Ali Isinak*, Vance Smith**, Fulberto D'Alessandro**, Harry Dearing***
*OMV-Albania, Tirana, Albania; **AVA Drilling Fluids SpA, Rome, Italy; ***Newpark Drilling Fluids, LLC, Houston, Texas USA

Application of a Complex Polyol Drilling Fluid in Albania

Abstract:

A 5360 m well, the Kanina 1, has been drilled near the Adriatic coast of Albania in the Vlora district near the town of Kanina. In this tectonically active region, drilling fluids that provide superior inhibition characteristics are required. For this well, a complex polyol - potassium carbonate based system has been successfully utilized in the critical intermediate sections from 1610 to 4653 m.

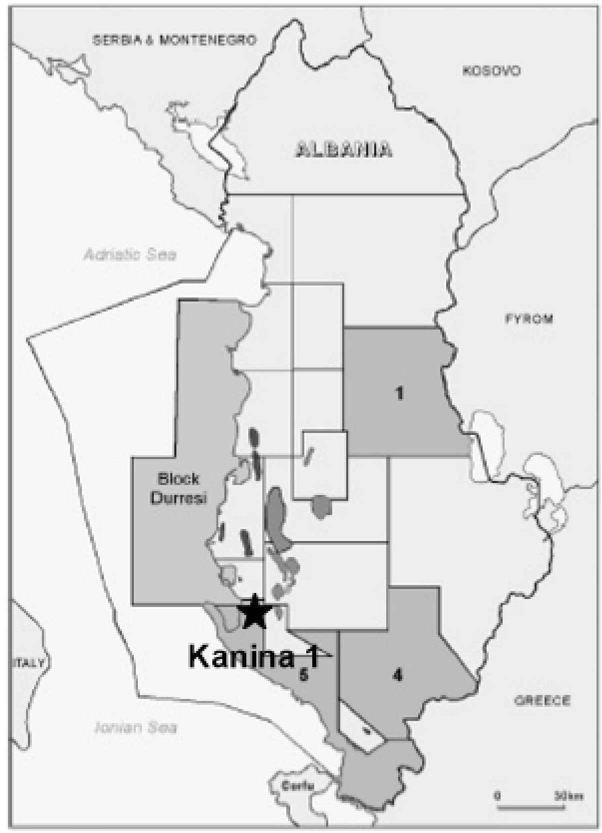
Mineralogical analysis of cuttings from the well indicates the formations drilled are reactive and dispersive. In the 16 in (406 mm), 12 1/4 in (311 mm), and 8 3/8 in (205 mm) hole sections, a 1,20 to 2,05 specific gravity (SG) mud has been utilized with 12 vol% of the complex polyol additive, 40 kg/m³ of potassium carbonate and 2 vol% of a lubricating, rate-of-penetration enhancing additive. Rates of penetration have been much higher than expected and PDC bit performance has been good in this inhibitive water based fluid. Additionally, a non-viscosifying additive, humalite, was used to control filtration properties in the complex polyol system.

The dilution rates to maintain mud properties were the same or lower than those programmed while maintaining reactive solids as measured by methylene-blue test in the 40 kg/m³ range. Analysis of caliper logs is complicated by the variable performance of the under-reamers used to drill the 16 in (406 mm) section. 13 3/8 in (340 mm) casing was set at 2764 m without incident. At this time, drilling continued in the 12 1/4 in (311 mm) section to 4622 m with a mud SG of 2,05. Due to a tool failure a sidetrack was necessary. A cement plug was set and a 9 5/8 in (244 mm) liner was successfully run to 4072 meters. An 8 3/8 in (213 mm) sidetrack was drilled to casing depth of 4653 m in 15 days with no major problems experienced. A 7 inch liner was set at 4653 m. The complex polyol fluid was displaced from the well. Drilling continued in the 5 7/8 in (149 mm) production section with a low-solids polymer drill-in fluid system to a depth 5362 m. At this depth, the reservoir was evaluated and completion operations were commenced.

