorrect pressure setting.

II. Application of Lean Six-Sigma in the Oil and Gas Industry

Several lean six sigma studies have been conducted in the oil and gas industry. One application was through a study that was carried out to improve Propane C3 recovery in Gas Plant with lean six-sigma approach. Following the assessment on the low C3 recovery in NGL (Natural Gas Liquid) products, an implementation plan was generated and results showed a 70% increase of NGL total yield [1]. Moreover, a lean six-sigma project was conducted to reduce the lead-time for refurbishing wellhead valves. Following the data collection and analysis on refurbishing process, a set of recommendations have been proposed and the implementation resulted in reducing the refurbishment lead

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time from 53 to 3 days [2]. The approach was applied in a refinery in order to improve profitability by energy optimization and reduce energy intensity index (EII) and reduce emissions. Following the implementation phase, the EII has improved resulted in a cost avoidance of $ 1.4MM/year [3]. A recent research was conducted that applied the conception of lean six-sigma into the process optimization of equipment maintenance. The researchers have built a model based on design of experiment approach. The outcome showed that the optimization model based on design of experiment is feasible and effective, however with some shortcomings and deficiencies in lean six-sigma management. It was recommended to introduce lean six-sigma for process optimization system to accomplish the aim of continuous improvement for equipment maintenance process [4].

In the oil and gas upstream field, a lean six-sigma project was conducted for water injection pumps. These pumps are used to maintain the oil reservoir pressure by injecting high-pressure water in the boarders of the reservoir. Frequent failures have been observed in these pumps that include vibration alarms, internal corrosion, damaged impellers, mechanical seal failures and coating failures. The target was to increase the mean time between failures MTBF from 1 failure per pump per year to 0.5 per year. The repair cost per pump per year is about 0.5 million dollars, upon implementing the recommendations out of the study, it is anticipated to result in a cost avoidance of 0.25 million dollars per pump per year [3].

III. Case study

Several failures have been reported for the choke valves in the oil field understudy. A total of 37 failed choke valves have been reported affecting the availability of the production wells and causing deviation from the production targets. A six-sigma team was form to come up with recommendations to reduce the failure rate aiming to increase availability of production wells as well as meeting production targets for producing wells.

The project started with problem definition through statistical analysis of the current performance and quantification of failed choke valves for certain period of time. The problem definition breaks down into problem statement, project objective, and project benefits. This involves using the supplier-input-process-output-customer SIPOC table to gain better understanding of the current process. The process also involved brainstorming session to identify potential root causes of the problem. Classifying and rating these causes are achieved by use of the following Lean Six- sigma tools: a “fishbone” diagram, cause-and-effect matrix, and failure mode and effect analysis (FMEA). This is followed by the root cause analysis technique using five (5) whys concept. Finally implementation plan was generated incorporating all of the process improvement recommendations.

A. Define Phase

The project started with define phase that gives a clear problem definition using the supplier-input-process-output-customer (SIPOC) tool. This tool describes the step-by-step process for the choke valves cycle as shown in Figure 2. The first process is the design and manufacturing of the choke valve. The inputs to this process are the specifications, drawings and standards and the supplier is the proponent. The output of this process is a designed and manufactured choke valve. The customer is the proponent. The second process is the testing of choke valve. The inputs to this process are testing standards, visual inspection procedure and new choke valve, the suppliers are Inspection department for the standards and the manufacturer for the new choke valve. The output of this process is a tested choke valve; the customer is the metals unit. The third process is the installation of choke valve. The inputs to this process are tested choke valve, installation procedures, and site preparation and getting a work permit, the suppliers are the field service and metals units. The output of this process is an installed choke valve; the customer is the field service unit. The fourth process is operation of choke valve. The inputs to this process are installed choke valve and pressure setting received from production engineering, the suppliers are the field service unit and production engineering. The output of this process is controlled oil production and water injection; the customers are the Gas Oil Separation Plant and injection wells. The fifth process is maintenance of choke valve. The input to this process is the preventive maintenance program and procedure; the supplier is maintenance electrical crew. The output of this process is valve electrically maintained, the customer is the field service unit. The sixth process is repair and replacement of choke valve. The inputs to this process are operation notification and work order; the supplier is the field service unit. The output of this process is valve repaired or replaced; the customer is the field service unit.

