ECD Analysis of 26in Hole with VETCO DAT

Objective

Studying the ECD and the various parameters affecting it, and trying to find a way to optimize the ECD while drilling the next hole section or any other wells in the same environment. This hole section was drilled using Sea Water from 30in shoe down to 5631ft and then 9.5ppg WBM utilizing the Pump and Dump Method.

Theory

It is known that ECD is a measure of the differential pressure in the annulus, pressure drop in the annulus and it is affected by:

1. Pressure drop due to friction, fluid annular velocity is this parameter and the Pump rate (GPM) can be considered as a representative for the annular velocity parameter.
2. Solids or cuttings loading in the drilling fluid (cuttings suspension), as more cuttings result in more increase in the average mud weight, and ROP can be considered as a representative of the cutting suspension parameter, increase in mud weight, parameter.
3. To study the effect of the previously mentioned parameters the data for ECD should be normalized by subtracting the Average Mud Weight (Effective MW) that takes into account the two gradients drilling as there will be
    - Mud column inside the annulus below the WHH or ML
    - Sea water column above the ML
    - Air gap from the MSL to the RKB

Input Data or Source of Data

1- Sperry Sun provides Mud Logging Data that we use it to get the following plots:
- ROP in fph vs. Depth (ft)
- Pump output rate gpm vs. Depth (ft)
- Average Mud Density in ppg vs. Depth (ft)

2- Pathfinder Directional Drilling Data that we use it to get the following plots:
- ECD in ppg vs. Depth (ft)

Steps of Analysis

To get a full description of the relation between the drilling parameters and their inter-effects the data were sorted to get three types of plots (shown in the Full Excel Work Book):

- Data during the sweeps only at the approximate depths of sweeps, as defined from Sperry Sun data (plot not shown in this document).
- All the normal drilling operations data inclusive of the sweeps (*Figure #1*).
- Drilling operations data inclusive of the sweeps with Depth in feet (x-axis) plotted against ROP in ft/hr (y-axis 1) and Delta ECD [defined as ECD minus Effective Mud Weight] in ppg (y-axis 2). *(Figure #2)*
- Because the data set for the sweeps was not accurately recorded depth based, the effect of the sweeps has not been removed to normalize the ECD and Delta ECD trends.

Observation and Results

1. ECD and ROP trend almost parallel to each other, however it should be noted that the time taken for the ECD to increase (1^{st} slope of the ECD curve of both Figure #1 and #2) is a function of the annular capacity and time taken to generate sufficient suspended cuttings in the fluid column so as to increase the effective fluid gradient below the mud line.
2. The peaks relative to the 50bbl sweeps are pronounced at the start of the hole section when the sweep to hole volume ratio is “high”. As the hole volume increases and the sweep volume remains constant the effect of the sweeps begin to flatten out as a function of (1) reduction in the sweep to hole volume ratio, and (2) sweeps being retained in hole for a longer time.
3. At approximately 5,179ft-RT it is evident that the ECD, and Delta ECD gradients begin to diverge from the previous parallel (normal) trend of ROP and Flow Rate (Figure #1 and #2). Flow rate remained relatively constant with a mean average increase in annular velocity of less than 5ft/min, however ROP decreased slowly as either (1) formation competence increased, OR, (2) WOB increased but ROP decreased as a result of pump out forces across the balled bit and stabilizers. The ROV was used to survey the Bulls Eye intermittently during connections and it was observed that there was no flow out of the 4 x 3in Annular Outlet Valves. It was also noted during the displacement to 11.0ppg 3% KCL Pad Mud that there was no flow out of the 4 x 3in Annular Outlet Valves on the 30in LP Wellhead Housing. This may explain the divergence from the normal trend (reduced annular flow area and consequently increased friction loss at the Mud Line). As the

annular flow area reduced (reason: it would appear that the 4 x 3in Annular outlet valves were packed or packing off from solids). It was again observed during the 1st POH attempt that there were no returns from any of the 4 x 3in outlets. On all occasions there appeared to be full returns from the top of the DAT.

