THE GRAPH-ANALYTIC METHOD OF OPTIMUM PUMPAGE CHOICE
BY CRITERION "MECHANICAL DRILLING SPEED"

PhD. Eng. Igor CHUDYK, Assoc. Professor
PhD. Eng. Volodymyr ARTYM, Assoc. Professor
PhD. Eng. Roman KARPYK, Assoc. Professor
PhD. Eng. Ruslan Rachkevych, Assoc. Professor

at Ivano-Frankivsk National Technical University of Oil and Gas, Ukraine

Abstract: The paper is dedicated to graph-analytic method of application allows without applying composite calculations to spend choice of optimum pumpage during sinking of borehole (immediately on the object), allowing simultaneously great many of the factors: gravities of rock and drill fluid; plastic viscosity and dynamic stress of shear drilling fluid; well bore and floor space of a stope back with cavernosity allowance; drill-pipes exterior diameter; drilling fluid minimum return velocity and subsidence of a mud in him; mechanical drilling speed.

Key words: well drilling, drilling fluid, borehole bottom, mechanical drilling speed, pumpage

1 Introduction

The qualitative and opportune clearing of mine working from drilled rock with the help of drilling fluid (DF) is one of pacing factors for mechanical speed ($V_m$) magnification at well drilling. The mud is taken out poorly, repeatedly milled and predetermines driving decrease at its poor feeding on a. On the other hand, there were following negative consequences at exuberant expenditures during drilling mud flushing [1, 2, 4]:

1 Mud aggregation on a borehole bottom and his repetitive crunching at the symmetrical schema of flushing channels allocation in a rotary drill bit.

2 Turbulence and flow swirling DF in annular space (AS) and mud units formation.

3 The growth of DF hydraulic losses and differential stress on a borehole bottom, that precludes with disclosure of fractures and magnification $V_m$.

4 Developing of keyseats and cavernosity magnification.
5 Reinforced wear of fluid ends of mud pumps, inserted journals, screwed joints of drill-pipes (DP), bearings of drill bit and their flushing channels.

6 Magnification of absorptions occludings.

7 Overexpenditures of energy and fuels and lubricants oils etc.

Usage of the hydraulic program at large specific consumptions $DF$, for each concrete case, should originate at minimum material and power expenditures, in view of advantages and disadvantages of a well flushing. On existing of studies in the given direction it is known, that thus is spent more as 70 % of energy indispensable for a building of a well [4]. It is ground known analytical and experimental researches [1, 4] is installed, that with existing constructions of drill bit, the mud pumps and DP cannot essentially be augmented $V_m$ at the expense of the overexpenditure of hydraulic horsepower. The program of flushing, which one is built up in the projects and will be realised in practice, envisons specific consumptions $DF$ in limits 0,005-0,09 litre per second [1, 2 etc.]. Thus, allowing incontrolled quantity of pumpage, their feeding for a spacing of boring by one a dia of a drill bit should be maintained permanently. Allowing that the drill bit entities already have on the balance of installation with the adjustable electrical actuation of pompes, becomes economically and technological illogical to maintain washover of a well with their constant feedings at $V_m$ as at 0,5 m an hour, and 10 m per hour. Therefore the development of policy of boring with optimum expenditures $DF$, depending on $V_m$, is an indispensable condition for diesel oil saving and electrical power with simultaneous decrease to abtragung and rises of a motor-operational life of oil and gas machinery.

For supply of effective flushing of a well during its boring there is a number of conditions of choice of optimum expenditure $DF$ [1]:

1. Clearing of a bottom hole from выбуренной of formation.
2. Supply of indispensable return velocity $DF$ in $AF$.
3. Supply of a maximum allowable concentration of a mud $C$ in $DF$.
4. At boring incline wells in composite conditions (talus and collapses, balling-up, tight pull, fit etc).
5. Supply of indispensable stress and hydraulic horsepowers on a bottom hole by sprays of a water jet bit and his performance as a whole.
6. Core recovery of a mud from a bottom hole without gripping by their filling fingers of rolling cutters.

