Reliability Analysis of Centrifugal Pumps System Justifies Improvements in Gas Plant

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INTRODUCTION

Over the past several years, reliability has become an ever-increasingly important topic and component in the organizational continuous improvement tool box. Higher plant reliability reduces process and equipment failures costs as failure disruption decreases production output which in turn limits gross margin. Additionally, equipment failures also increase the probability of having a catastrophic environmental accident and the potential for increasing safety related accidents.

The strong competitive environment between companies to secure business and the current world financial crisis are forcing organizations to explore ways to reduce operating costs. A popular approach to reduce operating costs is to reduce expenditures on equipment maintenance. While results can be obtained by reducing investments in equipment, this approach is very short sighted. It is not unusual that deferred investments will re-surface and cost 2 to 5 times more than if addressed in the early stages of failure development.

The purpose of this paper is to objectively demonstrate that an approach focused on reliability, availability and maintainability prediction will help to detect pieces, equipments and systems that require improvements helping to maintenance managers to make the right decision analyzing a centrifugal pump system in a gas plant.

DEVELOPMENT

The primary function of a NGL Recovery Gas Plant is to recover the rich component of gas (ethane, butane, propane and gasoline) known as “Soup” .This soup is dispatched to a fractionating plant where the components are recovered again and then are sold to the market.

The centrifugal pump system analyzed is a critical part of the process, basically is the core of business. The main purpose of the centrifugal pumps is to take the soup out of the main recovery tower to send the NGL (Natural Gas Liquids) to the dispatching area (See Figure-1).

The pumps system is composed by two centrifugal pumps disposed in parallel, one pump is operating and the other pump is waiting to be demanded. The system for the reliability analysis is called “Stand-by redundancy” type 1 of 2, just one pump is in operating mode and the other pump is waiting for failure of the first pump. These are two-stage centrifugal pumps type (WTB) vertically splited; they are designed for heavy duty in refineries, electric centrals and for general services.

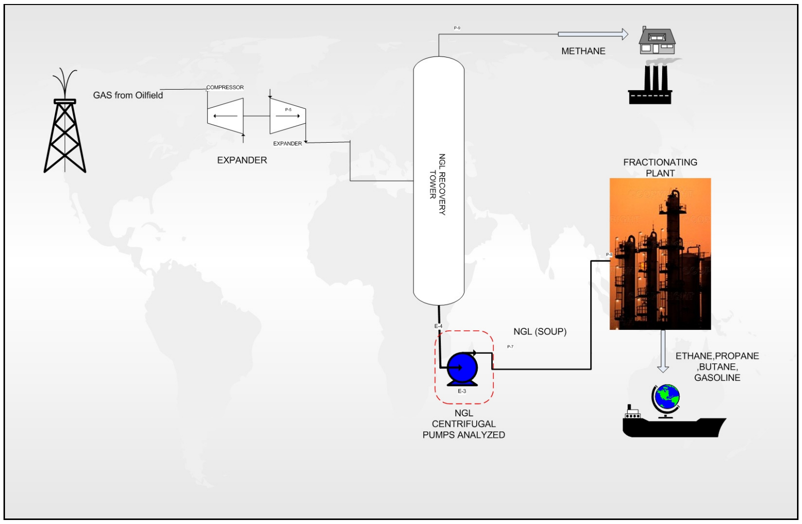

Figure-1. Typical NGL Recovery Gas Plant Lay Out

An important piece of equipment are mechanical seal, due to a leakage of NGL to the atmosphere could be dangerous. For this reason reliability of mechanical seal in these types of pumps is a key aspect for the process to maintain safety and gross margin levels as high as possible.

Root Cause Failure Analysis (RCFA)

The RCFA is a technique that permits to find out the cause of failure, which could be a physical root or a human root. The purpose of RCFA is to resolve problems that affect plant performance and avoid recurrence problems. There are several technique used such as FMEA, Failure Tree, Ishikawa, 5 Why's and statistical analysis. In this case study we have used 5 Whys technique, Weibull analysis (statistical technique) and we have used physical evidence to determine the causes that made to the centrifugal pump system breaking down frequently during lasts years.

