CADE/CAODC DRILLING CONFERENCE
October 23 & 24, 2001
Calgary, Alberta Canada

TITLE:	**New Additive Lowers Costs and Improves Rheology in Water-Based drilling Fluids**	**PAPER NO. 2001-024**
AUTHOR(S):	**Brent Warren, Q'Max Solutions Inc.** **Peter van der Horst, Akzo Nobel Chemicals bv** **Theo A.van't Zelfde, Akzo Nobel Chemicals bv**	**Page 1 of 10**

ABSTRACT:

The rheological and filtration control properties of bentonite based drilling fluids are greatly influenced by other ionically charged drilling fluid additives. Flocculation of bentonite with cationic species such as salts generally improves rheology while simultaneously worsening filtration control properties. Conversely, highly charged anionic species such as thinners/dispersants often improve fluid loss of bentonite muds at the expense of rheology.

The new drilling fluid additive described in this paper enhances the rheological properties of bentonite by providing a weak flocculation of the bentonite. Rheology can be varied by using the proper concentrations of bentonite and the new additive. No deterioration of filtration control is observed with use of the additive. Use of the weak flocculating additive results in 30-50% less bentonite usage and up to 50% less fluid loss polymer (i.e. polyanionic celluloses, starches, etc.) required. In addition, the combination of the new additive and bentonite has replaced Xanthan polymer as a rheological modifier prior to logging at a fraction of the Xanthan polymer cost. As a result, cost savings on drilling fluid materials on wells have varied from 20 to 50% with the greater savings seen on deeper wells.

This paper describes the development of the new drilling fluid additive and focuses primarily on field performance in the Western Canadian basin. Selected field studies from the over 1000 wells drilled to date will demonstrate the versatility of the new additive as a rheological enhancer/filtration control agent. Additional information is provided on the excellent environmental/disposal aspects and the formation non-impairment capabilities of the new additive.

INTRODUCTION:

The simplest drilling fluid commonly used in Western Canada is the gel-chemical mud. This fluid has a number of inherently desirable properties including:

- simplicity of design
- ease of use in the field
- adequate rheological and filtration control properties
- simple environmental disposal requirements
- low cost

A large majority of the wells drilled in Western Canada, especially those in W2 through W4 ranges, use gel-chemical drilling fluids to drill the potential hydrocarbon bearing zones.

Fresh water, bentonite clay and polymers are the basic ingredients of the fresh-water gel-chemical mud systems. The clay and the polymers in these drilling fluid systems take care of the desired rheology profile (viscosity enhancement) and filtration control. As we, of course, aspire to keep the overall cost of drilling as low as possible, a new polymer additive and gel-chemical mud system has been developed which made it possible to use less clay and less polymer while achieving an even better rheological profile. This water-soluble polymer is an amphoteric cellulose ether, which means that the cellulose ether backbone contains anionic groups as well as cationic groups. The overall performance of the drilling fluid having a lower solids and polymer content is obtained by a subtle interaction between the clay and the amphoteric polymer, giving a weakly flocculated polymer-clay drilling fluid system.

This paper deals with the chemistry of the amphoteric cellulose ether and the interactions of new amphoteric species with clay (as compared to regular CMC and PAC). The physico-chemical characteristics of the amphoteric cellulose ether which can be altered to modify the degree of flocculation of the clay in the water based drilling fluid system is also discussed. The cost advantage obtained will be shown by the field examples where the use of the newly developed system is compared to conventional PAC or CMC based gel-chemical system.

CHEMISTY OF THE AMPHOTERIC CELLULOSE ETHER:

Comparison of CMC/PAC and Amphoteric Cellulose Ethers

The new additive is an amphoteric cellulose ether having anionic carboxymethyl groups as well as cationic quaternary ammonium groups attached to the cellulose polymer backbone. The chemistry of the production of amphoteric cellulose ether is very similar to those of the other cellulose ethers. The cellulose is suspended in a diluent to which sodium hydroxide is added to form the reactive and amorphous alkali cellulose. Sodium monochloroacetic acid (NaMCA) is then added which reacts with the alkali cellulose at increased temperature. So far this is similar to making either CMC (carboxymethyl cellulose) or PAC (polyanionic cellulose) depending on the substitution level of the carboxymethyl groups. To prepare the amphoteric cellulose, an additional alkylation reaction is performed with glycidyl trimethylammonium chloride (GTAC) which then forms the cationic quaternary ammonium groups of the product. As byproducts of the reaction with MCA and GTAC, sodium chloride and the hydrolyses products of MCA and GTAC are formed which can be removed by extraction of the product with a washing liquid (usually a water / alcohol mixture).[1]

A schematic presentation of the chemical structure of amphoteric cellulose ether is shown in Figure 1.

