Oil-Base Systems

Introduction

This chapter covers the specifics of the VERSA oil-base systems. They are non-aqueous systems as described in general in the Non-Aqueous Emulsions chapter. The oil in these systems functions as a continuous external phase of a water-in-oil-emulsion (invert) mud. The VERSA systems are named according to the base oil used and according to special application (function). The primary systems are:

System Name	Base Oil
VERSADRIL®	Diesel
VERSACLEAN®	Mineral oil
VERSAVERT®	Ultra low-tox mineral oil

Other VERSA names are used from time to time for new or unique base oils. Regardless of the base oil, these systems can often use the same additives and similar formulations. While most VERSA systems use products from the VERSA product line, some may use additives from the NOVA system product line, depending on the base oil and environmental monitoring and regulations.

Two special application systems are VERSAPORT™ and VERSACORE.™ Each of these systems can be formulated with any base oil. VERSAPORT systems have elevated Low-Shear-Rate Viscosity (LSRV) and are formulated for high-angle and horizontal drilling. VERSACORE systems are all-oil coring fluids designed to produce minimal changes to the core.

VERSA systems differ from NOVA systems in the kinds of base liquids used.

VERSA systems differ from NOVA systems in the kinds of base liquids used. VERSA systems' base oils either originate from or are difficult to distinguish from oils refined from crude oil. NOVA systems base liquids are synthetic materials and are easily distinguishable from those oils refined from crude oil.

Regardless of the system name, there are two general categories that can be applied to all VERSA systems:

1. **Conventional.** Conventional VERSA systems normally use VERSAMUL® emulsifier and VERSACOAT® wetting agent in the formulation, have low filtration rates, and utilize lime to form calcium-base soaps. These are "tight" and very stable emulsions that have zero API (100 psi) fluid loss. They usually have high electrical stability and a controlled High-Temperature, High-Pressure (HTHP) fluid loss of less than 10 cm^3 at 500 psi and 300°F, with no water in the filtrate.
2. **Relaxed-filtrate.** Relaxed-filtrate VERSA systems normally use VERSACOAT as the emulsifier and VERSAWET® as the wetting agent in the formulation, have high filtration rates, and rely on "surfactant" chemistry to form the emulsion (do not require lime to form calcium soaps). These are slightly less stable emulsions, purposefully run with higher HTHP filtrates than conventional invert emulsion muds. It is normal for them to have some water in the HTHP filtrate. They may also have measurable API (100 psi) filtrate. The emulsions are loose and the electrical stability will be lower than that of conventional invert emulsion muds. Relaxed-filtrate systems normally do not contain fluid-loss-control additives. Relaxed-filtrate systems are designed for cost effectiveness and to increase penetration rates. *NOTE: A relaxed-filtrate system can easily be converted to a conventional system, but a conventional system cannot be converted to a relaxed system.*

Systems

VERSA systems are invert-emulsion, oil-base muds that can be formulated...

The VERSA systems are invert-emulsion, oil-base muds that can be formulated and engineered to meet a wide range of applications and requirements. The following system descriptions and formulations are presented as a basis and guide for the wide range of fluids that are possible with the VERSA oil-base product line.

CONVENTIONAL VERSA SYSTEMS

Conventional VERSA systems are tightly emulsified, temperature-stable, invert-emulsion, oil-base drilling fluids. Conventional systems can be formulated for any oil mud application. (Due to the large number of base oils available, some areas use special system names. Occasionally the base oil will be named using the system name followed by a "B" suffix, such as VERSAVERT B.)

VERSAMUL is the primary emulsifier for conventional VERSA systems.

VERSAMUL is the primary emulsifier for conventional VERSA systems. VERSAMUL must react with lime to form a calcium soap to act as an emulsifier. The system must be kept alkaline at all times to function properly. One pound of lime should be added to the system for each pound of VERSAMUL added. Additional lime should be added as required to maintain 3 lb/bbl of excess lime in the system. (A similar product, VERSAVERT P, is used in the North Sea and other areas. The "P" suffix indicates that it is the "primary" emulsifier.)

VERSACOAT is the primary wetting agent for conventional VERSA systems and provides secondary emulsification. (A similar product, VERSAVERT S, is used in formulations for the North Sea and other areas instead of VERSACOAT. The "S" suffix indicates that it is the "secondary" emulsifier.)

VG-69® organophilic clay is used to viscosify the fluid to support weight material and provide gel strengths. A number of other organophilic clays are available, including VG-PLUS,™ VG-HT,™ VERSAVERT VIS and others depending on the formulation and requirements. If additional viscosity is required, VERSAMOD™ or VERSA-HRP® can be used.

Calcium chloride brine is normally used as the internal phase of the invert emulsion. The amount of brine, or Oil:Water Ratio (OWR), will affect properties and formulation. Any concentration of calcium chloride up to 38% by weight can be used.

The VERSA systems usually have a sufficiently low fluid loss with the basic formulation. However, if ultra-low fluid loss is required, VERSATROL® I is the preferred filtration control additive. VERSALIG® can be used if asphalt and gilsonite are not allowed. The VERSAVERT systems use the filtration-control additive VERSAVERT F, a resin copolymer. Pilot testing should be performed to determine the exact amount of VERSATROL I, VERSALIG or VERSAVERT F to be used in a particular formulation.

When mixing a conventional system, the following order of addition is recommended:

1. Oil.
2. Organophilic clay (VG-69).
3. VERSA-HRP or VERSAMOD.
4. Lime.
5. VERSAMUL.
6. VERSACOAT (allow to mix for 20 min).
7. $CaCl_2$ brine (add slowly).
8. Weight material.
9. VERSATROL I (allow to mix for 30 to 60 min).

CONVENTIONAL VERSA SYSTEM FORMULATION CHARTS (25% BY WT $CaCl_2$ BRINE: 96% SALT PURITY)

Oil:Water Ratio →	70:30	80:20	90:10
VERSAMUL (lb/bbl)	6 - 8	8 - 10	8 - 10
VERSACOAT (lb/bbl)	1 - 2	1 - 2	2 - 3
Lime (lb/bbl)	6 - 8	8 - 10	8 - 10
VG-69 (lb/bbl)	2 - 4	2 - 3	1 - 1.5
VERSATROL I (lb/bbl) (if required)	4 - 6	6 - 8	8 - 10

Oil:Water Ratio	Mud Weight (lb/gal)	Oil (bbl)	Water (bbl)	$CaCl_2$ (lb/bbl)	M-I BAR® (lb/bbl)
70:30	8.5	0.625	0.265	32.6	22.7
	9	0.613	0.259	31.9	49.7
	10	0.588	0.249	30.6	103.8
	11	0.563	0.235	29.3	157.8
80:20	12	0.609	0.150	18.5	226.3
	13	0.581	0.143	17.7	279.6
	14	0.552	0.136	16.8	332.9
	15	0.524	0.129	15.9	386.2
90:10	16	0.555	0.061	7.5	451.9
	17	0.523	0.057	7.1	504.4
	18	0.491	0.054	6.6	557.1

NOTE: 1 lb/bbl is equal to 2.85 kg/m^3.

