Abstract

Bearing failure of roller cone bits may result in a time-consuming fishing job, and lead to significant increase in drilling costs. The bearing failure generally comes from over wear of frictional pairs (surfaces between the journal and bearing of the cone). A bearing wear model has been developed to predict the wear status through multi-variable nonlinear regression analysis based on field data. The wear model considers four variables including weight on bit (WOB), revolution per minute (RPM), diameter of bit and hours drilled as a function of IADC bit bearing wear. Some abnormal bit run field reported bearing failures were removed in order to acquire the best regression of the field data. A failure probability model is then introduced to predict the survival probability of the bit, the parameter of which is obtained through statistics of more than 500 bit runs.

The wear status, including instantaneous and cumulative wear, for different roller cone bits and different wells drilled in Western Canada is simulated respectively with the wear model.

A good correlation coefficient was obtained for different IADC bit types including both milled tooth and insert roller cone bits. The cumulative wear values from the model match close those from the field.

The wear model and the failure probability model can help drilling engineers evaluate bearing wear status during real time drilling operations through simulation, and make a decision on when to pull out the bit in time to avoid bearing failures and the possibly lost cones. Better bearing wear predictability will result in better drilling results and effect the total drilling cost.

Introduction

Wear is very common in operation of mechanical products, especially to those with frictional pairs. There exist two main reported bit wears of rollercone bits during oil drilling operation with roller cone bits: cutting structure wear and bearing wear. Bearing failure wear should be paid more attention because bearing failure may in some cases produce catastrophic event whose consequences interrupt well progress and lead to significant remedial operations and costs.

The failure of a bearing is not necessarily the catastrophic event sometimes described. It takes typically several hours after the damage to the bearing for the cone to fall off. With the use of normalised down-hole mechanical parameters and simple logic, the torque created by the excess friction in the bearing and the torque caused by the locked cone dragging on the bottom of the hole can be differentiated from changes in lithology or drilling parameters (Lesage, M.L.G., 1988). Neural network have been successfully used in different fields due to their capability to identify complex relationship when sufficient data exist. A new model was successful in predicting the condition of the bit. Input: lithology, torque, ROP, WOB, RPM, HSI. Output: bit wear, including bearing wear and tooth wear (Bilgesu, H.I., 1997, 1988).

Some researchers have put forward empirical formulae about bearing wear of roller cone bits since more than half century. The prediction of bearing wear is much more difficult than prediction of tooth wear. A bearing wear formula used to estimate bearing life is given by (Bourgoyne, 1991)
\[
\frac{db}{dt} = \frac{1}{\tau_B} \left( \frac{w}{100} \right)^{h_B} \left( \frac{w}{4d} \right)^{h_d}
\]  
Eq.1

Insert breakage rather than tooth wear is the primary cutting structure concern at high mechanical horsepower levels. Field experimentation yields data on allowable WOB and RPM to avoid insert breakage. Below these WOB and RPM restrictions, insert wear is negligible, so the remaining unknown in WOB and RPM optimization is bearing life (Doiron, H.H., 1987). Journal bearing insert bit runs without excessive insert breakage or gauge wear typically fail due to seal/bearing wear. The factors affecting seal and bearing surface wear are numerous and complex. A well known wear equation was selected to characterize generalized wear in a journal bearing (Doiron, H.H., 1987)

\[
V = \frac{cLx}{p}
\]  
Eq.2

When a critical volume of material has been removed, the bearing failure will occur. After modification, the formula is changed to:

\[
V = K \cdot WOB \cdot RPM \cdot Hours
\]  
Eq.3

The bearing wear is proportional to the frictional work, which mainly depends on the travel distance and contact pressure between two surfaces of cone and journal. The travel distance and contact pressure are related to rotary speed of bit and weight on bit. The maximum contact pressure \( p_{\text{max}} \) can be calculated according to Hertzian contact theory.

\[
p_{\text{max}} = \left( \frac{1}{\pi(1 - \mu^2)} \right) \cdot \frac{\text{W}}{\text{L}} \cdot \left( \frac{1}{r_j} - \frac{1}{r_c} \right)^{0.5}
\]  
Eq.4