As is well known for CMC, PAC and other cellulose ethers, the characteristics of these materials can be varied by having different average numbers of substituents per glucose unit and different molecular weights.[2] Commonly in the drilling of wells, either a low-viscosity or high-viscosity PAC is used in a gel-chemical mud. In the same manner, the product parameters can also be varied on the amphoteric cellulose ether as follows:

Average number of sodium carboxymethyl groups per glucose unit (DS_{CM})

Average number of quaternary ammonium groups per glucose unit (DS_{QN})

Average molecular weight of the polymer (MW, and MW distribution)

As will be explained later on, the anionic carboxymethyl groups in general possess the capability to disperse the clay in a particular mud system while the cationic quaternary ammonium groups strongly interact with the negative surface of the clay platelets. Depending upon the molecular weight of the cellulose, the cationic component might result in bridging flocculation, as seen in potassium salt-based muds (i.e. K_2SO_4). The new additive has been developed in such a way that a balance is obtained in the dispersing and flocculating behavior of the bentonite clay in order to obtain the desired rheology of a gel-chemical system. This means that the DS_{CM} of amphoteric cellulose ether is in the range of 0.8 – 1.0 and the DS_{QN} in the range of 0.05 – 0.25. Therefore, at a high molecular weights of polymer, only a few cationic groups are required to obtain the desired amount of weak flocculation.

Window of Opportunity – the Right Balance between Flocculation and Dispersion

As the rheology of the new amphoteric cellulose ether polymer containing drilling fluid systems is based on the interaction between polymer and clay, the new polymer additive performs best in systems containing smectite types of clays. Bentonite is the most commonly used clay in drilling muds because it provides excellent rheological and filtration properties to the mud, especially in combination with polyelectrolytes like CMC and PAC. Bentonite clay, which is primarily montmorillonite, exists as very thin platelets (sheets). The clay platelets exhibit a superior ability to swell uniformly in fresh water upon shear application. The swelling of the dehydrated agglomerated bentonite clay when it is contacted with water is caused by a penetration of water molecules in between the clay platelets. The swelling pressure is so strong that the layers separate into smaller aggregates and even into individual unit layers with a thickness of 10 Å. Thus, in fresh water a relatively stable suspension of the hydrated clay can be obtained.

In aqueous suspensions, the edges of the bentonite platelets are positively charged while the faces are negatively charged. Because of these opposite charges there is an interaction with the positive edges and negative faces. However, in a fresh water hydrated bentonite suspension (without electrolytes) these electrostatic interactions are rather weak because of the thick bounded water layer around the clay platelets. This thick water layer keeps the particles far enough from each other so that the bentonite is almost completely dispersed. Nevertheless, a very weak flocculation of this system occurs as is seen by the gelation properties and yield stress.

A variety of water soluble polymers are often added to bentonite based drilling fluids. They serve a number of useful purposes such as increasing viscosity and controlling filtration rates, which often are directly related to the degree of flocculation and aggregation of the bentonite clay particles in the drilling mud. For example, to build up a good filtercake to minimize filtrate loss into the formation, the clay suspension should be in a deflocculated condition. Sodium carboxymethyl cellulose (CMC) and polyanionic cellulose (PAC) are two of the more widely used anionic polymers in drilling fluids to control viscosity and filtration rates. In fresh water, low DS CMC's adsorb on bentonite while higher DS CMC's (e.g. PAC's) shows a decreased amount of adsorption. A small amount of a low DS CMC (DS = 0.7) is sufficient to realize complete dispersion of the bentonite as the CMC adsorbs on the positive edges of the platelets. This complete dispersion results in a reduction of the gel-strength to almost zero. In general a good dispersed bentonite/CMC suspension gives a good build-up of the filter-cake and an excellent fluid loss reduction performance is obtained. Such a mud system does not demonstrate significant gel-strength and yield point. In order to maintain gel strengths and yield point in these bentonite clay/CMC or PAC suspensions, additional bentonite is required.