Table 1: Conventional system — barite formulations.

Oil:Water Ratio	Mud Weight (lb/gal)	Oil (bbl)	Water (bbl)	$CaCl_2$ (lb/bbl)	FER-OX® (lb/bbl)
70:30	8.5	0.627	0.265	32.7	21.1
	9	0.617	0.261	32.1	46.8
	10	0.597	0.252	31.1	98.3
	11	0.578	0.244	30.1	149.7
	12	0.558	0.236	29.1	201.2
	13	0.538	0.228	28.0	252.6
80:20	14	0.588	0.145	17.9	316.6
	15	0.566	0.140	17.2	367.5
	16	0.544	0.134	16.5	418.4
90:10	17	0.584	0.064	7.9	482.3
	18	0.558	0.061	7.5	532.7

NOTE: 1 lb/bbl is equal to 2.85 kg/m^3.

Table 2: Conventional system — FER-OX formulations.

(NOTE: VERSA-HRP or VERSAMOD may be needed for additional viscosity and gels depending on the base oil used. VERSA-HRP is particularly applicable prior to transporting muds to the rig. Use the calculation listed below to determine the amount of VERSA-HRP and to adjust the amount of VG-69.)

VERSA-HRP/VG-69 CALCULATION

Calculate the reduced VG-69 by multiplying the amount of VG-69 listed in the table above by 0.80:

VG-69 = VG-69 (lb/bbl) x 0.80

Calculate the amount of VERSA-HRP by multiplying the amount of VG-69 listed in the table above by 0.40:

VERSA-HRP = VG-69 (lb/bbl) x 0.40

Example:

Oil:water ratio	70:30
VG-69 (lb/bbl)	4 (from table above)

New VG-69 (lb/bbl) = 4 x 0.80 = 3.2

VERSA-HRP (lb/bbl) = 4 x 0.40 = 1.6

VERSAVERT SYSTEM

The VERSAVERT system and products are widely used in Norway and the North Sea. As mentioned above, the basic products are VERSAVERT B (base oil), VERSAVERT P (primary emulsifier) and VERSAVERT S (secondary emulsifier). Other products used in this system include VERSAVERT F (fluid loss), VERSAVERT VIS (organophilic clay) and VERSAVERT M (rheology modifier).

Other products may be used in these systems, including products named with a "C" suffix (indicating "conditioner"), an oil-wetting agent to help prevent and correct water-wet solids, and products named with a "T" suffix (indicating "thinner"), an oil-base mud dispersant similar to VERSATHIN.®

Additive	Material	Function	Concentration
VERSAVERT B	Ultra-low-tox mineral oil	Continuous phase	65 - 95% (vol)
Freshwater	Freshwater	Water phase	5 - 35% (vol)
$CaCl_2$	Calcium chloride	Salinity and water-phase activity	100 - 250 kg/m^3
VERSAVERT P	Tall oil polyamide	Primary emulsifier	10 - 25 kg/m^3
VERSAVERT S	Polyamide	Secondary emulsifier and fluid loss	6 - 20 kg/m^3
VERSAVERT F	Resin copolymer	Fluid loss	0 - 20 kg/m^3
VERSAVERT VIS	Organo - hectorite	Viscosifier	20 - 30 kg/m^3
VERSAVERT M	Dimer fatty acid	Rheology modifier	0 - 10 kg/m^3
Lime	Calcium hydroxide	Alkalinity control	0 - 25 kg/m^3
M-I BAR	Barite	Density control	As required

NOTE: 1 lb/bbl is equal to 2.85 kg/m^3.

Table 3: VERSAVERT system — barite formulation.

Relaxed-filtrate Versa systems

Relaxed VERSA systems are less tightly emulsified fluids resulting in higher fluid loss that helps to maximize penetration rates. These economical systems combine the inhibitive properties inherent in oil-base drilling fluids with high penetration rates.

Relaxed-filtrate VERSA systems use VERSACOAT as the primary emulsifier, VERSAWET as the wetting agent and VG-69 and VERSA-HRP as viscosifiers and gelling agents. Calcium chloride ($CaCl_2$) brine at 25% by weight normally comprises the internal phase, but any desired percent by weight up to 38%, may be used. Fluid-loss additives are generally not used in relaxed systems.

When mixing a relaxed system, the following order of addition is recommended:

1. Oil.
2. Organophilic clay (VG-69).
3. VERSA-HRP or VERSAMOD.
4. VERSACOAT.
5. VERSAWET.
6. Lime (allow to mix 20 min).
7. $CaCl_2$ brine (add slowly).
8. Weight material (allow to mix for 30 to 60 min).

Relaxed Versa System Barite Formulation Chart (25% by wt $CaCl_2$ brine: 96% salt purity)

Oil:Water Ratio →	75:25	80:20	85:15	90:10
VERSACOAT (lb/bbl)	2 - 3	3 - 4	4 - 5	5 - 6
VERSAWET (lb/bbl)	1 - 2	2 - 3	2 - 3	3 - 4
VG-69 (lb/bbl)	8 - 10	6 - 8	6 - 8	4 - 6
Lime (lb/bbl)	1 - 2	1 - 2	1 - 2	1 - 2

Oil:Water Ratio	Mud Weight (lb/gal)	Oil (bbl)	Water (bbl)	$CaCl_2$ (lb/bbl)	M-I BAR (lb/bbl)
75:25	8.5	0.703	0.231	28.5	21.5
	9	0.690	0.227	27.9	49.0
80:20	10	0.703	0.173	21.4	111.7
	11	0.675	0.166	20.5	166.1
	12	0.646	0.159	19.6	220.5
	13	0.617	0.152	18.8	274.9
85:15	14	0.622	0.108	13.3	335.8
	15	0.591	0.103	12.7	389.9
90:10	16	0.590	0.065	8.0	449.8
	17	0.558	0.061	7.5	503.5
	18	0.526	0.058	7.1	557.3

NOTE: 1 lb/bbl is equal to 2.85 kg/m^3.

Table 4: Relaxed systems — barite formulations.

(NOTE: VERSA-HRP or VERSAMOD may be needed for additional viscosity and gels depending on the base oil used. VERSA-HRP is particularly applicable prior to transporting muds to the rig. Use the calculation listed below to determine the amount of VERSA-HRP and to adjust the amount of VG-69.)