B. Measure Phase

To quantify the problem, data gathering was initiated on the failures rate of choke valves, which facilitates the measure phase. Based on data collection for a given period, a total of 37 choke valves have been reported for the field understudy representing 15% of the total number of choke valves. The types of failures have been combined into one type, as the concern is whether the valve is failed or not, regardless of mode of failures. A statistical tool - process capability analysis was used to find the process sigma analyzing the current performance of the process, table I. Therefore, the team formulated the project objective to reduce the failure rate by 50% that is equivalent to Z valve of 2.94, table II This means any choke valve failure that is greater than 7.5 % is considered as defect.

C. Analysis Phase

Finding the root cause of the problem is the next step. This is achieved by use of the following lean six sigma tools: fishbone diagram, cause-and-effect matrix and failure mode and effect analysis (FMEA). The fishbone diagram, which enables the team to explore the causes, is conducted in a brainstorming session among team members. The cause-and effect matrix prioritizes the causes or identifies which elements contribute most to cause problems. This involves use of rankings on all elements identified as the potential of

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causing the problem. Fishbone diagram and cause-and effect matrix are shown in Figure 3 and Table III respectively.

The potential causes were classified into five main categories: material, design, manufacturing, maintenance and process. Each category has one or more sub-causes. Under material, one sub-cause that is selection of materials for internal parts was identified. The sub-causes related to design were design of choke valve, diameter of holes in the plug or cage and position of holes. One item was identified under manufacturing that is quality of manufacturing. Inadequate preventive maintenance program was classified under maintenance. A total of six process related points were listed, i.e. type of well fluid whether water or oil, possibility of foreign particles coming out of the well,

a) Choke valve

b) Choke valve actuator

c) Plug (left) and Cage (right)

d) Choke valve seat

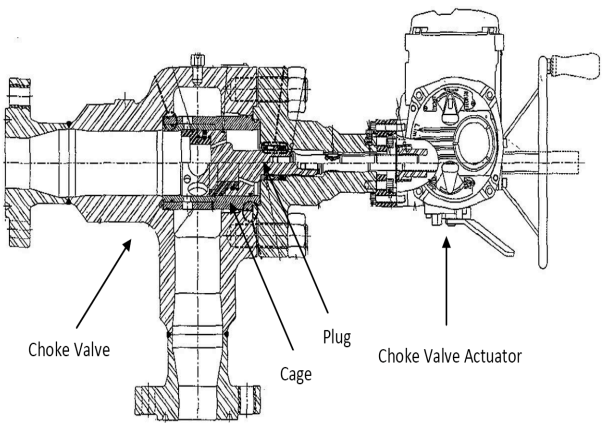

Fig. 1. Choke valve main components.

incorrect pressure setting, improper functioning of choke valve through mismatch in percentage opening of the valve or valve isolation inability, inadequate stroking or exercising the opening and closing actions of the choke valve and possibility of high temperature of fluid. Bar and Pie charts of the potential causes and valve failures are shown in Figures 5 and 6.

In the cause and effect matrix, the four failures: cage damage, seat damage, plug damage or actuator failure were assigned with rating based on frequency of occurrence experienced and reported by maintenance mechanical team. Then, each potential cause was assigned with rating to quantify magnitude of the failure based on team perspective in a session conducted for that purpose. After that, the products of both ratings are added to find the weight for each cause. The team decided to include all causes scoring

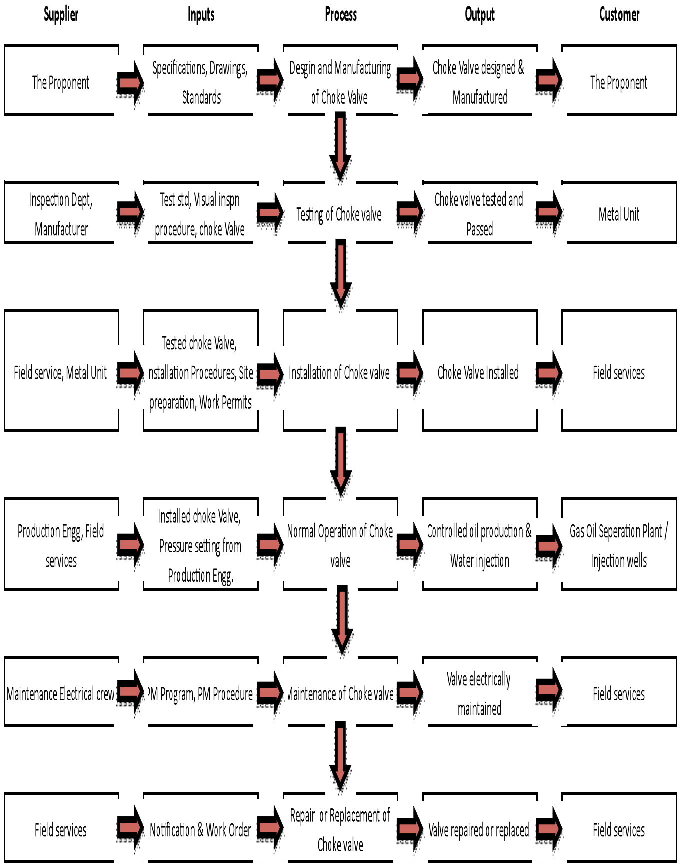

Fig. 2. SIPOC flow chart.

higher than 50 in the failure analysis. A total of 9 out of 12 causes scored higher than 50; showed with asterisks in the second column.