During the gas plant start-up has been detected a several quantities of solid particles in the main gas stream making to the mechanical seals of the NGL pumps failure, and break down the system. These solid particles most of them sand remained inside the piping during erecting the plant were the cause of centrifugal pump system failures. The last two years centrifugal pumps system has suffered some break downs due to leakage through the mechanical seal. However, there weren't solid particles in the main gas stream that could affect the seal face lubrication. Figure 2 shows the physical evidence in mechanical seal that there are marks regarding to run dry (lack of fluid for face lubrication). The 5 why's analysis have concluded that gas operating conditions in the NGL centrifugal pump system have changed; pressure and temperature were unstable affecting the mechanical seal lubrication. For this reason a Weibull analysis has been performed.

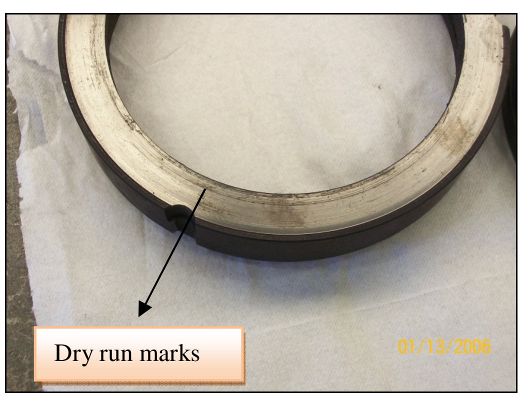

Figure-2. Seal face with lack of lubrication marks

Weibull Analysis

The Weibull analysis is a widely technique used for statistical data analysis. In this particular case this type of analysis permits to determine the failure behavior of the mechanical seal (early life, random life or wear-out). The Weibull distribution is widely used because it has a great variety of shapes which enables it to fit many kinds of data, especially data relating to product life. The Weibull frequency distribution (or probability density function) has two important parameters: β is called the *shape parameter* because it defines the shape of this distribution and η is the *scale parameter* defines the spread of the distribution. The β parameter represents the failure pattern of component under study, for instance if $\beta < 1$ the piece is failing in the early life, if $\beta = 1$ the failure rate is constant and the piece is failing in the section of useful life of the bath curve (see figure-3) and if $\beta > 1$ the piece or component analyzed is failing due to wear-out and a scheduled maintenance is justified.

$$\lambda(t) = \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1} \qquad \textit{Eq.1}$$

$$R(t) = e^{-\left(\frac{t}{\eta}\right)^{\beta}} \qquad \textit{Eq.2}$$

Where:

R(t): Reliability value
λ(t): Failure rate
t: Mission time (hours)
β: Shape parameter
η: Scale parameter (hours)

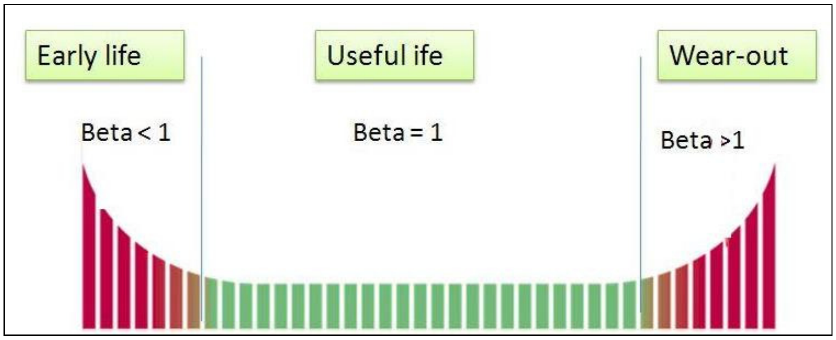

Figure-3. Bath curve

For this particular analysis of mechanical seal failure, data from mechanical seal failure were collected from CMMS system to determine the time to failure for every mechanical seal and then to be computed in a specific software for Weibull Analysis (Reliasoft). Table 1 shows the result of Weibull analysis for mechanical seal of NGL pumps.

Table-1. Weibull analysis results

Equipment	BETA	ETA(hours)
NGL Pump A	1,13	4866,5
NGL Pump B	0,84	6513

Graphing equations 1 and 2 with Weibull results for 17520 hours (see figure 4 and 5).