Versa-HRP/VG-69 calculation

Calculate the reduced VG-69 by multiplying the amount of VG-69 listed in the table above by 0.80:

VG-69 = VG-69 (lb/bbl) x 0.80

Calculate the amount of VERSA-HRP by multiplying the amount of VG-69 listed in the table above by 0.40:

VERSA-HRP = VG-69 (lb/bbl) x 0.40

Example:

Oil:water ratio 75:25
VG-69 (lb/bbl) 10 (from table above)

New VG-69 (lb/bbl) = 10 x 0.80 = 8
VERSA-HRP (lb/bbl) = 10 x 0.40 = 4

RELAXED VERSA SYSTEM FER-OX FORMULATION CHART (25% BY WT $CaCl_2$ BRINE: 96% SALT PURITY)

Oil:Water Ratio →	70:30	80:20
VERSACOAT (lb/bbl)	3 - 8	2 - 6
VERSAWET (lb/bbl)	1 - 2	2 - 3
VG-69 (lb/bbl)	2 - 10*	2 - 8*
Lime (lb/bbl)	2 - 4	2 - 4

*See specific mud weights below.

Oil:Water Ratio	Mud Weight (lb/gal)	Oil (bbl)	Water (bbl)	$CaCl_2$ (lb/bbl)	VG-69 (lb/bbl)	FER-OX (lb/bbl)
70:30	8.5	0.653	0.276	34.0	8 - 10	12.6
	9	0.643	0.272	33.5	6 - 8	39.0
	10	0.624	0.264	32.5	6 - 8	91.9
	11	0.605	0.255	31.5	4 - 6	144.9
	12	0.585	0.247	30.5	4 - 6	197.8
	13	0.566	0.239	29.5	2 - 4	250.7
80:20	14	0.621	0.153	18.9	6 - 8	313.0
	15	0.599	0.148	18.2	6 - 8	364.9
	16	0.577	0.142	17.5	4 - 6	416.8
	17	0.555	0.137	16.8	4 - 6	468.7
	18	0.532	0.131	16.2	2 - 4	520.6

NOTE: 1 lb/bbl is equal to 2.85 kg/m³.

Table 5: Relaxed systems — FER-OX formulations.

(NOTE: VERSA-HRP or VERSAMOD may be needed for additional viscosity and gels depending on the base oil used. VERSA-HRP is particularly applicable prior to transporting muds to the rig. Use the calculation listed below to determine the amount of VERSA-HRP and to adjust the amount of VG-69.)

VERSA-HRP/VG-69 CALCULATION

Calculate the reduced VG-69 by multiplying the amount of VG-69 listed in the table above by 0.80:

VG-69 = VG-69 (lb/bbl) x 0.80

Calculate the amount of VERSA-HRP by multiplying the amount of VG-69 listed in the table above by 0.40:

VERSA-HRP = VG-69 (lb/bbl) x 0.40

Example:

Oil:water ratio 70:30
VG-69 (lb/bbl) 8 (from table above)

New VG-69 (lb/bbl) = 8 x 0.80 = 6.4
VERSA-HRP (lb/bbl) = 8 x 0.40 = 3.2

VERSAPORT systems utilize elevated low-shear-rate viscosities...

When engineering a VERSAPORT system, a six-speed VG meter is required to check the rheological properties.

VERSAPORT SYSTEMS

VERSAPORT systems utilize elevated low-shear-rate viscosities to provide improved hole cleaning in high-angle wells. A VERSAPORT system consists of any VERSA system treated with an LSRV rheology modifier. A VERSAPORT system can be either a conventional or relaxed-filtrate system. Either VERSAMOD or VERSA-HRP can be used to modify the LSRV of the conventional VERSA systems. However, only VERSA-HRP is recommended to modify the LSRV of relaxed-filtrate VERSA systems. *NOTE: VERSAMOD is not used in relaxed systems because it requires a high lime content to be effective, and these systems do not normally use a high lime content.*

VERSAMOD is an organic gelling agent that increases the LSRV and gel strengths with minimal effect on high-shear-rate viscosities. Increased water content (lower OWR) improves the performance of VERSAMOD, and the concentration needed to achieve the desired effect is lower. It also requires the addition of a pound of lime for each pound of VERSAMOD used to achieve the desired effect. VERSAMOD must be subjected to high shear conditions or increased temperature to fully yield its maximum effect. Since most liquid mud plants do not have the ability to expose VERSAMOD to conditions that will fully activate it, care must be taken not to overtreat when mixing VERSAMOD or other fatty-acid additives at a mud plant. Once on the rig, they will readily yield when sheared through the bit and exposed to temperature, producing excessive rheological properties if overtreated.

VERSA-HRP is the preferred viscosifier to increase rheology for supporting weight material prior to shipping the mud to the rig. It yields better in the mud plant and will produce a more stable viscosity as the system is circulated through the well. VERSA-HRP is a polyamide gelling agent that increases the yield point and gel strengths with minimal effects on the plastic viscosity. Unlike VERSAMOD, which interacts with the emulsified water phase, VERSA-HRP works on and requires active solids (organophilic clay or drill solids) to viscosify a fluid.

When engineering a VERSAPORT system, a six-speed VG meter is required to check the rheological properties. Tables 6 and 7 are formulation charts for conventional VERSAPORT systems. The following order of addition is recommended, when mixing a VERSAPORT system:

1. Oil.
2. Organophilic clay (VG-69).
3. Lime.
4. VERSAMOD or VERSA-HRP.
5. VERSAMUL.
6. VERSACOAT (allow to mix for 20 min).
7. $CaCl_2$ brine (add slowly).
8. Weight material.
9. VERSATROL I (allow to mix 30 to 60 min).

VERSAPORT SYSTEM FORMULATION CHARTS (25% BY WT $CaCl_2$ BRINE: 96% SALT PURITY)

Oil:Water Ratio →	60:40	70:30	80:20
VERSAMUL (lb/bbl)	6 - 8	5 - 7	4 - 6
VERSACOAT (lb/bbl)	0	0 - 1	0 - 1
Lime (lb/bbl)	8 - 10	8 - 10	8 - 10
VG-69 (lb/bbl)	1 - 3	1 - 3	1 - 3
VERSATROL I (lb/bbl)	0 - 4	2 - 5	3 - 6
VERSAMOD* (lb/bbl)	1 - 2	2 - 4	3 - 5

Oil:Water Ratio	Mud Weight (lb/gal)	Oil (bbl)	Water (bbl)	$CaCl_2$ (lb/bbl)	M-I BAR (lb/bbl)
60:40	8.5	0.549	0.361	44.6	10.0
	9	0.539	0.354	43.7	37.4
	10	0.517	0.340	41.9	92.2
	11	0.496	0.324	40.2	147.0
70:30	12	0.550	0.233	28.7	217.9
	13	0.525	0.222	27.4	272.0
	14	0.500	0.211	26.0	326.0
80:20	15*	0.535	0.132	16.3	393.9
	16*	0.506	0.125	15.4	447.2

*At higher mud weights, it is often advantageous to use a combination of VERSA-HRP and VERSAMOD at the mud plant to avoid excessive viscosity after the fluid is displaced and circulated.
NOTE: 1 lb/bbl is equal to 2.85 kg/m³.

Table 6: VERSAPORT system – barite formulations.