The new amphoteric cellulose ether features an additional interaction with the bentonite clay because of the introduction of the cationic groups in the material. Because of the strong interaction of the cationic groups of the new cellulose ether with the bentonite particles, it is a very efficient material to provide gel-strengths and yield stress to fresh water bentonite based muds. More particularly, the strong interaction of the cationic quaternary ammonium groups of amphoteric polymer with the bentonite particles causes bridging flocculation, which produces the desirable rheology. Additionally, the extent of flocculation can be regulated by the DS_{QN}, i.e., the more cationic groups attached to the cellulose backbone the more pronounced the flocculation. However, while increased flocculation is beneficial for rheology, it is detrimental to the fluid loss reducing capability. Increasing bentonite clay flocculation will decrease the fluid loss reduction ability. For example, a material with a rather low DS_{QN}, like the amphoteric cellulose ether, gives a weakly flocculated system which provides the drilling fluid the desired gel-strength and yield stress and also gives adequate fluid loss reduction. It also has been found that when the rather low DS_{QN} is combined with a high molecular weight cellulose ether polymer, the amount of bentonite used can be reduced significantly. Another advantage of an amphoteric cellulose ether is that it is compatible with commonly used (anionic) polymers like CMC, PAC and starch. In situations where the fluid loss needs further reduction than can be provided by the amphoteric polymer, CMC, PAC and starch materials can easilybe used to achieve the desired fluid loss control.

LABORATORY FINDINGS AND FORMULATIONS:

In order to improve on the time proven gel-chemical drilling fluid using the amphoteric cellulose ether chemistry described above, three criteria needed to be met. Those criteria as listed below, if met, would be the driver to use this new drilling fluid system in the field:

- rheological properties equal to or better than a gel-chemical system
- filtration control properties equal to or better than a gel-chemical system
- total drilling fluids costs LOWER than a gel-chemical system

The final criteria, lower costs for the amphoteric cellulose system, should be achievable with the prospect of using less bentonite and less polymer to produce the desired rheological and filtration control properties.

Standard Formulation and Drilling Fluid Properties

Table 1 shows the drilling fluid properties obtained for the new amphoteric cellulose compared to a standard high MW, high viscosity PAC material. As seen in the data, good rheological and fluid loss properties are achievable with the new amphoteric cellulose ether at concentrations of 30 kg/m3 of bentonite and 0.5 kg/m3 of amphoteric polymer. A standard gel-chemical formulation requires additional bentonite and PAC polymer to match the fluid properties of the amphoteric cellulose ether based mud.

Based upon the amphoteric cellulose ether formulation (0.5 kg/m3 of polymer and 30 kg/m3 of bentonite) and the PAC formulation (1.0 kg/m3 of PAC and 45 kg/m3 of bentonite), the estimated selling prices of the two systems in the field are as follows:

- amphoteric cellulose ether mud - $14.30/m^3$
- PAC gel-chemical mud - $20.60/m^3$

The laboratory work has proven that the new amphoteric cellulose ether based system has met the desired requirements by showing improved rheological properties and similar filtration control to gel-chemical muds. A significant price savings is also anticipated as the amphoteric cellulose system is estimated to be approximately 30% less costly than a PAC based gel-chemical drilling fluid. In addition, significant savings potential exists in trucking costs due to of lesser amounts of additives being used.

Similarities of Amphoteric Cellulose Ether System to Gel-Chemical Muds

Although the new amphoteric polymer based system has shown some significant improvements over a gel-chemical fluid, many similarities exist in the two types of drilling fluids. These similarities are not unexpected given the slight change of polymer chemistry from a polyanionic cellulose ether polymer to an amphoteric cellulose ether polymer.

Effects of Contaminants

Simulation of drilling through anhydrite produced similar results for both gel-chemical and amphoteric polymer mud systems. Gypsum or calcium nitrate added to the systems in small concentrations initially gave rise to higher fluid losses and slight decreases in rheology (Table 2). Higher concentrations of calcium increased both the rheology and fluid loss, with the greater increases in rheology seen with a gel chemical system, presumably due to the higher initial bentonite concentration.

Soda ash was effective in both fluid types in preventing the flocculation effects due to the calcium.

Formation Impairment Considerations

The amphoteric cellulose ether system should perform no worse than a gel-chemical drilling fluid system in terms of damaging a hydrocarbon-bearing zone. In practical applications, the amphoteric cellulose fluid may be slightly better in some applications due to the lower concentration of bentonitic solids contained within the system. As per best recommended practices, core flow work and return permeability studies will provide the best answer as to the amount of damage caused by a gel-chemical or an amphoteric cellulose ether drilling fluid.

Table 3 provides comparative results for a gel-chemical and amphoteric polymer based fluids. In this particular study, both fluids were essentially non-damaging with the amphoteric polymer fluids return permeability being slightly higher than the gel-chemical mud.