Next, the failure mode and effect analysis (FMEA) shown in Table IV used to detail the causes, includes finding the potential failure mode, identifying the impact of this failure on the customer, identifying potential causes of this failure, and recognizing the current control mechanism to mitigate the failure. Each element in this FMEA analysis was rated according to FMEA standard rating guidelines, and the analysis was carried out in a brainstorming session. The team decided to include all causes, showed with asterisks in the sixth column, having RPN higher than 200 in the failure analysis based on team perspective in a session conducted for that purpose with one exception, which is incorrect pressure setting. This cause was included in the analysis due to its criticality for operation personnel. The causes repeated in cause and effect matrix and in FMEA were combined in

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four main items: design of choke valves, foreign particles, inadequate preventive maintenance program and incorrect pressure setting.

All data were collected to verify the findings from the cause and effect matrix and FMEA. Appropriate statistical tool, i.e. Pareto Chart in Figure 6 was used to analyze the data. The chart clearly shows that the design of choke valve is the main contributors in choke valves failures as about 78% of failures were related to this subject. After that, five-why analysis, Table V was used to verify the root cause behind these failures. This was conducted in a brainstorming session with suggested short and long-term solution for each cause contributing in choke valves failures. The last two columns show these recommendations for the process improvement.

Table I

Process capability analysis

Description	Unit	Count
No. of failures (defects)	D	37
No of choke valves in Field	U	241
No. of Opportunities	O	1
Defects per unit	DPU	0.153527
Defects per Opportunities	DPO	0.153527
Defects per Million Opportunities	DPMO	153527
Process Sigma	**Z**	**2.52**

Table II

Current performance and goal

	DPMO	Process sigma, Z
Current	153527	2.52
Goal	74689	2.94

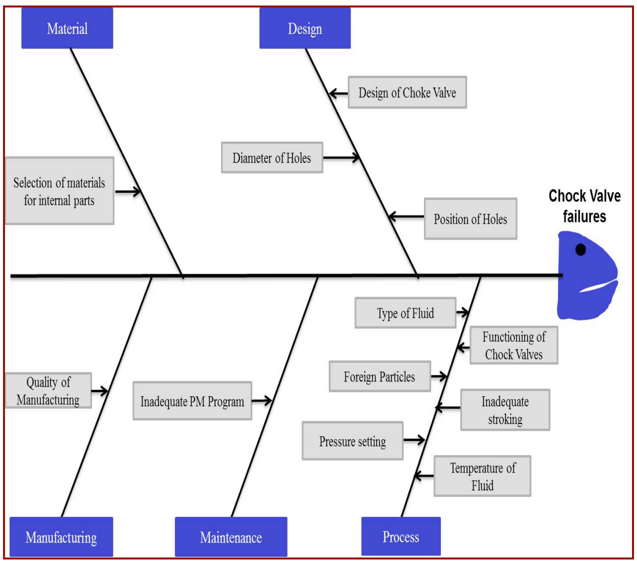

Fig. 3. Fishbone diagram

Table III

Cause and effect matrix

Key Process input	Rating	Key Process output				Total
		6	8	7	5	
		Cage damage	Plug damage	Seat damage	Actuator failures	
Improper material selection of internal parts	9*	54	72	63	45	**234**
Functioning of Choke Valves	9*	54	72	63	45	**234**
Type of Fluid	3*	18	24	21	15	**78**
Design of Choke Valves	3*	18	24	21	15	**78**
Quality of Manufacturing	3*	18	24	21	15	**78**
Foreign particles	9*	54	72	63	45	**234**
Inadequate PM Program	3*	18	24	21	15	**78**
Diameter of Holes	1	6	8	7	5	**26**
Position of Holes	1	6	8	7	5	**26**
Pressure setting	9*	54	72	63	45	**234**
Temperature of Fluid	3*	18	24	21	15	**78**
Inadequate stroking	1	6	8	7	5	**26**
Total		**324**	**432**	**378**	**270**	**x**