Oil:Water Ratio	Mud Weight (lb/gal)	Oil (bbl)	Water (bbl)	$CaCl_2$ (lb/bbl)	FER-OX (lb/bbl)
60:40	8.5	0.551	0.362	44.6	9.5
	9.0	0.542	0.356	43.9	35.5
	10	0.525	0.345	42.6	87.5
	11	0.508	0.334	41.2	139.5
70:30	12	0.572	0.242	29.8	207.4
	13	0.552	0.233	28.8	258.9
	14	0.533	0.225	27.7	310.3
80:20	15*	0.580	0.143	17.6	376.0
	16*	0.557	0.137	16.9	426.9

*At higher mud weights, it is often advantageous to use a combination of VERSA-HRP and VERSAMOD at the mud plant to avoid excessive viscosity after the fluid is displaced and circulated.
NOTE: 1 lb/bbl is equal to 2.85 kg/m³.

Table 7: VERSAPORT system — FER-OX formulations.

VERSACORE systems are all-oil or minimal water-containing oil-base systems.

Low HTHP values are a very good indicator of the ability of a coring fluid to minimize fluid invasion.

VERSACORE SYSTEMS

VERSACORE systems are all-oil or minimal water-containing oil-base systems. These systems are used most often for coring operations where the invasion of drilling fluid containing emulsified water or changes in wettability from high concentrations of emulsifiers and wetting agents is undesirable. VERSACORE systems can be formulated from any base oil, using several approaches.

The difficulty with these all-oil systems is obtaining adequate viscosity, just as with the early oil-base muds. One solution is to use a very high concentration, 15 to 30 lb/bbl, of asphaltic additives such as VERSATROL I or STABIL HOLE.® Another approach involves using the combination of VERSA-HRP with an organophilic clay and a lesser amount of VERSATROL I. A third approach uses the combination of some asphalt, some organophilic clay and an oil-viscosifying polymer. A number of such polymers exist, and they require specific pilot testing to identify an appropriate formulation. Polymeric viscosifiers can be used to further enhance the viscosity of the basic VERSACORE system. Regardless of the actual formulation, VERSACORE systems develop more viscosity when special high-yielding organophilic clays are used, such as VG-HT or VERSAVERT VIS.

These systems can be formulated with minimal amounts of emulsifier and wetting agent because they do not contain added water. In addition, the selection of an emulsifier and wetting agent is less important. In fact, the selection of a powerful emulsifier and wetting agent (such as VERSAMUL and VERSAWET as is normally used in other oil-base systems) may be undesirable due to their ability to change wettability. Systems can be easily formulated with just 1 lb/bbl VERSAMOD and 1 lb/bbl VERSACOAT so that core wettability is affected less. Although no water is added to the system, they usually pick up water from the pits during the displacement and while drilling so that actual water contents are in the 3 to 5% range.

Low HTHP values are a very good indicator of the ability of a coring fluid to minimize fluid invasion. One advantage to using a high concentration of VERSATROL I is the low HTHP values. Bridging agents are extremely important in minimizing core invasion in addition to low HTHP values. Barite and ground calcium carbonate (such as LO-WATE™ or SAFE-CARB™) are excellent bridging agents. The quantity and the particle size distribution of the bridging agent are important. As a general rule of thumb, 15 to 30 lb/bbl of a bridging agent with a median particle size one-half to one-third the largest pore-throat diameter is needed to initiate bridging. Table 8 gives VERSACORE formulations using LO-WATE (calcium carbonate) as a bridging agent and M-I BAR for density.

When mixing a VERSACORE system, the following order of addition is recommended:

1. Oil.
2. Organophilic clay.
3. VERSA-HRP.
4. Lime.
5. Emulsifier or wetting agent: VERSACOAT, VERSAMOD, VERSAWET, VERSAMUL, etc. (allow to mix for 20 min).
6. VERSATROL I (allow to mix for 30 to 60 min).
7. Weight materials.

VERSACORE System Formulation Chart LO-WATE and M-I BAR

Mud Weight (lb/gal)	Oil (bbl)	Organo-clay* (lb/bbl)	VERSA-HRP (lb/bbl)	Emulsifier and Wetting Agent** (lb/bbl)	Lime (lb/bbl)	LO-WATE (lb/bbl)	VERSATROL I (lb/bbl)	M-I BAR (lb/bbl)
7.5	0.91	11.4	3.8	2 - 4	1 - 2	16.3	16.3	9
8.0	0.89	11.0	3.7	2 - 4	1 - 2	16.0	16.0	35
9.0	0.86	10.2	3.4	2 - 4	1 - 2	15.5	15.5	88
10.0	0.83	9.4	3.1	2 - 4	1 - 2	15.0	15.0	141
11.0	0.79	8.6	2.9	2 - 4	1 - 2	14.5	14.5	194
12.0	0.76	7.8	2.6	2 - 4	1 - 2	14.0	14.0	247
13.0	0.73	7.0	2.3	2 - 4	1 - 2	13.5	13.5	300
14.0	0.70	6.2	2.1	2 - 4	1 - 2	13.0	13.0	353
15.0	0.66	5.4	1.8	2 - 4	1 - 2	12.5	12.5	406
16.0	0.63	4.6	1.5	2 - 4	1 - 2	12.0	12.0	459
17.0	0.60	3.8	1.3	2 - 4	1 - 2	11.5	11.5	512
18.0	0.57	3.0	1.0	2 - 4	1 - 2	11.0	11.0	565

*VG-HT, VERSAVERT VIS or similar high-yielding organophilic clay.
**1 lb/bbl VERSACOAT and 1 lb/bbl VERSAMOD are recommended.
NOTE: 1 lb/bbl is equal to 2.85 kg/m^3.

Table 8: Generic VERSACORE formulations.

Products

BASE OILS

This section describes the typical properties of some base oils used for VERSA systems that are listed in Table 9.

Diesel oil composition may differ somewhat from one refiner to another, but most #2-grade diesel is acceptable for use in oil-base muds without requiring changes in mud formulations. Some refiners add pour-point suppressants to their diesel oils in cold climates (and change the grades they sell) during the winter months. This may affect the performance of mud additives. The diesel oil should be pilot tested if this is suspected to be a problem.

Mineral oils vary widely in composition and properties depending on the crude oil, refining process and "cut." The properties of mineral oil from one company are usually consistent, but the properties of mineral oils from different companies vary widely. One method used to compare mineral oils is the aromatic content. Various methods exist for measuring and reporting the aromatic content of oils. One proposed standard is called the Polycyclic (or polynuclear) Aromatic Hydrocarbon (PAH) content reported as phenanthrene. These phenanthrene aromatic values are approximately 1/10 of normal reporting values, considerably less than the values normally used to express aromatic content. Using this PAH measure, standard mineral oils such as used in VERSACLEAN systems contain ~0.35% PAH as phenanthrene.

Ultra-low-toxicity systems, such as the VERSAVERT system, use base mineral oils that may be classified as **Enhanced Mineral Oil** (EMO). These are highly purified materials having lower PAH content. One proposed standard for EMOs is to have a PAH content of about 0.001% as phenanthrene.

