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Enhancement of Pit Depth Rank Statistical Analysis for Estimating Remaining Casing Life

Willord J. Garcia, Carlo Paul P. Morente, Diana Marie Z. Lejano and Edson B. Emoricha

Energy Development Corporation, One Corporate Center, Julia Vargas cor. Meralco Ave, Ortigas, Pasig City, Philippines

garcia.wj@energy.com.ph, morente.cp@energy.com.ph, lejano.dmz@energy.com.ph and emoricha.eb@energy.com.ph

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ABSTRACT

Pit depth rank (PDR) chart is a statistical tool used to analyze multifinger caliper data. The method of analysis with PDR charts, which is based on the Extreme Value Theory is used to predict the probability of penetration depths greater than what was recorded exist on the sampled casings. Predictions are inferred from a regression line fitted to the pit depth values against pit depth rank plot. Modifications to the PDR charts were applied to improve the fit of this regression line. In this study, the Gumbel distribution was used as the working equation of the pit depth rank analysis. Caliper survey data were selected and categorized per sample size. In addition to this, plotting positions were used in the calculation. Performance indicators that measured the goodness of fit of the regression line were used to determine the plotting position with the best fit. Fits better than those from Normal PDR were achieved through the aforementioned method; furthermore, a correlation between the sample size and the improvement of regression fit was observed.

1. INTRODUCTION

Multifinger calipers are used to detect damages present inside a production casing. A multifinger caliper is a well logging tool that records the inside diameter of the casing string against depth through feeler arms that extend radially outward from the tool body. Centralizers keep the body of the tool at the center of the casing string while the ends of the feeler arms rest on the casing walls. As the tool is pulled through the wellbore, springs allow the feeler arms to extend or retract depending on the distance of the casing wall from the body of the tool. Thus, the extent of the opening of the feeler arms or penetration depth reflects the inner diameter of the wellbore, i.e. if feeler arms are more extended, penetration is deeper, thus the wellbore diameter is larger. The degree of change in the penetration depth is measured as pit depth values. Significant changes in penetration depth may mean problems with the wellbore casing. Casing thinning and pitting, both observed as increased penetration depth, are a concern for steamfield operators. If not remedied, the compromised casing could leak or, at worst, burst and result in uncontrolled blowout of the well. Accurately estimating the degree of casing thinning or pitting is therefore an important part of ensuring the integrity of the well's casing and, consequently, the safe operation of the well.

The resolution of the recorded samples at a particular depth is limited by the number of feelers and the casing diameter. Generally, the resolution of the caliper data increases as the number of feelers increases and decreases as the inside diameter increases. As no data is gathered between the feeler arms, there is a possibility that a deeper penetration may exist between the sampling points. However, statistical methods can be applied to predict the probability of a deeper penetration that may not have been detected by the caliper feeler, one such statistical method is the Pit Depth Rank (PDR).

2. NORMAL PIT DEPTH RANK ANALYSIS

PDR analysis is a statistical method based on the Extreme Values Distribution Theory (Eldredge, 1957). For this method, the deepest penetration recorded per casing joint is obtained and then sorted according to their pit depth values in decreasing order. The frequency of each pit depth value is counted; then the average rank is calculated based on each value's frequency (Table 1). The "Range of Rank" in Table 1 represents the "frequency" of the pit measurement value for the individual casing lengths, The PDR Chart is constructed as a lin-log scatter plot of pit-depth values against their average rank. Linear regression is used to generate a best fit line based on the data. (Figure 1)

Table 1. Pit Depth by Rank Count and Average Rank

Pit Depth	Range of Rank	Average Rank
0.37	1, 2	1.5
0.35	3	3
0.25	4, 5	4.5
0.24	6 to 12	9
0.23	13 to 21	17
0.21	22 to 32	27
0.19	33 to 38	35.5
0.18	39 to 41	40
0.17	42 to 44	43
0.16	45	45
0.15	46	46

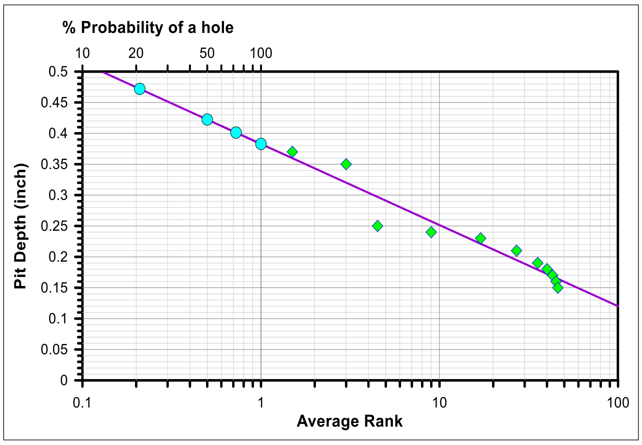

Figure 1. Pit Depth Rank Chart

The point wherein the regression line intersects the vertical line of average rank= 1 represents the maximum probable penetration (MPP) for the data sample. In this case, where the casing penetration is measured by finger actuators it is also the actual maximum depth measured for each casing length, but there is a high probability that a greater penetration exists between the finger contact points.

