CHAPTER 13

Synthetic Systems

Introduction

In the early 1980s, efforts were made to reduce the environmental impact of oil-base muds by substituting more highly refined petroleum products, referred to as *mineral* oils, for diesel oil as the base fluid in invert emulsion oil muds. Muds made with these more refined oils were less toxic than muds made with diesel oil, but many still contained sufficient aromatic compounds to be environmentally objectionable, and they did not degrade rapidly.

An environmentally acceptable substitute for these mineral-oil drilling fluids was first seen with the use of a mud made from a synthetic-base fluid (an ester) in the Norwegian sector of the North Sea in March 1990. Other synthetic-base muds quickly followed. An ether-base synthetic-base mud was used offshore Norway later in 1990. The first Poly-Alpha Olefin (PAO) was used in May 1991. Other synthetic-base fluids were introduced to the industry in the following order: Linear Alkylbenzene (LAB), acetal, Linear Alpha Olefins (LAO), Internal Olefins (IO) and Linear Paraffins (LP). These compounds may be found in petroleum and other sources, but they should not be called synthetic-base fluids unless they are synthesized or manufactured. The use of pure feedstocks and strict control of the manufacturing process assure that synthetic-base fluids will not contain trace amounts of priority pollutants as even the purest highly refined and processed liquids do.

Drilling with Synthetic-Base Muds (SBMs) has become commonplace in both the Gulf of Mexico and North Sea areas as well as other regions such as the Far East, Australia, Mexico and South America. Because of the evolving marketplace, it is viewed that the industry has moved to at least the second generation of synthetic-base fluids. The boundary which separates first- from second-generation SBMs is generally delineated by both the cost and kinematic viscosity of the synthetic-base liquid.

Typically, second-generation synthetic-base muds are cheaper and thinner. Therefore, the first-generation SBMs can be considered to be based on ester, ether and poly-alpha olefin, while the second generation is based on linear alpha olefins, internal olefins and linear paraffins. A listing of first- and second-generation synthetic-base liquids is as follows:

First-Generation	Second-Generation
Ester	LAB
PAO	LAO
Ether	IO
Acetal	LP

The acetal-base mud is considered to be a first-generation type primarily due to its cost, while the defunct linear alkylbenzene is the first entry to the second-generation type, synthetic-base mud because of its price and kinematic viscosity.

The general definition of a synthetic material is something that is produced by chemical synthesis.

The general definition of a synthetic material is something that is produced by chemical synthesis. Synthetic-base fluids must meet two criteria to be used in drilling fluids. First, they must meet local environmental standards and regulations for the discharge of drill cuttings into the sea. If the cuttings have to be collected and transported to land, then there is no advantage in using a synthetic-base mud rather than an oil-base mud other than from a health and safety perspective. Second, the synthetic material must be the base fluid for a stable mud system with the inhibitive properties of an invert-emulsion oil mud.

Due to the complexity of issues surrounding SBM, this chapter, in addition to providing an overview of M-I's synthetic systems, will also provide an overview of the chemistries, environmental issues and special precautions that may be required when using an SBM.

General Systems Descriptions

Synthetic fluids are used as the base fluid or continuous phase of invert-emulsion muds.

Synthetic fluids are used as the base fluid or continuous phase of invert-emulsion muds. These muds behave like oil-base muds. The products used to make and maintain SBMs are similar to, or in some cases, are the same as those used to build and maintain oil-base muds. These products are emulsifiers, wetting agents, Low-Shear-Rate Viscosity (LSRV) modifiers, filtration-control additives, viscosifiers and thinners.

The products used in synthetic invert emulsion muds can be used in oil-base invert emulsion muds, but products for oil-base muds should, in general, not be used in synthetic-base muds. Many of the products in oil-base muds contain refined oils that would contaminate a SBM. Different oil- and synthetic-base fluids have distinctly different chemical and physical properties and they will require different product concentrations to achieve the same mud property. Estimates of the chemicals required to make a mud should not be based on formulations made with different base fluids. It is recommended to pilot test if this is uncertain.

