Sari

Kata Kunci : pemboran Radial, pemindahan cutting, kandungan solid dalam cutting, ROP (rate of penetration) optimum.

Abstract
Oilfield maturity and oil production declining worldwide becomes the main reason that makes many companies have been trying to improve the recovery factor of the reservoir reserves with many methods in term of drilling, production and reservoir engineering. Dealing with that condition, radial drilling technology seems as an alternative, because with applying radial drilling technique we can improve the drainage efficiency from the known layer. It means that radial drilling technique become as a promising method to be applied in many mature oilfields worldwide. Radial drilling technique has been tested, developed, and applied in more than 500 wells and has already reach more than 27000 feet (8230 m) hole length. Radial drilling was applied to increase wellbore drainage radius which can increase hydrocarbon production from 200% until 400%. This paper shows the cutting transport calculation process for several value of jet flow. The study of this paper is based on radial drilling case in Golfo San Jorge Basin (Argentina), with those field data we can calculate the optimum ROP using solid content sensitivity analysis for each jet flow value and as the result of this paper is the relationship between the value of ROP, solid content, and jet flow value. The results of this paper study can be applied in other oilfields as long as the oilfield’s drilling tool configuration is same with the configuration of Golfo San Jorge Basin drilling tools which used in this paper calculation. But the cutting transport calculation procedure in this paper can be applied in any oilfields.

Keyword: radial drilling, cutting transport, solid content, optimum ROP (rate of penetration)

I. INTRODUCTION
Radial drilling also called Water Jet Drilling, Ultra-short Radius Radial Drilling, and Horizontal Radial System which is process consists making small horizontal perforations by using water jets at high pressure (jetting). The diameter of these lateral horizontal perforations is of approximately 2 inches (5,08 cm) and up to 330 ft (100 m) of extension each, at the same production level. Each one has a bending radius as small as 1 ft (30 cm) and is made in two steps : first, the casing is perforated with a 0.75 inch mill (19,05 mm), and then the horizontal extension is made with high-pressure fluid jetting. (Figs. 1 and 2).

The main factor that affects radial drilling successfullness is the cutting transport process while radial drilling is made, because when the cutting transport process doesn’t work
appropriately, it can cause pore plugging in the borehole.

Based on that fact, a cutting transport calculation has to be made on this radial drilling operation to determine the optimum ROP from solid content sensitivity analysis for each jet flow value. At the end of this paper, there will be some conclusion due to this radial drilling cutting transport calculation.

II. BASIC THEORY

Radial drilling operation was applied in order to increase the drainage radius and increase hydrocarbon production as the result. In many references, radial drilling technique can increase hydrocarbon production from 200% until 400%.

In designing and calculating radial drilling operation parameters, such as lateral radial length, number of radial, direction of radial, pressure loss in bit (nozzle), cutting velocity and many else, it’s very depend on reservoir properties itself, such as reservoir thickness, reservoir pressure, horizontal and vertical permeability, gravity drainage, etc. This application combines the following important factors (Ref. 1):
1. Low cost, it’s applied to existing wells (new wells are not required).
2. Low geological uncertainty
3. Low environmental risk.

Among various reasons for this technique to increase production, the following could be highlighted (Ref. 3):
1. Improves the conductivity of an important area around the well (improving drainage efficiency).
2. Possibility to define direction of the perforations.
3. Helps the mobilization of viscous oils.
4. Connect to areas of better petrophysical conditions.
5. Allows intervention of oil reservoirs limited by close by aquifers

Radial drilling cutting transport calculation can be done by optimizing parameters, such as ROP, jet flow, and cutting velocity transport which could be designed and calculated by using this following equation:

\[ m_{\text{cutting generation}} + m_{\text{injection fluid}} = m_{\text{total}} \]  

(1)

Equation (1) can be rearrange to become:

\[ A_{\text{lateral hole}} \times ROP \times \rho_f \times \text{Jet Flow} = m_{\text{total}} \]  

(2)

To calculate the percentage of solid we can derive an equation from equation (1):

\[ \% \text{Solid} = \frac{m_{\text{cutting generation}}}{m_{\text{total}}} \times 100\% \]  