Because \( r_j, r_c \), and \( L \) are proportional to \( D_b \), the diameter of the bit, \( p_{\text{max}} \) can be expressed as (Kelly J.L. Jr, 1990):

\[
p_{\text{max}} \propto \frac{(WOB)^{0.5}}{D_b}
\]  
Eq.5

The bearing life parameter is given as:

\[
l_b = 60 \cdot RPM \cdot T \cdot (WOB)^{0.5}
\]  
Eq.6

**Bearing wear model**

From the above it can be seen that the bearing wear of a roller cone bit is mainly related to the two important drilling parameters, WOB and RPM. In fact bearing wear is a complex process, concerning with many factors, such as bit type, formation, BHA, and down hole conditions. Therefore the two independent variables WOB and RPM are selected to model bearing wear.

In addition, the wear is related to bit diameter \( D_b \) as well as time which should be in the model. In order to make the model more flexible, each variable is assigned a power. A synthetic coefficient \( K \) is introduced, so the final model is assumed as follows:

\[
BW = K \cdot (D_b)^a \cdot T^b \cdot (WOB)^c \cdot (RPM)^d
\]  
Eq.7

If we know the depth drilled or \( H_{\text{out}} - H_{\text{in}} \), and the interval of measuring is one meter, the instantaneous accumulative bearing wear is:

\[
Bwa = BW_0 + K \cdot \sum_{i=1}^{H_{\text{out}} - H_{\text{in}}} \left( \frac{1}{ROP_i} \right)^b \cdot (D_b)^a \cdot (WOB_i)^c \cdot (RPM_i)^d
\]  
Eq.8

**Field data collection**

The data are obtained from a database of drilling parameters records, and a total number of 500 bit runs are extracted. These drilling data were measured in hundreds of western Canada wells.
Coefficients of bearing wear model
Among the 500 sets of bit runs only selective runs were used to do the regression analysis (Figure 1). According to some of the field data (Table 1), multiple variables nonlinear regression is applied. The analysis coefficients and coefficient of multiple determination are shown in Table 2. When some of coefficients are assigned fixed values, the model becomes other researchers’ models (for examples by Kelly and Doiron).

From Table 2 it can be seen that the coefficient of multiple determination of both Kelly and Doiron model has a low value. However, this doesn’t always mean the higher the value of coefficient of multiple determination, the better the final bearing model.

Application of bearing wear model
After the coefficients in the model are obtained, it can be used to predict the bearing wear under certain conditions (Figure 2, Figure 3, Figure 4, Figure 5, and Figure 6). The different models reported in the literature to predict the bearing wear were compared to the results from the new model with field data.

Two groups of field data are used to verify the bearing models. Table 3, Figure 7 and Table 4, Figure 8 reflect the prediction results of different models respectively.

We find that the authors’ model can make a better prediction than other models in calculating both the instantaneous and cumulative wear. Although the model without any assignment has the best prediction for cumulative wear, it couldn’t be used to predict instantaneous wear. We also assigned different coefficients to form Bourgoynes’s model, but couldn’t get good results. Therefore each model has its own application conditions or application limits. The practicability of these empirical formulae mainly depends on the accuracy of original data. Through comparison of different models, the bearing wear model obtained by the authors of this paper has a better prediction than other models (Table 5). However it could be improved by using more and better drilling data. If possible the bearing model can be modified for roller cone bits with different IADC code, which means each IADC class has its own set of coefficients.

In addition, the model can be used to total hours if given other parameters. For example, assume that the used bits will continue to be used till totally worn out, then the left hours can be predicted. Figure 9 can show clearly the additional hours (hatched parts)

\[
T = \left( \frac{Bw}{K \cdot (D_b)^a \cdot (WOB)^c \cdot (RPM)^d} \right)^{\frac{1}{\eta}}
\]

Eq.9

The left hours can be used for drilling engineers to make decision on when to pull out the bits.