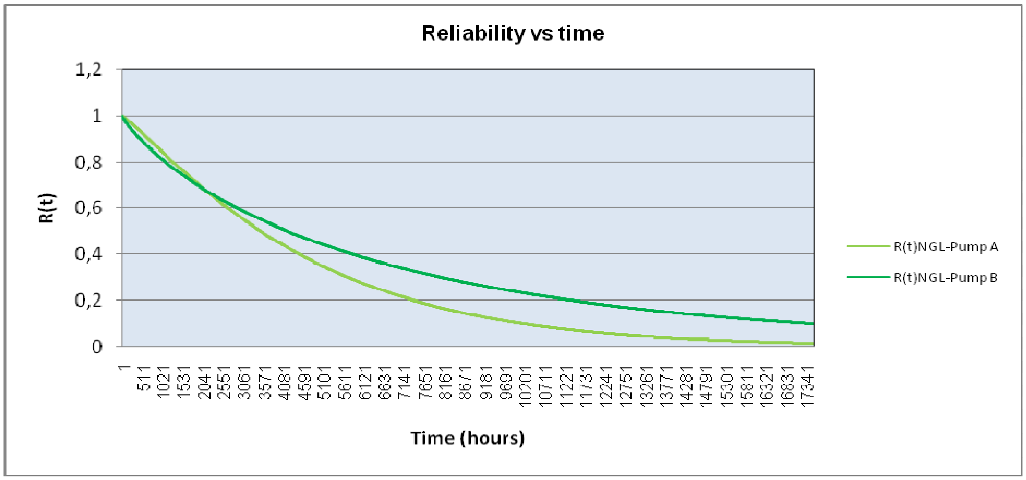

Figure-4. Mechanical seal Reliability curve at 17520 hours

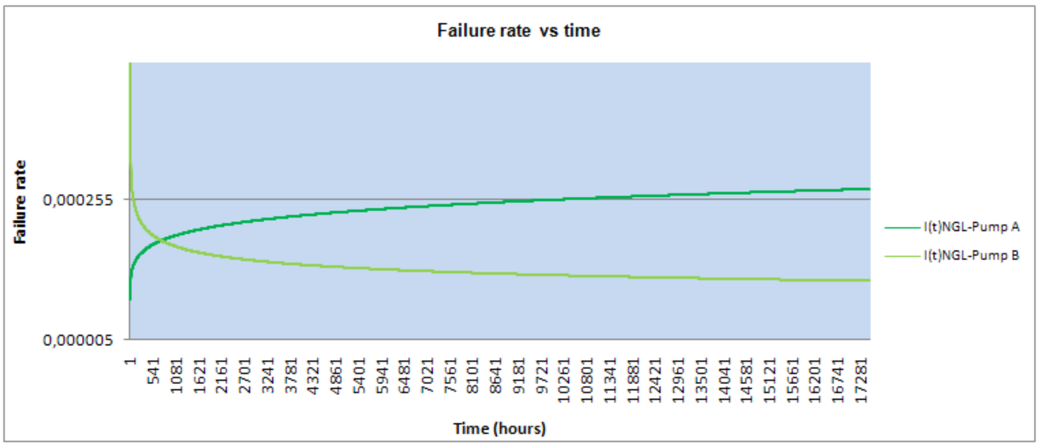

Figure-5. Mechanical seal Failure rate curve at 17520 hours

From the Weibull analysis performed on mechanical seal, Pump A is failing in a random way (could be caused due to the variation of process parameters) and Pump B is failing on infant mortality zone of the bath curve (could be caused by a combination of variable process condition i.e. pressure and temperature, lack of maintenance procedures and or a poor mechanical condition of shaft seal).

Making comparison between Weibull parameters from the mechanical seal of both pumps against a typical mechanical seal in Oil&Gas industry, it is clear that the life of mechanical seal analyzed in this paper is significantly lower than a typical mechanical seal (Beta=1,4 and Eta=25.000hours).

Calculating MTTF (Mean Time To Failure) for mechanical seals:

$$MTTF = \int_0^{\infty} R(t).dt \quad \text{Eq.3}$$

$$MTTF = \eta\Gamma(1+\frac{1}{\beta}) \quad \text{Eq.4}$$

Use Table-2 To evaluate Gamma function

Table-2.

