International Journal of Engineering and Modern Technology (IJEMT) E-ISSN 2504-8848
P-ISSN 2695-2149 Vol 8. No. 3 2022 DOI: 10.56201/ijemt www.iiardjournals.org

Investigation of Valve Failures Using Statistical Analysis of Proof Test Data

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DOI: 10.56201/ijemt.v8.no3.2022.pg8.22

Abstract
This research work examined pressure relief valve (PRV) failures by using statistical analysis of proof test data obtained from the computerized maintenance management system (CMMS) of Liquefied Natural Gas (LNG) facilities site. This study comparatively investigated the 30 months approved inspection interval for the proof test of PRVs by the Department of Petroleum Resources (DPR) of Nigeria. In this research, failure rate and failure behaviour of PRVs were evaluated and analyzed using bathtub curve. Aging effect of PRV using regression analysis and the cause of failures were also analysed. Least square multiple linear regression was the statistical tool used for the analysis with the aid of EXCEL. After thorough analysis, the study depicted drop in failure rate at different times (years) at the bathtub curve. Also, the statistical analysis found that the ageing effect from five spring loaded PRVs evaluated was at most 0.4% per year with 95% confidence and the amount of variance explained per time was minimal (R-Square 7.6%). It was recommended that the inspection interval (30 months) as approved by DPR for proof test of PRVs was optimal with regard to the required integrity condition of the PRVs since test frequencies yielded better result and consequently less risk. Also, further testing and investigation should be pursued to determine if longer intervals between inspections were possible. Furthermore, analysis from the investigation of cause of failure showed that corrosion was a cause of PRV failure and contact area factors such as sticking and cold welding.

Keywords: *Aging trend, Hazard function, Maintenance, Normal distribution, Pressure, Relief valves, Reliability, Ratio.*

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1. INTRODUCTION

Valve is one of the most common mechanical devices used in plant or industrial facilities to avoid disaster during process operation. Different types of valve perform different functions. Some are used to start or stop flow in pipelines and others used to regulate flow in pipeline.
The investigated valves in this research work are the Pressure relief valves (PRVs). A pressurized relief valve (PRV) is a type of valve that controls or limits the pressure in a system by allowing the pressurized fluid to escape.
When all other safety measures fail, it's utilized in pressurized equipment to protect people and property (Malek, 2005). For overpressure protection, pressure relief valves are mounted

on process equipment and pipelines. They work by releasing a volume of fluid from within the plant when a specified maximum pressure is reached, safely lowering the excess pressure. It also reduces the risk of other system components being damaged as a result of its operation. It is critical to be able to comprehend and control PRV performance. PRVs as safety valves may be the only remaining mechanism in many industrial plants to prevent catastrophic collapse under overpressure conditions. It is critical that any such valve be capable of functioning at all times and under all conditions. In normal operation, the PRV would be closed and would only open in the event of an overpressure occurrence. Unless an overpressure event occurs and the valve fails to open, if the valve is trapped in the closed position, it will be unnoticeable in operation (Bukowski, 2007). It is desirable to find valve failure before an overpressure event that may lead to damage/injury occurs. Proof testing is the only technique to find these otherwise invisible flaws.

According to the Nigerian DPR, all PRVs at LNG plant facilities are subjected to periodic inspections that take place every 30 months on average. In the LNG valve repair workshop, valves are hauled in from the field and proof tested by gradually increasing inlet pressure until the valve pops open (proof test). The test pressure (TP) or "as found" lift pressure (proof test) at which the valve opened during the inspection test is then compared to the set pressure (SP), the pressure at which the valve was planned to open, to determine the valve's performance.

Proof tests are usually performed as part of routine inspection and maintenance. The PRVs must be inspected and serviced on a regular basis (Gross& Harris, 2008). In most facilities, the test period is not clearly defined; instead, a company guidance document or previous plant history is used to determine the maintenance interval (Gross& Harris, 2008). In most cases, prior performance data from the plant is used to set the PRV proof test and revision interval. When the quality test data, statistical tool, and failure analysis support the intervals, they can be safely expanded (Gross & Harris, 2006).