Bearing failure probability
The life of a roller cone bit bearing mainly depends on the seal, so if the seal fails the bearing will fail quickly. The survival probability of the bit bearing after L hours can be expressed as the following (Kelly, 1988):

\[
P_s (L) = e^{-\frac{1}{h}dFQ}
\]

Eq.10

The failure probability is:

\[
P_f (L) = 1 - P_s (L)
\]

Eq.11

Where

\[
h = \frac{1}{Q} \cdot \frac{dF}{dl}
\]

Eq.12

We used the 500 bit runs to make statistical analysis for the bearing seal, and calculated the h of roller cone bits with different IADC codes. The analysis results are shown in Table 6.

Take an IADC517 bit as example, after the bit runs 30, 70, 120 hours respectively, its survival probability is:

\[
P_s (30) = e^{-\frac{1}{h}dFQ} = e^{-30^{+0.003833}} = 89.14\% ; \quad P_s (70) = 76.47\% ; \quad P_s (120) = 63.13\%
\]
And its failure probability correspondingly is:

\[ P_f(30) = 1 - P_s(30) = 1 - 89.14\% = 10.86\%; \quad P_f(70) = 23.53\%; \quad P_f(120) = 36.87\% \]

So, the survival or failure probability of a roller cone bit can also be used for drilling engineers to make decision on when to pull out the bits.

**Conclusions**

- A bearing wear model for roller cone bits has been developed to predict the wear status, including instantaneous and cumulative wear. The cumulative wear values from the model match those from the field. The model can also be used to predict the left hours of the used bit under certain conditions.

- A bearing failure probability model is introduced to predict the survival probability a certain amount of hours after a roller cone bit runs.

- The wear model and the failure probability model can help drilling engineers evaluate bearing wear status during real time drilling operations through simulation, and make a decision on when to pull out the bit in time to avoid bearing failures and the possibly lost cones.

- The authors’ model has a better prediction compared to other researchers’. The performance of the bearing wear models and bearing failure probability in this paper depends on the quality and quantity of the collected drilling data.

**Acknowledgements**

The authors would like to give thanks to Husky Energy for providing field data for this paper.

**Nomenclature**

- \( a \) = coefficient
- \( b \) = fractional bearing life that has been consumed, Eq.1
- \( c \) = coefficient, Eq.7
- \( B_1 \) = bearing wear constant
- \( B_2 \) = bearing wear constant
- \( B_1 \) = bearing wear exponent
- \( B_2 \) = bearing wear exponent
- \( B_w \) = bearing dull grade, (0-8)
- \( B_w0 \) = initial dull grade, if new bit, it is 0
- \( c \) = wear coefficient, Eq.2
- \( d \) = coefficient
- \( d_0 \) = bit diameter, inches
- \( D_0 \) = bit diameter, inches
- \( E_j, E_c \) = modulus of elasticity for journal and cone
- \( F \) = number of bit with bearing failure
- \( H_{in} \) = depth put in, m
- \( H_{out} \) = depth pulled out, m
- \( Hours \) = time
- \( K \) = coefficient, obtained by regression according to the field data as shown in Table 1.
- \( l \) = life parameter
- \( L \) = load on sliding surface, Eq.1
- \( L \) = length of the bearing, Eq.4
- \( l_b \) = bearing life parameter
- \( N \) = rotary speed, rpm
- \( \rho \) = hardness of material
- \( P_{max} \) = maximum contact pressure
- \( p_f \) = failure probability
- \( p_s \) = survival probability
- \( Q \) = number of bit in service
$R_r$, $R_c$ = radii for journal and cone