M-I has seven different synthetic-base systems, not all of which are still currently active. Each contained a different base fluid for the continuous phase. They are as follows:

System Name	Base Liquid
AQUAMUL I*	Ether
AQUAMUL II*	Acetal
ECOGREEN	Ester
NOVADRIL®*	Poly-alpha olefin
NOVAPLUS®	Internal olefin
NOVATEC™	Linear alpha olefin
PARADRIL™	Paraffin

* No longer actively marketed.

The system of choice depends on the particular local conditions (environmental, regulatory, logistical and commercial) as well as the technical needs of the particular application. The local operations management will address the marketplace concerns, while the technical limitations of a particular fluid are determined by its base-fluid chemistry (see "Chemistry of Synthetics" section). The table below can be used as a general guideline to the technical application of M-I's synthetic-base systems.

System Name	General	High Temperature	High Density	Deepwater	High Water Content
AQUAMUL I	x	x			
AQUAMUL II	x	x	x	x	x
ECOGREEN	x				
NOVADRIL	x	x			
NOVAPLUS	x	x	x	x	x
NOVATEC	x	x	x	x	x
PARADRIL	x	x	x	x	x

The two basic factors for deciding the technical application of a synthetic-base fluid are kinematic viscosity and thermal or chemical stability.

The two basic factors for deciding the technical application of a synthetic-base fluid are kinematic viscosity and thermal or chemical stability. Thinner base fluids such as those used in the NOVAPLUS, NOVATEC or PARADRIL systems are better for deepwater and high-density applications. High-temperature applications must avoid the use of esters (ECOGREEN) due to problems with thermal degradation or hydrolysis of the base ester.

Systems and Formulations

This section will discuss the three primary Synthetic-Base Muds (SBMs) which M-I markets. These are NOVAPLUS, the SBM with an internal olefin as the continuous phase; NOVATEC, the SBM with a linear alpha olefin as the continuous phase; and ECOGREEN, the SBM with an ester as the continuous phase. As will be seen, many aspects, including some products, are the same as those for M-I's conventional invert-emulsion or non-aqueous systems. There are, however, some important differences and these will be emphasized throughout the remainder of this chapter.

Products used in both M-I's synthetic-base systems and in the VERSADRIL® and VERSACLEAN® systems are listed below and discussed in Chapter 12, Oil-Base Systems.

VERSA Product	Function
VG-69®, VG-PLUS™	Rheology
VERSAGEL®	Rheology
VERSAGEL HT, VG-HT™	High-temperature rheology
VERSA SWA®	Supplemental wetting
VERSA-HRP®	Rheology modification
VERSALIG®	HTHP fluid-loss control
Calcium chloride ($CaCl_2$)	Water phase activity
Lime ($Ca(OH)_2$)	Alkalinity
Calcium oxide (CaO)	Alkalinity

NOTE: Product composition for products used in M-I's synthetic-base systems is critical to environmental compliance. That is why it is important to use only those products recommended for that particular mud system. Products that contain diesel oil, mineral oil or aromatic-containing compounds must not be added to any of M-I's synthetic-base systems. Products such as VERSAMUL®, VERSACOAT®, VERSAMOD™, VERSATROL® and gilsonite (to name a few) should not be used in M-I's synthetic-base systems. If you are unsure about whether or not a product can be added to one of M-I's synthetic-base systems, contact your local M-I office or M-I's environmental department.

The NOVAPLUS system…uses internal or isomerized olefins as its continuous phase.

THE NOVAPLUS SYSTEM

The NOVAPLUS system is M-I's synthetic-base system that uses internal or isomerized olefins as its continuous phase. NOVAPLUS systems are tightly emulsified and can be engineered to have a low fluid loss or be stable to temperatures in excess of 350°F (176°C). The drilling properties and limitations are the same as those for conventional (diesel or mineral oil) invert systems. $CaCl_2$ brine is recommended for the internal phase. The most common concentration of $CaCl_2$ brine is 25% by weight, which has a density of 10.3 lb/gal (1.23 SG). Higher concentrations of $CaCl_2$ brine can be used, but the $CaCl_2$ concentration should not exceed saturation, which is 40% by weight. To be on the safe side, the $CaCl_2$% concentration should stay below 35% by weight. At concentrations above this, the internal phase can become destabilized and severe problems may occur with the system.