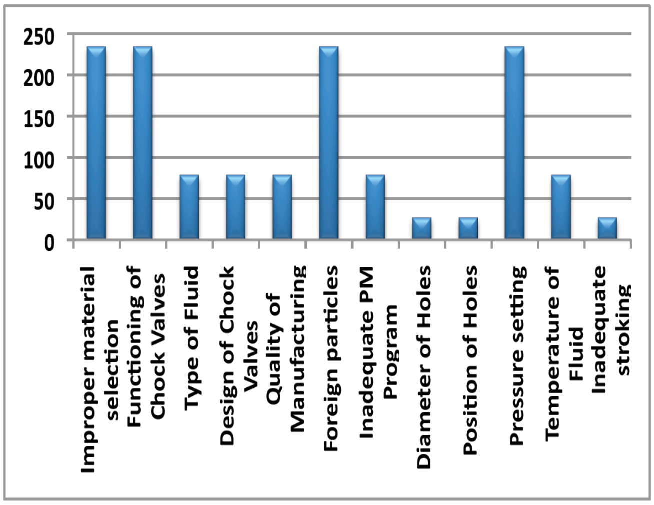

Fig. 4. Bar Chart of the potential causes

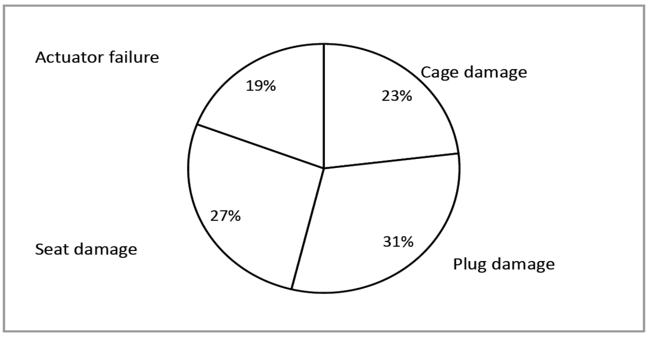

Fig. 5. Pie Chart of the valve failures

Table IV

Failure Mode and Effect Analysis

Function	Potential Failure Modes	Potential Effects	Sev.	Potential Causes	Occ.	Potential controls	Det.	RPN
Control the production and injection rates for oil and water wells	Damage of Cage	Malfunctioning of Choke Valve (Passing Valve)	8	Improper material selection of internal parts	9*	Standards	5	360
	Damage of Plug			Functioning of Choke Valves	7*	Pressure setting by Production Engineering	4	224
	Damage of Seats			Type of Fluid	5*	No Controls	10	400
	Actuator failures			Design of Choke Valves	5	Standards	5	200
				Quality of Manufacturin g	5	Inspection (QC/ QA)	5	200
				Foreign particles	7*	No Controls	10	560
				Inadequate PM Program	4	Electrical PM	3	96
				Diameter of Holes	3*	No Controls	10	240
				Position of Holes	3*	No Controls	10	240
				Pressure setting	7*	Manual adjustments	3	168
				Temperature of Fluid	5*	No Controls	10	400
				Inadequate stroking	3*	No Controls	10	240

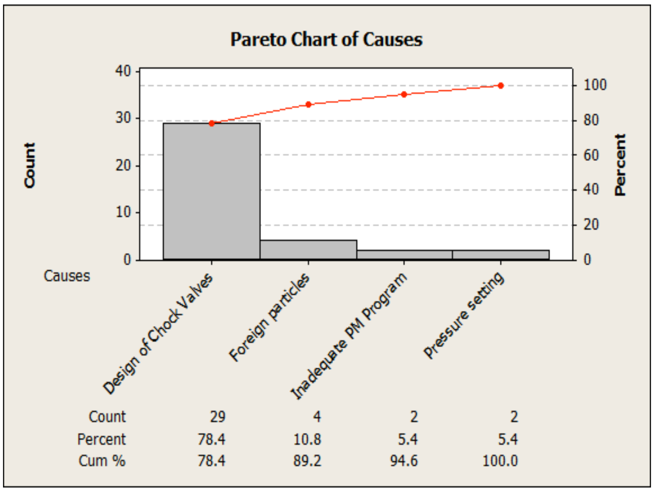

Fig. 6. Pareto Chart

D. Improvement and Control Phases

The identified recommendations have been consolidated in an implementation plan, Table VI, which contains the causes, actions required, responsible discipline and expected time of completion. Upon completion of this plan, the control phase is started by monitoring of the implemented improvements to maintain gains, and ensure corrective actions are taken when necessary.