$RPM$ = bit rotary speed, rpm

$ROP_i$ = instantaneous ROP corresponding to drilled depth $Hi$

$RPM_i$ = instantaneous RPM corresponding to drilled depth $Hi$

$t$ = time, hours

$T$ = Hours drilled

$V$ = rotary speed, rpm, Eq.1

$v$ = volume of seal/bearing , Eq.2

$w$ = weight on bit

$W$ = bit weight, 1000 lbf, Eq.1

$WOB$ = weight on bit

$WOB_i$ = instantaneous WOB corresponding to drilled depth $Hi$

$x$ = distance traveled

$\mu$ = Poisson's ratio for the two materials

$\tau_b$ = bearing wear constant, hours

References


# Table 1 Selected bit runs for regression analysis

<table>
<thead>
<tr>
<th>Size(mm)</th>
<th>Make</th>
<th>IADC</th>
<th>Depth (out)(m)</th>
<th>Distance drilled(m)</th>
<th>Hours</th>
<th>ROP(m/hr)</th>
<th>Weight(klb)</th>
<th>RPM</th>
<th>Pump press.(psi)</th>
<th>MUD WT(kg/m³)</th>
<th>Bearing Dull</th>
</tr>
</thead>
<tbody>
<tr>
<td>222</td>
<td>REED</td>
<td>447</td>
<td>2561</td>
<td>181</td>
<td>41</td>
<td>4.41</td>
<td>15.83</td>
<td>105.83</td>
<td>6861</td>
<td>192</td>
<td>2</td>
</tr>
<tr>
<td>200</td>
<td>HUGHES C</td>
<td>117</td>
<td>1100</td>
<td>147</td>
<td>6</td>
<td>24.5</td>
<td>13.00</td>
<td>160.00</td>
<td>3079</td>
<td>1046</td>
<td>1</td>
</tr>
<tr>
<td>222</td>
<td>HUGHES</td>
<td>517</td>
<td>1435</td>
<td>416</td>
<td>91.75</td>
<td>4.53</td>
<td>13.11</td>
<td>75.83</td>
<td>6546</td>
<td>1066</td>
<td>4</td>
</tr>
<tr>
<td>222</td>
<td>HUGHES</td>
<td>537</td>
<td>1519</td>
<td>84</td>
<td>27.25</td>
<td>3.08</td>
<td>14.71</td>
<td>66.43</td>
<td>5041</td>
<td>1094</td>
<td>1</td>
</tr>
<tr>
<td>222</td>
<td>HUGHES</td>
<td>517</td>
<td>1058</td>
<td>694</td>
<td>76.75</td>
<td>9.04</td>
<td>12.00</td>
<td>86.39</td>
<td>4398</td>
<td>1010</td>
<td>4</td>
</tr>
<tr>
<td>222</td>
<td>HUGHES</td>
<td>517</td>
<td>1103</td>
<td>737</td>
<td>82.25</td>
<td>8.96</td>
<td>10.89</td>
<td>81.05</td>
<td>3542</td>
<td>1003</td>
<td>4</td>
</tr>
<tr>
<td>159</td>
<td>VAREL</td>
<td>517</td>
<td>1368</td>
<td>132</td>
<td>59.25</td>
<td>2.23</td>
<td>10.00</td>
<td>93.57</td>
<td>6198</td>
<td>1183</td>
<td>3</td>
</tr>
<tr>
<td>159</td>
<td>REED</td>
<td>437</td>
<td>1404</td>
<td>36</td>
<td>22.75</td>
<td>1.58</td>
<td>10.00</td>
<td>103.75</td>
<td>6075</td>
<td>1187</td>
<td>2</td>
</tr>
<tr>
<td>222</td>
<td>HUGHES</td>
<td>517</td>
<td>1180</td>
<td>484</td>
<td>64.25</td>
<td>7.53</td>
<td>10.67</td>