(3)

We can also calculate the exit velocity of the cutting from hole inside casing using the equation derived from equation (1), but firstly we have to calculate the mixture density between cutting and water (injection fluid):

\[ \rho_{\text{mixture}} = \frac{(\rho_c \times (100 - \% \text{solid})) + \rho_{\text{cutting}} \times \% \text{solid}}{100} \]  

(4)

\[ v_{\text{exit}} = \frac{q_{\text{exit}}}{A_{\text{annulus pipe}} - \text{borehole}} \]  

(5)

\[ v_{\text{exit}} = \frac{m_{\text{total}}}{\rho_{\text{mix}} \times A_{\text{annulus pipe}} - \text{borehole}} \]  

(6)

2.1 Description of Radial Drilling Equipment (Ref. 1)

It basically has a coiled tubing special unit and fittings.

1-unit:
Similar equipment to coiled tubing with the following characteristics:
1. ½ inch pipe, up to 13500 ft long and 10000 psi working pressure
2. Monitoring and command cab
3. Source of hydraulic power
4. Triplex pump (2-5 gpm) of flow rate and high pressure (10000 psi)
5. Injection head with hydraulic drive (pull = 10000 lbs) optional, only for units operating at more than 6500 ft

2-fittings:
1. Anchor: lowered with the work string of the workover unit and has three functions:
   1. Maintain the tool outlet hole on the side of casing; the positioning is just with simple pressure generated by a band located on the opposite side
   2. Guide the tool to go from vertical to horizontal in 1 ft through a forged duct in the interior
   3. Prevent reactive torque of the downhole motor while the casing is perforated, through longitudinal guides where a groove is located on the body of the motor

2-2 BHA for the perforation of the casing (Fig. 2), formed by the following elements:
1. ¾ inch mill (1.905 cm)
2. Elbow or articulated joint
3. Nipple with lock
4. 1 11/16 inch downhole motor (4.29 cm)

2-3 Drilling BHA (Figs 3 and 4)
1. Jet with three bores oriented forward and three towards back
2. 328 ft Kevlar flexible hose of ½ inch (1.27 cm)

2.2 Description of The Radial Drilling Execution Process (Ref. 1)
First, a workover rig is set up and the well is conditioned consisting in:
1. Take out the production string
2. Calibrate to the bottom of the well or at least below the layer where the perforations will be made
3. Ensure there are no leaks in the casing
4. Test the layer to determine the flow rate and type of fluid, in order to evaluate the improvement

Then lower the work string with the baffle anchor to the desired depth, the depth is verified with wireline records. After that, the radial drilling rig is mounted, the BHA is assembled for the casing perforation and the first run is made for the casing milling. Once the milling casing is finished, the cutting tool is pulled out.

The drilling BHA is assembled and the second run is made circulating with an intermediate flow rate. Once the BHA is close to the baffle shoe, the flow rate is increased and the tool is slipped allowing for the introduction into the anchor. Once the hose enter the formation, it will move horizontally in the formation due to the force generated by the distribution of jet nozzles.

It is important to control the driving speed, because if it is too slow, the formation could be washed leaving the backwards jets without enough backup to generate the necessary force to continue advancing, and once the tool is static, starting it again is impossible due to existing friction forces. When the tool gets to the end of the lateral, it is taken out with a high pumping rate to clean the new bore.

When the operation is finished, the coiled tubing is pulled of and the workover string is turned clockwise to place the baffle anchor in the next position to drill and repeat the process explained before.

At the end, the radial drilling rig is dismounted and the test tool is lowered to evaluate the production of perforated area. Then, the final installation is lowered and the workover rig is dismounted. The estimated time for the perforation of the four laterals is 24 hours and the whole operation lasts for five days.