At most plant, system outage of most PRVs maintenance is expensive and should be done once a year. When the PRV is removed for maintenance, it may still be in good functioning order despite the lack of data and analysis to validate test intervals. Any valve might be kept in service for another year if the failure rate was not predicted to increase during that time (Urbanik, 2004). To make the argument trustworthy, you'll need good test data and statistical techniques. When backed by quality test data, statistical tool, and failure, safely extending PRV test intervals can deliver considerable reliability gains and cost savings over the lifetime of a valve. The greatest way to improve the maintenance interval or the usable life of a valve is to look at previous reliability (performance).

There were no symptoms that could indicate the condition of the PRV, implying that the proof test is the only measure that is available that can indicate the condition of the PRV. The proof test is a test that imitates the actual operating condition of the PRV and therefore gives an indication whether the PRV would have opened during its time in service. In an ideal situation the PRV has to open at the SP. However, ratio R_p, calculated by equation (1) is a conversion of the test pressure. In general, the ratio Rp is a good health indicator for the condition of the PRV (API 581, Bukowski and Goble, 2009; Chien et al, 2009) from which we can also conclude the point PRV failed the proof test.

$$R_p = \frac{TP}{SP} \qquad (1)$$

Where:
R_P is the aging factor or aging effect
TP is the test pressure
SP is the set pressure

The "as found" condition of the PRV, or the expected lift pressure at the time it is removed from operation, is termed the proof test.
The PRV is removed from the process and pressurized on a test bench until it opens; the "test pressure" is the pressure required to open the valve (TP). In normal functioning, each PRV has a "set pressure" (SP), which is the pressure over which the valve should open.
During proof testing, $R_p = \frac{TP}{SP}$ is recorded. Data available for this research is extracted from LNG plant facility database.

Proof test data is widely used for predicting PRV reliability in several literatures:
Gross and Harris (2006) analysed the aging factor (ratio TP/SP) overtime for PRVs by plotting the values of PRVs from 1 to 6 years in pertain and subsequently fitting a regression line. They were able to describe whether the times in service contributed to failure. They show that the maximum slope was 2.3% for soft seated PRVs with a small inlet (< $^3/_4$”), implying that the time in service has a minimal influence on the aging trend. The result of this conclusion is that when the PRV fails the proof test, it has already failed prior to installation, implying that a test before installation should reduce the failures among PRVs. However, Gross and Harris (2006) were not clear about the status of the PRV that were part of their analysis. For instance, were the analysed PRVs new or were they revised.

Adadande *et al.* (2014) suggested that to manufacture reliable products, system reliability should be maintained over the time. Hence went forward to carry out reliability analysis of PRV manufacturing system using fault tree analysis method. Weibull ++ software was used for time to failure data analysis in the study.

Chien *et al.* (2009) suggested ANOVA method for carrying out the analysis of reliability of safety valve. The methodology used focused on failure data collection, grouping of data and analysis carried out. This method establishes a semi-quantitative reliability based improvement methodology which shows a plan, do correct and action (PDCA) loop.

Quantal response analysis is a one method for analysing inspection data (Nelson, 1972). Bukowski and Goble (2009) applied quantal response analysis and provided a brief description of the steps that have to be taken. Trying to understand this method and apply it to the data should provide an estimation of the probability of failure. Bukowski and Goble (2009) use quantal response data to evaluate maintenance intervals for PRV.

Although, thorough analysis were done by these authors on valve failure data analysis, design analysis and flow through valves, the authors made it quite easier for one to appreciate how failure data can help determine useful life intervals on PRVs and understand issues that affect valve stability in operation. There is the gap on “what periodic inspection interval can PRVs undergo in order not to cause significant increase in the probability of failure and not affect the stability of PRV operation?" asked by practitioners.

To address this gap, this study evaluate failure rate, analyse failure behaviour, investigate the ageing trend of PRVs base on 30 months averaged approved intervals for inspection of PRVs and investigate cause of PRVs failure.