<td>80.00</td>
<td>3722</td>
<td>1008</td>
<td>4</td>
</tr>
<tr>
<td>200</td>
<td>SECURITY</td>
<td>537</td>
<td>2610</td>
<td>78</td>
<td>35.5</td>
<td>2.20</td>
<td>16.00</td>
<td>65.83</td>
<td>6448</td>
<td>1141</td>
<td>2</td>
</tr>
<tr>
<td>200</td>
<td>D.B.S.</td>
<td>537</td>
<td>2221</td>
<td>271</td>
<td>77</td>
<td>3.52</td>
<td>17.29</td>
<td>67.14</td>
<td>5532</td>
<td>1038</td>
<td>3</td>
</tr>
<tr>
<td>200</td>
<td>HUGHES/C</td>
<td>537</td>
<td>2345</td>
<td>59</td>
<td>16</td>
<td>3.69</td>
<td>14.33</td>
<td>75.00</td>
<td>7013</td>
<td>1065</td>
<td>1</td>
</tr>
<tr>
<td>222</td>
<td>REED</td>
<td>527</td>
<td>2081</td>
<td>163</td>
<td>23.5</td>
<td>6.94</td>
<td>13.13</td>
<td>61.88</td>
<td>5619</td>
<td>992</td>
<td>2</td>
</tr>
<tr>
<td>155.6</td>
<td>REED</td>
<td>537</td>
<td>3162</td>
<td>206</td>
<td>64.5</td>
<td>3.19</td>
<td>7.43</td>
<td>60.57</td>
<td>8575</td>
<td>1023</td>
<td>3</td>
</tr>
<tr>
<td>200</td>
<td>H.C.</td>
<td>517</td>
<td>1597</td>
<td>1099</td>
<td>80</td>
<td>13.74</td>
<td>14.67</td>
<td>99.17</td>
<td>4329</td>
<td>1054</td>
<td>4</td>
</tr>
<tr>
<td>349</td>
<td>RUSSIAN</td>
<td>117</td>
<td>129</td>
<td>129</td>
<td>4.25</td>
<td>30.35</td>
<td>4</td>
<td>142.67</td>
<td>4333</td>
<td>1211</td>
<td>1</td>
</tr>
<tr>
<td>311</td>
<td>SMITH</td>
<td>616</td>
<td>84</td>
<td>27.25</td>
<td>3.08</td>
<td>5.5</td>
<td>175</td>
<td>6437</td>
<td>1185</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>311</td>
<td>J &amp; L</td>
<td>158</td>
<td>158</td>
<td>19.00</td>
<td>8.32</td>
<td>6.5</td>
<td>137.5</td>
<td>6000</td>
<td>1048</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>311</td>
<td>J &amp; L</td>
<td>620</td>
<td>295</td>
<td>27.25</td>
<td>10.83</td>
<td>10.75</td>
<td>171.7</td>
<td>14799</td>
<td>1096</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>222</td>
<td>SMITH</td>
<td>517</td>
<td>1890</td>
<td>40</td>
<td>10.00</td>
<td>4.00</td>
<td>17.75</td>
<td>87.5</td>
<td>15810</td>
<td>995</td>
<td>1</td>
</tr>
<tr>
<td>251</td>
<td>KINGDREA</td>
<td>117</td>
<td>617</td>
<td>248</td>
<td>51.75</td>
<td>4.79</td>
<td>6.35</td>
<td>181.5</td>
<td>9865</td>
<td>1100</td>
<td>6</td>
</tr>
<tr>
<td>311</td>
<td>KINGDREA</td>
<td>169</td>
<td>151</td>
<td>15.00</td>
<td>10.07</td>
<td>6</td>
<td>130</td>
<td>6252</td>
<td>1042</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