Environmental Fate

Gel-chemical drilling fluids used in Western Canada are often disposed of via landspreading-while-drilling technique. This technique is simple and of low cost and is practiced when available. The criteria to meet this technique are to have all ingredients pass a Microtox bioassay and be listed on the PSAC list.[3]

The amphoteric cellulose ether based fluid also passes the Microtox assay, is on the PSAC listing and can be disposed of by landspread-while-drilling method. The Microtox values for the amphoteric cellulose are shown in Table 4.

FIELD STUDY RESULTS:

The new amphoteric cellulose ether system has been proven to be very effective in the field. To date, over 2500 wells throughout Alberta have used this new system to lower drilling fluid costs, while maintaining good rheological and filtration control properties of the muds.

Example from 39-21 W4 Area of Alberta.

Wells in this area are typically drilled with a gel-chemical fluid and are for the most part relatively trouble free. Wells in the study varied from 1350 to 1471 m in total depth with mud-up occurring between 1150 and 1290 m. Table 5 shows the comparison of costs for wells in the study drilled with a gel-chemical and amphoteric polymer based systems. The results clearly show that the cost for the drilling fluid (when mudded-up) and the usage of bentonite and polymer (either PAC or amphoteric cellulose) were less for the amphoteric cellulose system. Interval costs for the amphoteric cellulose system were 42% less than the corresponding gel-chemical fluid costs. The average usage and costs shown in Table 5 are also highlighted in Figure 2.

Table 6 and Figure 3 show the rheological and filtration control property averages for the gel-chemical and amphoteric polymer systems. Similar to the results described earlier in the laboratory section of the paper, the rheological properties of the amphoteric cellulose ether based system were markedly improved over the gel-chemical based system. The amphoteric system had a higher Yield Point, higher and less progressive gel strengths and a significantly lower consistency index value (“n” value) than the gel-chemical average. In addition, the fluid loss control results for both systems were similar.

Example from 62-12 W5 Area of Alberta.

Table 7 presents the results from another amphoteric cellulose ether study. The area is commonly drilled with gel-chemical drilling fluids. Although the drilling in the main hole mud section is usually without major problems, difficulty in logging at total depth is an issue in the area. As a result, gel-chemical drilling fluids often use Xanthan gum polymers to boost the low-end rheology prior to logging to increase the likelihood of trouble-free logging run(s).

As evident in Table 7, the amphoteric cellulose ether grouping of wells used less bentonite, less polymer and had lower interval costs than the offset gel-chemical wells. Cost savings over the interval averaged 38% for the amphoteric polymer system. It is worth noting that the average total well depth for the amphoteric cellulose fluid group was 230 m greater than the gel-chemical group and that the average meters of drilling with mud was also 160 m greater. Some of the savings were as a result of the Xanthan polymer usage that averaged 0.7 sacks for the amphoteric polymer wells and 3.7 sacks for the gel-chemical wells. The wells drilled with amphoteric polymer achieved increased rheology prior to logging by adding small amounts of bentonite and amphoteric cellulose.

Figure 4 presents the average results of the wells listed in Table 7.

CONCLUSIONS:

1. Amphoteric Cellulose Ether polymer chemistry represents a significant breakthrough in the drilling fluids industry. This type of polymer provides both an enhancement to rheological and filtration control properties of fresh water drilling fluids.
2. The rheological and filtration control properties of fresh water bentonitic muds containing amphoteric cellulose ethers can be varied greatly, depending upon the degrees of substitution of the carboxymethyl (DS_{CM}) and quaternary (DS_{QN}) groups and polymer molecular weight.
3. The drilling fluid containing the new amphoteric cellulose ether requires less bentonite and less polymer than gel-chemical muds to achieve similar filtration control and improved rheological properties.
4. The new amphoteric cellulose ether system costs less than a typical gel-chemical system. Chemical savings with the new system should be ~ 20-50% as compared to offset wells drilled with gel-chemical muds. The examples shown in this paper showed savings of 38-42%.
5. Contaminants such as anhydrite can be treated out in the new amphoteric polymer system in a manner similar to a gel-chemical mud.
6. Core flow return permeability studies suggest that the new amphoteric cellulose system will have a similar or slightly better ability to minimize formation impairment.
7. The new amphoteric cellulose ether system is environmentally easy to manage and can be disposed of by landspreading-while-drilling.
8. Cost savings on trucking of mud additives will occur due to less usage of materials at the wellsite.

