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Invert Emulsion Fluid System with Enhanced Rate of Biodegradation

Josiane Durrieu, TotalFinaElf; Saddok Benaissa and Dave Clark, INTEQ Drilling Fluids

Abstract

In the last few years, regulations to minimize environmental impact from drilling operations have lead the industry to generate several environmentally friendly synthetic based drilling fluids. Base fluid toxicity and their chemical biodegradation in a marine environment are important parameters in assessing the impact of discharging fluids used on offshore drilling operations. Discharge of cuttings at sea is being evaluated around the world, to further protect the marine environment. Increasingly, cuttings are shipped onshore and processed or re-injected. In both cases, it burdens the cost of the drilling operations, and still may have a negative impact on the environment. This paper will discuss a newly developed and optimized process to enhancehe rate of biodegradation of currently used mineral, synthetic or ester based fluids. The process consists of using a treatment comprising organic nitrogen and phosphorus compounds combined with fatty acids which are added to a typical synthetic-based drilling fluid. Extensive laboratory work and research have been conducted. Results indicate this non-toxic and more readily biodegradable approach will have a greater reduced impact on the environment than the currently available synthethic fluids.

Introduction

In the past few years discharge restrictions of oil base mud cuttings into the sea and other environmentally sensitive areas, lead to the development of synthetic-based fluids. To offset the high cost of cutting injection, shipment and treatment, the search for a greener, more economical drilling fluid became apparent and continues today. This paper focuses on a more readily biodegradable drilling fluid approach, which maintains the high performance of standard synthetic-based fluids. Previous laboratory work conducted by the authors indicated that the rate of biodegradation of synthetic and mineral base fluids could be enhanced by incorporation a special additive to the drilling fluid system. This special additive is referred to as booster fluid in this paper. Refer to SPE paper 61212 for previous investigation and findings. Extensive laboratory testing was conducted and the resulting obtained data confirmed the ecological importance of this novel drilling fluid. Mineral oil, linear alpha olefins (LAO), isomerized olefins (IO) and ester base fluids behave differently. Their toxicity and biodegradation properties can vary widely. A major hurdle in this study was to find a compromise between toxicity and biodegradation rate while, maintaining adequate fluid properties. The booster fluid can be added to synthetic IO, LAO, paraffin, mineral oil or ester base invert fluid. Because of its high performance characteristics, thorough lab testing was conducted on IO base fluid. Stable drilling fluid with low yield point and adequate 6 and 3 rpm Fann 35 readings, result in the IO system's hole cleaning and barite suspension. This system is applicable for deep water drilling and difficult HPHT wells. While the coming introduction of new EPA regulations may result in making this process unnecessary to meet new guidelines, the work is encouraging since it appears fluids can be boosted to degrade more effectively.

Previous work

Initial toxicity and biodegradation work was conducted on a booster component comprised of three additives including an acid, a nitrogen source and a phosphorus source. In this paper these booster additives will be referred to as Fatty acid, Nitrogen and Phosphorus respectively. Test results indicated that a synthetic fluid treated with this booster fluid biodegraded aerobically faster that the base fluid alone. Unfortunately, it exhibited a level of toxicity not passing the minimum acceptable EPA levels using the Gulf of Mexico protocol. Table 1 lists booster fluid composition and corresponding fluid properties. The rates of biodegradation and toxicity values are presented in Table 2 and Figure 2. The LC50 range finder tests were conducted on emulsion fluids treated with the booster fluid to evaluate the toxicity level. The positive increases in biodegradation combined with the less than desirable toxicity results on the initial work direected the team to an optimization process.

Optimization

The major part of the optimization process was devoted to the booster fluid to ensure that it is both non-toxic and more biodegradable than a regular synthetic fluid. The booster fluid in this optimization still consists of three key components, a phosphorous compound, organic nitrogen and a fatty acid source. The optimization testing included evaluation of three other products to provide phosphorus. These phosphorus source products are referred to in this paper as Phosphorus 1, 2 and 3. Three booster fluids made with different phosphorus were formulated. The final corresponding products were each added to invert emulsion drilling fluid. Laboratory testing indicated that all three components had varying degrees of toxicity and had different effects on the fluids rheological properties and emulsion (Table 3). To achieve the highest rate of biodegradation it was necessary to go through a screening process to determine the optimum concentration of each component of the booster fluid. Based on results only the Phosphorus 3, exhibited lower toxicity level and a stable drilling fluid. This source was selected as the primary component of the booster fluid. A *Mysidopsis bahia* LC 50 range finder value of 54,700 ppm was obtained with the Phosphorus 3 treated drilling fluid. The next step was to evaluate the rate of biodegradability of the least toxic booster fluid. Aerobic biodegradation tests were conducted on several booster formulations using the Phosphorus 3 as a source of phosphorus, while maintaining the fatty acid and the nitrogen source. The booster fluid concentration added to an invert fluid is generally around 5 - 10% by volume of final barrel of mud, depending upon the type of the base oil.

Environmental impact

Marine toxicity tests

The toxicity effects of this biodegradable fluid and its impact on marine organisms were investigated. A 96 hour Range Finder was conducted on *Mysidopsis bahia* species and results indicated that the treated fluid had 54,700 ppm, exceeding the Gulf of Mexico minimum limit of 30,000 ppm suspended particulate phase (SPP) (Table 7). Sediment reworker test was also conducted on the crustacean, *Leptocheirus plumulosus*. Results show both fluids passing the 96 hours LC testing protocol.