III. Radial Drilling Cutting Transport Calculation Analysis
Based on literature, after radial drilling project is done, the oil production will be increase to 200% until 400%. The success of radial drilling operation is depend on some parameters, such as:
1. Cutting transport, refer to hole cleaning. It is the most important parameter which affect radial drilling technique success, because when small borehole was made inside the casing size with high ROP (rate of penetration) will cause a large amount of cutting which can’t be transport to the surface and as the result will block the reservoir pore and decrease the oil production. So, we have to design an optimum cutting transport process that can elevate cutting up to the surface.
2. Water blocking, due to high injection pressure and high pumping rate (jet flow) will make the injected water block the oil production.
3. Borehole position, correct position of the radial drilling borehole will increase oil production because the perforation is made in the correct layer.
4. Reservoir characteristics refer to well scenario such as well with secondary recovery project, viscous oils, low permeability layer, completed well and many else.

In this paper, the analysis will be all about the cutting transport calculation using solid content sensitivity analysis to determine optimum ROP for each jet flow value due to limited data.

3.1 Cutting Transport Calculation
Cutting transport problem occurred when large amount of cutting was made due to high ROP can’t be elevated to the surface and left inside the borehole and then block the productive layer pore due to high injection pressure. The pore blocking by cutting is temporary because the block will release from the pore slowly due to differential pressure between borehole and reservoir.

Evaluation on this problem can be done with calculate the percentage of solid content which is the percentage of solid content of fluids inside annulus and the exit velocity when fluids exit from the borehole inside casing. This calculation use data from radial drilling
parameter, such as jet flow, ROP, and tools configuration, just like as the following table:

<table>
<thead>
<tr>
<th>Jet flow</th>
<th>2-5 gpm</th>
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</thead>
<tbody>
<tr>
<td>Borehole Diameter</td>
<td>2 inch</td>
</tr>
<tr>
<td>OD Pipe</td>
<td>1 inch</td>
</tr>
<tr>
<td>ID Pipe</td>
<td>0.5 inch</td>
</tr>
</tbody>
</table>

In this calculation we assume that for the optimum cutting transport, the percentage of solid content is no more than 2% that will result the optimum ROP for each jet flow value.

As a calculation example, there is the calculation at 2 gpm jet flow and 2% percentage of solid:

Using equation (3) we can calculate:

\[ 2\% = \frac{m_{\text{cutting generation}}}{m_{\text{total}}} \times 100\% \]

\[ m_{\text{cutting generation}} = 0.002 \ m_{\text{total}} \]

After that, we substitute the relationship above into equation (2):

\[ 0.002 \ m_{\text{total}} + \left( 2 \times 8.33 \right) \left( \frac{lb}{min} \right) = m_{\text{total}} \]

\[ m_{\text{total}} = \left( \frac{100}{99.998} \right) \times 16.66 \left( \frac{ft^3}{min} \right) \]

\[ m_{\text{total}} = 16.67668 \left( \frac{lb}{min} \right) \]

\[ m_{\text{cutting generation}} = 0.002 \]

\[ * 16.67668 \left( \frac{lb}{min} \right) \]

\[ m_{\text{cutting generation}} = 0.0166767 \left( \frac{lb}{min} \right) \]

Finally we can get ROP for 2 gpm Jet Flow using equation (2), we assume \( \rho_{\text{bulk}} = 2.65 \) gr/ml:

\[ ROP = \frac{m_{\text{cutting generation}}}{A_{\text{lateral hole}} \times \rho_{\text{cutting}}} \]

\[ ROP = 0.004625002 \left( \frac{ft}{min} \right) \]

And then we have to calculate the \( \rho_{\text{mix}} \) using equation (4):

\[ \rho_{\text{mix}} = \frac{(62.4 \times (100 - 2)) + (62.4 \times 2.65 \times 2)}{100} \]

\[ \rho_{\text{mix}} = 62.420592 \left( \frac{lb}{ft^3} \right) \]

The exit velocity is calculated using equation (6):

\[ v_{\text{exit}} = \frac{16.67668 \left( \frac{lb}{min} \right)}{(4 \times 144) \left( \frac{ft^3}{min} \right) - 60 \times 62.4010296 \left( \frac{lb}{ft^3} \right)} \]

\[ v_{\text{exit}} = 0.272357 \left( \frac{ft}{s} \right) \]

There is the plot between ROP and solid percentage for 2 gpm jet flow that show sensitivity analysis to get optimum ROP value which is ROP at 2% solid percentage value. Complete plot for 2, 3, 4, and 5 gpm jet flow will be presented in Appendix B.