Additive	Function	Concentration (See Table 2)
NOVAPLUS B (IO1618)	Continuous phase	60 - 95% vol., liquid phase
Freshwater	Water phase	5 - 40% vol., liquid phase
$CaCl_2$	Salinity, water phase	15 - 30% wt water phase
VG-69	Viscosifier	3 - 10 lb/bbl (9 - 30 kg/m^3)
NOVAMUL®	Primary emulsifier	6 - 8 lb/bbl (17 - 23 kg/m^3)
NOVAWET™	Wetting agent	2 - 4 lb/bbl (6 - 11 kg/m^3)
NOVAMOD™	Rheology modifier	1 - 3 lb/bbl (3 - 9 kg/m^3)
Lime	Alkalinity control	4 - 8 lb/bbl (11- 23 kg/m^3)

TABLE 1: NOVAPLUS system additives.

The products for the NOVAPLUS system are listed in Table 1 with their function and typical concentration. A brief description of each product is given below.

- NOVAPLUS B is the internal olefin-base liquid for the NOVAPLUS synthetic-base mud system and may be referred to either as NOVAPLUS B or as IO1618 (internal olefin C16 to C18).
- NOVAMUL is a liquid primary emulsifier for the NOVADRIL, NOVAPLUS and NOVATEC synthetic-base mud systems. NOVAMUL provides excellent emulsion stability, preferential wetting of solids by the continuous phase, filtration control and temperature stability.
- NOVAWET surfactant is a liquid wetting agent used in NOVADRIL, NOVAPLUS and NOVATEC synthetic-base systems. It will increase the preferential wetting of the solids in the continuous phase. It can aid in emulsion stability and High-Temperature, High-Pressure (HTHP) fluid-loss control. Additionally, it can be used to reduce the overall amount of synthetic-base mud retained on drill cuttings.
- NOVAMOD is a liquid organic gelling agent for NOVADRIL, NOVAPLUS and NOVATEC synthetic-base mud systems. NOVAMOD increases the LSRV and gel strengths with minimal effect on the high-shear-rate viscosity. Its primary application is in large-diameter directional, high-angle, horizontal and extended-reach wells to improve hole-cleaning ability or cuttings-carrying capacity. The higher the water content of the SBM, the lower the concentration of NOVAMOD is needed to achieve the desired effect. NOVAMOD requires the addition of lime at equal pound per barrel ratios to function properly.
- NOVATHIN liquid deflocculant is used as a thinner and conditioner for the NOVADRIL, NOVAPLUS and NOVATEC synthetic-base mud systems. It reduces viscosity and gel strengths in the mud without the need for dilution or changing the synthetic-to-water ratio.

NOVAPLUS FORMULATION CHART BARITE (25% BY WT $CaCl_2$ BRINE: 96% SALT PURITY)

Table 2 lists are generalized formulations based on typical drilling demands that dictate that lower mud densities can have higher water contents, or that higher densities require higher synthetic contents. The amount of emulsifier, wetting agent, fluid-loss-control additive and viscosifier will vary, depending on mud density, Synthetic-to-Water Ratio (SWR), required fluid properties or thermal stability. For example, a 9 lb/gal (1.08 SG) 90:10 synthetic/water ratio NOVAPLUS system would require more viscosifier and less wetting agent than shown in Table 2. As always, pilot testing is recommended prior to action taken at the rig.