# Table 2 Coefficients in the models

<table>
<thead>
<tr>
<th>Assign b (Author’s Model)</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>R²2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00073151</td>
<td>-0.20000</td>
<td>1.00000</td>
<td>0.15000</td>
<td>1.1158</td>
<td>0.76309</td>
</tr>
<tr>
<td>Assign a, b, c and d (Kelly model)</td>
<td>0.00017894</td>
<td>1.00000</td>
<td>0.50000</td>
<td>1.00000</td>
<td>0.57886</td>
</tr>
<tr>
<td>Assign a, b, c and d (Doiron model)</td>
<td>4.91411E-5</td>
<td>1.00000</td>
<td>1.00000</td>
<td>1.00000</td>
<td>0.18570</td>
</tr>
</tbody>
</table>

# Table 3 Comparison of the field data to the estimated from the wear model

<table>
<thead>
<tr>
<th>Size(mm)</th>
<th>Make</th>
<th>IADC</th>
<th>Depth (out)(m)</th>
<th>Distance drilled(m)</th>
<th>Hours</th>
<th>Weight(klb)</th>
<th>RPM</th>
<th>Bearing Dull</th>
<th>Estimation</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>251</td>
<td>KINGDREA</td>
<td>117</td>
<td>617</td>
<td>248</td>
<td>51.75</td>
<td>6.35</td>
<td>181.5</td>
<td>6</td>
<td>5.01</td>
<td>16.50%</td>
</tr>
<tr>
<td>159</td>
<td>REED</td>
<td>437</td>
<td>1404</td>
<td>36</td>
<td>22.75</td>
<td>10.00</td>
<td>103.75</td>
<td>2</td>
<td>1.85</td>
<td>7.50%</td>
</tr>
<tr>
<td>222</td>
<td>HUGHES</td>
<td>517</td>
<td>1058</td>
<td>694</td>
<td>76.75</td>
<td>12.00</td>
<td>86.39</td>
<td>4</td>
<td>3.61</td>
<td>9.75%</td>
</tr>
<tr>
<td>222</td>
<td>HUGHES</td>
<td>517</td>
<td>1103</td>
<td>737</td>
<td>82.25</td>
<td>10.89</td>
<td>81.05</td>
<td>4</td>
<td>3.92</td>
<td>2.00%</td>
</tr>
<tr>
<td>222</td>
<td>HUGHES</td>
<td>517</td>
<td>1180</td>
<td>484</td>
<td>64.25</td>
<td>10.67</td>
<td>80.00</td>
<td>4</td>
<td>3.00</td>
<td>25.00%</td>
</tr>
</tbody>
</table>
Table 4 Comparison of the field data to the estimated from the wear models

<table>
<thead>
<tr>
<th>Size(mm)</th>
<th>Depth out(m)</th>
<th>Hours</th>
<th>Weight(klb)</th>
<th>RPM</th>
<th>Bearing Dull</th>
<th>Author's Model</th>
<th>Kelly's Model</th>
<th>Doiron's Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>222</td>
<td>158</td>
<td>27</td>
<td>5.33</td>
<td>114.17</td>
<td>3</td>
<td>1.71858</td>
<td>1.26</td>
<td>0.81</td>
</tr>
<tr>
<td>222</td>
<td>240</td>
<td>72</td>
<td>9.90</td>
<td>79.00</td>
<td>5</td>
<td>3.315363</td>
<td>3.21</td>
<td>2.78</td>
</tr>
<tr>
<td>159</td>
<td>329</td>
<td>102.25</td>
<td>9.93</td>
<td>90.00</td>
<td>5</td>
<td>5.803864</td>
<td>5.19</td>
<td>4.49</td>
</tr>
<tr>
<td>311</td>
<td>428</td>
<td>31.25</td>
<td>11.00</td>
<td>161.25</td>
<td>3</td>
<td>3.019152</td>
<td>2.99</td>
<td>2.72</td>
</tr>
<tr>
<td>222</td>
<td>944</td>
<td>74.25</td>
<td>15.17</td>
<td>89.44</td>
<td>3</td>
<td>4.171956</td>
<td>4.63</td>
<td>4.95</td>
</tr>
<tr>
<td>311</td>
<td>324</td>
<td>42.25</td>
<td>10.00</td>
<td>179.00</td>
<td>3</td>
<td>4.521251</td>
<td>4.28</td>
<td>3.72</td>
</tr>
<tr>
<td>200</td>
<td>455</td>
<td>87.25</td>
<td>14.56</td>
<td>82.22</td>
<td>3</td>
<td>4.5291</td>
<td>4.90</td>
<td>5.13</td>
</tr>
<tr>
<td>200</td>
<td>182</td>
<td>49.5</td>
<td>12.88</td>
<td>89.38</td>
<td>3</td>
<td>2.769028</td>
<td>2.84</td>
<td>2.80</td>
</tr>
<tr>
<td>311</td>
<td>153</td>
<td>15.25</td>
<td>5.3</td>
<td>150</td>
<td>2</td>
<td>1.219155</td>
<td>0.95</td>
<td>0.60</td>
</tr>
<tr>
<td>222</td>
<td>387</td>
<td>12.00</td>
<td>5.5</td>
<td>142</td>
<td>1</td>
<td>0.969924</td>
<td>0.72</td>
<td>0.46</td>
</tr>
</tbody>
</table>