REFERENCES:

1. “Quaternary Nitrogen Containing Amphoteric Water Soluble Polymers and Their Use in Drilling Fluids”, International Patent Application Number PCT/EP00/02884, Publication Number WO 00/60023, October 12, 2000.
2. “Drilling Fluid Selection, Performance and Quality Control”, Kelly Jr., John, J. Petroleum Technol., p 889, 1983
3. “On-Site Monitoring of Drilling Fluids Toxicity”, Strohl, A.W. and Hoskin, S.J., SPE Paper 26005, presented at the SPE/EPA Exploration and Production Environmental Conference, San Antonio, Texas, 1993

TABLES:

TEST MATERIAL	TEST MATERIAL CONC. (g/L)	BENTONITE* CONC. (g/L)	PV (mPa.s)	YP (Pa)	10 sec. GEL (Pa)	10 min. GEL (Pa)	API-FL (mL/30 min.)
Base Fluid	0	30	5	2	0.5	4	16
Hi Vis PAC	0.5	30	8	3	1	7	12.5
	1.0	30	10	4	2	9	11.5
	1.0	45	17	8	7	22	10.0
Amphoteric cellulose	0.5	30	12	8	6	14	10.5

* - Natural gel

Table 1: Laboratory Comparison of Rheological and Fluid Loss Properties of Amphoteric Cellulose Ether vs. Standard PAC Material. Other Ingredients in all Muds were: Fresh Water, Caustic to pH of 10 and 4% Rev Dust as Drilled Solids.

SYSTEM	$[Ca^{++}]$	$[Na_2CO_3]$	PV	YP	10 sec GEL	10 min GEL	API-FL

	(mg/L)	(g/L)	(mPa.s)	(Pa)	(Pa)	(Pa)	(mL/30 min)
Gel-chemical	0	0	17	8	7	22	10.0
	150	0	13	6	5	19	13.0
	400	0	18	25	13	21	44.5
	400	1.08	16	9	8	24	10.5
Amphoteric cellulose	0	0	12	8	6	14	10.5
	150	0	8	6	3	8	13.0
	400	0	13	19	11	19	39.5
	400	1.08	12	7	6	12	11.5

Table 2: Comparison of the Effects of Calcium on Gel-Chemical and Amphoteric Cellulose Ether Systems. Gel-chemical formulation was 45 kg/m^3 Natural gel, 1.0 kg/m^3 HiVis PAC, pH 10 with Caustic and 4% Rev Dust; amphoteric Cellulose Ether formulation was 30 kg/m^3 Natural gel, 0.5 kg/m^3 Amphoteric Cellulose, pH 10 with Caustic and 4% Rev Dust.

SYSTEM	INITIAL PERMEABILITY (mD)	MUD LEAKOFF (cc/240 minutes)	REGAIN PERMEABILITY (mD [%])	REGAIN DRAWDOWN (kPA)
Gel-chemical	1.21	3.7 *	0.86 [71]	138
			0.96 [79]	345
			0.98 [81]	690
			1.07 [88]	1379
Amphoteric cellulose	19.5	2.7 *	13.1 [67]	55
			17.8 [91]	276
			19.5 [100]	1241

* - system did not achieve seal on leak-off test

Table 3: Return Permeability studies on Gething sandstone using gel-chemical and Amphoteric Cellulose Mud Systems. Test conditions included: temperature of 82 ^{o}C, net overburden pressure of 34100 kPag, mud overbalance pressure of 1600 kPag in a gas reservoir.

Amphoteric cellulose concentration (g/L)	EC_{20} result (%)	EC_{50} result (%)
0.3	> 91	> 91
0.7	> 91	> 91

Table 4: Microtox results for neat Amphoteric Cellulose Ether. Results of > 91% is Considered non-toxic by the Microtox Assay.

WELL LSD	SYSTEM	TOTAL DEPTH [mud-up depth] (m)	MAIN HOLE MUD COSTS ($)	BENTONITE (sacks)	PAC (sacks)	AMPHOTERIC CELLULOSE (sacks)
01-40-21 W4	Gel-chemical	1429 [1290]	2665	161	4	
26-39-21 W4	Gel-chemical	1425 [1200]	4848	166	9	
34-39-21 W4	Gel-chemical	1471 [1150]	5973	160	18	
30-39-20 W4	Gel-chemical	1351 [1150]	4987	153	14	
Averages		**1419 [1200]**	**4618**	**160**	**11.3**	
33-39-20 W4	Amphoteric cellulose	1407 [1230]	3134	76		8
09-40-19 W4	Amphoteric cellulose	1422 [1225]	2305	106		3
35-39-21 W4	Amphoteric cellulose	1415 [1269]	2526	90		3
Averages		**1415 [1240]**	**2655**	**91**		**5**

Table 5: Costs and Volume Usages in Main Hole (Mudded-up interval only) for Gel-chemical and Amphoteric Cellulose Ether Mud Systems. All Wells Were Drilled within a Nine Month Time Frame and with a 200 mm Bit in the Main Hole Section.