Biodegradation tests

To assess the aerobic biodegradation we use an apparatus whose principle is based on the microorganisms' respiration (Figure 1). The samples to be tested are seeded with aerobic microorganisms in reactors. The oxygen is supplied by electrolysis of copper sulfate in an acid solution. The CO_2 resulting from biodegradation is absorbed by a lime solution. When bacteria consume O_2, a negative pressure in the testing reactor provides a supply of oxygen. The result of the test is presented in terms of milligrams of consumed oxygen. As reference an admitted biodegradable substance is used.

The next step was to target a drilling application of this novel fluid in the Gulf of Mexico. Several fluid formulations and biodegradation tests were conducted to meet the current EPA regulations. At the time of testing the EPA regulations dictated that any new synthetic base fluid had to perform equal to or better than a C16-C18 isomerized olefin which in this paper is referred to as Standard base oil. For purpose of comparison, isomerized olefin (IO), synthetic paraffin (SP), refined paraffin (RP) and ester (E) base oils and corresponding invert mud was evaluated.

Aerobic biodegradation tests were conducted on base oils, corresponding invert drilling fluids with and without booster fluid. Results are presented in the form of oxygen consumption versus time in days. Data for base oils and muds are represented in Tables 4 and 5 and their oxygen consumption trends are shown in Figure 3 and 4. Complete data for fluid B with and without booster are not completely reported because the testing was in progress during the preparation of this manuscript. Overall these results clearly indicate the different rates of biodegradation of the base oils and muds. The positive aspect of this work is definite enhancement of the rate of biodegradation provided by this novel booster fluid additive.

Bioremediation tests

Biodegradation rate is an effective way to assess how fast micro-organisms can degrade a discharged base fluid, therefore permitting benthic fauna and marine life to re-colonize the cuttings piles.

Colonization experiments with autonomous landers were conducted on the deep sea floor at a depth of 1300 meters to evaluate the response of macrobenthos to various types of oil-based muds and cuttings. The purpose was to determine whether the macrobenthos behavior is caused by organic enrichment solely and/or is also influenced by other sources of stressers (e.g. toxicity). Three autonomous landers, each with 16 colonization trays, were deployed for period of 9 months. The trays were filled with an inert substance (glass beads) enriched with different type of organic substances (fish flour, oil bases muds and cuttings)
Taxonomic composition and diversity indices of organically enriched and oil contaminated trays were fairly similar. These experimental results suggest that response to drilling fluids and cuttings contamination was mainly due to the organic enrichment rather than other sources of stress such as toxicity.

Results indicated that there was no damage to the deepwater marine organisms, supporting the novelty of this high performance additive to meet the environmental challenges facing drilling fluids in sensitive deepwater environments. Unfortunately data collected during the testing are still in progress and/or confidential and cannot be presented in this paper.

Laboratory evaluation

This new drilling fluid formulation and properties are similar to those of conventional synthetic fluids. The typical synthetic mud additives such as organo-clay, emulsifier, wetting agent, brine and weight material are all compatible. Figures 5 to 8 and Table 6. The only foreign additive needed to trigger the biodegradation process is the booster fluid. This new invert system is easy to maintain and is engineered the same as a standard synthetic drilling fluid.

Contamination testing and fluid stability

Evaluation of these new mud systems included the use of several laboratory methods to monitor behavior and fluid stability. They included resistance to contaminants, temperature and time stability. Also studied was the fluid effect on elastomers. Results of these tests show a stable fluid with good rheological properties can be formulated. See Table 6 for fluid properties after heat aging 16 hours at 150°C (300°F).

Return permeability tests conducted on Berea sandstone cores show that the system is non-damaging to production zones. This also indicates that even with the addition of booster fluid the drilling fluid system behaves as a conventional synthetic-based fluid.

Elastomers testing

Fluid samples were submitted for elastomers testing. Results of tests conducted on commonly used elastomers do not reveal any significantly detrimental effects. It is therefore concluded that this fluid is compatible with the particular elastomers tested. Test results are shown in Tables 8 and 9.

Benefits of the system

The tests also indicated that the addition of booster fluid would dramatically increase the biodegradability of the drilling fluid. This significantly reduces the environmental impact that results from the offshore dumping of drill cuttings generated with oil-base drilling fluids. This has a measurable impact on the cost and risk of offshore operations, and may eliminate the need to transport drill cuttings to shore bases for disposal in the future.

Field application

The mysid shrimp 96-hour LC50 toxicity test results exceeded the limit required by the EPA rendering the system usable in the Gulf of Mexico. Based on lab generated data and results of seabed surveys, the system can be environmentally accepted for potential use offshore UK, Norway and West Africa and other environmentally sensitive areas.

Discussion

Fluid formulated with IO base oil shows stable properties after heat aging for 24 and 72 hours at 300° F. The HPHT and the emulsion remained stable indicating the absence of hydrolysis. Drill solids contamination resulted in a relatively small change in the properties especially in high temperature testing.

Conclusion

An improved, more biodegradable synthetic drilling fluid can provide performance equal to conventional invert fluids at different oil water ratios, at high density, under high temperature conditions and in the presence of common contaminants encountered while drilling.

Based on research data the rate of biodegradation of a synthetic fluid can be enhanced several folds with the addition of booster fluid thus making it more compliant for use in environmentally sensitive areas.

Toxicity and bioaccumulation tests conducted on this system indicate that cuttings impregnated with this fluid can be discharged offshore, causing minimal harm to marine life organisms.

Preliminary results from the sea bed surveys conducted in a deep water offshore environment confirmed that this biodegradation enhancement approach is of a high ecological importance. It allows the oil on the seafloor to biodegrade faster, thus a faster recovery of the sea bed environmental equilibrium.