There is the chart that shows the differences relationship between ROP and solid content percentage for 2-5 gpm jet flow. This chart will be also presented in Appendix B.

From the chart above, we can say that ROP value is increasing when jet flow value is also increasing. At the same value of solid content percentage, the value of ROP will increase for the increasing of jet flow value.

We also can see from the chart above that for the same value of solid content, the differences of ROP value for each jet flow is also increasing caused by the bigger slope for the bigger value of solid content. That statement is
very logic because when we injecting water with high jet flow value then more cutting is occurred in the drilling process. At 2% of solid content which is the upper limit for optimum ROP value, we can see that the difference of ROP value for each jet flow value is more or less 0.05 ft/min.

IV. CONCLUSION

a. Based on literature, radial drilling technique becomes a solution for a mature oilfield and low oil production. With radial drilling technique we can decrease damage radius and increase drainage radius and as a result we can increase production to 200% until 400% from previous one. Radial drilling operation is depend on several parameters such as, cutting transport, water blocking, borehole position, and reservoir characteristics (well scenario). The most important parameter is cutting transport process.

b. The optimum ROP for each jet flow value is at 2% solid percentage which is the upper limit of a good cutting transport.

c. Optimum ROP for 2 gpm jet flow:
   - 0.0942934 ft/min

   Optimum ROP for 3 gpm jet flow:
   - 0.1414401 ft/min

   Optimum ROP for 4 gpm jet flow:
   - 0.188586801 ft/min

   Optimum ROP for 5 gpm jet flow:
   - 0.2357335 ft/min.

d. The value of ROP will increase when jet flow and solid content value are also increasing or we can say in other words that the value of ROP is equivalent with the value of solid content and jet flow.

e. For the same value of solid content, the differences of ROP value is increase when the jet flow value is increase for the bigger value of solid content caused by the slope for each jet flow is increasing.

f. The difference of optimum ROP at 2% solid content for each jet flow value is more or less 0.05 ft/min.

V. NOMENCLATURE

\( m \) = mass flow (lb/min)
\( \rho_{\text{cutting}} \) = cutting density (gr/ml)
\( \rho_{\text{fluid}} \) = fluid density (lb/cuft)
ROP = Rate of Penetration (ft/min)

REFERENCES

Appendix A:

### 2 gpm Jet Flow

<table>
<thead>
<tr>
<th>$m_{cutting\ generation}$ (lb/min)</th>
<th>$m_{injection\ fluid}$ (lb/min)</th>
<th>$m_{total}$ (lb/min)</th>
<th>Solid frac</th>
<th>$v_{exit}$ (ft/s)</th>
<th>ROP (ft/min)</th>
<th>$\rho$ mixture (lb/ft$^3$)</th>
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<td>16.67668</td>
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<th>Solid frac</th>
<th>$v_{exit}$ (ft/s)</th>
<th>ROP (ft/min)</th>
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<th>v exit (ft/s)</th>
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<th>v exit (ft/s)</th>
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Appendix B:

2 gpm Jet Flow

\[ y = 5.105x - 0.004 \]

3 gpm Jet Flow

\[ y = 7.658x - 0.006 \]
Radial Drilling Cutting Transport Calculation Using Solid Content Sensitivity Analysis
to Determine Rate of Penetration (ROP)

4 gpm Jet Flow

\[ y = 10.211x - 0.008 \]
\[ R^2 = 0.9994 \]

5 gpm Jet Flow

\[ y = 12.76x - 0.009 \]
Figure 1: Representative Diagram of Perforated Laterals
Glossary of Fig 2:
Motor de fondo: Downhole motor
Niple con guias: Nipple with guides
Unión articulada: articulated joint
Fresa: mill
Ancla: Anchor

Figure 2: Diagram of Tool to Perforate Casing

Glossary Figure 3:
Manguera de Kevlar : Kevlar Hose
Boquilla: Nozzle

Figure 3: Diagram of Tool for the Formation Drilling
Figure 4: Diagram of the Drilling Nozzle