Introduction

In planning a deep exploration well in block 5 exploration area of Albania (see map Figure 1), it was realized that the KCl mud system used in the past would not provide the performance required. The drilling fluid selected should provide a high degree of wellbore stability and the capability of attaining the high density required to counteract pore pressure and elevated tectonic stresses. A complex polyol fluid was selected for this well that met these requirements. Formulated with potassium carbonate, a high concentration of a complex polyol blend, a high performance lubricant and a unique stabilizing agent, the fluid system was used to drill the 16 in (406 mm), 12 1/4 in (311 mm), and 8 3/8 in (213 mm) from 1610 to 4653 m with mud densities up to 2,05 SG.

Figure 1 - Well Location



Geological considerations are of paramount importance and are discussed first with the expected and actual formation lithologies explained. An earlier well, the Rodoni 1 is discussed briefly. After reviewing the fluid design, each section is discussed in detail. The well is then summarized with recommendations for future wells. The 26 in (660 mm) and 18 in (457 mm) hole sections experienced considerable drilling fluid subsurface losses and drilling blind without fluid returns was required. A detailed discussion of these intervals and the solutions that allowed drilling to proceed is available[1].

Geological Discussion and Mineralogical Analysis

As shown in the geological cross section of Figure 2, the well penetrates into the Ionian Basin Carbonates after drilling mostly lower Miocene sediments. These sediments consist of shale and marly limestone from 1600 to 3000 m. From 3000 m to the top of the Ionian carbonate the formations are shale interbedded with sandstone and limestone. During the well, the mineralogy and cation exchange capacity of the cuttings were determined to gauge the reactivity of the cuttings. Standardized analysis procedures were used in the determination of the mineralogy and cation exchange capacity[2].

A summary of the results of these analysis are given in Table 1 on a following page. The cuttings analysis shows that throughout the hole sections drilled with the complex polyol fluid, the shale remained reactive to near the top of the Ionian carbonate section. The analysis indicates that the clays present in the marl rich shale and mud stone found in the Miocene formations are mostly Illite, but there is also a substantial amount of smectite and smectite dominated mixed-layer clays. The presence of 9 to 21 wt% of kaolinite clay in all the samples also contributes to the dispersive nature of these formations. The cation exchange capacity of most of the samples was well above 20 milliequivalents per 100 g (meq/100g). This is considered high for illite dominated, marl rich shale. The information obtained from the bulk mineralogical analysis that is unusual compared to shale from other regions was the presence of a consistent amount of feldspar (iron oxide) in the samples.