The use of this greener fluid can minimize and possibly eliminate the usually high cost associated with hauling, treatment and disposal or injection of drill cuttings.

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References

1. Davies, J.M.: “Pseudo Oil Muds (POBMs). “How Can Their Environment Impact Be Minimized?”, paper presented at IBC Conference on the prevention of Oil discharge from Drilling Operations - The Options, Aberdeen, Scotland, June.15-16, 1994.
2. Davies, J.M., *et al.*: “Effects of the Use of Oil-Based Drilling Muds in the North Sea,” Marine Pollution Bull., 1984. 363.
3. Durrieu J., Zurdo C., Benaissa S. Clark, D.: “Environmentally Friendly Invert Fluid Systems with Enhanced Rate of Biodegradation,” paper SPE 61212 International Conference on Health, Safety

and the Environment, Stavanger. June 26-28, 2000

4. Friedheim, J.E., Pantermueehl, R.M.: “Superior Performance with Minimal Environmental Impact: A novel Nonaqueous Drilling Fluid,” paper SPE/IADC 25753 presented at the SPE/IADC Drilling Conference, Amsterdam, Feb.23-25, 1993.
5. Jones, R.D., Hulse, M., Redden, J.: “The Development and Performance of a Nontoxic Oil Mud,” Drilling, April, 1983. P.47.
6. McKee, J.D.A., Dowrick, K., Astleford, S.J., “A New Development Towards Improved Synthetic Based Fluid”, paper SPE/IADC 29405 presented at the SPE/IADC Conference, Amsterdam, Feb. 28 – March 2, 1995
7. Peresich, R.L., Burell, B.R, Prentice, G.M.: “Development and Field Trial of a Biodegradable Invert Emulsion Fluid,” paper SPE/IADC 21935 presented at the 1991 SPE/IADC Drilling Conference, Amsterdam, Mar.11-14, 1991.
8. Rushing, J.H., Churan, M.A., Jones, F.V.: “Bioaccumulation from Mineral Oil-Wet and Synthetic Liquid-Wet Cuttings in a Estuarine Fish, *Fundulus Grandis*,” paper SPE 23350 presented at the First International Conference on Health, Safety & Environment in Oil & Gas Exploration & Production, The Hague, Nov.10-14, 1991.
9. Schaanning, M.T.., Pettersen, O., Oen, H., Efraimsein, E., Kjellberg, F., Koniecny, R., Oreld, F., Rustad, I.: “Test of Degradation of Novadril II Drill Mud on Cuttings Under Simulated Seabed Conditions,” Draft Niva Report 0-94066, Nov. 30, 1994.
10. Steber, J., Herold, C.P., Henkel, KgaA, Limia, J.M.: “Anaerobic Biodegradation of Organic Carrier Fluids for Invert Emulsion Drilling Fluids”. Offshore vol. 54, Number 9, Sept. 1994

SI Metric Conversion Factors

bbl × 1.589873	E–01	= m^3
gal × 3.785412	E–03	= m^3
cp. × 1.0	E–03	= Pas
inch × 2.54	E+00	= cm
lbm × 4.535924	E–01	= kg
ft × 3.048	E–01	= m
psi × 6.894757	E+00	= kPa
psi × 6.894759	E–02	= bar
ppg × 2.853	E+00	= kg/m^3
lbm/gal × 1.198264	E+02	= kg/m^3
lb/100 ft^2 × 4.788026	E–01	= Pa
(°F-32) ÷1.8	E+00	= °C

Table 1 - Fluids formulations – Optimization of the booster fluid

Form. No.	Ref.	F1	F2	F3	F4	F5	F6	F7	F8	F9
Fatty Acid, %	0	0	0	0	5	5	5	10	10	10
Phosphorus , %	0	15	10	5	15	10	5	15	10	5
Organic N2, %	0	15	10	5	15	10	5	15	10	5
OWR	69/31	77/23	74/26	72/28	79/21	77/23	74/26	82/18	79/21	76/24
Density, SG	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Properties after HR 16 hrs @ 250 F										
Fann 600 rpm	68	53	47	63	43	48	51	49	43	55
Fann 300 rpm	43	29	26	37	25	28	29	29	25	31
PV, cP	**25**	**24**	**21**	**26**	**18**	**20**	**22**	**20**	**18**	**24**
YP, lb/100 ft^2	**18**	**5**	**5**	**11**	**7**	**8**	**7**	**9**	**7**	**7**
Gel, 10”	10	1	2	5	2	2	3	4	2	4
Gel, 10’	26	4	5	10	6	6	6	7	5	5
HTHP, 80°C/ 35 bars, mls	3	2	2	2	3	2	2	3	3	3
E.S., Volts	660	180	130	520	230	200	480	230	270	270

Table 2 - Aerobic biodegradation – oxygen consumption (mg/l) versus days – booster optimization

Time, (days)	Control Olive Oil	Control Bacteria	Untreated Mud	F1	F2	F3	F4	F5	F6	F7	F8	F9
0	0	0	0	0	0	0	0	0	0	0	0	0
3	316	98	340	711	204	267	90	2	545	5	393	123
6	752	251	471	1323	584	833	93	9	1006	9	887	187
12	1552	323	1130	2232	1317	1541	107	52	1780	1478	1850	300
18	2341	355	2120	3077	1890	1994	806	1034	2322	2840	2784	402
24	3102	373	2580	3933	2348	2341	1171	1579	2766	4132	3659	494
36	4549	408	2790	5598	3121	2852	1444	2193	3828	8588	5390	656
42	5229	467	3246	6394	3459	3071	1517	2387	5424	10789	6180	721
48	5884	535	3532	7130	3783	3283	1580	2586	6797	12229	6737	781
54	6505	538	3740	7673	4123	3488	1650	2794	7776	13213	7152	836
60	7107	544	3910	8136	4477	3695	1738	3012	8640	14040	7515	882
72	8232	553	4020	8960	5233	4120	2006	3495	9846	15440	8159	969
% increase.	-	-	-	222	-	-	-	-	225	386	203	-
Fatty Acid, %	0	0	0	0	0	0	5	5	5	10	10	10
Phosphorus , %	0	0	0	15	10	5	15	10	5	15	10	5
Organic N_2, %	0	0	0	15	10	5	15	10	5	15	10	5
OWR	-	-	69/31	77/23	74/26	72/28	79/21	77/23	74/26	82/18	79/21	76/24
Mud Weight, SG	-	-	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10

