Inclination and azimuth evaluation point determinations in “YMN” Field “AMR-10” reservoir by using minimum of curvature method

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Abstract. Oil is utilized diversely in the world; starting as cooking material, manufacture fuel, until gas for vehicles. To obtain oil reserve, a drilling from the surface to the reservoir is required. The kind drilling chosen in this research is a directional drilling where the drill bit is aimed several degrees towards targeted formation, which is not vertically located under the reservoir. The planning process of directional drilling includes drilling trajectory planning and BHA composition utilization planning during the process. To determine inclination point and azimuth in AMR-10 drilling trajectory was formed by using radius of curvature method, and compare its result with actual trajectory counted by using minimum of curvature method, by calculation vertical depth, build-up rate, radius, azimuth trajectory, dogleg value, ratio factor, north and east direction, and horizontal movement. Based on the calculation of reservoir trajectory planning of AMR-10 reservoir, the vertical depth value is at 6540.9 ft. and horizontal movement from drilling starting point is 2290.3 ft. with azimuth angle of 202.68°. Based on the calculation and survey data, we can see that an inclination of 1.76° was occurred at 149.2 ft.MD and azimuth angle of 206.6° at similar depth.

1. Introduction
One of the most popular non-renewable energy sources in the world is crude oil. Oil is utilized diversely in the world; starting as cooking material, manufacture fuel, until gas for vehicles. To obtain oil reserve, a drilling from the surface to the reservoir is required. Reservoir itself is a place to accumulate oil and gas from the center of the earth [1,2].

The kind drilling chosen in this research is a directional drilling where the drill bit is aimed several degrees towards targeted formation, which is not vertically located under the reservoir. Planning in directional drilling includes drilling trajectory planning and BHA composition planning that is important to determine drilling angle [3].

To determine drilling angle in AMR-10 reservoir, its inclination and azimuth evaluation point must be acknowledged. To do that, drilling trajectory planning was made by utilizing radius of curvature method, and compares it with the actual drilling trajectory counted with minimum of curvature method, analyzing deviations inside the reservoir such as formation factor, drilling parameter, and BHA adjustment. In one research written by Grace, 2010 and Short, 1993, which provided comparisons of drilling trajectory resulted from several, minimum of curvature method produce the most accurate calculation and produce a nearly identical trajectory with the actual one [4,5].
2. Research methods

Inclination point evaluation tendency and azimuth determinations of AMR-10 reservoir in YMN field was conducted by utilizing minimum of curvature method, with several parameters including depth calculation (MD), inclination and azimuth [6].

The first step required in this process to determine inclination and azimuth evaluation points of AMR-10 reservoir is by calculating vertical depth, build up rate, azimuth direction radius, dogleg severity, ratio factor, north and east directions, and horizontal movement [7]. After all calculations are finished, the next step is to draw directional reservoir profile diagram, which will be compared with the actual reservoir profil [8].

3. Results and discussion

Directional drilling conducted in AMR-10 reservoir is a drilling activity aimed to produce oil from lower root gutter formation layer in 6294 ft. depth. The profile of AMR-10 reservoir is a build and hold type that contains three parts; vertical part, build up part, and tangent part. AMR-10 reservoir is located in coordinate of 9873770.78 degrees north and 328854.71 degrees east. AMR-10 reservoir’s depth target is at 6986.3 ft. with coordinate of 9873131.33 degrees north and 328583.73 degrees east. Drilling process will be conducted vertically until it reaches kick-off point at 500 ft. After passing the kick-off point, drilling is continued with 2°/100 ft. angle on azimuth 202.68°. This build up rate will be maintained until it reaches 22.74°. After reaching the targeted inclination, drilling will be continued with the same angle until it reaches the target.

Table 1. AMR-10 reservoir drilling program data.

| Dog Leg Servility (deg/100 ft.) | 2 |
|-------------------------------|---|
| True Vertical Depth (ft.)     |   |
| Measured Depth (ft.)          |   |
| Kick off Point, Start Build   | 500 | 500 |
| End of Build, Start Hold      | 1636.8 | 1607.2 |
| Tangent End, Total Depth      | 6986 | 6541 |
| Azimuth                       | 202.68° |
| Build up rate                 | 2°/100 ft. |
| Maximum Inclination           | 22.74° |
| Datum System                  | Ground Level |
| Measured Depth References     | Rotary Kelly Bushing |
| Surface Coordinate            | North (m) | East (m) |
| Target Coordinate             | 9873770.78 | 328854.71 |
|                               | 9873131.33 | 328583.73 |

AMR-10 reservoir trajectory calculation planning was conducted by using radius of curvature method. Several parameters required in the calculation, obtained from AMR-10 reservoir drilling program are; kick-off point, build up rate, formation target depth, vertical depth, reservoir surface coordinate, and formation target coordinate [9,10]. The following calculations are the result of trajectory planning by using radius of curvature method:

- Vertical Section Length until KOP
  \[ V_1 = \text{KOP} - 0 \]
  \[ V_1 = 500 - 0 = 500 \text{ ft.} \]

- Radius Length of Build Up Section 1 (R1)
  \[ R_1 = \frac{5730}{(BUR)} \]
  \[ R_1 = \frac{5730}{(2°/100 \text{ ft.})} = 2865 \text{ ft} \]
- **Measurement Depth on Build Up Section 1 (MD)**
  \[ V_1 + \left( \frac{\pi R}{180} \right) \]
  \[ MD = 500 + \left( \frac{\pi \times 2 \times 2865}{180} \right) = 600.01 \text{ ft} \]

- **Vertical Depth on Build Up Section 1 (V2)**
  \[ V_2 = V_1 + \left[ \frac{180 \times \Delta MD \times (\sin I_2 - \sin I_1)}{\pi \times (I_2 - I_1)} \right] \]
  \[ V_2 = 500 + \left[ \frac{180 \times 100.01 \times (\sin 2^\circ - \sin 0^\circ)}{\pi \times (2^\circ - 0^\circ)} \right] = 600.01 \text{ ft} \]

- **Horizontal Movement on Build Up Section (D1)**
  \[ D_1 = R - [R \cos(I)] \]
  \[ D_1 = 2865 - [2865 \cos(2^\circ)] = 1.745 \text{ ft} \]

- **Vertical Depth on Tangent Section (V3)**
  \[ V_3 = V_2 + \left[ \Delta MD \tan \cos(I) \right] \]
  \[ V_3 = 1607.5 + [(1737.1 - 1637.1) \times \cos(22.74)] = 1699.69 \text{ ft} \]

- **Horizontal Movement on Tangent Section 1 (D2)**
  \[ D_2 = D_1 + [\Delta MD \tan \sin(I)] \]
  \[ D_2 = 222.7 + [(1737.1 - 1637.1) \times \sin(22.74)] = 261.36 \text{ ft} \]

After planning the trajectory by using method of curvature, to determine the inclination point and azimuth, the actual survey trajectory is calculated with minimum of curvature method. The next examples are the calculation of minimum of curvature method in AMR-10 reservoir:

- **Measurement Depth Addition (ΔMD)**
  \[ \Delta MD = MD_2 - MD_1 \]
  \[ \Delta MD = 510.5 - 447.1 = 63.4 \text{ ft} \]

- **Dog Leg (DL)**
  \[ DL = \cos^{-1}[(\cos(I_2 - I_1) - (\sin(I_2)\sin(I_1))x[1 - \cos(A_2 - A_1))] \]
  \[ DL = \cos^{-1}[(\cos(2.55 - 1.93) - (\sin(1.93)\sin(2.55))x[1 - \cos(215.38 - 206.84))] \]
  \[ = 0.71 \text{ deg} \]

- **Ratio Factor (RF)**
  \[ RF = \frac{360}{DL \times \pi} \times \tan\left(\frac{D_2}{2}\right) \]
  \[ RF = \frac{360}{0.71 \times \pi} \times \tan\left(\frac{0.71}{2}\right) = 1.00051 \]

- **Vertical Depth Addition (ΔTVD)**
  \[ \Delta TVD = \left\{ \left( \frac{180}{\pi} \right) \times \left( \frac{\Delta MD}{I_1 - I_2} \right) \times (\sin I_2 - \sin I_1) \right\} \times RF \]
  \[ \Delta TVD = \left\{ \left( \frac{180}{\pi} \right) \times \left( \frac{63.4}{2.55 - 1.93} \right) \times (\sin 2.55 - \sin 1.93) \right\} = 63.38 \text{ ft} \]

- **Horizontal Movement Addition (ΔD)**
  \[ \Delta D = \left( \frac{\Delta MD}{2} \right) \times (\sin I_1 + \sin I_2) \times (RF) \]
\[ \Delta D = \left( \frac{63.4}{2} \right) x (\sin 1.93 + \sin 2.55) x (1,00051) = 2.48 \text{ ft} \]

- **North Changes (\(\Delta North\))**
  \[ \Delta North = \left( \frac{\Delta MD}{2} \right) x [ (\sin I_1 \times \cos A_2) + (\sin I_1 \times \cos A_1) ] x (RF) \]
  \[ \Delta North = \left( \frac{63.4}{2} \right) x [ (\sin 2.55 \times \cos 215.38) + (\sin 1.93 \times \cos 206.84) ] x (1,00051) \]
  \[ = -2.11 \text{ ft} \]