4. The VETCO DAT total flow area is approximately 30% of the 26" x 5-1/2in DP Annulus. Consequently it is expected that with flow being constant, there would be a greater friction loss at the top of the 30in LP WHH. While this number is not quantifiable from the data set, the effective ECD, specifically the Delta ECD will have an artificial component due to this friction loss.
5. While drilling with Sea Water the average ECD minus Delta ECD was approximately 0.25ppg. The effectiveness of the hi-vis sweeps are very evident during this phase of the hole and as such, if included in the average the effective ECD jumps up to 0.29ppg. This can be seen clearly in both Figure #1 and Figure #2. *Again it should be noted that the DAT artificially increases the apparent gradient.*
6. After the 5000ft step change it is also noticeable that the ECD and Delta ECD try to "flatten" out at approximately 5200, 5350 to 5400 and at 5500ft-RT, indicating that the annulus may have been clearing, either at the 30in LP Housing or in the lower annuli.
7. At ±5696ft a sharp decrease in the Delta ECD is noted, this is approximately 30ft after the start of Pump & Dump (Figure #2). Interesting that the low data point is subsequently followed by a progressive increase in the Delta ECD (Figure #2). Again, ROP is fairly consistent, however Flow Rate was reduced by approximately 200gpm during the start up of the Pump and Dump; what is interesting here is that the ECD readings do not show as pronounced a change as does the Delta ECD (Figure #1 vs Figure #2). ECD shows a consistent increasing trend (Polynomial Trend Line in Figure #1) even though there is a drop commensurate with flow rate, but, Delta ECD changes drastically and the trend is on the decrease (Figure #2). It is well understood that in larger hole sizes fluid shear stresses and annular friction relative to annular velocity has less effect on ECD than that of cuttings loading. The larger hole size with a consistent ROP, regardless of the change in fluid density should not show a change in the Delta ECD. So, what is happening at approximately 5179ft? Why does the "normal" trend change?
8. It is proposed that this steadily increasing ECD and Delta ECD is a progressive loss of annular flow area above the DPM Sub on the BHA. While the argument is subjective to interpretation it is the opinion of the Well Site Supervisor that the ramp-up is a function of plugging / packing off of the 3in Annular Outlets on the 30in LP Wellhead. The tendency observed for the ECD and Delta ECD to try to flatten out within the general ramp-up is due to clearing of the cumulative annular restrictions up to and including the 30in LP Wellhead (as described earlier). The final part of the Delta ECD (Figure #2) curve also never approaches the previous peaks and previous trends, however the flow rate has increased. Additionally the ECD (Figure #1)

flattens out, on its own suggesting that the system has stabilized and that the ECD may be normal at +0.4ppg above Effective Mud Weight.

9. From approximately 5800ft (±170ft from the start of P&D) the flow rate is back up to the previous ±1200gpm as it was using sea water. It is clear on Figure #1 that the ECD continues to trend up and eventually flattens out at roughly 9.4ppg EMW. However, on Figure #2 the Delta ECD never approaches the average that is was for the period just prior to the P&D. It is not being suggested that the fluid type has anything to do with the distinct changes and averages of the Delta ECD, however taking into account that the flow rate was reduced and then increased again, the annular restrictions to flow may have been partially cleared due to the increased fluid velocity across the restriction.

10. Figure #2: After the instantaneous drop in Delta ECD commensurate with the reduction in flow rate (roughly 0.25ppg excluding the highest point) the data density from the low point at ±5696ft up to the point at which it tends to level out again at ±5786ft suggests that the trend is (1) abnormal: Flow Rate has increased and almost simultaneously the ECD and Delta ECD have stabilized with no allowance for cuttings lag time to the mud line, and (2) subsequently normalizing as the cuttings loading is reduced over time as evidenced by the decreasing trend in the Delta ECD. Again it is proposed that the system is being influenced by an annular restriction, possibly getting cleaned up with higher flow rates and after “shocking” the restrictive mechanism with a change in flow rate.