Table 3 - Evaluation of booster components

Composition	Phosphorus 3	Phosphorus 1	Phosphorus 2
Density, ppg	**11.0**	**11.0**	**11.0**
O/W ratio	**80/20**	**80/20**	**80/20**
Base fluid, ml	0.561	0.561	0.561
Fatty acid, ml	34.1	34.1	34.1
Organic N2, gm	27.4	27.4	27.4
Phosphorus 3, ml	41	-	-
Phosphorus 1, ml	-	41	-
Phosphorus 2, ml	-		41
Initial Properties			
600/300	93/56	121/84	160/106
200/100	42/27	68/51	86/68
6/3	7/6	24/22	60/27
PV	**37**	**37**	**54**
YP	**19**	**47**	**52**
10sec/10Min Gels	7/8	21/27	28/45
E.S, Volts	**780**	**1380**	**1220**
Hot Roll Properties	***@300°F***	***@300°F***	***@300°F***
600/300	69/43	66/39	157/91
200/100	33/21	30/19	75/47
6/3	9/8	6/5	7/4
PV	**26**	**27**	**66**
YP	**17**	**12**	**25**
10sec/10Min Gels	8/12	6/8	5/10
E.S, Volts	530	290	270
HTHP (300°F), mls	6	4	3

Table 4 - Biodegradation – oxygen consumption (mg/l) versus days – Base oils

Days	Control Olive Oil	Oil A Olefin	Oil B Paraffin	Oil C Exp Olefin	Oil D Ester
0	0	0	0	0	0
1	813	1341	288	201	3394
2	867	1551	383	271	4063
6	1145	2108	504	355	6532
8	1710	2433	537	380	7394
12	1942	3146	630	443	9880
14	2114	3487	685	493	14416
16	2420	4058	785	533	16961
20	2655	5125	1051	561	21206
22	3016	5705	1141	573	21685
26	3429	8830	1521	649	21751
32	3603	10410	1935	662	21800
34	3670	11058	2082	676	21812
36	3694	11709	2209	689	21831

Table 5. - Aerobic biodegradation – effect of booster on invert muds

Days	Control Bacteria	C16/18 Oil Reference	Mud A	Mud A +booster	Mud B	Mud B +booster	Mud C	Mud C + booster
0	0	0	0	0	0	0	0	0
1	112	1341	249	44	539	1051	329	409
2	176	1551	405	2000	390	1265	351	670
6	276	2108	450	5851	2672	5825	378	1064
8	326	2433	498	6800	3037	10104	444	1186
12	426	3146	621	9503	6067	14968	468	1479
14	507	3487	711	13500	9736	16571	478	1627
16	520	4058	877	15026			506	1841
20	530	5125	1006	15500			561	2105
22	540	5705	1112	15860			770	2233
26	573	8830	1288	16402			933	2334
32	582	10410	1353	16680			990	2400
34	595	11058	1378	16808			1012	2410
36	598	11709	1385	16942			1015	2426
% increase.	-	-		1200	-	-		239
Booster %	0	0	0		0		0	
OWR	-	-	80/20	80/20	80/20	80/20	80/20	80/20
M. W, SG	-	-	1.10	1.10	1.10	1.10	1.10	1.10

Table 6 - Effect of booster on fluid stability

Fluid number	1	2	3	4	5	6	7	8	9	10	11
ISOTEQ, liter	613.05	584.60	516.58	417.95	516.58	516.58	516.58	516.58	516.58	516.58	516.58
Fatty Acid, l/m3	40.83	39.00	34.14	27.62	34.14	34.14	34.14	34.14	34.14	34.14	34.14
Phosphorus 3, l/m3	48.60	46.00	40.95	33.13	40.95	40.95	40.95	40.95	40.95	40.95	40.95
Organo-Clay, kg/m3	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00
Emulsifier, kg/m3	15.70	15.70	15.70	15.70	15.70	15.70	15.70	15.70	15.70	15.70	15.70
Wetting agent. Kg/m3	17.30	17.30	17.30	17.30	17.30	17.30	17.30	17.30	17.30	17.30	17.30
Lime, kg/m3	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Water, l/m3	176.77	155.00	151.54	125.45	151.54	151.54	151.54	151.54	151.54	151.54	151.54
CaCl2, kg/m3	58.13	46.50	49.83	41.25	49.83	49.83	49.83	49.83	49.83	49.83	49.83
Organic N2, kg/m3	32.29	31.00	27.24	22.04	27.24	27.24	27.24	27.24	27.24	27.24	27.24
F.L. reducer, kg/m3	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Barite, kg/m3	--	203.0	604.2	1222.3	604.2	604.2	604.2	604.2	604.2	604.2	604.2
Drill solids, %	--	--	--	--	3.00	6.00	9.00	3.00	3.00	300	300
Salt water, %	--	--	--	--	--	--	--	5.00	15.00	--	--
Aging Temp, °F	180	180	180	180	300	300	300	300	300	300	300
Aging Time, Hours	16	16	16	16	16	16	16	16	16	48	72
Oil Water Ratio	80/20	82/18	82/18	80/20	80/20	80/20	80/20	75/25	69/31	80/20	80/20
PROPERTIES @ 120 °F, after Hotrolling											
Density, sg	0.97	1.10	1.44	1.84	1.45	1.48	1.51	1.43	1.41	1.44	1.44
Fann 600 rpm	28	34	69	119	85	90	105	86	110	60	47
Fann 300 rpm	17	21	43	72	50	50	59	49	68	34	25
Fann 6 rpm	3	4	9	13	6	3	6	4	10	4	2
Fann 3 rpm	2	3	8	12	5	2	5	3	8	3	2
PV, cps	**11**	**13**	**26**	**47**	**35**	**40**	**46**	**37**	**42**	**26**	**22**
YP, lb/100ft2	**6**	**8**	**17**	**25**	**15**	**10**	**13**	**12**	**26**	**8**	**3**
Gels, lb/100ft2	3/5	4/6	8/12	13/18	6/8	3/6	6/10	5/8	10/11	4/5	2/5
HPHT 300°F/500 psi	**11**	**7**	**6**	**5**	**34**	**30**	**28**	**34**	**28**	**56**	**80**
E.S, Volts	260	330	530	480	220	260	240	170	130	320	120