System	VERSADRIL	VERSACLEAN	VERSAVERT
Base oil	#2 diesel	Mineral oil	Enhanced mineral oil
Density (SG)	0.83 - 0.86	0.80 - 0.86	0.81
Viscosity (cSt* at 106°F)	3 - 4	2 - 3	3 - 4
Flash point (°F)	150 (130 min.)	212 (150 min.)	>239
Pour point (°F)	14	-0.4	-74
Aniline point (°F)	149 (135 min.)	169 (150 min.)	194
Aromatics (normal reporting units)	18 - 30%	1 - 15%	nil
Aromatics PAH (as phenanthrene)	~3%	~0.35%	~0.001%

*cSt = centistokes.

Table 9: Typical base oil properties.

ADDITIVES

VERSAMUL is a blend of liquid emulsifiers, wetting agents, gellants and fluid-stabilizing agents. It is used as the primary emulsifier in the conventional VERSA systems and can often be used as the only product needed to form the basic oil-in-water emulsion. VERSAMUL reacts with lime to form calcium soap. This calcium soap acts as the emulsifier in the tightly emulsified conventional low-filtrate systems. Initial system formulations require 4 to 10 lb/bbl (11.4 to 28.5 kg/m^3), depending on the properties desired and other components in the system. For VERSAMUL to function effectively, one pound of lime must be added for every pound of product. An excess lime content of 3 lb/bbl must be maintained. VERSAMUL forms an extremely tight emulsion and is stable at high temperatures.

VERSACOAT surfactant is a multi-functional liquid additive used as a wetting agent for the conventional VERSA systems and as a primary emulsifier in the relaxed VERSA systems. Secondary benefits include improved thermal stability and HTHP filtration control. The product is effective over a wide temperature range and in the presence of contaminants. VERSACOAT also reduces the adverse effects of water contamination. Initial system formulations require from 1 to 8 lb/bbl (2.85 to 22.8 kg/m^3), depending on desired properties and other components in the system. This polyamide-base material is a versatile and economical additive.

VERSACOAT also reduces the adverse effects of water contamination.

VERSAWET surfactant is a concentrated liquid and powerful oil-wetting agent used in relaxed-filtrate systems where the excess lime content is less than 2 lb/bbl. It is an excellent wetting agent that is especially effective in systems using difficult-to-wet FER-OX (hematite). Initial system formulations require 1 to 4 lb/bbl VERSAWET (2.85 to 11.4 kg/m^3). It is also effective at oil-wetting barite and drill solids, and at reducing the adverse effects of water contamination. VERSAWET is an oil-base mud thinner and wetting agent at low alkalinity but acts more like an emulsifier at high alkalinity. Overtreatment with VERSAWET will thin the mud at low alkalinity and viscosify it at high alkalinity.

VG-69 organophilic clay is the primary viscosifier and gelling agent used in most oil-base systems. VG-69 is an amine-treated bentonite, which provides viscosity and gel structure to increase carrying capacity and suspension properties, providing support for weight materials and improved cuttings removal. VG-69 also aids in filter-cake formation and filtration control. Typical concentrations range from 2 to 10 lb/bbl (5.7 to 28.5 kg/m^3). Depending on the base oil, higher concentrations of VG-69 may be needed to have the same rheological properties as a comparative diesel-oil mud. In addition, VG-69 does not yield as rapidly in some base oils and when mixing new fluids in mud plants. Care must be taken not to overtreat because when it is exposed to shear and temperature in the well it will fully yield. Water acts as a polar activator in these systems, and the performance of VG-69 is enhanced by lower oil-to-water ratios (higher water content).

VG-PLUS organophilic clay is an improved viscosifier and gelling additive for all non-aqueous fluids, including NOVA synthetic-base and VERSA oil-base systems. VG-PLUS is an amine-treated bentonite that improves the carrying capacity, gel strength and suspension of weight material. It will also assist in improving filter-cake quality and filtration control. VG-PLUS has particular application in mixing plants and when building new fluids, to provide viscosity for fluids that have not been exposed to shear and temperature. Typical concentrations range from 2 to 10 lb/bbl (5.7 to 28.5 kg/m^3). Water acts as a polar activator in these systems and the performance of VG-PLUS is enhanced by lower oil-to-water ratios (higher water content).

VG-HT organophilic clay is a premium viscosifier and gelling agent for use in VERSA oil-base/pseudo-oil-base and NOVA synthetic-base systems exposed to high temperatures. This high-quality, amine-treated hectorite is used to increase carrying capacity and suspension properties, providing support for weight materials and improved drill cuttings removal in high-temperature wells. VG-HT also aids in filter-cake formation and filtration control. Typical concentrations range from 2 to 10 lb/bbl (5.7 to 28.5 kg/m^3). Water acts as a polar activator in these systems and the performance of VG-HT

Granular or powdered $CaCl_2$ should be used instead of flakes or pellets...

Quick lime is a highly reactive chemical and should not be used in situations where it might come into contact with water...

is enhanced by lower oil-to-water ratios (higher water content).

Calcium chloride ($CaCl_2$) salt is used in most oil-base mud systems to reduce the activity (A_w) of the mud for shale inhibition. High-purity (95 to 98% purity) granular or powdered calcium chloride is preferred to tech grade (77 to 80% purity) or flaked products. Care should be taken to identify the grade of $CaCl_2$ that is being used when preparing VERSADRIL and VERSACLEAN systems. Granular or powdered $CaCl_2$ should be used instead of flakes or pellets, especially when it is being added to an existing mud. Stock 11.6 lb/gal calcium chloride brine used for workovers and completions can be diluted and used instead of sacked materials. See the appropriate salt table for activity vs. percent-by-weight salt correlation in the Non-Aqueous Emulsion chapter.

Lime (hydrated or slaked lime — $Ca(OH)_2$) is used in all oil-base muds for alkalinity control to increase the P_{OM} and maintain some excess lime. In conventional systems, it is used in higher concentrations as a source of calcium for forming calcium soaps with the primary emulsifiers. It is used in all oil-base mud systems as a source of alkalinity when drilling acid gases (CO_2 and H_2S).