2 Discussions
At engineering and choice of optimum expenditure $DF$, the registration $V_m$ is resolved by the writer in the previous operation [3] on the basis of a solution of a set of equations (1):

\[
\begin{align*}
\frac{V_m \cdot S_{BB}}{Q + S_{BB} \cdot V_m} &= \frac{\rho_{AS} - \rho_{DF}}{\rho_R - \rho_{DF}} \\
\frac{4V_m \cdot S_{BB}}{(V_{\min} - V_0) \cdot (4S_{BB} - \pi d_e^2)} &= \frac{\rho_{AS} - \rho_{DF}}{\rho_R - \rho_{DF}} \\
\frac{4Q}{4S_{BB} - \pi d_e^2} - V_0 &= \left[0.015(D_e - d_e) \left(\frac{4Q}{4S_{BB} - \pi d_e^2}\right)^2 \rho_{AS}\right] - 0.15 \\
&= \left[(D_e - d_e) \tau_0 + 6\eta \left(\frac{4Q}{4S_{BB} - \pi d_e^2} - V_0\right)\right] - 0.15
\end{align*}
\]

(1)

where $\rho_R, \rho_{AS}, \rho_{DF}$ - gravity of rock $R$, $DF$ in $AS$ and in $DP$;

$\eta, \tau_0$ - plastic viscosity and dynamic stress of shear $DF$;

$D_w, S_{BB}$ - well bore and floor space of a borehole bottom with cavernosity allowance;

$d_e$ - exterior diameter $DP$;

$Q$ - pumpage;

$V_{\min}, V_0$ - minimum return velocity $DF$ in $AS$ and subsidence of a slime in him;

$V_m$ - mechanical drilling speed.

The practical implementation of a set of equations (1) in the hand-held mode is enough composite tasks. The operating solution is possible with the help of a computer, but at well drilling it is problematic enough. Reasonable for usage during support of drilling activities there are graph-analytic method of applications, which one are designed behind calculated models. They allow operatively, on the basis of a definite volume of input datas without conducting calculuss, to receive indispensable result short enough. Therefore for industrial conditions of choice of optimum expenditure $DF$ indispensable the graph-analytic method of application with a following succession is.

1. For definition of conventional diameters of fragments of a mud $R$, which one were derivated as a result of breaking down of a stope back by a cone rock bit, the dependence (2) will be used [4], according to which one the table 1 is constructed:

\[
d_e = 0.56 \cdot \sqrt{l \cdot (t - b)}
\]

(2)
where \( t, l, b \) - maximum ratings of a pitch between cutter teeths, their altitude and width.

Table 1

Sizes of arms of roller cones and fragments of a mud derivated them teeths

<table>
<thead>
<tr>
<th>The type of a bit</th>
<th>The bit diameter, mm from</th>
<th>( l ), mm main</th>
<th>( l ), mm heel teeth</th>
<th>( t ), mm main</th>
<th>( t ), mm heel teeth</th>
<th>( b ), mm from</th>
<th>( d_e ), mm from</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>158,7 200</td>
<td>9</td>
<td>24</td>
<td>20</td>
<td>42</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>212,7 250,8</td>
<td>11</td>
<td>25</td>
<td>32</td>
<td>60</td>
<td>11</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>269,9 349,2</td>
<td>14</td>
<td>26</td>
<td>40</td>
<td>70</td>
<td>12</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>374,6 790</td>
<td>16</td>
<td>28</td>
<td>45</td>
<td>80</td>
<td>16</td>
<td>19</td>
</tr>
<tr>
<td>MC</td>
<td>158,7 200</td>
<td>8</td>
<td>23</td>
<td>23</td>
<td>36</td>
<td>8</td>
<td>11</td>
</tr>
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<td>212,7 250,8</td>
<td>10</td>
<td>24</td>
<td>28</td>
<td>45</td>
<td>9</td>
<td>12</td>
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<td></td>
<td>269,9 349,2</td>
<td>13</td>
<td>25</td>
<td>34</td>
<td>50</td>
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<td>13</td>
</tr>
<tr>
<td>C</td>
<td>76 120,6</td>
<td>4</td>
<td>13</td>
<td>9</td>
<td>17</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>132 151</td>
<td>5</td>
<td>17</td>
<td>12</td>
<td>20</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>158,7 200</td>
<td>7</td>
<td>22</td>
<td>15</td>
<td>26</td>
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<td>8</td>
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<td></td>
<td>212,7 250,8</td>
<td>9</td>
<td>21</td>
<td>19</td>
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<td>22</td>
<td>36</td>
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<td>11</td>
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<td></td>
<td>374,6 490</td>
<td>14</td>
<td>30</td>
<td>27</td>
<td>40</td>
<td>11</td>
<td>13</td>
</tr>
<tr>
<td>CT</td>
<td>158,7 200</td>
<td>6</td>
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<td></td>
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<td>9,5</td>
<td>23</td>
<td>21</td>
<td>30</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>T</td>
<td>76 120,6</td>
<td>3,5</td>
<td>11</td>
<td>7</td>
<td>13</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>132 151</td>
<td>4</td>
<td>15</td>
<td>9</td>
<td>16</td>
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<td>6</td>
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<td></td>
<td>158,7 200</td>
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<td></td>
<td>212,7 250,8</td>
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<td>11</td>
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<td>374,6 490</td>
<td>11</td>
<td>25</td>
<td>22</td>
<td>30</td>
<td>11</td>
<td>14</td>
</tr>
</tbody>
</table>