Table 7 - Toxicity data – booster with Phosphorus 3

Test Method	Result
Sediment Reworker Test using Leptocheirus plumulosus	96 hr. LC50 = >27 ml/kg
Drilling Fluids Toxicity Test using Mysidopsis bahia	96 hr. RF =54,7000 ppm SPP

Table 8 - Fluid effects on volume and hardness of various elastomers

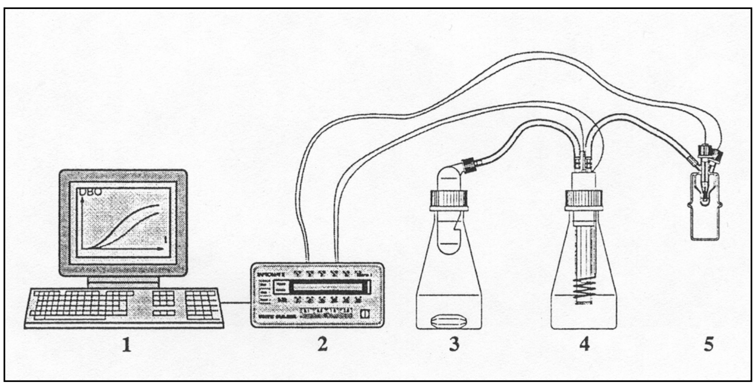
Test Temp./Pressure, °C/psi	179/5000	179/5000
FKN, Fluroelastomer, Viton	30.70	Brittle
FEPM, Aflas	13.80	-5
NBR, Nitrile	3.85	0
HNBR, Hydrogenated nitile	9.76	-5
NITRILE	--	--

Table 9 - Fluid effects on specific physical characteristics for selected elastomers

Elastomer	TestDuration	Temp., °C	Volume Change, %	Hardness Change, %	T. Strength chg.,N/mm2	Elongation Change, %	Reactivity 1=low,3=high
F	72 hr	150	-0.6	-3	-2.5	-25	1