Quick lime (CaO) is sometimes used as a source of calcium and alkalinity in oil-base muds. In humid or wet (rainy) environments, hydrated lime should be used instead of quick lime. In conventional systems, quick lime will react with the emulsifiers to form calcium soaps. Quick lime reacts with water to evolve heat and form calcium hydroxide (lime, $Ca(OH)_2$). The evolution of heat may be helpful in building emulsions. Quick lime can be used in oil-base mud systems as a source of alkalinity when drilling acid gases (CO_2 and H_2S). *CAUTION: Quick lime is a highly reactive chemical and should not be used in situations where it might come into contact with water, such as high humidity and rainy climates! When it gets wet, heat is generated that can cause fire or injury. Quick lime is a strong irritant and precautions should be taken to prevent inhalation and skin exposure.*

VERSA-HRP, a polyamide liquid, increases the yield point and gel strengths of both conventional and relaxed filtrate systems with minimal effects on the plastic viscosity. The primary application of VERSA-HRP is the mixing of new VERSA systems, but it can be used with any type of oil to increase the carrying capacity and improve its shear-thinning characteristics. The recommended concentration of VERSA-HRP for the initial makeup of new fluids is 1 to 4.5 lb/bbl (2.85 to 12.83 kg/m^3) of VERSA-HRP in combination with 4 to 12 lb/bbl (11.4 to 34.2 kg/m^3) of organophilic clay. VERSA-HRP can also be used in sweeps and viscosified spacers. VERSA-HRP does not viscosify oil. It requires active solids (organophilic clay or drill solids) to viscosify. *NOTE: VERSA-HRP should be pilot tested before it is added to a mud system.*

VERSA SWA, an amphoteric surfactant for all oil-base muds, is a powerful supplemental wetting agent that aids in oil-wetting solids. It can reverse water-wetting, even in badly contaminated muds. It is particularly useful when complex salts are drilled or water flows are encountered. Small treatments (usually less than 1 lb/bbl) are adequate. The product is a supplemental wetting agent intended only to be used in conjunction with the primary wetting agent, and is often kept in inventory as a contingency item. *Pilot testing is recommended before treatment.*

VERSAMOD, an organic gelling agent, is a liquid rheology profile modifier for oil-base mud systems. It increases the LSRV and gel strengths with minimal effect on its high-shear-rate viscosities. Its primary application is in large-diameter directional wells where improved hole cleaning is needed. Water improves the

The* VERSAPORT *system uses* VERSAMOD *to obtain its rheology profile.

VERSATHIN tends to work best in high solids-muds…

performance of VERSAMOD and the concentration needed to achieve the desired effect is less at low oil:water ratios. Normal concentrations range from 1 to 4 lb/bbl (2.85 to 11.4 kg/m^3) of VERSAMOD, depending on the brine content. The VERSAPORT system uses VERSAMOD to obtain its rheology profile. It requires the addition of a pound of lime for each pound of VERSAMOD used, to achieve the desired effect. Because of the lime requirement, VERSAMOD is not as effective in relaxed-filtrate systems as it is in conventional systems.

VERSATROL I gilsonite is a temperature-stable, naturally occurring weathered asphalt. It is an effective filtration-control additive and plugging agent that can be used at bottom-hole temperatures up to and in excess of 400°F. VERSATROL I enhances emulsion stability and imparts minimum viscosity increases. Treatments range from 2 to 8 lb/bbl (5.7 to 22.8 kg/m^3) of VERSATROL I as a fluid-loss-control agent in most systems. Pilot testing should be conducted to determine the actual concentration needed for each application. At high concentrations, VERSATROL I can be used to increase the viscosity of the system. Difficult-to-viscosify fluids like VERSACORE will use between 15 and 30 lb/bbl (43 to 86 kg/m^3) of VERSATROL I to obtain adequate viscosity.

VERSALIG amine-treated lignite is used as a fluid-loss-control agent. VERSALIG is an alternative to the commonly used gilsonite/asphalt base fluid-loss agents like VERSATROL I or STABIL HOLE. Recommended treatments range from 2 to 12 lb/bbl (5.7 to 34.2 kg/m^3) for most applications. Pilot testing should be conducted to determine the concentration for each application.

VERSATHIN, a liquid, oil-base mud dispersant, is designed to reduce the yield point and gel strengths. Additions of VERSATHIN result in a less-viscous fluid without the need for dilution or changing the oil:water ratio. Recommended treatment levels range from 1 to 2 lb/bbl (2.85 to 5.7 kg/m^3) of VERSATHIN. VERSATHIN tends to work best in high solids-muds as it tends to disperse aggregating solids. *NOTE: VERSATHIN must be pilot tested before being added to a mud system.*

VERSAVERT P primary emulsifier blend is based on polyamides and modified fatty acids designed for use in the VERSAVERT system. It is a primary emulsifier or “basic package” and can be used alone to form tight water-in-oil emulsions. It is particularly effective when used in conjunction with VERSAVERT S. This product is similar in function to VERSAMUL (in a conventional system) and has application in many systems.

VERSAVERT S secondary emulsifier is used in the VERSAVERT system to provide high emulsion stability and solids wetting. It is primarily a secondary emulsifier. Although it can be used alone to form a water-in-oil emulsion, it is more effective when used in conjunction with VERSAVERT P. This product is similar in function to VERSACOAT (in a conventional system) and has application in many systems.

VERSAVERT F filtration additive is a resin copolymer used in the VERSAVERT system. It is used to provide supplementary fluid-loss control and has application in many systems.

Properties

__Plastic viscosity should be maintained at minimum values to optimize bit hydraulics and penetration rates.__

__Low filtrates reduce the loss of expensive fluids to the formation…__

It is difficult to specify exact ranges for mud properties such as the plastic viscosity, yield point and gel strengths due to the wide range of applications. Many variables affect the value of these properties including the base oil's properties; temperature; the type, size and concentration of solids; oil:water ratio; brine concentration; and the overall stability of the mud. Determining whether these properties are in the correct range for a given mud weight depends heavily on the fluid properties needed for the well conditions. For example, a high yield point and gel strengths are needed for carrying capacity in large-diameter holes, but these properties may not be desirable in small-diameter holes with mud of the same weight.

Plastic viscosity should be maintained at minimum values to optimize bit hydraulics and penetration rates. If the plastic viscosity trends upward over a period of time without increases in the mud weight, it usually indicates that fine solids are building up in the mud. Increases in the volume percent solids even from weight material will increase the plastic viscosity. Decreases in the oil:water ratio (higher water content) will increase the plastic viscosity.

Yield point and gel strengths are governed by two requirements. The first is the need to maintain sufficient thixotropy (gel structure) to suspend weight material and cuttings, plus provide carrying capacity. The second requirement is to minimize annular pressure losses and Equivalent Circulating Densities (ECDs). The yield point and gel strengths can be increased with additions of VG-69, VERSAMOD or VERSA-HRP. They can be reduced with additions of VERSATHIN or the base oil.

The allowable solids content depends on the oil:water ratio, the water-phase density and the volume and specific gravity of the solids. Solids are abrasive, and they increase the cake thickness, plastic viscosity, pressure losses, the need for chemical treatments and the likelihood of water wetting the solids. The low-gravity solids should be kept as low as economically possible with solids-control equipment.

The alkalinity (P_{OM} or V_{SA}) of an oil-base mud is an indication of the excess lime in the mud. The P_{OM} of a conventional controlled filtrate system should be maintained above 2.5 cm^3 of 0.1 N sulfuric acid. The emulsion may become unstable if the P_{OM} of a conventional system falls below 2.5 for an extended period of time. The P_{OM} is normally maintained at 1 to 2 cm^3 of 0.1 N sulfuric acid in relaxed filtrate systems to buffer against acid gases. *NOTE: M-I bases all recommendations concerning alkalinity treatments on the API V_{SA} (P_{OM}) method. If the operator desires, M-I will determine the P_{OM} by both the API method and the "Back Titration" method. However, all treatment decisions will be made exclusively based on the API P_{OM} (direct) method.*

The HTHP filtrate (300°F and 500 psi) of conventional systems is usually less than 10 cm^3. Low filtrates reduce the loss of expensive fluids to the formation and reduce the likelihood of differential sticking in highly permeable formations. Relaxed systems normally do not use a filtration-control additive, and may contain some water in the HTHP filtrate.