2. For definition of magnitude of rate of sedimentation of a fragment \( R \) for \( DF \) the empirical-formula dependence will be used [4]:

\[
V_0 = 3 \cdot \sqrt{d_f \cdot \frac{\rho_R}{\rho_{DF}} - 1}.
\]  

On these datas (tab. 1) and dependence (3) it is possible to receive plot dependence (fig. 1) for miscellaneous \( \rho_{DF}, \rho_R \).

3. The solution of the system (1) institutes unknowns \( Q, V_{min}, \rho_{AS} \) the tables for choice of optimum feeding \( DF \) also are reshaped, depending on \( V_m \) (tab. 2). For clearness of
comprehension of the graph-analytic method of application we shall reduce an example of choice of optimum expenditure $DF$.

**INPUT DATAS:** $V_m = 10$ m/h; $C = 0.03$; $d_e = 114.3$ mm; $D_W = 190.5$ mm, $\rho_R = 2750$ kg/m$^3$; $\rho_{DF} = 1350$ kg/m$^3$; cavernosity coefficient $K = 1.16$; categories of $R$ hardness - "T".

1. Behind tab. 1, 190.5 mm agree with a category of hardness $R$ "T" and dia of a bit $D = 190.5$ mm, the size of $R$ fragments will be from $(3.3 - 8.3)$ mm 8 mm Are received because large on sizes the fragment of a mud requires accordingly a high speed of move $DF$ in $AS$.

2. According to plot dependence (fig. 1) at $\rho_R = 2750$ kg/m$^3$ and $dr = 8$ mm, we select $V_o = 0.27$ m/s.

3. According to plot dependence (fig. 2), for $D = 190.5$ mm and $K = 1.16$ are instituted $S_{BB}$. 

![Fig. 1 Plot dependence of an alteration of speed of precipitation in DF of R fragments from their sizes](image-url)
Fig. 2 Plot dependences of variation of the floor space of a borehole bottom on bit diameter and cavernosity coefficient

4. According to Tab. 2, for $V_m$ and obtained datas $V_o$ and $S_{BB}$ agrees, the optimum expenditure $DF$ is selected. At $V_o = 0.27 \text{ m/s}$, $S_{BB} = 0.033 \text{ m}^2$ and $V_m = 10 \text{ m/h}$ the optimum pump capacity will be in ranges between (5.7 - 8.1) l/s and (8.6 - 12.5) l/s.

The court order $Q$ at $V_{01} = 0.15 \text{ m/s}$ and $S_{BB} = 0.033 \text{ m}^2$ is spent:

$$Q_1 = \frac{V_2 \cdot (S_{BB} - s_1) - V_1 \cdot (S_{BB} - s_2)}{s_2 - s_1} = \frac{8.1 \cdot (0.033 - 0.03) - 5.7 \cdot (0.033 - 0.04)}{0.04 - 0.03} = 6.42 \text{l/s}.$$ 

Calculation $Q$ at $V_{02} = 0.3 \text{ m/s}$ and $S_{BB} = 0.033 \text{ m}^2$.

$$Q_2 = \frac{V_2 \cdot (S_{BB} - s_1) - V_1 \cdot (S_{BB} - s_2)}{s_2 - s_1} = \frac{12.5 \cdot (0.033 - 0.03) - 8.6 \cdot (0.033 - 0.04)}{0.04 - 0.03} = 9.77 \text{l/s}.$$ 