Table V

Five-Whys analysis

S.#	Causes	Why 1	Why 2	Why 3	Why 4	Why 5	Solutions	
							Short term	Long term
1	**Design of Choke Valves - Diameter of holes, position of holes**	Improper material selection of internal parts	Information given to vendor is not full	Actual operating conditions changes	Initial study based on assumptions & not on actual conditions	--	Approach material specialists (CSD) & check for proper material selection	Upgrade the choke valve material based on feedback received from Specialists
			Material selected for other field is not suitable for Qatif	Process parameters are different in Qatif	--		Ensure availability of Spare parts for choke valves	--
2	**Foreign particles**	Left over from Rig activities	Cleaning procedure not adequate	100% cleaning is not feasible	--	--	Emphasize on proper Rig cleaning activities as per procedures	Study the feasibility of installing strainer upstream the choke valve to avoid foreign particles
3	**Inadequate PM Program**	Lack of awareness on Choke valve PM	Inadequate Procedures	--	--		Review existing procedure & update accordingly	--
		Lack of Man power	--	--	--	--	--	--
4	**Pressure setting**	Value unable to withstand the pressure setting	Improper selection of valve	--	--		Review the design pressure for the choke valve	Upgrade the choke valve material based on feedback received from Specialists

Table VI

Implementation Plan

S.#	Causes	Actions	Who	When	Status	Remarks
1	Design of Choke Valves - Diameter of holes, position of holes, etc	Approach material specialists (CSD) & check for proper material selection	Reliability Engineer	Q1 - 2013	Closed	
2		Upgrade the choke valve material based on feedback received from Specialists	Field service operations Engineer	Q3 - 2013	Open	To be decided based on the outcome of Action 1
3		Ensure availability of Spare parts for choke valves	Maintenance Engineer	Q1 - 2013	Closed	
4	Foreign particles	Emphasize on proper Rig cleaning activities as per procedures	Production Engineer	Immediate	Closed	
5		Study the feasibility of installing strainer upstream the choke valve to avoid foreign particles	Field service operations Engineer	Q1 - 2013	Open	
6	Inadequate PM Program	Review existing PM procedure & update accordingly	Maintenance Engineer	Q1 - 2013	Closed	
7	Pressure setting	Review the design pressure for the choke valve	Field service operations Engineer	Q1 - 2013	Open	
8		Upgrade the choke valve material based on feedback received from Specialists	Field service operations Engineer	Q3 - 2013	Open	To be decided based on the outcome of Action 7

Finally, a payoff matrix shown in Table VII was constructed. The payoff matrix is a decision analysis tool that summarizes pros and cons of a decision in a tabular form. It lists payoffs (negative or positive returns) associated with all possible combinations of alternative actions. The matrix had three ranking levels (low, medium and high) in order to link each action in the implementation plan with the magnitude of work required to accomplish this task versus the benefits expected upon completion. There were three actions identified with Low cost, three with Medium cost and one with High cost ranking. In the benefits section, a total of six actions identified with Medium and one with High benefit rankings.

IV. Conclusion

The analysis identified four main causes of choke valves failures: design of choke valves, existence of foreign particles coming out of the well, inadequate preventive maintenance program and incorrect pressure setting. A set of short and long term solution for each cause contributing in choke valves failures has been established, which formulated the implementation plan for the process improvement. The recommendations out of the study included approaching material specialists at Consulting Services Department and check for proper material selection, upgrade the choke valve material based on feedback received from specialists, ensure availability of spare parts for choke valves, emphasize on proper Rig cleaning activities, study the feasibility of installing strainer upstream the choke valve to avoid foreign particles, review existing preventive maintenance procedure and update accordingly and review the design pressure for the choke valve.

Table VII

Pay-off Matrix

S.#	Actions	Effort / Cost	Benefit
1	Approach material specialists (CSD) & check for proper material selection	Low	Medium
2	Upgrade the choke valve material based on feedback received from Specialists	High	High
3	Ensure availability of Spare parts for choke valves	Medium	Medium
4	Emphasize on proper Rig cleaning activities as per procedures	Low	Medium
5	Study the feasibility of installing strainer upstream the choke valve to avoid foreign particles	Low	Medium
6	Review existing preventive maintenance procedure & update accordingly	Medium	Medium
7	Review the design pressure for the choke valve	Medium	Medium

Moreover, the anticipated reduction in failure rate following the implementation would result in cost avoidance by 50% based the 50% target reduction in choke valves failures. The cost is associated with maintenance work required to rectify the failures and the cost for the shutdown of the oil or water well during the repair period.

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