Strong emulsions require high voltages to coalesce the water droplets and break down the emulsion.

The $CaCl_2$ content of the mud should be maintained at a concentration that will balance or be equal to the A_W of the formation.

EMULSION STABILITY

The Electrical Stability (ES) is a relative indication of emulsion stability. It is a measure of the voltage required to break down the emulsion and allow the emulsified water droplets to connect (i.e., coalesce) allowing electrical current to flow. Strong emulsions require high voltages to coalesce the water droplets and break down the emulsion. The electrical stability is recorded in volts. There are several main factors that affect electrical stability:

- **Water content.** As the water content increases, the distance between the water droplets decreases, allowing for easier electrical circuit completion through coalescence and a reduction in the electrical stability.
- **Water-wet solids.** A water-wet solid has a thin film of water on its surface that functions to conduct electricity like a water droplet. Solids in an invert emulsion reduce electrical stability when they become water-wet.
- **Emulsification.** The degree of emulsification affects water droplet size. Droplets are normally larger in new and unstable mud systems, resulting in low emulsion-stability values. Increased shear and temperature exposure will form smaller droplets and a better emulsion. This increases electrical stability values as does increased emulsifier and wetting agent concentration.
- **Temperature.** The temperature at which the electrical stability measurement is made will change the value obtained. This temperature should always be recorded with the electrical stability value. For trend analysis, the same temperature should be used.
- **Type of solids.** The type of solids in the mud will influence the electrical stability. For example, FER-OX (hematite) and other iron oxide materials may reduce the electrical stability of an invert emulsion mud.

Electrical stability is an important indicator of emulsion stability, but it should not be used as an absolute value or indication of its condition. A mud with a high but declining electrical stability may not be as stable as a mud with a lower but stable electrical stability. Muds with extremely low emulsion stability will have filtrate and rheological indications as well as low and declining electrical stability values. Low electrical stability may be a cause for concern, but an established trend of declining electrical stability values is more serious and requires immediate action. The electrical stability values are relative to the system from which they are recorded. A well-defined downward trend or a rapid drop indicates the emulsion is weakening.

Electrical stability measurements should be made and recorded routinely. These values should be plotted so trends can be easily seen. Trends upward or downward indicate changes in the system. An analysis of sequential mud checks will indicate possible causes of the change.

SALINITY AND CONTROLLED ACTIVITY

Calcium chloride ($CaCl_2$) content should be tested by titration and compared with the A_W of the cuttings when running a controlled activity mud. The $CaCl_2$ content of the mud should be maintained at a concentration that will balance or be equal to the A_W of the formation. $CaCl_2$ concentrations above 38% are not recommended due the near saturation of the brine, which can cause fluid instability. Salt crystallization from supersaturated solutions heating and cooling can produce water-wet solids and unstable emulsions. Sodium chloride and complex blends of magnesium,

A_W is a measure of the chemical potential for water to be transferred between mud and shales.

potassium, calcium and sodium chloride brines can also be used in the internal phase. A variety of other organic non-chloride materials can be used to decrease the activity of the water phase in addition to the inorganic chloride salts like sodium and calcium chloride.

Water activity (A_W) is a measure of the chemical potential for water to be transferred between mud and shales. Activity is measured using the vapor pressure (relative humidity) of shale or mud, or it can be estimated based on the chemical composition of the brine (salinity). Pure water has an A_W of 1.0. Calcium chloride brines used in most non-aqueous emulsion muds have an A_W between 0.8 (22% wt) and 0.55 (34% wt). Lower values for activity are more inhibitive.

Clay-containing formations swell and are weakened by the adsorption of water. The possibility exists that the water from an emulsion mud can alter shales if the A_W of the shale is lower than the activity of the mud. The key to inhibition is to "balance" the activity of the mud with that of the shale so that the adsorption of water onto the shales is theoretically reduced to zero.

The transfer of water between an emulsified brine and a shale is often compared to osmosis. In osmosis, a solvent (water) diffuses through a semipermeable membrane from a low concentration of solute or salt, to a high concentration of solute or salt, to equalize the concentrations. The theory of controlled activity describes the oil-base or synthetic fluid and emulsifiers surrounding the water droplets as a semipermeable membrane. Shale control using this controlled (or balanced) activity is limited mainly to oil-base and synthetic emulsion muds. Water-base muds containing additives (such as glycols and silicates) exhibit only weak semipermeable membrane characteristics.

$CaCl_2$ is normally used to obtain activities from 1.0 to 0.40. Sodium chloride (NaCl) may be used to obtain activities from 1.0 to 0.75 (saturated NaCl). A wide variety of alternative internal-phase chemicals can be used to reduce activity. However, many alternative materials may not provide sufficiently low activity to achieve adequate inhibition. Most shales were formed in marine environments containing complex salts with calcium chloride, magnesium chloride and sodium chloride the most common salts present. These complex salts often have a greater affinity for water than sodium chloride brine, even when saturated. Calcium chloride brines are used as the internal phase of most oil-base muds as they can balance the formation salinity of most formations.

When $CaCl_2$ is added to a saturated NaCl brine, the activity is reduced but the effect is not cumulative. Activity is based on mutual solubility. Since $CaCl_2$ has a greater solubility than NaCl, sodium chloride will precipitate as fine solids at conditions above saturation.

The activity of mud and shale samples is measured with a hygrometer. The sample being checked is placed in a flask and tightly sealed with a stopper containing the hygrometer probe. The sample is given time to equalize the moisture content of the air space in the flask. The percent relative humidity, corrected for temperature, is recorded as the "Activity" (decimal value) of the sample.

VERSA systems can be formulated with either $CaCl_2$ or NaCl brines. The use of these salts in combination is not recommended, as the solubility of NaCl is limited in the presence of $CaCl_2$.

Displacements

It is desirable to have the displacing fluid slightly heavier than the fluid being displaced.

The following section applies to displacing an existing mud with an oil-base mud. Many of the principles used here also apply to displacing an oil-base mud with cement or a water-base mud. However, the spacers used would be different.

SUMMARY

1. Have a predisplacement meeting with tool pusher, company man and mud engineer to discuss displacement procedure and coordinate sequence of events.
2. Drill out and perform leak-off or formation-integrity tests.
3. Prior to the displacement, condition existing wellbore fluid to obtain the minimum acceptable viscosity and gel strengths.
4. Have all oil-base mud on location prior to displacement.
5. Have bit on bottom or close to bottom as the oil-base mud clears the bit.
6. Use large-mesh screen on shale shaker during displacement and 1 to 2 circulations afterward.
7. Spacers generally should be 200 to 500 ft in length.
   a) Water (water-base in hole).
   b) Viscosified oil or viscous oil mud.
8. Use pump rates to obtain turbulent flow.
9. Do not stop or slow pumps for any reason.
10. Reciprocate and rotate drill pipe during displacement.