The study used Proof test data report from LNG plant facility based on the regulatory requirement approved by Department of Petroleum Resources (DPR) to determine if the time interval is justifiable enough in improving the reliability of the PRVs in service: According to the mineral oils safety regulation -1997 part II, 29, 7; every relief valve and safety valve must be inspected at least once every 30 months, or at such shorter intervals as are necessary to keep them in good working order and ensure that they operate effectively whenever the maximum allowable working pressure (MAWP) is applied and pass full design quality at those pressures.

2. MATERIALS AND METHODS

The materials used primarily were the data generated from the proof test of pressure relief valves (PRVs) subjected to periodic inspection which occurs on average of 30months base on Department of Petroleum Resources (DPR) requirement.

The "as found" condition of the PRV, or the expected lift pressure when it is taken from service, is considered in the proof test. The PRV is removed from the process and pressurized on a test bench until the valve opens; the "test pressure" is the pressure required to open the valve (TP). In normal operation, each PRV has a "set pressure" (SP) over which the valve should open.

From the data generated from the proof test of PRV, the hazard function (failure rate) of the PRV was calculated as:

$$h(t) = \frac{Number of\ valves\ failing\ in\ the\ time\ interval}{Number\ surviving\ the\ interval}$$

$$= \frac{r_f}{N_s} \qquad (2)$$

Where:

h(t) is the hazard function (failure rate)

r_f is the number of valves failing in the time interval

N_s is the number surviving the interval

2.1 Bathtub Curve

The failure rate of pressure relief valves (PRVs) appears to follow the traditional bathtub curve (Urbanik, 2004). A plot of the failure rate with time for most items produces a curve that resembles a bathtub sketch.

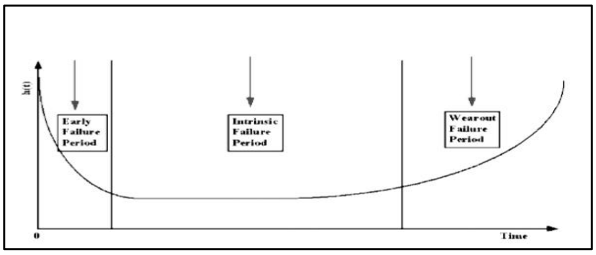


Figure 1: Bathtub Curve (Courtesy of e. Handbook of statistical method)

2.2 Data Analysis Technique

Data analysis technique involves the mathematical and statistical tools. The work used bathtub curve to analyse the failure rate of a PRV and ordinary least square (OLS) multiple linear regression to analyse the aging trend (effect) of PRVs. The statistical analysis was utilized to study the relationship between the independent and dependent variables, as well as to identify the demographic factors that cause PRV to age significantly. OLS was chosen because it minimizes the error sum of squares and offers a variety of other benefits like as un-biasedness, consistency, low variation, and efficiency. This analysis will be done by the use of EXCEL.

The independent variable is known as predictor variable, whereas the dependent variable is known as response variable or criterion variable.
The ratio of Test Pressure divided by Set Pressure (TP/SP) is the dependent variable in our study, whereas Time (year) is the independent variable.
TP/SP data collected from 2004 – 2019 were the measures of the dependent variable and Number of times in years the PRVs were tested for the period 2004-2019 as our independent variable.

2.3 Model Specification

The translation of a connection into precise mathematical form is known as model specification. The dependent variable is TP/SP, while the independent variable is Times.

$$\frac{TP}{SP} = \beta_0 + \beta_1 Time + \varepsilon \qquad (3)$$

Where:
$\frac{TP}{SP}$ is the dependent variable
$Time$ is the independent variable
β_0 is the constant of intercept
β_1 is the slope or coefficient
ε is the error term

2.4 Analysis of Data with XLSTAT

Ordinary least squares regression often called linear regression is available in EXCEL using the XLSTAT add- on statistical software. Data files generated by the proof test were analysed in the XLSTAT.

3. RESULTS AND DISCUSSION

3.1 Failure Rate

Table 1 is the descriptive statistics results extracted from LNG plant facility, 3499 valves proof tested from 2009 to 2018. The failed valves were analysed with 232 valves from Rp≥ 1.03 failures and 61 from Rp≥1.10 stuck shut failures.

The data content is based on failure of any valve proof test higher than 1.03 and 1.10 of the valve set pressure.