Table 5 Comparison of relative error of the wear models

<table>
<thead>
<tr>
<th>Relative Error</th>
<th>Author's Model</th>
<th>Kelly's Model</th>
<th>Doiron's Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Group</td>
<td>12.11%</td>
<td>18.89%</td>
<td>25.71%</td>
</tr>
<tr>
<td>Second Group</td>
<td>28.36%</td>
<td>34.37%</td>
<td>42.73%</td>
</tr>
</tbody>
</table>

Table 6 Bearing Failure Statistic Results of Different IADC Roller Cone Bits

<table>
<thead>
<tr>
<th>IADC</th>
<th>Total Number</th>
<th>Effective Seal</th>
<th>Failure Seal</th>
<th>0-8</th>
<th>Failure Percentage</th>
<th>Average Hours</th>
<th>h</th>
</tr>
</thead>
<tbody>
<tr>
<td>114-227</td>
<td>21</td>
<td>8</td>
<td>1</td>
<td>12</td>
<td>11.11%</td>
<td>24.00</td>
<td>0.00462963</td>
</tr>
<tr>
<td>417</td>
<td>9</td>
<td>5</td>
<td>0</td>
<td>4</td>
<td>0.00%</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>427</td>
<td>8</td>
<td>2</td>
<td>0</td>
<td>6</td>
<td>0.00%</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>437</td>
<td>46</td>
<td>22</td>
<td>5</td>
<td>19</td>
<td>18.52%</td>
<td>50.40</td>
<td>0.003674309</td>
</tr>
<tr>
<td>447</td>
<td>51</td>
<td>31</td>
<td>1</td>
<td>19</td>
<td>3.13%</td>
<td>43.00</td>
<td>0.000726744</td>
</tr>
<tr>
<td>517</td>
<td>129</td>
<td>54</td>
<td>15</td>
<td>60</td>
<td>21.74%</td>
<td>56.71</td>
<td>0.003833386</td>
</tr>
<tr>
<td>527</td>
<td>57</td>
<td>32</td>
<td>10</td>
<td>15</td>
<td>23.81%</td>
<td>45.63</td>
<td>0.005217954</td>
</tr>
<tr>
<td>537</td>
<td>89</td>
<td>41</td>
<td>13</td>
<td>35</td>
<td>24.07%</td>
<td>44.00</td>
<td>0.00547138</td>
</tr>
<tr>
<td>547</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0.00%</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>547</td>
<td>16</td>
<td>8</td>
<td>3</td>
<td>5</td>
<td>27.27%</td>
<td>54.00</td>
<td>0.005050505</td>
</tr>
<tr>
<td>617</td>
<td>57</td>
<td>34</td>
<td>4</td>
<td>19</td>
<td>10.53%</td>
<td>42.88</td>
<td>0.002454831</td>
</tr>
<tr>
<td>627</td>
<td>12</td>
<td>7</td>
<td>1</td>
<td>4</td>
<td>12.50%</td>
<td>68.75</td>
<td>0.001818182</td>
</tr>
<tr>
<td>637</td>
<td>4</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>0.00%</td>
<td>0.00</td>
<td></td>
</tr>
</tbody>
</table>
Figure 1. Regression analysis results

A: Instantaneous wear  
B: Cumulative wear

Figure 2 Wear estimation of Hughes 517 bit

A: Instantaneous wear  
B: Cumulative wear

Figure 3 Wear estimation of Reed 437 bit
A: Instantaneous wear  
B: Cumulative wear

**Figure 4** Wear estimation of Reed 117 bit

A: Instantaneous wear  
B: Cumulative wear

**Figure 5** Wear estimation of Reed 537 bit

A: Instantaneous wear  
B: Accumulative wear

**Figure 6** Wear estimation of Reed 617 bit
Figure 7 Comparison of field data to values from bearing wear models (First Group Data)

Figure 8. Comparison of field data to values from bearing wear models (Second Group Data)

Figure 9 Left hours prediction of used roller cone bits