β	$\frac{MTBF}{\eta}$	β	$\frac{MTBF}{\eta}$	β	$\frac{MTBF}{\eta}$	β	$\frac{MTBF}{\eta}$
0.0	∞	1.0	1.000	2.0	0.886	3.0	0.894
0.1	10!	1.1	0.965	2.1	0.886	3.1	0.894
0.2	5!	1.2	0.941	2.2	0.886	3.2	0.896
0.3	9.261	1.3	0.923	2.3	0.886	3.3	0.897
0.4	3.323	1.4	0.911	2.4	0.886	3.4	0.898
0.5	2.000	1.5	0.903	2.5	0.887	3.5	0.900
0.6	1.505	1.6	0.897	2.6	0.888	3.6	0.901
0.7	1.266	1.7	0.892	2.7	0.889	3.7	0.902
0.8	1.133	1.8	0.889	2.8	0.890	3.8	0.904
0.9	1.052	1.9	0.887	2.9	0.892	3.9	0.905
						4.0	0.906

Example for NGL Pump A

$$MTTF_{PumpA} = \eta\Gamma(1+\frac{1}{\beta})$$

$$\beta = 1{,}13$$

$$\eta = 4866{,}5 hours$$

$$\frac{MTTF_{PumpA}}{\eta} = 0{,}9578 \Rightarrow tableGammaFunction$$

$$MTTF_{PumpA} = 0{,}9578 * 4866{,}5 = 4661 horas$$

Table-3. MTTF values for mechanical seals

Pump	MTTF/η	MTTF(hours)	η	β
Pump A	0,9578	4661,134	4866,5	1,13
Pump B	1,1	7164,3	6513	0,84

Where:
Γ(1+1/β): Gamma Function
η: Characteristic Life (hours)
β: Weibull Shape parameter
MTTF: Mean Time To Failure (hours)

Reliability Analysis for the NGL pumps system

Because of the NGL recovery gas plant would not stop for the next two years it was necessary to get the reliability parameters of the NGL centrifugal pumps system with the objective to know the risk of to continue operating the pumps system in these conditions.

The NGL centrifugal pumps units are arranged in parallel mode, being part of a Standby system with passive redundancy (one pump is operating and the other is waiting in stand-by mode for a failure of first pump).More specifically, the system contains a total of k+1 units, and as soon as the operating unit fails, the operator replace the failed unit with one of the standby unit. Figure 6 shows the block diagram of standby system.

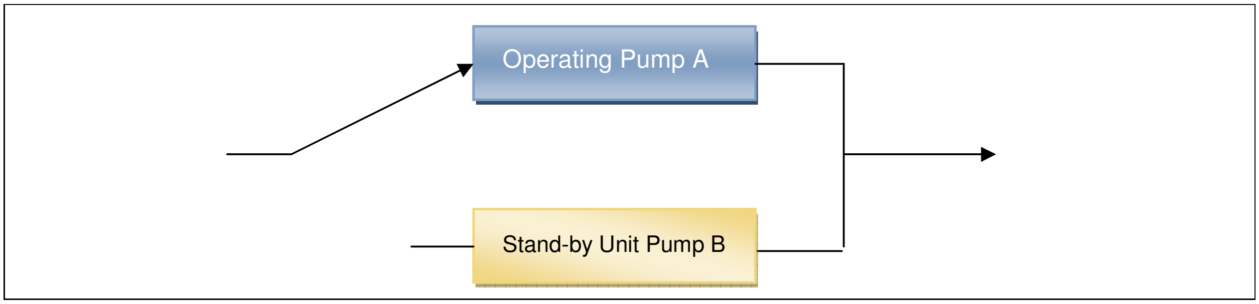

Figura-6. Standby system diagram

For a system with two pumps with two different failure rates the equation to calculate the reliability value is Eq.5:

$$R_{SB} = e^{-\lambda 1t} + R_{sw}\left(\frac{\lambda 1}{\lambda 2 - \lambda 1}\right)\left(e^{-\lambda 1t} - e^{-\lambda 2t}\right) \quad \text{Eq.5}$$

Where:

RSB: Reliability Standby system
RSW: Reliability of switch mechanism (100%)
$\lambda 1$ = Global Failure rate operating unit 1
$\lambda 2$ = Global Failure rate operating unit 2
t = Mission time (hours)

Most of the times some pieces of equipment failure rates are not available (because they never failed). Because of this to establish the global failure rates the use of international standards database like API, OREDA or others are required. The failure tree for the NGL centrifugal pump is shown in figure 7.