The hazard function or failure rate for the time interval for the two ratios is calculated using equation (2)

Table 1: Results of Hazard Function for Rp≥1.03 and Rp≥1.10 Failed PRVs

Time (year)	Number of tested valve (N)	Number Failed $R_p \geq 1.03$	Number Failed $R_p \geq 1.10$	h(t) $R_p \geq 1.03$	h(t) $R_p \geq 1.10$
2009	524	33	12	0.0103	0.0037
2010	151	30	10	0.0094	0.0031
2011	290	19	9	0.0059	0.0028
2012	350	20	8	0.0062	0.0025
2013	337	11	4	0.0034	0.0012
2014	252	19	5	0.0059	0.0016
2015	245	19	3	0.0059	0.0009
2016	661	16	1	0.0050	0.0003
2017	190	14	2	0.0044	0.0006
2018	499	15	7	0.0047	0.0022
Total	3499	232	61		

Table 2: Inspection report data set of RVs

TAG	Pressure (Bar)	ratio R=TP/SP						
314RV-305	12.0	1.00	0.93	1.01	1.00	1.06	0.99	1.02
215RV-004B	19.58	1.02	1.02	1.03	1.00	0.99	1.02	1.03
311RV-032	10.0	1.00	1.02	0.96	1.01	1.02	1.01	1.03
311RV-031	10.0	1.00	1.01	1.02	1.11	1.02	1.02	1.05
747RV-0.16	12.24	1.00	1.01	1.04	1.05	1.01	1.01	1.02

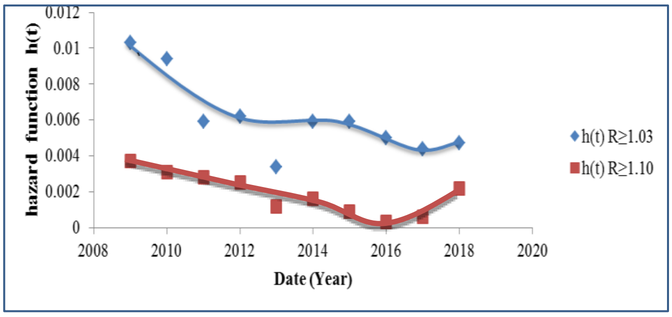


Figure 2: Hazard Function vs. Date (Year)

The two hazard functions are displayed in Figure 2 for failure defined as Rp≥1.03 and the other defined as Rp≥1.10.
The Figure 2 shows a chat of accumulated quality data of the hazard function (failure rate) related to years of maintenance action. The chat basically supports the bathtub curve. It shows that maintenance action carried in year 2009 recorded high valve failure rate of the two hazard functions defined by Rp≥1.03 and Rp≥1.05. Rp≥1.03 curve shows no significant difference in the failure rate between the years 2011 to 2017, the failure rate appears to be statistically flat within this period (intrinsic period) and an inflection point is seen to occur from the year 2017. Rp≥1.10 shows continuous drop in failure rate and a strong upturn at year 2016.

Failure defined by Rp≥1.03 and Rp≥1.10 statistically shows drop in failure rate after bench test which signifies decrease in probability of failure (POF) of the tested PRVs over time.

3.1 Statistical Analysis

The goal of the statistical analysis was to look into the relationship between TP/SP and time, as well as to identify demographic variables that lead to considerable aging.