The probability of obtaining penetrations higher than MPP is estimated by extending the regression line beyond average rank=1 and projecting the pit depth value onto the rank axis to the casing wall thickness. Therefore, it is vital that the generated regression line closely fit the data plots in order to increase the accuracy of the values inferred using the regression line.

3. ENHANCED PIT DEPTH RANK ANALYSIS

A number of studies had been made that utilized Type 1 extreme value distributions to analyze and predict corrosion pit depth. A study made by Shibata (1994), utilized the Gumbel distribution to predict the maximum pit depth of an oil tank plate. A report made for UK's Health and Safety Executive (TWI Ltd., 2002), illustrate methods for analyzing corrosion pits of pipelines using Type 1 extreme value distributions. In line with this, this study has been made to determine the possible effect on the regression fit by incorporating the Gumbel distribution in PDR analysis.

3.1 Type I Extreme Value Distribution (Gumbel Distribution)

Gumbel distribution is a Type 1 extreme value distribution, which has been used to analyze corrosion pit depth. The normal PDR formula used in determining the probability of a penetration is expressed in the equation 1.

$$y = b\ln(x) + a \quad (1)$$

Where y is the pit depth higher than the MPP, x is the probability, and b and a are scale parameters based on regression line. Transforming **Error! Reference source not found.** to Gumbel distribution, (Yahaya et al., 2012) the PDR formula is expressed in the equation 2.

$$y = b\,ln(-\,ln(x)) + a \quad (2)$$

The updated PDR formula is the working equation in computing the probability of a penetration higher than the MPP.

3.2 Probability Plotting Position

Five plotting positions were used and compared with the normal PDR plot to assess which plot has the best regression fit. These plotting positions have been studied to have the best plot performance in a Type 1 extreme value distribution (Yahaya, et al., 2012).

Table 2. Probability plotting positions

Authors (Reference)	Formula	Authors (Reference)	Formula
Blom **(Adeboye & Alatise, 2007)**	$P_i = \frac{i-0.375}{n+0.25}$	Gringorten (Adeboye & Alatise, 2007)	$P_i = \frac{i-0.44}{n+0.25}$
Landwehr **(Makkonen, 2006)**	$P_i = \frac{i-0.35}{n}$	Weibull (Hirsch, 1981)	$P_i = \frac{i}{n+1}$
Laplace **(Lund, Jenkins, & Wilchfort, 1995)**	$P_i = \frac{i+1}{n+2}$		

where i is the rank while, n is the number of observations

4. PERFORMANCE INDICATORS

Performance indicators were used to quantitatively measure which plotting position has the best plot fit. The Residual Mean Square (σ^2) is a plot performance indicator used for error measurement, while Coefficient of Determination (R^2) is used for accuracy measurement.

4.1 Residual Mean Square

Residual mean square (σ^2) measures the error between the dependent variable observation and the predicted values from the fitted function. It depicts how well the regression fits the actual data points. The equation is defined as in equation 3

$$S^2 = \frac{\Sigma(Y-\hat{Y})^2}{n-2} \tag{3}$$

Where $\hat{Y}$ denotes the predicted value of Y and $n - 2$ is the residual degrees of freedom, which is the sample size minus the number of parameters (the parameters are a and b).

4.2 Coefficient of Determination

Coefficient of Determination (R^2) is the linear correlation coefficient that measures the strength and direction between two variables (Junninen et al,, 2004).

$$R^2 = \left[\frac{1}{n} \times \frac{\Sigma(x_i-\bar{x})+(y_i-\bar{y})}{\sigma_x\sigma_y}\right]^2 \tag{4}$$

where n is the number of observations, x_i is the observed values , y_i is the predicted values, $\bar{x}$ is the mean of the observed values, $\bar{y}$ is the mean of predicted values, σ_x is standard deviation of observed values and σ_y is standard deviation of predicted values.