SWR → (Mud Weight)	**60:40 (8.5 - 10 lb/gal)**	**70:30 (11 - 13 lb/gal)**	**80:20 (14 - 16 lb/gal)**	**90:10 (17 - 18 lb/gal)**
NOVAMUL	6 - 10 lb/bbl	5 - 9 lb/bbl	4 - 8 lb/bbl	3 - 7 lb/bbl
NOVAWET	1 - 2 lb/bbl	1 - 2 lb/bbl	2 - 3 lb/bbl	3 - 4 lb/bbl
NOVAMOD	0.5 - 1 lb/bbl	1 - 1.5 lb/bbl	0.5 - 1.0 lb/bbl	0 lb/bbl
Lime	4 - 8 lb/bbl	4 - 8 lb/bbl	3 - 7 lb/bbl	2 - 6 lb/bbl
VG-69	2 - 4 lb/bbl	3 - 6 lb/bbl	3 - 6 lb/bbl	2 - 5 lb/bbl
VERSA-HRP	As required	As required	As required	As required

Synthetic:Water Ratio	**Mud Weight (lb/gal)**	**IO1618 (bbl)**	**Water (bbl)**	**$CaCl_2$ (lb/bbl)**	**M-I BAR (lb/bbl)**
60:40	8.5	0.542	0.375	46.2	9.4
	9	0.531	0.368	45.3	36.8
	10	0.510	0.354	43.6	91.3
70:30	11	0.566	0.253	31.2	162.1
	12	0.542	0.242	29.9	216.0
	13	0.517	0.232	28.6	269.8
80:20	14	0.566	0.147	18.1	339.7
	15	0.538	0.140	17.2	392.9
	16	0.509	0.133	16.4	446.0
90:10	17	0.547	0.063	7.7	514.0
	18	0.516	0.059	7.3	566.4

NOTE: 1 lb/bbl = 2.85 kg/m^3.

Table 2: NOVAPLUS system formulations.

The NOVATEC system…uses Linear Alpha Olefins (LAOs) as its continuous phase.

NOVATEC SYSTEM

The NOVATEC system is M-I's synthetic-base system that uses Linear Alpha Olefins (LAOs) as its continuous phase. NOVATEC systems are tightly emulsified and can be engineered to have a low fluid loss and be stable to temperatures in excess of 350°F (176°C). The drilling properties and limitations are the same as those for conventional (diesel or mineral oil) type invert systems. $CaCl_2$ brine is recommended for the internal phase. The most common concentration of $CaCl_2$ brine is 25% by weight, which has a density of 10.3 lb/gal (1.23 SG). Higher concentrations of $CaCl_2$ brine can be used, but the $CaCl_2$ concentration should not exceed saturation, which is 40% by weight. To be on the safe side, the $CaCl_2$% concentration should stay below 35% by weight. At concentrations above this, the internal phase can become destabilized and severe problems may occur with the system.

The products for the NOVATEC system are listed in Table 3 followed by a brief description.

- NOVATEC B is the LAO-base liquid for the NOVATEC synthetic-base mud system and may be referred to as NOVATEC B or as LAO1416 (Linear Alpha Olefin C14 to C16) or LAO1618 (Linear Alpha Olefin C16 to C18).
- NOVATEC P is the primary emulsifier for the NOVATEC synthetic-base mud system. NOVATEC P can be used alone to form tight water-in-olefin emulsions, but is particularly effective when used in conjunction with NOVATEC S. It provides high emulsification and wetting and contributes to the HTHP fluid-loss control of the NOVATEC system. NOVATEC P is a liquid and does not contain hydrocarbon solvents.
- NOVATEC S is the secondary emulsifier in the NOVATEC synthetic-base mud system. The product is designed for use in the NOVATEC system to provide high emulsion stability and organic wetting. NOVATEC S can be used alone to form tight water-in olefin-emulsions, but is particularly effective when used to complement NOVATEC P. When used in combination, NOVATEC S and NOVATEC P react to form very tight emulsions and impart powerful wetting properties. NOVATEC S contributes to the HTHP fluid-loss control of the NOVATEC system. It is a liquid and does not contain hydrocarbon solvents.
- NOVATEC F is a liquid fluid-loss reducer for the NOVATEC synthetic-base mud system. NOVATEC F is used to provide supplementary fluid-loss control in the NOVATEC system normally at high synthetic/water ratios and at temperatures above 300°F (149°C). NOVATEC F effects rapid reduction in HTHP filtration when used at relatively low concentration levels. NOVATEC F is stable to high temperatures (> 390°F (200°C)).