Table 2

<table>
<thead>
<tr>
<th>$V_o$, m/s</th>
<th>0,15</th>
<th>(0,27)</th>
<th>0,3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_m$, m/h</td>
<td>0,02</td>
<td>0,03 (s_1)</td>
<td>0,04 (s_2)</td>
</tr>
<tr>
<td>$S_{BB}$, m$^2$</td>
<td>5</td>
<td>2</td>
<td>0,03 (s_1)</td>
</tr>
<tr>
<td>$Q_1$</td>
<td>$Q_2$</td>
<td>$Q_1$</td>
<td>$Q_2$</td>
</tr>
<tr>
<td>8</td>
<td>2,9</td>
<td>5,1</td>
<td>7,3</td>
</tr>
<tr>
<td>10</td>
<td>3,3</td>
<td>5,7 (v_1)</td>
<td>8,1 (v_2)</td>
</tr>
<tr>
<td>12</td>
<td>3,6</td>
<td>6,2</td>
<td>8,8</td>
</tr>
</tbody>
</table>
From the held calculations is obtained: $Q_1 = 6.42 \text{ l/s at } V_{01} = 0.15 \text{ m/s}$ and $Q_2 = 9.77 \text{ l/s at } V_{02} = 0.3 \text{ m/s}$. For $V_0 = 0.27 \text{ m/s}$ is instituted $Q$:

$$Q = \frac{Q_2 \cdot (V_0 - V_{01}) - Q_1 \cdot (V_0 - V_{02})}{V_{02} - V_{01}} = \frac{9.77 \cdot (0.27 - 0.15) - 6.42 \cdot (0.27 - 0.3)}{0.3 - 0.15} = 9.1 \text{ l/s}$$

As a result of engineering expenditure $DF$ is installed, that in input datas will respond $Q = 9.1 \text{ l/s}$. If to take into account a coefficient of admission 0.75 - 0.8 [1, 4] and loss up to 25% in screwed joints of a drill column [5], the values of optimum pump capacity are necessary for augmenting for 50% ($Q = 15 \text{ l/s}$). If to spend choice $Q$ agrees of the guidelines [1, 2, 4 etc.], we shall receive for input datas magnitude 23 l/s, that testifies to the considerable overexpenditure of energy concerning implementation of the hydraulic program of flushing of a well.

The off-line power drive of mud pumps can be diesel, diesel electric, turbine, according to the theory and practice of boring. It is known, that its variety is selected, quitting c:

1. Drilling method. 2. Geological conditions of boring. 3. Availability of fuels and lubricants oils, their cost. 4. Assembly and dismantling performances of driving.
5. Proficiencies of the servicers etc. [6].

As of today economic efficiency of usage of power drives in a structure of drill units institute ground of datas concerning exploitation or expertise of industrial trials close behind the performances. For an effectiveness criterion the robots of internal combustion engines take expenditures of propellant.

For a mud pump БРН-1 as an driving the diesel motor $B2 - 450$ with performance curves (fig. 3) will be used. At revolutions of a crankshaft with frequency $n = 1300 \text{ rpm}$ propellant consumption $G$ compounds 72 kg/h. Thus the pump capacity compounds 34.8 l/s and stress - 9.8 MPa with a coefficient of admission $\alpha = 0.86$. For the given type of drive of decrease of pump capacity it is possible at the expense of shift of bushes and cylinder pistons, or decrease of an amount of double strokes (rotating speed of a crankshaft of an actuating motor). Therefore, if necessary decreases of pump capacity up to 25 l/s the shaft speed of an actuator will vary and will compound:

$$n_s = Q_\nu \cdot \frac{n_\nu}{Q_\nu} = 25 \cdot \frac{1300}{34.8} = 933 \text{ rpm.}$$

Fig. 3 Schema of performance curves of a diesel motor:
1 - B2-300; 2 - B2-400; 3 – B2 - 450
According to a fig. 3, at such revolutions the propellant consumption $G$ will compound 60 kg/h, that on 20 % it is less, than at the previous mode of flushing of a well. It at boring by one chisel of a well during 30 - 40 h will stipulate saving diesel fuel 350 - 500 l, that in a money's worth compounds $350 - $500.

3. Conclusions

1. The designed graph-analytic method of application allows without applying composite calculations to spend choice of optimum pumpage during sinking of borehole (immediately on the object), allowing simultaneously great many of the factors: gravities of rock and drill fluid; plastic viscosity and dynamic stress of shear drilling fluid; well bore and floor space of a stope back with cavemosity allowance; drill-pipes exterior diameter; drilling fluid minimum return velocity and subsidence of a mud in him; mechanical drilling speed.

2. On the basis of a practical example is installed not only technological performance of the given method of application, but also the saving of energy of diesel fuel is obtained. It confirms necessity of usage of the given method of application at well boring by domestic gas and oil producing firms of Ukraine with the purpose of saving energy consumptions and facilitiess as a whole on the projects of digging.

4 Bibliography

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