5. RESULTS AND DISCUSSION

Survey data from three (3) wells with sample sizes ranging from 30 to 100 were used. These sample sizes are based on the sample size frequently recorded on caliper survey. The sample sizes were categorized as small for n=30, medium for n=50, and large for n=100. The samples were sorted and ranked as in the normal PDR analysis.

For each dataset, five PDR charts applying each of the five probability plotting positions were constructed. Regression lines were generated to fit the plots and their plot performances were evaluated using plot performance indicators to determine which of the plotting position has the best fit.

From the residual mean squares of the regression lines (Table 3) all three datasets have a lower calculated error for all the probability plotting positions than the normal PDR. In addition, the measured error values approache zero as the sample size increases.

The results obtained using the coefficient of determination (Table 4) give a similar result wherein the use of plotting positions resulted in better fits. The plotting positions which were determined to have a higher accuracy resemble those plotting positions that performed well in Table 3. Also, accuracy measures tend to improve as the sample size increases.

Table 5 is a tabulation of the MPP's per plotting position. Based on the result, the inferred MPP of each plotting position is different. The changes are attributed to the improvement of the plot fit as evident through results of the plot performance indicators.

Although changes on the MPP are subtle, they could still affect thinning rate of the casing. The effect of these changes is highlighted in

Comparison	Small	Medium	Large
Normal PDR	1.4737	0.8197	0.2750
Plotting position (best fit)	1.2468	0.9266	0.3862

Note: calculation based on well survey interval period at 0.435in casing wall

where the remaining life of the casing was calculated based on the MPP. The result indicates a percent change of about 13% to 40% between the normal PDR and the best fit plotting position.

Overall, comparisons of the PDR analyses indicate a refinement in the predicted values, which is attributed to improvement of the regression fit. Based on the results, there are two ways to improve the regression fit, first is by increasing the sample size of the data and second is by incorporating a type 1 extreme value distribution to the normal PDR.

Table 3. Residual Mean Square, σ^2

Probability plotting position	Small (n = 30)	Medium (n = 50)	Large (n = 100)
Normal PDR	2.2691E-04	3.5983E-04	4.2517E-05
Weibull	9.1393E-05	2.1379E-04	6.0133E-05
Blom	1.0069E-04	1.9133E-04	3.0421E-05
Landwehr	1.3225E-04	1.8525E-04	1.1165E-05
Laplace	1.1007E-04	2.3395E-04	5.8572E-05
Gringorten	1.0095E-04	1.8683E-04	2.5318E-05

Note: Better plot fit as value approaches zero

Table 4. Coefficient of Determination, R2

Probability plotting position	Small (n = 30)	Medium (n = 50)	Large (n = 100)
Normal PDR	0.735277	0.845786	0.989271
Weibull	0.893374	0.908374	0.984826
Blom	0.882534	0.918004	0.992324
Landwehr	0.845708	0.920606	0.997183
Laplace	0.871590	0.899737	0.985220
Gringorten	0.882223	0.919929	0.993611

Note: Better plot fit as value approaches 1

Table 5. Maximum Probable Penetration

Probability plotting position	Small (n = 30)	Medium (n = 50)	Large (n = 100)
Normal PDR	0.1238	0.1814	0.2781
Weibull	0.1391	0.1823	0.2535
Blom	0.1318	0.1755	0.2481
Landwehr	0.1246	0.1686	0.2428
Laplace	0.1394	0.1825	0.2535
Gringorten	0.1301	0.1740	0.2470

Table 6. Remaining Casing Life, years

Comparison	Small	Medium	Large
Normal PDR	1.4737	0.8197	0.2750
Plotting position (best fit)	1.2468	0.9266	0.3862

Note: calculation based on well survey interval period at 0.435in casing wall

6. CONCLUSION

Incorporating Type 1 Extreme Value Distribution in a PDR or the enhanced PDR analysis has been found to be a more effective method of modelling maximum pit depth per casing data compared to the normal PDR analysis. The improved representation of the data suggests that the enhanced PDR analysis is a more reliable method for determining the MPP and the probability of penetrations higher than the MPP. The enhanced PDR analysis consistently performed better in all sample sizes based on performance indicators, which measured a lower error and a higher accuracy as compared to the normal PDR analysis. The result plays a big role in resource management, especially in estimating the remaining life of a casing. An accurate estimate of the casing life could be used to determine the timing for casing relining, thus maximing the well production life. It also aids in developing the frequency of the caliper survey thus preventing unwanted or unplanned surveys, which could help decrease the maintenance cost of the well.

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