Figure 2 - Geological Cross Section

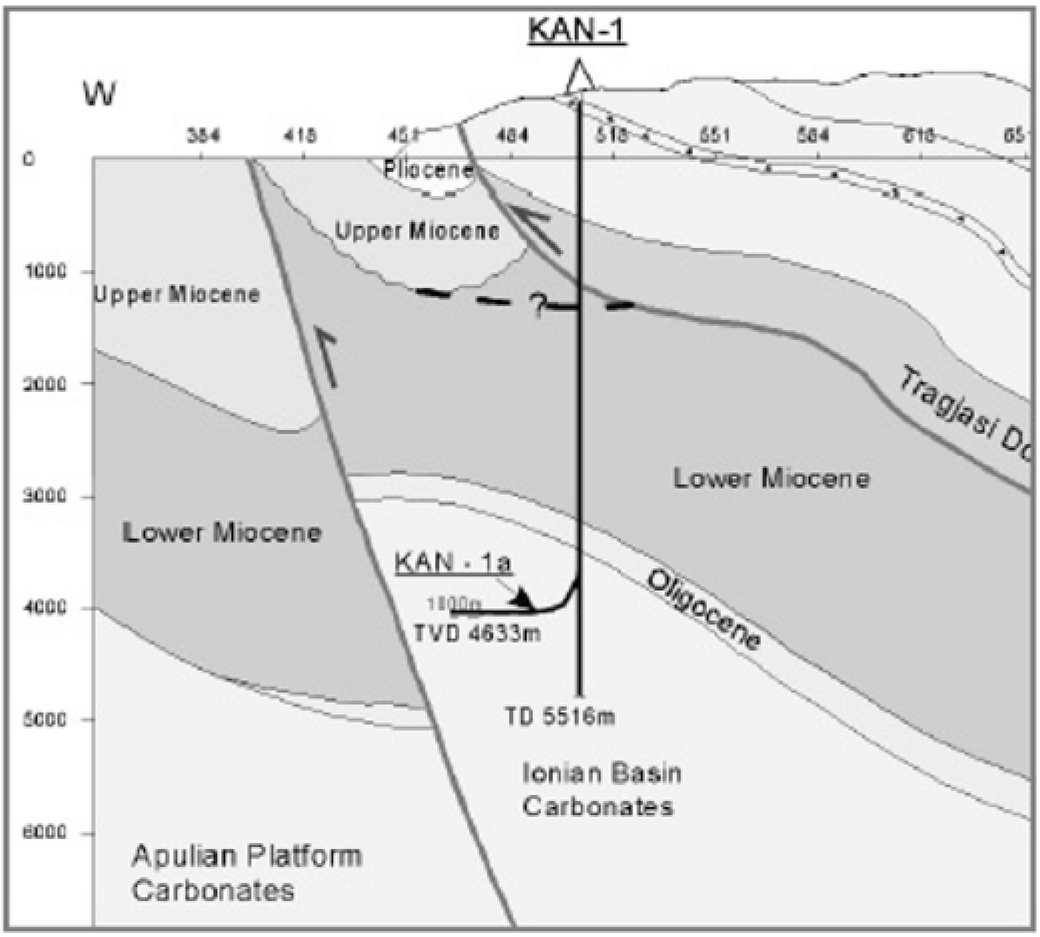


Table 1 - Summary of Mineralogical Analysis

*Bulk Minerals**	*2250m*	*2450m*	*2900m*	*3100m*	*3500m*	*3525m*	*4200m*	*4300m*	*4325m*	*4400m*	*4500m*	*4600m*	*4775m*
Quartz	56	-	9	16	6	18	27	25	6	19	15	13	6
Feldspar	-	-	5	11	4	14	13	14	3	13	10	12	3
Calcite	44	100	20	25	26	14	13	19	20	16	21	24	22
Dolomite	-	-	4	3	4	2	1	1	2	2	1	2	2
Total Clay	-	-	56	45	53	51	46	41	62	51	53	50	60
*Clay Fines***													
Kaolinite	-	-	17	9	13	12	20	21	19	19	13	13	14
Chlorite	-	-	11	10	10	12	14	8	14	12	11	11	12
Illite	-	-	26	30	35	27	27	26	29	31	30	30	29
Smectite	-	-	14	17	17	18	15	12	15	13	16	16	12
Mixed-layer	-	-	31	33	25	32	23	32	23	26	29	29	33
Illite/smectite	-	-	39 / 61	38 / 62	34 / 66	25 / 75	29 / 71	32 / 68	34 / 66	30 / 70	30 / 70	30 / 70	21 / 79
CEC***	-	-	35,6	28,8	18,9	28,2	12,9	23,5	19,9	13,6	16,7	10,5	18,7
Sodium	-	-	4,7	0,9	6,2	1.2	1,0	0,3	6,2	0,9	1,1	1,1	4,8
Potassium	-	-	0,6	8,7	0,4	9,6	5,0	6,7	1,1	5,5	6,1	6,2	1,3
Magnesium	-	-	4,0	0,7	1,9	1,5	1,6	1,2	3,0	1,0	0,7	1,1	1,8
Calcium	-	-	22,3	10,0	20,8	11,3	9,7	12,1	21,5	8,9	9,1	9,6	21,4

* Bulk mineral contents from random-oriented powder analysis, estimated weight percent (wt%)

** Analysis from oriented clay slides, estimated weight percent (wt%) of clay fraction

*** Cation exchange capacity, milli-equivalents per 100 gram (meq/100g)

Previous Well Experience

The Rodoni 1 well drilled previously in offshore Albanian waters had utilized a potassium chloride polymer mud. Problems with control of the fluid properties and with wellbore stability occurred with the use of this system in the Miocene section. For these reasons, an alternative to potassium chloride was desired.