DISPLACEMENT TECHNIQUES

The most efficient type of displacement occurs when the total volume of oil-base mud can be displaced in one rapid, continuous operation without stopping or slowing the pumps. Regardless of the displacement technique used, there are several factors common to all displacements that influence a good displacement and prevent cross contamination.

- **Density.** It is desirable to have the displacing fluid slightly heavier than the fluid being displaced. Because the displacing fluid is below the fluid being displaced in the annulus, the heavier density maintains segregation of the two fluids (the lighter fluid tends to float, the heavier fluid tends to sink). If a lower-density, oil-base mud must be used to displace a higher density fluid, it may be advantageous to reverse circulate.
- **Spacers.** The ideal spacer would thin the fluid, maintain turbulence of the fluid being displaced and viscosify the displacing fluid. The difference in the viscosity at the interface reduces the tendency of the fluids to intermix. Conditioning the existing fluid to reduce the viscosity and yield point is just as important as the spacer fluid. Reducing viscosity, using a thinning spacer and turbulent flow in the fluid being displaced reduces channeling and intermixing. Spacer volume is usually selected based on some annular length, with a 200- to 500-ft (61- to 152-m) column in the annulus being typical. These lengths should be selected with well control and other engineering factors considered. Typical spacers are:
  1. Water-base being displaced with oil-base:
     - Water *or,*
     - Water, followed by viscosified oil or viscous oil-base mud.
  2. Oil-base being displaced with water-base:
     - Oil *or,*
     - Oil, followed by viscosified water or viscous water-base mud.

Drill pipe is usually not positioned concentrically even in a vertical well...

The velocity profile in turbulent flow is flat and covers all of the annulus, with only a small boundary layer.

- **Pipe position and movement.** Drill pipe is usually not positioned concentrically even in a vertical well, and will be close to the wall of the hole. This eccentric annulus causes fluids to channel up through the larger side of the hole (just like the hole-cleaning situation in a horizontal well). This leaves a portion of the annular cross section uncirculated so that old mud is left behind the drill pipe on the narrow side of the hole. For this reason, the pipe should always be rotated and reciprocated during all displacements. Rotating the pipe forces the mud from behind the pipe out into the flow stream and moves the pipe around in the annulus. This changes the flow path and allows the entire cross section to be circulated, producing a more uniform displacement.
- **Pump rate.** Displacements should always be done at a pump rate high enough to ensure turbulent flow, if possible. The velocity profile in turbulent flow is flat and covers all of the annulus, with only a small boundary layer. This accomplishes several things. It results in minimal intermixing of the two fluids. It promotes a more thorough displacement of the mud in the hole by "scrubbing" the hole with turbulence, and it can clean wall cake better if an open hole section is exposed.
- **Contamination.** Contamination of some of the displacing fluid by the fluid being displaced may occur. Any fluid that is noticeably contaminated with water-base mud or wall cake should be discarded. The remaining contamination should be treated with emulsifier and/or wetting agent to ensure that water becomes emulsified and that the solids are in an oil-wet condition. Pretreatment for contamination is not recommended. The most effective treatments can be made after the displacement.
- **Conditioning and stabilization.** Once an oil-base mud system has been displaced, a period of circulating and conditioning time is required before it becomes fully stabilized. This is especially evident in newly prepared systems. Contamination from the waterbase mud system during the displacement can destabilize a system, making the importance of a good displacement even more important. After displacement, it is usually necessary to use higher than normal treatments for a few days until the system becomes stabilized. These increased treatments may include emulsifiers, wetting agents and viscosifiers.
- **Completed displacement indicators.** In some instances, it is difficult to identify when the displacing fluid returns to the shale shaker, especially when minimal intermixing occurs so that a viscous interface is not seen. Occasionally a few sacks of Lost-Circulation Material (LCM) are pumped in the leading edge of the displacing fluid as a marker. While pit volume and pump strokes are the best measures to use, other indicators listed below aid in determining when the displacement is complete or when to start returning mud to the active pits:
  1. Mud weight measurements, if the weight of the two fluids differ.
  2. Electrical stability measurements or pH.
  3. Change in viscosity.
  4. Change in color or surface appearance from grainy to glossy or shiny.
  5. Presence and subsequent elimination of water-wet solids on the shaker screens.

Lost Circulation

Increasing pump rates too rapidly after connections and trips can cause lost circulation with oil-base fluids.

Lost circulation with oil muds can quickly become intolerable due to the costs involved. In some instances, the chances of losing returns increase with oil-base drilling fluids due to the viscosifying effect of pressure on oil as compared to water. Consequently, strict controls must be maintained to minimize the viscosity and/or circulation rate. This will reduce the annular pressure losses and decrease the risk of losing circulation.

Another reason for the increased risk of losing returns with oil-base muds is their low leak-off values. The properties of oil make it an excellent fracture fluid, thereby increasing the chance of breaking down the formation. Its oil-wetting character hinders the formation's healing. For this reason, oil muds are not recommended for testing casing shoes and fracture pressures.

Increasing pump rates too rapidly after connections and trips can cause lost circulation with oil-base fluids. Oil muds thin with increasing temperatures generated while circulating and thicken with lower temperatures during periods of quiescence. The failure to bring the pumps up to speed slowly can put much higher circulating pressures on the formation. It is not uncommon for circulating standpipe pressures to decrease more than 100 psi as the mud heats to circulating temperature.

The procedures to follow in the event of lost circulation are similar to those with a water-base mud system. The use of LCM pills may be helpful under certain conditions. From 30 to 50 lb/bbl (86 to 143 kg/m^3) of lost-circulation material should be spotted at the thief zone. It is recommended that medium and/or fine grades of mica and/or NUT PLUG® be used in these pills. A blend of sized calcium carbonate particles has been used successfully in some areas. Fibrous, shredded materials such as wood fiber, shredded newspaper, etc. should be used with caution due to their detrimental effects upon the emulsion. In instances of severe lost circulation, a specially formulated high-fluid-loss diatomaceous earth slurry squeeze (Diaseal® M type), gunk squeeze or a cement squeeze may be the most practical approach.

In the most severe cases of lost circulation, where procedures have failed to regain total returns, the oil-base system should be displaced with a conventional water-base mud system.

Packer Muds

VERSA system fluids make excellent packer fluids for leaving in the annulus above a tubing packer after the well is completed. An oil-base packer offers the advantages of excellent temperature stability over long periods of time, excellent weight suspending characteristics and lasting protection of the metal goods from the effects of corrosion. Few, if any, water-base mud systems can offer these advantages simultaneously. For a more thorough discussion of this application see the section on packer fluids in the chapter on Non-Aqueous Emulsions.