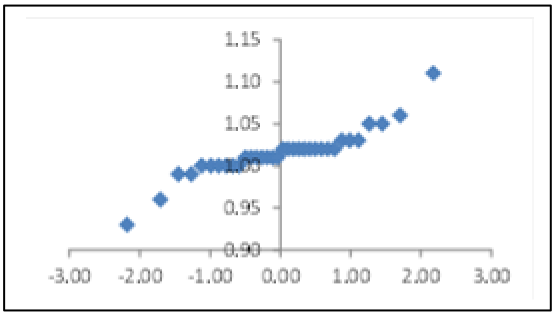


Figure 3: Normal Quantile plot

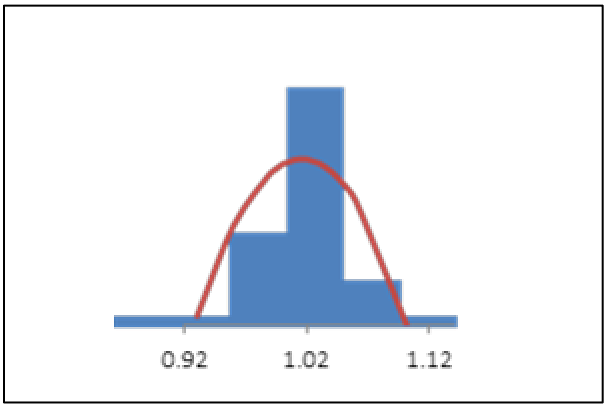


Figure 4: Normal Distribution

Table 3: Statistics for TP/SP for collected data set

Statistics	TP/SP
Mean	1.015429
Standard Deviation	1.024695
Upper 95%	0.93
Lower 95%	1.05
N	35

Figure 3 and Figure 4 illustrate the distribution of test data (Table 2) on normal distribution plot. The distribution is assumed normal. The projection with confidence of the population falls within tolerance (the set pressure for relief valves shall not exceed ±2%psi (0.138bar) for pressure ≤ 70psi (4.83 bar) and ±3% for pressure > 70psi (4.83bar)) see ASME VIII section 1 paragraph UG134(d)(1).

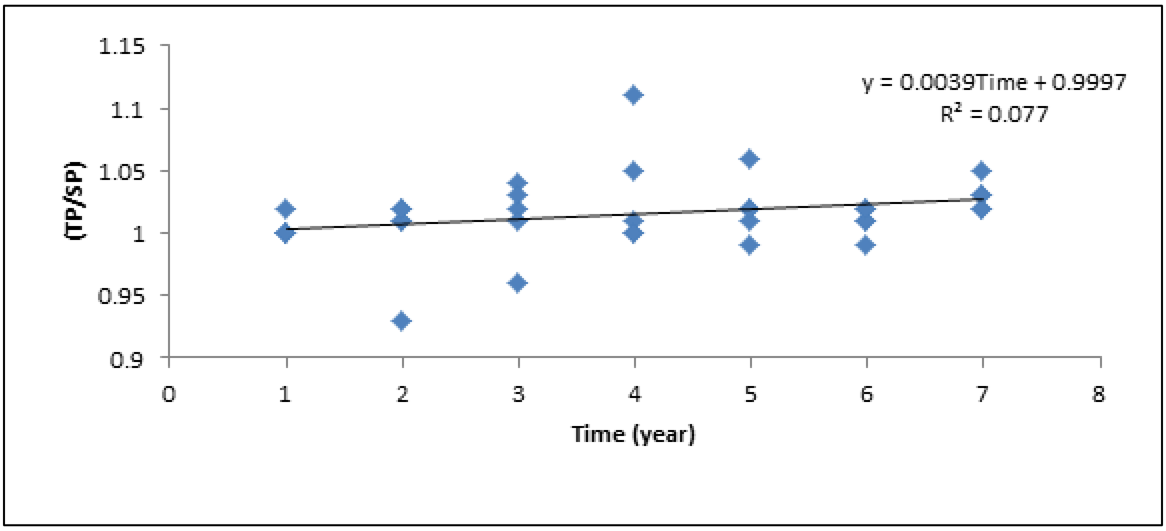


Figure 5: TP/SP by Time (year) Weighted Regression

Linear Fit

$$\frac{TP}{SP} = 0.0039\text{Time} + 0.9997$$

Table 4: Regression Statistics

Regression Statistics	
Multiple R	0.27745242
R Square	0.07697985
Adjusted R Square	0.04900954
Standard Error	0.0280194
Observations	35

Table 5: Parameter Estimate

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	0.99971429	0.010590336	94.39872777	9.8914E-42	0.978168084	1.021260487
Time (Years)	0.00392857	0.002368071	1.658975204	0.10659694	-0.000889306	0.008746449

A TP/SP by Time layout in Figure 5 shows a slope-fitted trend line. About 35 observations of proof test results (table 2) were statistically analysed to see if there was an aging trend or an increase in variation with time (linear regression). Most of the result shows no change in TP/SP. However, TP/SP verse time revealed increase in TP/SP (aging trend) to about 0.4% per year. This demonstrates that 12bar relieve valve is likely to pop at 12.00bar after one year

and 12.01bar after two years in service.
Also, variation in the proof test values is only 7.7% as measured by R-square. This regression analysis is made more visible in table 4 and table 5.