SYSTEM	DENSITY (kg/m^3)	FUNNEL VIS (seconds)	P. VISCOSITY (mPa.s)	YIELD POINT (Pa)	10 sec GEL (Pa)	10 min GEL (Pa)	"n" value (dimensionless)	API-FL (mL/30 min)
Gel-chemical	1065	45	12	4	3	9	0.70	8.0
Amphoteric cellulose	1080	51	17	10	5	7	0.54	7.5

Table 6: Average Rheological and Fluid Loss Control Values for the 39-21 W4 Wells. All Values are Derived from the Main Hole Mudded-up Sections and Reflect Values while Actively Drilling (not @ TD where Viscosity is Normally Increased for Logging).

WELL LSD	SYSTEM	TOTAL DEPTH [mud-up depth] (m)	MAIN HOLE MUD COSTS ($)	BENTONITE (sacks)	PAC (sacks)	AMPHOTERIC CELL. (sacks)	XANTHAN (sacks)
05-62-11 W5	Gel-chemical	1468 [1300]	6965	154	5		7
31-62-11 W5	Gel-chemical	1877 [1477]	10189	256	11		4
23-63-11 W5	Gel-chemical	1595 [1400]	6311	206	6		4
25-63-11 W5	Gel-chemical	1473 [1284]	4594	157	2		3
09-63-12 W5	Gel-chemical	1602 [1300]	6838	195	15		1
12-62-12 W5	Gel-chemical	1513 [1321]	5222	131	13		0
28-61-14 W5	Gel-chemical	1681 [1450]	14605	221	20		7
Averages		**1601 [1360]**	**7818**	**189**	**10.3**		**3.7**
19-62-15 W5	Amphoteric cell.	1941 [1500]	5701	170		9	1
20-61-14 W5	Amphoteric cell.	1723 [1301]	5379	151		4	1
21-61-14 W5	Amphoteric cell.	1825 [1474]	4101	152		2	0
Averages		**1830 [1425]**	**2655**	**158**		**5.0**	**0.7**

Table 7: Costs and Volume Usages in Main Hole (Mudded-up interval only) for Gel-chemical and Amphoteric Cellulose Ether Mud Systems. All Wells Were Drilled within a Six Month Time Frame and with a 200 mm Bit in the Main Hole Section.

FIGURES:

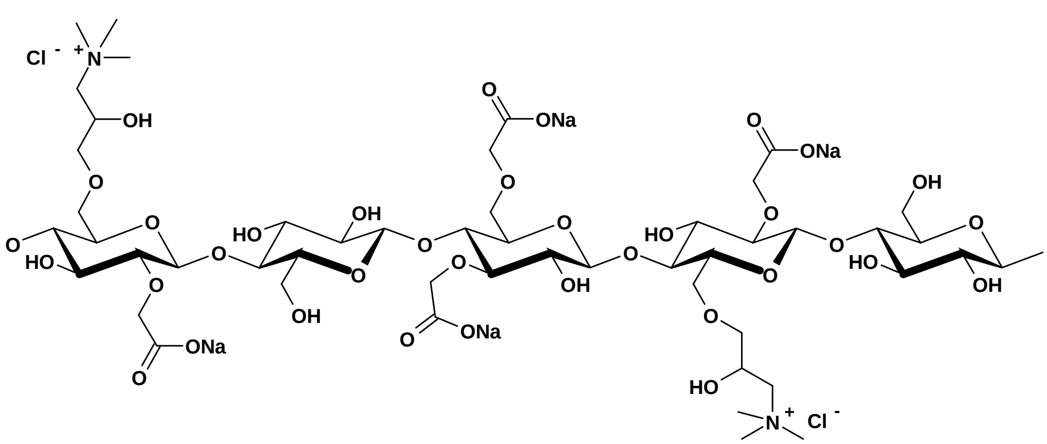

Figure 1: Simplified Depiction of the Amphoteric Cellulose Ether showing the Anionic and Cationic Attached Groups