Test Protocols: ASTM 0471, DIN 53521, DIN 53519, and DIN 53504

Figure 1 - Schematic of the Sapromat



1/2: Recorder/Control Panel
3: Reactor
4: Oxygen supplier
5: Pressure Gauge

Figure 2 - Evolution of the rate of biodegradation of IO base

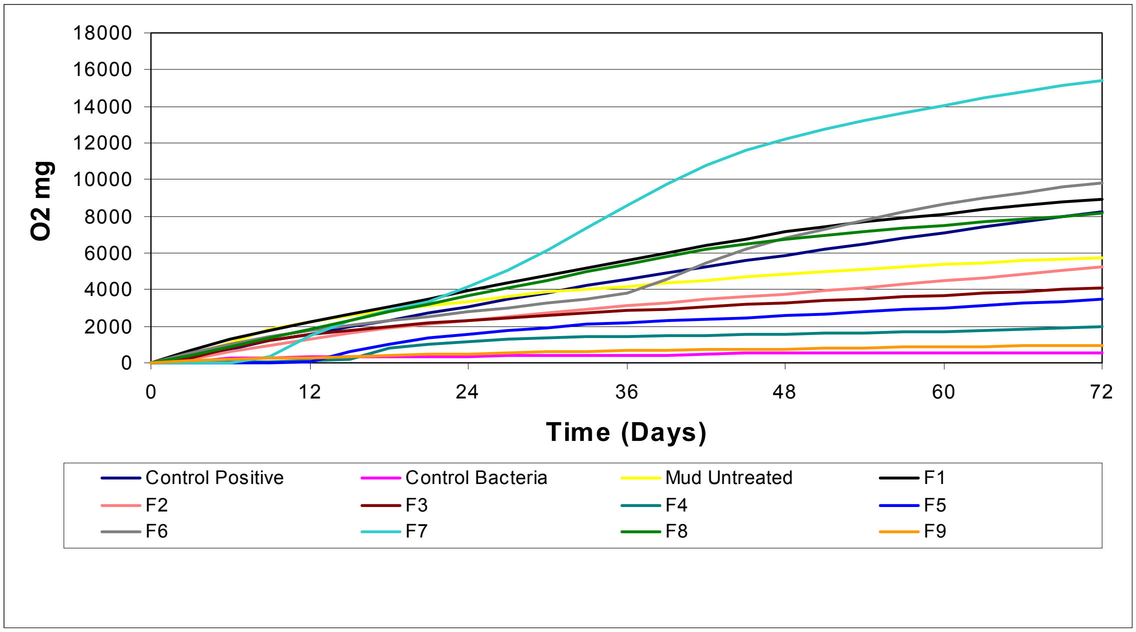


Figure 3 - Evolution of the rate of base oils biodegradation

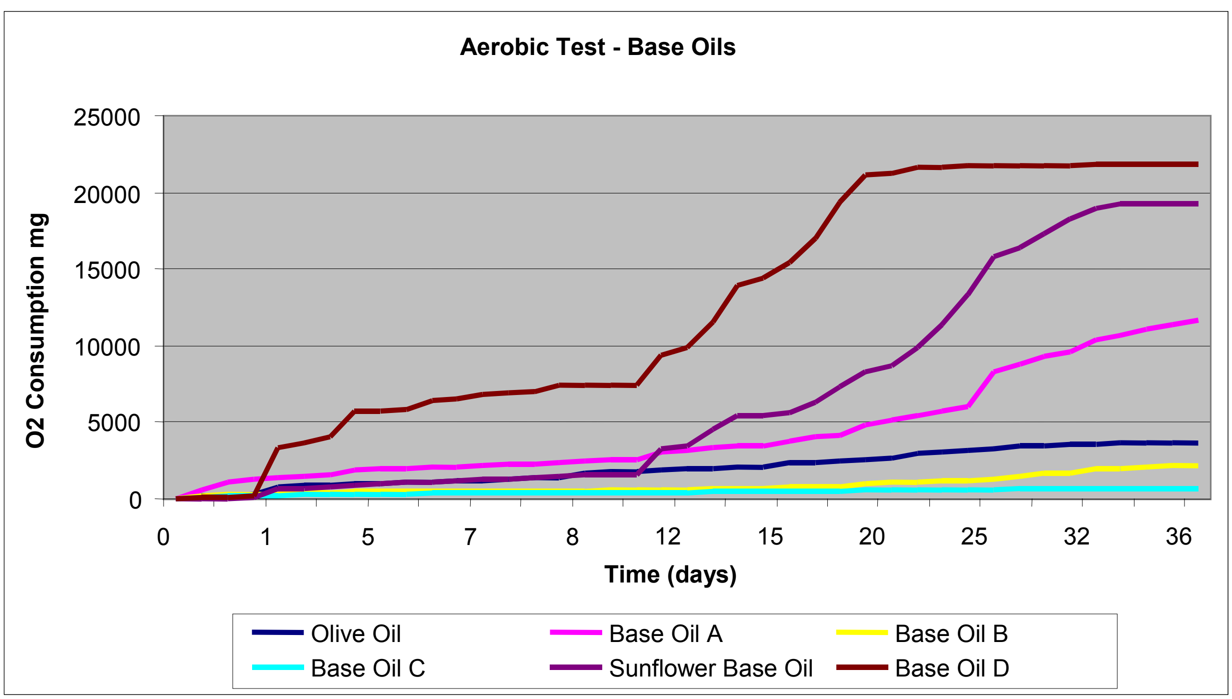