When a potassium chloride mud is utilized at high densities, the fluid properties related to viscosity and filtration control deteriorate. The combination of high viscosity polymers required for shale inhibition and the large amount of solids required for mud densities up to 2,0 results in a fluid that has a high viscosity and can still lack sufficient polymer for good inhibition and adequate filtration control. This can require the addition of dispersing agents like chrome lignosulfonate. Sloughing shale and thick filter cakes on porous formations can result in such drilling problems as poor hole cleaning and stuck pipe.

Drilling Fluid Design

Experience with complex polyol fluids in North America[3] and Algeria suggested that a fluid could be formulated in combination with potassium carbonate. The use of potassium carbonate is preferred over potassium chloride for two reasons. Potassium carbonate is more environmentally acceptable than potassium chloride in land operations. The carbonate ion present in the salt also offers the ability to precipitate with calcium in the pores of shale and help block the transfer of water and ions into shale. This aids in preserving its strength. Experience with potassium carbonate in the Mediterranean has confirmed its ability to aid in shale stability.[4]

Complex polyol fluids utilizing a product consisting of methyl glucoside[5] and polyglycerol[6] together have been used to control troublesome shale. The additive reduces the water activity of the fluid and provides an abundance of hydroxyl groups for hydrogen bonding. This results in the formation of a membrane with the shale that prevents the diffusion of ions between the drilling fluid and the shale[7]. Combined with the potassium carbonate and an emulsified phase stabilized with a suitable neutralized organic acid, superior shale stability is realized. Concentrations of 12 vol% and greater have been found to perform optimally as high performance drilling fluids. For the fluid in this well, a concentration of 12 to 15 vol% was recommended and maintained through the most critical sections. Since knowledge of the concentration of the complex polyol in the system is vitally important, simple volume accounting for additions is not sufficient in a long well where mud is reused. For this reason, a procedure using refractive index measurement is implemented. The refractive index is measured using a refractometer (see Figure 3) and reported in the units of degrees Brix. The Brix scale was developed for use in agricultural and food science. A correlation that subtracts the effects of the soluble ions from salt in the make up water and the potassium carbonate present in the mud is used to directly calculate the complex polyol concentration.

Figure 3 - Refractometers for measuring complex polyol content

When using complex polyol fluids to improve shale stability an emulsified phase is helpful in the proper formation of the membrane. Additionally, a properly selected emulsified phase will aid in rate of penetration by preventing bit balling and preferentially coating the drill string.[8] For this well, 2 vol% of a blend of high performance lubricating esters was chosen as the emulsified phase. Control of the fluid properties is further aided by use of a non-viscosifying stabilizing agent.

In the design of high density fluids for deep well drilling, the use of non-viscosifying additives to provide filtration control and fluid stabilization is important. The primary additive selected for this well was a material called humalite. This alkaline soluble blend of humates is obtained from sub-bituminous coal deposits. In addition to its high degree of alkaline solubility, it performs well in the presence of salts like sodium chloride and potassium carbonate. This contrasts with the performance of leonardite, a standard drilling fluids material which has a lower alkaline solubility and is ineffective in fluids containing appreciable amounts of salt.

Additional materials were programmed for the well including barite for density control, poly-anionic cellulose for filtration and viscosity, xanthan gum for viscosity and solids suspension, and potassium hydroxide for alkalinity control. Since these materials are understood by drilling personnel and encounter widespread usage, they will not be discussed in this paper.