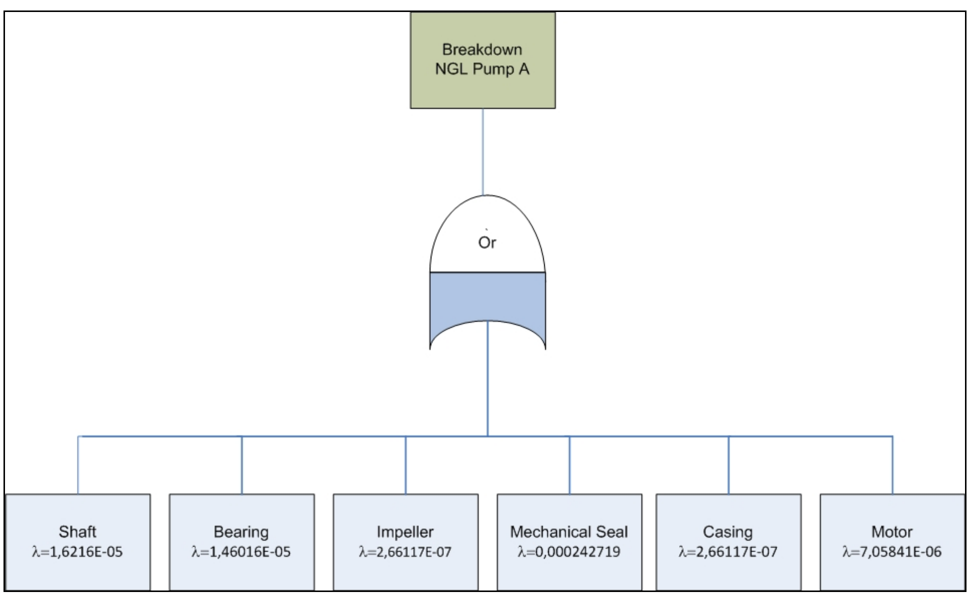

Figure 7. Failure Tree for NGL pump A

Considering to all failure modes are statistically independents and a failure of any component breakdown the pump, the global failure rate is the sum of all independent failure rates. For Pump A and B is the same procedure, the great difference in the failure rate are the values for mechanical seal (calculated in Weibull Analysis). In table 4 the failure rate for both pump are shown.

$$\lambda(global) = \lambda_{Shaft} + \lambda_{Bearing} + \lambda_{Seal} + \lambda_{impeller} + \lambda_{Casing} + \lambda_{Motor}$$

Table-4. Global Failure rate

Pump	Failure rate (f/h)
Pump A	0,000281128
Pump B	0,000169465

Applying equation 5 to calculate the reliability value for the NGL centrifugal pump system at two years for non interrupted operation (17520 hours), considering Rsw=1:

$$R_{SB\,System} = e^{-\lambda At} + \left(\frac{\lambda A}{\lambda B - \lambda A}\right)\left(e^{-\lambda At} - e^{-\lambda Bt}\right)$$

$$R_{SB\,System} = e^{-0{,}000169*17.520} + \left(\frac{0{,}000169}{0{,}000281 - 0{,}000169}\right) * \left(e^{-0{,}000169*17.520} - e^{-0{,}000281*17{,}520}\right) = 0{,}122$$

Calculating MTTF using equation 3 and the Availability (A) of the Pump System:

$$MTTF = \int_0^\infty R(t).dt$$

$$MTTF = \int_0^\infty e^{-\lambda t}.dt$$

$$A = \frac{MTTF}{MTTR + MTTF}$$

Where:

λA: Failure rate for Pump A
λB: Failure rate for Pump B
MTTF: Mean Time To Failure (hours)
MTTR: Mean Time To Repair (hours)
A: Availability