3.4 Cause of Failures Analysis

The core reason of individual PRV failure is addressed in addition to statistical analysis of proof tests.

Table 6: Inspection Report of 311RV-031

Date (Next Inspection Interval)	$ratio\ R = \frac{TP}{SP}$	Bench Test Result	Remark
November, 2004	1.00	RV Failed initial pop test at 10bar against 10bar SP	New valve setting adjustment done. Retested ok. RV first installation to equipment.
April, 2007	1.01	RV passed as received pop test at 10.1bar against 10bar SP	No adjustment. RV was then returned to service
September, 2009	1.02	RV passed as received pop test at 10.2bar against 10bar SP	No adjustment. The RV was then returned to service.
February, 2012	1.11	RV failed as received pop test by lifting at 11.1bar against 10bar SP due to sticking	RV was repaired, reset and tested ok.RV returned to service.
July , 2014	1.02	RV Passed as received pop test at 10.21bar against 10bar SP	No adjustment. RV returned to service
December, 2016	1.02	RV Passed as received pop test at 10.20bar against 10 bar SP	No adjustment. RV was returned to service
May, 2019	1.05	RV failed as received pop test at 10.5 against 10bar SP due to corrosion	RV stripped for repair, retested ok. RV returned to service.

Table 6 shows timeline results of a conventional PRV with tag number 311RV-031 installed on SIA vessel 2-V-1469 of LNG plant. The PRV has been tested for 7 times (Table 6) since installation. The first failure was recorded on February, 2012.The conventional PRV was brought to the LNG PRV workshop for inspection and revision base on the inspection time interval. The PRV was tested and it lifted above the 110% of the set pressure during initial as received pop test indicating failed to danger (FTD). Prior to investigating the following action was taken:

i. The PRV was stripped and the internal parts were inspected to establish what caused the PRV to record failed to danger (FTD). The inspection revealed corrosion and fouling within the bonnet area housing and spring. The corrosion product was as a result of water ingress (Plate 3) through the easing lever opening of the PRV bolted flange cap.
ii. The corroded valve internal parts were cleaned and polished

iii. The PRV disc, nozzle and spring were replaced with new ones

The second time this PRV failed was May, 2019. The valve recorded failure at pop test of 10.5bar as against SP of 10bar which is above the SP tolerance of 3% as recommended. The valve was then stripped for repair.
The photograph depicts the valve in its original state. Prior to cleaning and reconditioning, Plate 1 was taken in the valve shop. There were no noticeable signs of wear or damage. The movable pieces appear to be corroded, and the disk and seat appear to be stuck together. However, the causes of high first pop pressure and setting to set pressure must be comprehended. This seems to agree with one theory that "high proof test developed was that the seat and disc may have micro-welded, diffusion bonded or galled together".