<u>16 in (406 mm) Hole Section - 1610 m to 2675 m</u>

After setting casing at 1610 m, drilling began with a 12 1/4 inch (311 mm) bit with a 16 in (406 mm) under-reaming assembly. Progress with the bit and under-reamer assembly continued to a depth of 2246 m where the hole had become deviated to 6º/30 m. The use of the under-reamer was discontinued and a directional assembly using a 12 1/4 in (311 mm) bit was utilized to the section total depth of 2765 m. A 16 in (406 mm) under-reamer was then utilized to under-ream the 12 1/4 in (311 mm) portion of the section. After logging it was found that several sections of the hole were under gauge and that this would prevent the casing from reaching depth. This required another under-reaming effort. Due to the erratic nature of the under-reamer performance, it is difficult to analyze the caliper as it would relate to wellbore stability. No large wellbore breakouts were seen on the caliper. This suggests that the mud density was sufficient to maintain borehole stability and that the mud was effective in preventing instability. The average diameter for the section was 16,6 in (422 mm).

While drilling the section the mud density was increased from an initial density of 1,06 SG to 1,15 SG at 1827 m. At 2064 m an increase to 1,20 SG was implemented. A program of gradually increasing the mud density began at a depth of 2132 m and proceeded to a depth of 2246 m and a density of 1,30 SG. Another program of mud weight increase began at a depth of 2478 m to 1,70 SG at 2675 m.

Additive concentrations on the section were in the ranges specified by the drilling fluids design. When drilling first started in the 16 in hole section, the complex polyol content was 8 - 9 vol%. The volume was increased to 12 - 15 vol% range prior to encountering the first shale sections at around 2500 m. The potassium carbonate content was maintained at 40 kg/m³ from 2500 m. The ester lubricant blend was increased from 1 vol% to 2 vol% at approximately the same depth as the other key additives were increased to program values. Filtration control was achieved using humalite additions.

This section was drilled to total depth in 28 days. After logging and additional under-reaming, the hole was open a total of 44 days. A dilution rate of 5,2 m³ per m³ of hole drilled was below the programmed rate of 5,9. This resulted in the consumption of 300 m³ less mud than originally programmed for this section. The methylene blue test results for the mud that is used to estimate the amount of reactive formation solids in the fluid never exceeded 45 kg/m³ (16 lb/bbl) equivalent bentonite content.

<u>12 1/4 in (311 mm) Hole Section - 2765 m to 4622 m</u>

Originally programmed for a depth of 4005 m, this section reached a total depth of 4622 m. Due to concerns about deviation, a directional assembly was used to drill the interval. The mud density for the interval began at 1,50 SG and was increased to 1,65 SG at 3319 m. At 3398 m, the density was further increased to 1,70 SG. All the increases in mud density were based on onsite observations of cuttings, hole conditions (torque, drag, etc) and plots of drilling parameters (corrected “d” exponent). At 3562 m, a tendency for sticking of the drill string required a further density increase to 1,80 SG. At 3562 m more tight hole conditions lead to a further increase in mud density to 2,00. While drilling, the density was further increased to 2,05 the maximum for this well. Good hole conditions and adequate rate of penetration using a polycrystalline diamond compact bit in both rotary and sliding modes indicated that the mud density was correct for the pore pressure and tectonic stresses at this point in the well.

On a short trip from 3782 m, reaming from 3565 m was required to reach bottom. This portion of the hole remained problematic with reaming required on almost every trip through this interval. Drilling progressed to 4377 m where the pipe became differentially stuck with the bit at 3926 m. Over the next several days a number of attempts were made to free the pipe. Finally, after reducing the mud density to 1,65 SG and spotting a diesel oil based stuck pipe pill, the drill string was freed. After reaming the hole to total depth and increasing the mud density to 1,86 SG drilling proceeded to 4622 m. The recurring tight hole and back reaming of the upper hole section suggested that under-reaming the hole to 14 in (356 mm) could be used to clean up the hole and a liner set or drilling to proceed. While reaming with a 12 1/4 in by 14 in reaming assembly at 4158 m, the bit and under-reamer were left in the hole.