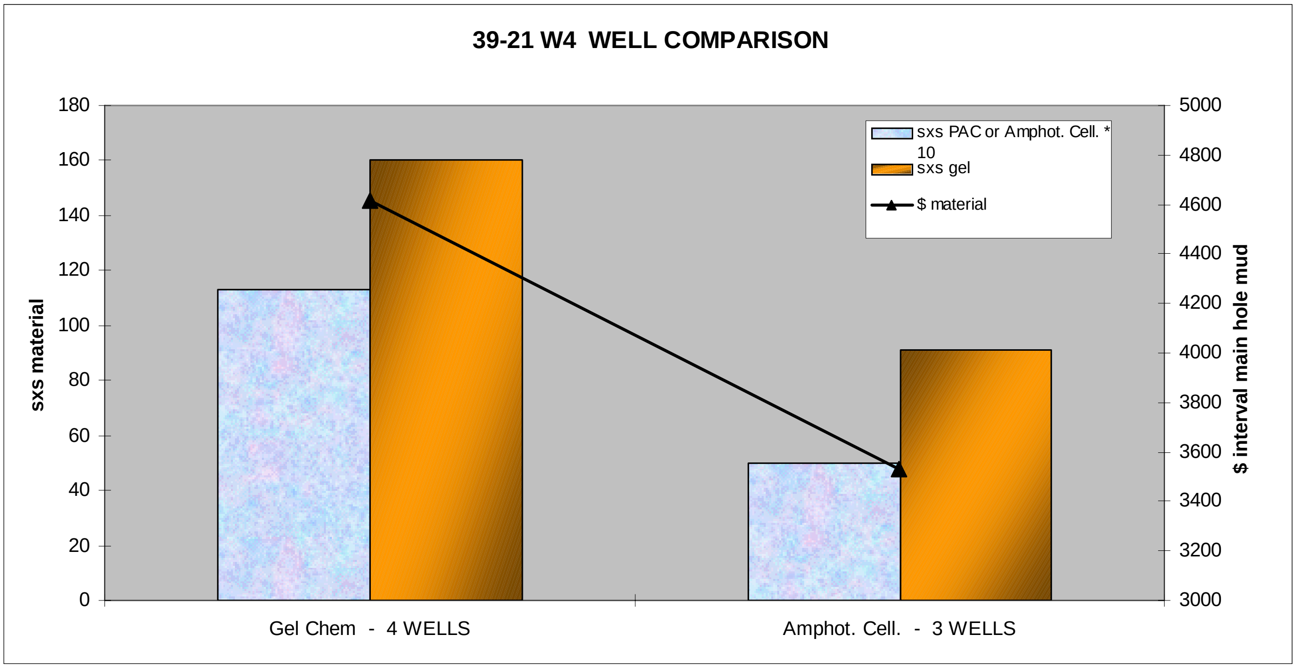

Figure 2: Average Main Hole Material Usage and Interval Costs for Gel-chemical and Amphoteric Cellulose Wells. Material Usage are in "bars" and Costs are Depicted by the Line. Note that sxs of PAC or Amphoteric Cellulose Material are Multiplied 10 fold.