Plate 1: Picture Depicting Occurrence of Corrosion

Plate 2 Picture of Cleaned PRV parts

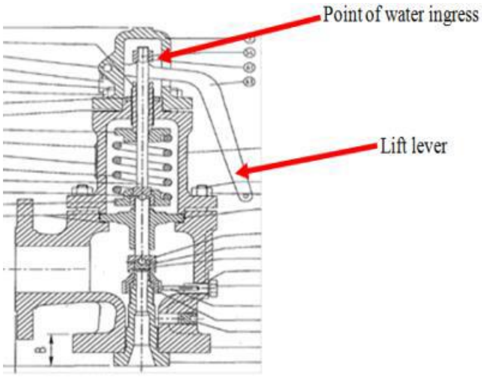


Plate 3: Picture Indicating Point of Water Ingress

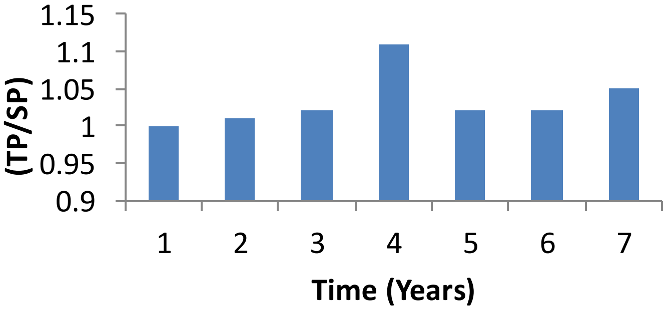
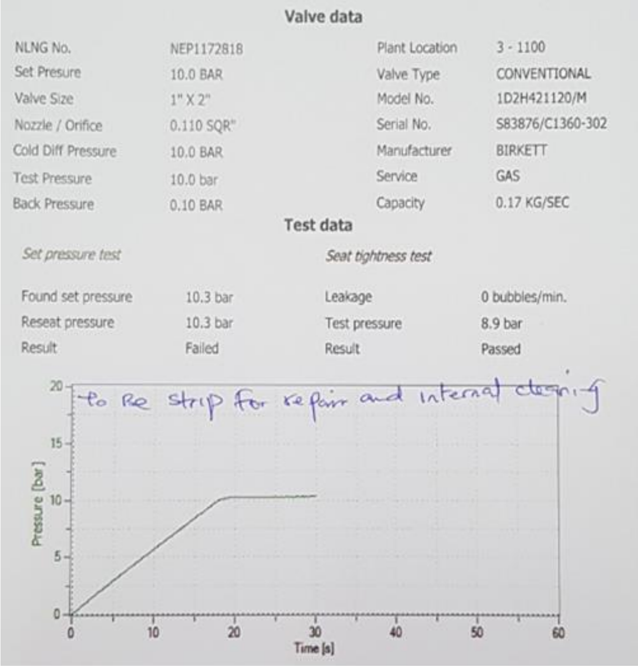


Figure 6: TP/SP by Time (Year) for 311RV-031



Valve data

NLNG No.	NEP1172818	Plant Location	3 - 1100
Set Presure	10.0 BAR	Valve Type	CONVENTIONAL
Valve Size	1" X 2"	Model No.	1D2H421120/M
Nozzle / Orifice	0.110 SQR"	Serial No.	S83876/C1360-302
Cold Diff Pressure	10.0 BAR	Manufacturer	BIRKETT
Test Pressure	10.0 bar	Service	GAS
Back Pressure	0.10 BAR	Capacity	0.17 KG/SEC

Test data

Set pressure test		*Seat tightness test*	
Found set pressure	10.3 bar	Leakage	0 bubbles/min.
Reseat pressure	10.3 bar	Test pressure	8.9 bar
Result	Failed	Result	Passed

to Re strip for repair and internal cleaning

Figure 7: Last Inspection report for 311RV-031

Figure 6 evaluates test result from data of Table 4. It depicts the trend in the inspection and maintenance of a relief valve with tag 311RV-031. Also, Figure 7 shows the last test report of 311RV-031. The RV failed as received pop test at 10.5bar against 10bar SP.

Generally, investigation of cause of failure showed that it is a combination of parts is essential for the performance of the PRV rather than individual parts. That is, in case two critical parts (disc and seat) of the PRVs are “connected” to each other either by factors such as sticking, cold welding and corrosion etc., the opening pressure is substantially higher, which result in failed proof test.

4 CONCLUSIONS

Data sets collected so far for this study revealed that the optimal time of 30 months as inspection interval for recertification of PRVs approved by DPR actually improves the reliability of PRV in service since it yielded better results and consequently less risk. In arriving to this conclusion theory driven approach and statistical analysis were used.

Failure rate of two failures (Rp≥1.03 and Rp≥1.10) data were evaluated and analyses revealed that every inspection period brought about drop in the failure rate of the PRVs. This analysis brought about the assumption that an increasing failure rate is present because of the selected inspection interval and the type of maintenance policy considered by the facility or company.