After an arm from a wire-line caliper tool was lost in the hole, the decision was made to set a 9 5/8 in (244 mm) liner and side track the hole. The fish was pushed to bottom with a bit and a liner was ran to 4067 m. The liner was cemented and cleaned out in preparation for drilling 8 3/8 in hole.

Additive concentrations were maintained at the designed levels up to the time the pipe became differentially stuck. After freeing the stuck pipe, the complex polyol content was allowed to deplete down to about 8 vol%. The potassium carbonate level was maintained at the design concentration of 40 kg/m^3. The ester blend lubricant content was increased to 3 vol% and maintained at that level. The humalite additive was used to control filtrates in the specified range with good control of both the API room temperature value and the HTHP filtrate. Typical values for the API filtrate were 3 to 4 mL/30 min and, for the HTHP, 6 to 8 mL/30 min at 80ºC.

This interval required 70 days to drill. An additional 38 days were required for under-reaming, logging, and setting the liner. Considerable amount of time was lost in reaming the troublesome zones from 3400 m to 3800 m. A caliper log was not obtained on this section, but fluid caliper measurements conducted by the mud logging company indicated a wash out of 68 vol%. The most reasonable explanation of this wash out is that the section was destabilized by drilling it under balanced or below the mud density at which it would be stable. Once the formation had been destabilized, increasing the mud density could not improve hole conditions.

Dilution rates for this section, when the hole wash out is taken into account, were 7,73 m^3 per m^3 of formation. The dilution rate for planning the well was 7,7. Since the hole was under-reamed and the wash out occurred, considerable more solids were generated than originally planned. This resulted in higher fluid costs than planned for or anticipated. A small increase in the dilution rate was noted when the complex polyol content was allowed to deplete.

8 3/8 in (213 mm) Hole Section - 4072 m to 4652 m

The sidetrack was drilled to casing depth in 15 days with no problems experienced. Mud weight was reduced from 1,82 SG to 1,65 SG with the help of the centrifuges and dilution volume while picking up the new BHA, and after drilling out of the cement.

Additive concentrations were similar to the latter part of the previous interval with 8 vol% of the complex polyol, 2 vol% of ester blend lubricant, and 36 kg/m^3 potassium carbonate. Dilution requirements were similar to those programmed for the well.

Drilling continued to 4646m where the limestone transition zone was again located. A logging while drilling tool was picked up and the hole was reamed to bottom while logging. At this time it was decided to slowly drill ahead monitoring log results to ensure the correct casing depth was selected. The final casing depth was called at 4655m, and a 7" liner was run to bottom and cemented without any problems.

A low solids polymer drill-in fluid was used for drilling a 5 7/8 in (149 mm) hole through the production zone. The fluid was designed to minimize formation damage and no fluid problems occurred while drilling the carbonate reservoir.

Summary

A complex polyol fluid was designed and implemented to drill three critical sections of an exploration well in Vlora province of Albania. The fluid performed as predicted in the well and the well was drilled to the geological objective. A portion of the hole from 3400 m to 3800 m became unstable and caused considerable time to be lost. It is theorized that this portion of the hole was destabilized by drilling under balanced or with a mud density too low for this tectonically stressed formation.

Recommendations

Further analysis of the logs and geological data from the well should be conducted to confirm the causes for the unstable interval. Pore pressure prediction and wellbore stress modeling can be utilized to further investigate this.

Improvements to the rig solids control equipment should be considered to reduce the amount of dilution required. The economics of recovering the complex polyol from the excess mud will also be evaluated. It has been found that the complex polyol can be recovered from excess mud on several wells drilled in Wyoming and on a well in Northern Italy. The cost of this compared to the amount of complex polyol saved will be determined and used for planning future wells.

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