Figure 4 - Evolution of the rate of biodegradation - muds with Phosphorus 3

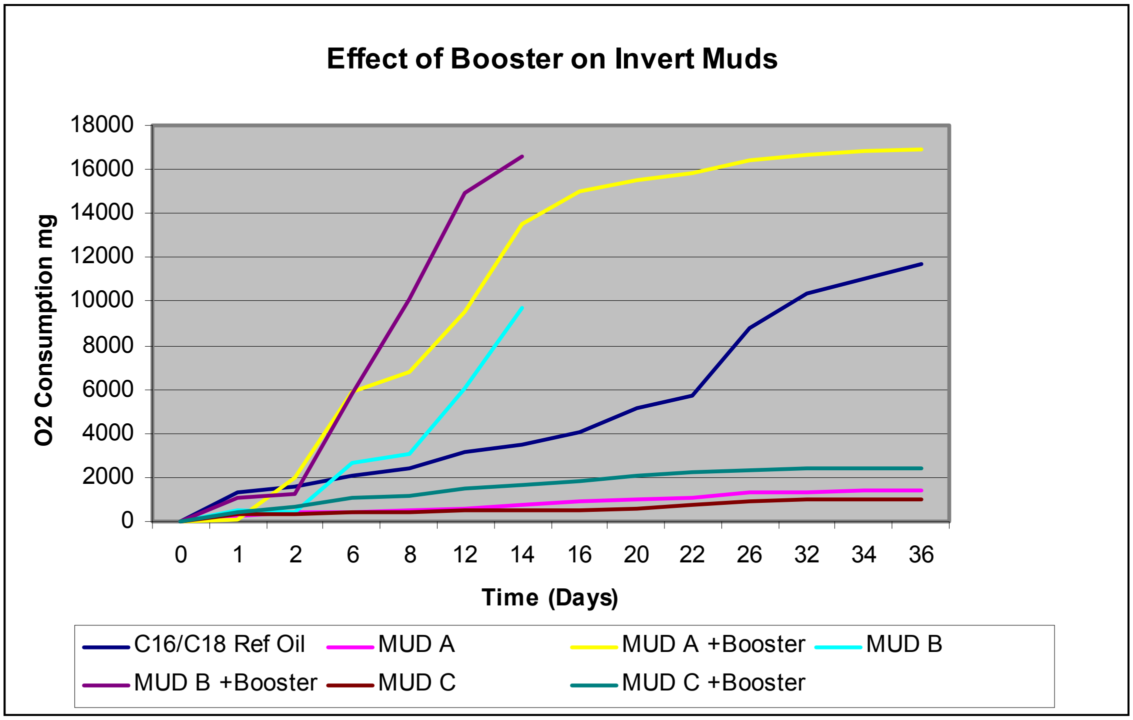


Figure 5 - Yield Point Evaluation of booster fluids on weighted fluids

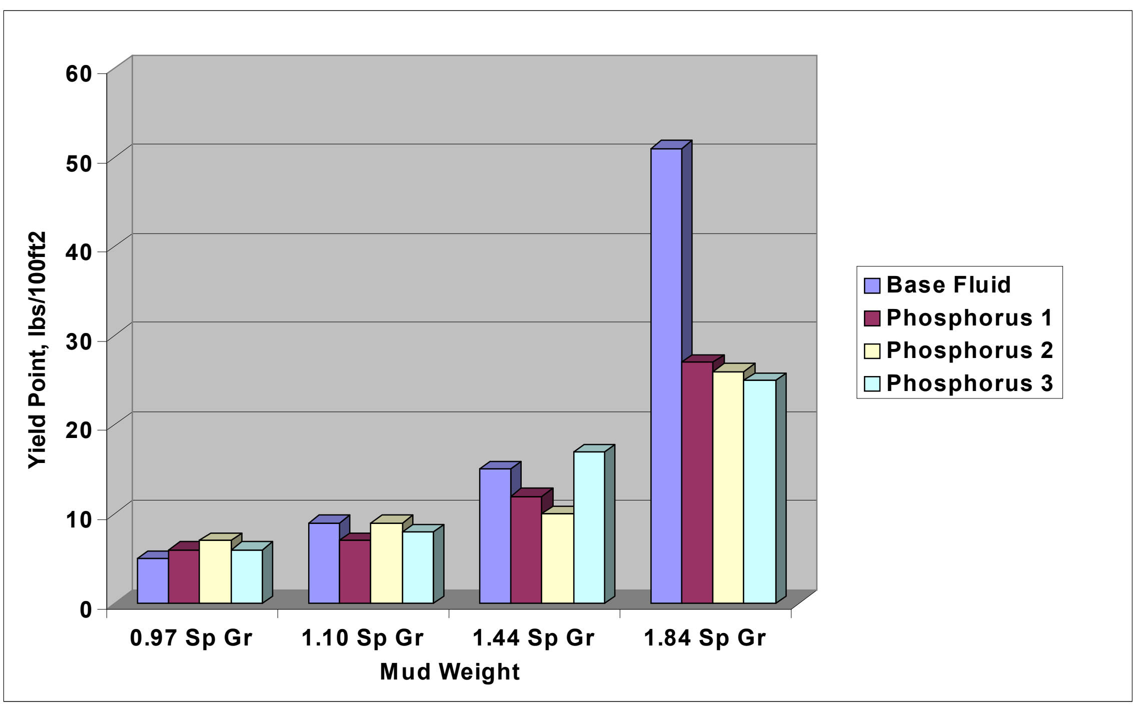


Figure 6 - Electrical Stability Evaluation of booster fluids on weighted fluids

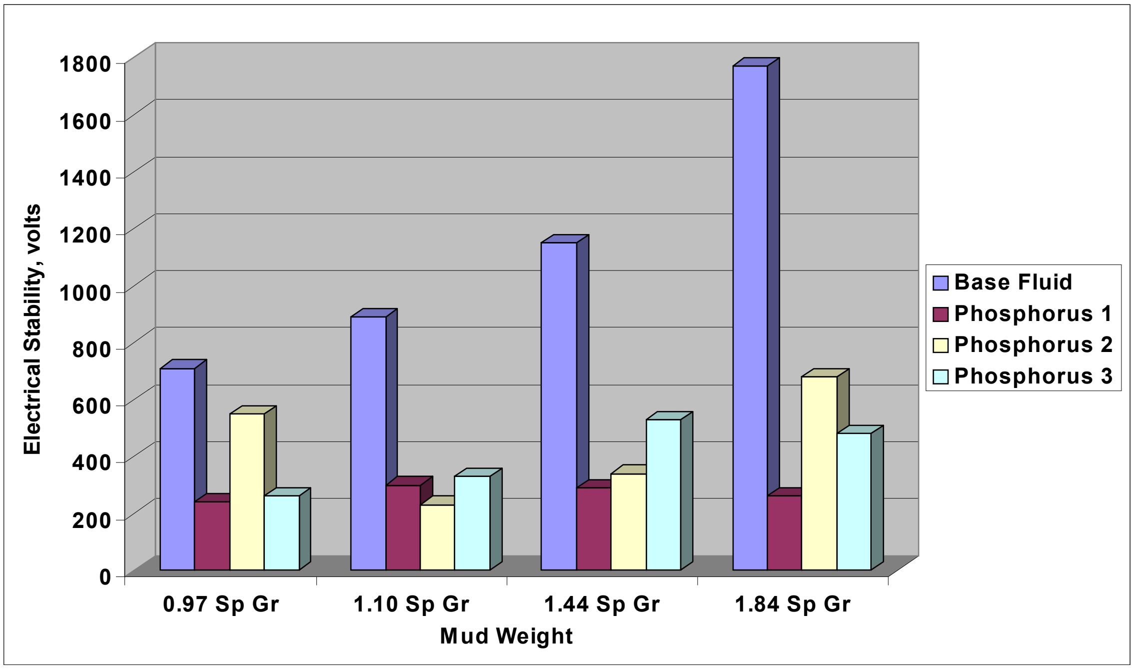
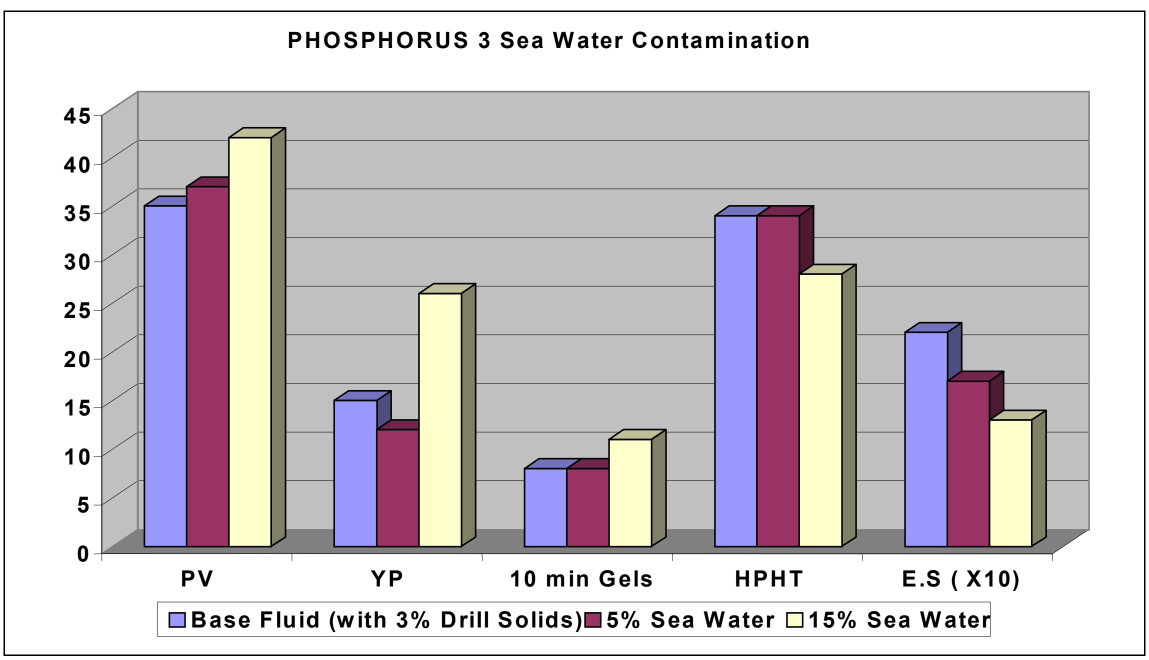