Also, TP/SP data collected and statistically analysed revealed that the aging effect (increase in TP/SP) for relief valve across all manufacture and different sizes is at most 0.4% per year with 95% confidence. Since the average estimated rise in TP/SP is at most 0.4 per cent per year and the amount of variance explained by time is negligible, time in service of PRVs has a minimal effect on valve performance across the 7 to 8 (years) time period of the study (R-square 7.6 per cent).

Cause of failure analysis revealed corrosion as cause of failure. Although many literatures seem to show that many failures could be explained by the influence of adhesion. Also the contact area is another important factor that is related to failure. It was found that, when two critical parts (disc and seat) of the PRVs are "connected" to each other either by factors such as sticking, cold welding and corrosion etc., the opening pressure is substantially higher, which result in failed proof test.

In conducting proof test of PRVs revealed that between the last proof test and the current proof test, PRVs failed. That is, the failure time is longer than the inspection time, and the exact time of failure is unknown.
PRVs can corrode and corrosion is formed under the influence of time, implying that an increasing probability of failure (POF) is expected. However, the results showed 0.4% aging trend among the PRVs, which might indicate that the recertification of PRVs by proof test are scheduled in a conservative interval, meaning that the actual time to failure is much longer than expected.

REFERENCES

Adadande, S. A. Naniwadekar, A.M.&Rajkumar, B.P. (2014).Reliability Analysis of Pressure Relief Valve Manufacturing System.*International Journal of Emerging Research and Technology*,*2*(2), 64-70.

API, R. (1991). 527, Seat Tightness of Pressure Relief Valves.*American Petroleum Institute (API) Recommended Practice*, *527,* 196 – 204.

ASME PCC-3 – (2007).Inspection Planning Using Risk-Based Methods: Published by the American Society of Mechanical Engineers, 2007.

Awati, M.V., Jadhar, S.G.&Vinay, G.P. (2014).Analysis of Pressure Safety Relief Valve UsingFinite Element Analysis.*International Journal of Engineering Development and Research*, *2*(3), 2968 – 2973.

Bukowski, J. V. (2007). Results of Statistical Analysis of Pressure Relief Valve Proof Test Data Designed to Validate a Mechanical Parts Failure Database. Technical Report, September, Exida, Sellersville, PA.

Bukowski, J. V.& Goble, W. M. (2009).Analysis of Pressure Relief Valve Proof Test Data.*Process Safety Progress*, *28*(1), 24-29.

Bukowski, J. V., Gross, R. E. & Goble, W. M. (2011). Probability of Initial Failure for Spring Operated Relief Valves. In *ASME 2011 Pressure Vessels and Piping Conference* (585-595).American Society of Mechanical Engineers.

Bukowski, J. V. Gross, R. E.& Goble, W. M. (2013). Investigation of Adhesion Formation in New Stainless Steel Trim Spring Operated Pressure Relief Valves. In *ASME 2013 Pressure Vessels and Piping Conference* (V05AT05A079-V05AT05A079).American Society of Mechanical Engineers.

Chien, C. H., Chen, C. H. & Chao, Y. J. (2009). A Strategy for the Risk-Based Inspection of Pressure Safety Valves.*Reliability Engineering & System Safety*, *94*(4), 810-818.

Ebeling, C. E. (2010). *An Introduction to Reliability and Maintainability Engineering*.Tata McGraw-Hill Education.

Emily, M., Robert, D. & Stephen, P. (2013). Evaluating Risk and Safety Integrity Levels for Pressure Relief Valves Through Probabilistic Modelling. *Journal of Pressure Vessel Technology*. 10(2): 13-15.

Gross, R. E.& Harris, S. P. (2006). Extending Pressure Relief Valve Inspection Intervals by Using Statistical Analysis of Proof Test Data.I *ASME 2006 Pressure Vessels and Piping/ICPVT-11 Conference*. American Society of Mechanical Engineers. 4, 211-219.

Gross, R. E.& Harris, S. P. (2008).Analysis of Safety Relief Valve Proof Test Data to OptimizeLifecycle Maintenance Costs.In *Reliability and Maintainability Symposium*, *2008.RAMS 2008*. *Annual*,312-316.

Hellemans, M. (2009).*The Safety Relief Valve Handbook: Design and Use of Process Safety Valves to ASME and International Codes and Standards*.