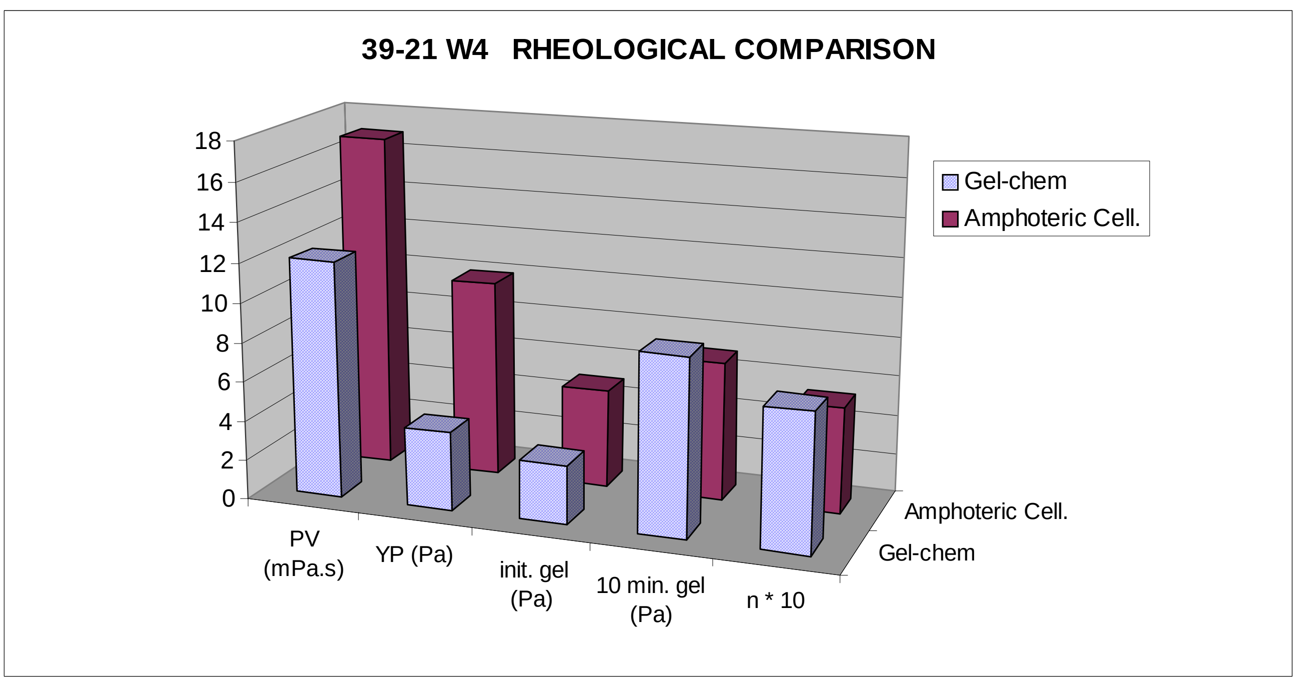

Figure 3: Average Rheological Data for Gel-chemical vs. Amphoteric Cellulose Ether Mud System Comparison.

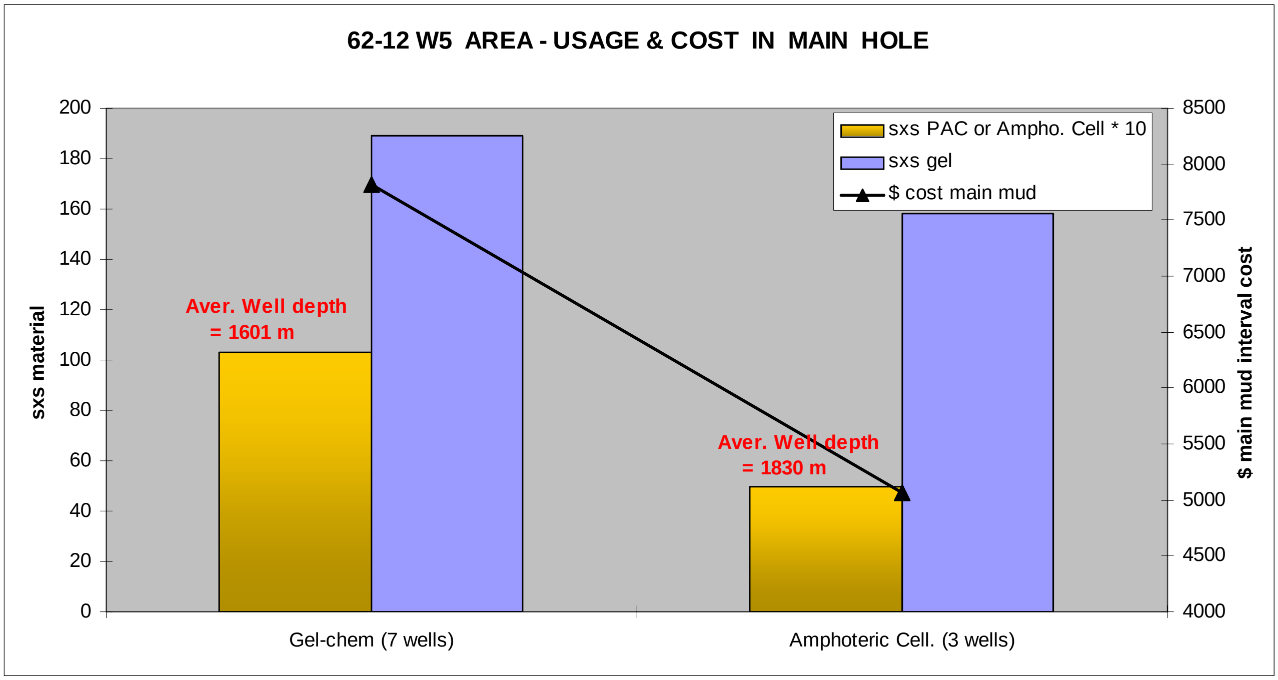

Figure 4: Average Main Hole Material Usage and Interval Costs for Gel-chemical and Amphoteric Cellulose Wells. Material Usage are in "bars" and Costs are Depicted by the Line. Note that sxs of PAC or Amphoteric Cellulose Material are Multiplied 10 fold.