In table-5 are summarized the reliability analysis for the NGL pump system

Parameter	NGL Pumps System
$R_{(17520)}$	0,1220
Average failure rate	0,000120
Expected Failure in 2 years	2,1035
MTTF	8329,0194
MTTR	21,0349
A (availability)	0,9975

It is well appreciated that the reliability value for the system a 17520 hours is too low with high chances to suffer a failure. However, availability value remain high (that is a typical figure in Oil&Gas industry due to the high redundancy on equipments). The cost of unreliability is the main cause of goes down gross margin in most industry, due to high frequency of failure, wasting time, labor hours and spending money in spare parts. High availability provides the opportunity to make money because the plant is ready to respond. Low reliability provides the opportunity to incur outages which cost money.

Cost Analysis

Cost analysis is the most important section of any reliability analysis. The main goal of this section is to turn the reliability numbers into money, money that will be used by Plant Maintenance Manager to justify improvements or to make right decision and avoid to loss the gross margin of the company. Clearly it is the responsibility of engineering departments to define the equipment failure rates and the consequences of engineering practices on the life equipment. Also it is the responsibility of engineers to convert the results of equipment life and failures into a financial format for clearly communicating within the organization.

This NGL pumps system expect 2,1 failures for the next two years which causes a cost of unreliability (COU) of USD 590.450. The cost of unreliability is divided in:

- Cost of spare parts
- Cost of labor hours per reparation
- Cost of loss production

$$COU = Cost_{Spareparts} + Cost_{labor} + Cost_{lossproduction}$$

- Cost of mechanical seal failures = 7.000 USD (per seal) x 8 (number of mechanical seal failures in both pumps A and B)= USD56.000
- Cost per mechanical seal reparation: MTTR= 10 hr * 2 technician * 21USD (cost of labor hour) *8 (number of mechanical seal failures)= 3.360USD
- Cost of loss production = 2,1 (number of failures) * 90 NGL Tons/h * 281 US$/Ton * 21hours (10 hours * 2,1 failures)= 531.090 USD

$$COU = \$56.000 + \$3.360 + \$531.090 = \$590.450$$

The cost of unreliability is **590.450USD.** The RCFA (The Root Cause Failure Analysis) and Weibull analysis have demonstrated that the mechanical seal of the centrifugal pumps is the main reason of high value of COU.

Technical Proposal

With financial figures, the technical proposal to make improvements in the NGL pumps system has been made.

1. To purchase one new pump
2. Replace the less reliable pump (pump A) with new one and the send to factory to recover the original shaft size
3. To Modify the currently API plan to become independent of process variables

In Table-6 it is summarized the total cost of technical proposal to improve reliability figures and reduce the COU.

Table-6.Techincal proposal cost

Proposal	Cost in USD
Purchase a new pump	220.000
Repair an old pump	15.000
API plan modification	82.000
Total Cost	**317.000**

The cost of unreliability for the NGL pumps system is $590.450, clearly an investment of $317.000 is well justified for improve reliability figures increasing the gross margin of the company.

CONCLUSIONS

From the failure analysis of mechanical seal several factor are the cause of pumps breakdowns, one is the process condition variable making to the seal face a dry run, other cause is the poor mechanical condition (wear) on the pump shaft due to the bad condition of the start up of the plant (dust in pipes run). The Weibull analysis has confirmed the early failures of the seal due to the causes mentioned before. An API plan modification is required to isolate the seal face lubrication from the process condition and the shaft pump restoration is required as well.

The reliability analysis shows that an improvement in the NGL centrifugal pumps system is required, if an immediately action is not taken the gross margin is going down year by year. The cost analysis is indicating that an investment in this system is well justified to improve the reliability figures.

Tracking the reliability values keeping the availability indicator in the monthly report is an action required to implement as soon as possible. In Oil&Gas industry is very common to find high availability numbers but low reliability figures, for this reason most companies could not advertise the loss money due to unreliability (high frequency failures). The cost of unreliability index is a simple and practical reliability tool for converting failure data into cost, helping to managers and the entire the organization to understand the problem within a piece of paper.

This paper shows how important is the Reliability Engineering applied. Those companies that start to implement this kind of tool in their sites will take several advantages against their competence.

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