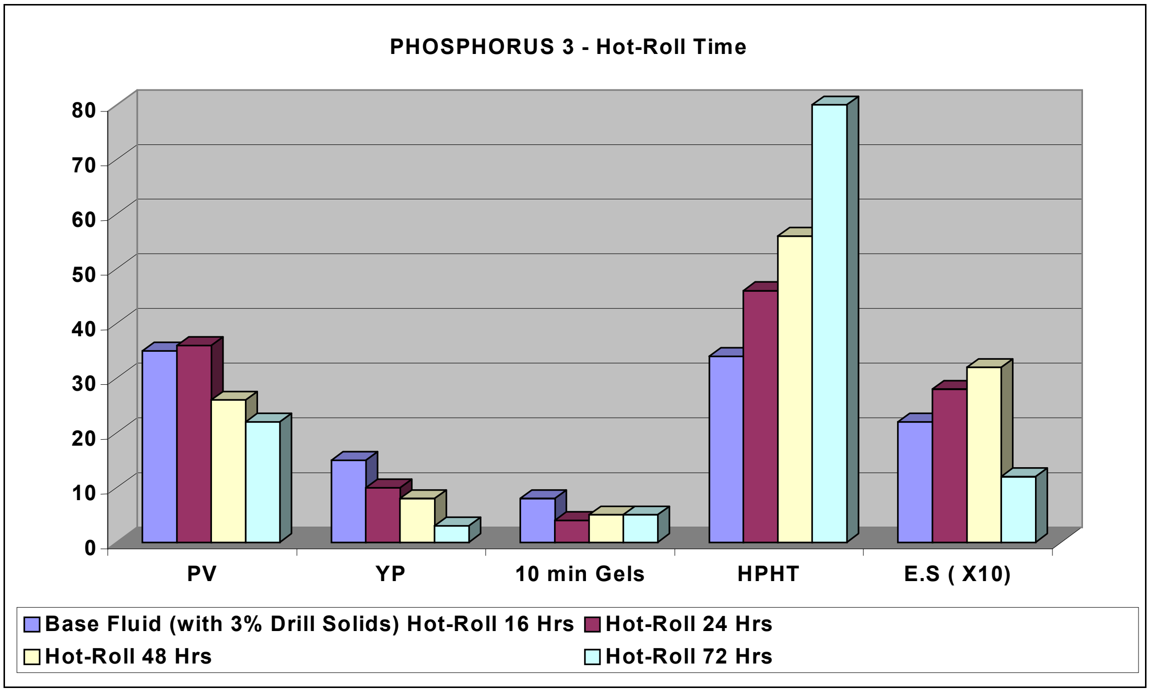


Figure 7 - Evaluation of seawater contamination on mud properties



Figures 8 - . Evaluation of time stability on mud properties



Glossary

PV = Plastic Viscosity
YP = Yield Point
HTHP = High temperature High Pressure
E.S = Electrical Stability
OWR = Oil Water Ratio
M.W, SG = Mud weight, Specific F.L Reducer = Fluid Loss Reducer