- **East Changes (\(\Delta East\))**
  \[ \Delta East = \left( \frac{\Delta MD}{2} \right) x [ (\sin I_2 \times \sin A_2) + (\sin I_1 \times \sin A_1) ] x (RF) \]
  \[ \Delta East = \left( \frac{63.4}{2} \right) x [ (\sin 2.55 \times \sin 215.38) + (\sin 1.93 \times \sin 206.84) ] x (1,00051) \]
  \[ = -1.29 \text{ ft} \]

- **Dog-Leg Servility (DLS)**
  \[ DLS = \left( (D \times 100) / \Delta MD \right) \]
  \[ DLS = ((0.71 \times 100) / 63) = 1.13 \text{ deg/100 ft} [8] \]

The following figure picture the result of planned trajectory and the actual trajectory:

![Figure 1](image-url)
Based on vertical projection comparison above, we can see that there are four inclination evaluation points. These four points were chosen because they are the starting point where inclination angle differences occurred between planned trajectory and the actual trajectory.

Based on actual and planning vertical projection, we can see that there is a difference of inclination angle at 446.1 ft. MD depth. In this depth, an angle of 1.93° was already formed. During planning process, the angle was started to form at kick-off point which is at 500 ft. MD. At early depth until 447.1 ft. MD, dogleg severity was also formed as much as 0.42°/100 ft., which eventually produces a 2.55° inclination angle at 500 ft.

A change of inclination angle approaching the planned trajectory can be seen in the second Inclination evaluation point at 1765.6 ft. MD. At this point, the planned angle was 22.74° meanwhile on the actual reservoir the angle is 20.57°. This depth is already penetrating tangent section where the value of the angle will be maintained to make sure that the drilling stay on track. However, in this depth, a change of angle has caused the actual trajectory to approach planning trajectory.

The third evaluation point can be seen at 4720.1 ft. MD depth. In this depth, a downward change in planning trajectory occurs. At this depth, a downward change happened on planning trajectory. The angle change at this point was started to happen when an angle of 19.86° was formed, meanwhile this depth is already inside the tangent section, which is corresponding with maintained angle formation of 22.75°. The last inclination evaluation point can be seen at 6798.9 ft. MD. At this depth, the actual trajectory experiences decrease in angle from 22.74° to 21.62°.

Azimuth evaluation point can be determined by comparing horizontal projection of planning and actual trajectories. The following figure pictures horizontal projection comparison between planning and actual trajectories.

![Figure 2](image-url)
Based on the comparison above, there are five trajectory azimuth evaluation points. These five points were chosen because they are the starting points of azimuth angle differences formation on actual trajectory.

The first azimuth evaluation point occurred at 447.1 ft. MD. On planning trajectory, azimuth angle should not be formed yet at this depth. However, in reality, azimuth angle of 206.24° S or 26.24° E was already formed. This azimuth angle was formed because there is an inclination deviation that should be at 0° because the drilling process is yet to pass kick off point.

The second azimuth evaluation occurred at 1138.5 ft. MD. At this depth, the drilling process was aimed to left side so it would approach the planned trajectory. At this depth, an azimuth deviation of 206.59° was occurred when it supposed to be maintained at 202.68°. At this depth, trajectory change happens a little bit to the left before it finally returns on planned trajectory.

The third azimuth evaluation point happens at 2206.2 ft. MD. At this depth, the formed azimuth angle is at 200.43°. Trajectory change at this depth is aimed to make sure that the actual trajectory is in accordance with planned trajectory. As planned, azimuth angle at this depth should be 202.68°.

The fourth azimuth evaluation point occurred at 4720.1 ft. MD. At this depth, drilling trajectory is moving a little to the left from planned trajectory. At this point, the azimuth angle formed is at 195.51°, meanwhile on the planning, the angle should already at 202.68°.

The last azimuth evaluation point occurred at 5099.2 ft. MD. At this depth, the angle formed is at 202.9°, meanwhile on planning it should be at 202.68°.

4. Conclusion

Based on the result of this research, the process conducted to determine evaluation point is through the planning and actual trajectories comparison by using radius of curvature and minimum of curvature methods that calculates vertical depth, build up rate, azimuth radius, dogleg severity, ratio factor, north and east directions, and horizontal movement. Based on the planning calculation, AMR-10 drilling is planned to reach final vertical depth of 6540.9 ft., and the horizontal movement from the original drilling point is 2290.3 ft. with azimuth angle of 202.68°. Based on survey data calculation, we can acknowledge that there are several points that should be evaluated, produced by differences of inclination and azimuth angles of the planned and the actual trajectories. These points are located at 447.1 ft. MD, 1138.5 ft. MD, 1765.5 ft. MD, 2206.2 ft. MD, 4720.1 ft. MD, 5099.2 ft. MD, and 6798.9 ft. MD.

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