Figure #1

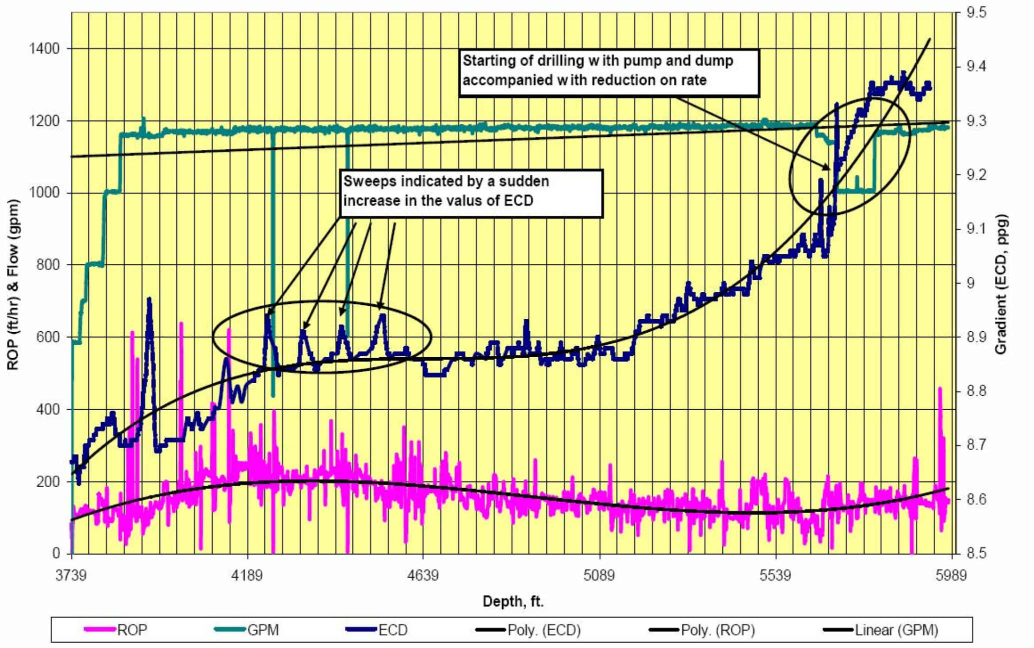
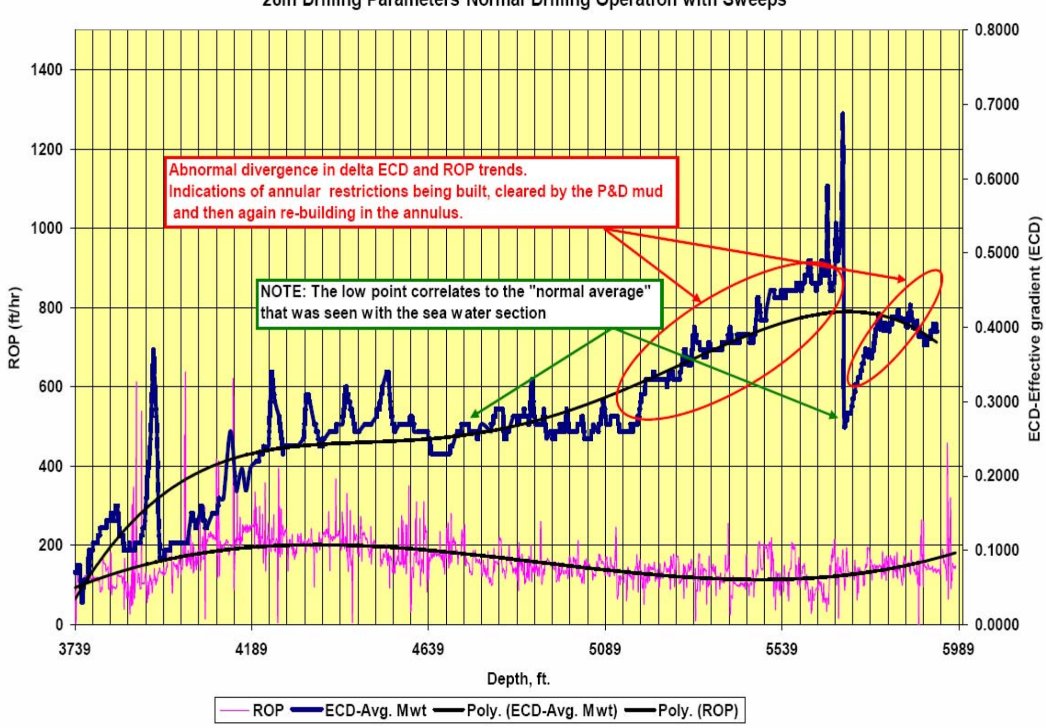


Figure # 2



Conclusion and proposed Lessons Learned

- The Delta ECD is more descriptive of the behaviors in the annulus below the mud line as they are a function of a shorter true vertical height as opposed to the ECD which is calculated over the total true vertical section of the water column and the hole below mud line. While they are both gradients and show the same relative changes, the Delta ECD simply allows for a more accurate snap shot of any point in time within the annulus and therefore it can be used to more readily detect potential hole problems.
- While there may be no short term practical solution to the flow area across the VETCO DAT we should be mindful that there is a lesser flow area than the 26in x Drill Pipe or BHA Annulus and that careful attention to the annular pressures and drilling parameters are required. This becomes increasingly important as the hole section length increases and P&D techniques are used to extend the hole section.
- BHA Design (Stabilisers above the Annular Pressure Sub) and Tool / BHA combinations need to be taken into account during design phase in order to ensuring that the annular pressure data is not artificially influenced and miss-interpreted at the well site. This is critical in environments where a minimum effective gradient is required below mud line.
- Employing the use of an upward ported jet sub below the top stabilizer will allow for an increase in (1) the total system flow while allowing the MWD / DPM combination to run within more normal flow parameters and (2) assist in keeping the upper stabilizer cleaner. This however requires some experimentation in order to get a practical feel for the required hydraulics with a PDM BHA.
- In a like environment the data and explanations presented should be repeated to see if the relative changes hold true or not.

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