Additive	Function	Concentration
NOVATEC B	Continuous phase	60 - 95% vol, liquid phase
Freshwater	Water phase	5 - 40% vol, liquid phase
$CaCl_2$	Salinity, water phase	15 - 30% wt water phase
VERSAGEL	Viscosifier	3 - 10 lb/bbl (9 - 30 kg/m^3)
NOVATEC P	Primary emulsifier	3 - 10 lb/bbl (8 - 30 kg/m^3)
NOVATEC S	Secondary emulsifier/ wetting agent	2 - 8 lb/bbl (6 - 22 kg/m^3)
NOVATEC F	Fluid loss control	3 - 7 lb/bbl (8 -20 kg/m^3)
NOVAMOD	Rheology modifier	1 - 3 lb/bbl (3 - 9 kg/m^3)
Lime	Alkalinity control	4 - 8 lb/bbl (11- 23 kg/m^3)

TABLE 3: NOVATEC system additives.

NOVATEC FORMULATION CHART BARITE (25% BY WT $CaCl_2$ BRINE: 96% SALT PURITY)

Table 4 lists generalized formulations based on typical drilling demands that dictate that lower mud densities can have higher water contents, that or higher densities require higher synthetic contents. Depending on mud density, SWR, required fluid properties or thermal stability, the amount of emulsifier, wetting agent, fluid-loss-control additive and viscosifier will vary. For instance, a 9 lb/gal (1.08 SG) 90:10 synthetic/water ratio NOVATEC system would require more viscosifier and less wetting agent than shown in the chart below. As always, pilot testing is recommended prior to action taken at the rig.

SWR → (Mud Weight)	**60:40 (8.5 - 10 lb/gal)**	**70:30 (11 - 13 lb/gal)**	**80:20 (14 - 16 lb/gal)**	**90:10 (17 - 18 lb/gal)**
NOVATEC P	6 – 8 lb/bbl	7 - 9 lb/bbl	8 - 10 lb/bbl	9 - 11 lb/bbl
NOVATEC S	2 - 4 lb/bbl	3 - 5 lb/bbl	4 - 6 lb/bbl	5 - 7 lb/bbl
NOVATEC F	3 - 5 lb/bbl	3 - 5 lb/bbl	4 - 6 lb/bbl	4 - 6 lb/bbl
NOVAMOD	0.5 - 1 lb/bbl	1 - 1.5 lb/bbl	0.5 - 1.0 lb/bbl	0 lb/bbl
Lime	4 - 8 lb/bbl	4 - 8 lb/bbl	3 - 7 lb/bbl	2 - 6 lb/bbl
VERSAGEL	2 - 4 lb/bbl	3 - 6 lb/bbl	3 - 6 lb/bbl	2 - 4 lb/bbl
VERSA-HRP	As required	As required	As required	As required

Synthetic:Water Ratio	**Mud Weight (lb/gal)**	**NOVATEC B (bbl)**	**Water (bbl)**	**$CaCl_2$ (lb/bbl)**	**M-I BAR (lb/bbl)**
60:40	8.5	0.527	0.373	46.0	12.2
	9	0.517	0.366	45.1	39.4
	10	0.495	0.352	43.4	93.8
70:30	11	0.548	0.252	31.0	165.4
	12	0.523	0.242	29.7	219.0
	13	0.498	0.231	28.5	272.6
80:20	14	0.538	0.146	18.0	341.3
	15	0.510	0.139	17.1	394.2
	16	0.482	0.132	16.3	447.1
90:10	17	0.516	0.062	7.7	515.4
	18	0.485	0.059	7.3	567.6

NOTE: 1 lb/bbl = 2.85 kg/m^3.

Table 4: NOVATEC system formulations.

The ECOGREEN system... uses an ester as its base liquid.

ECOGREEN SYSTEM

The ECOGREEN system is M-I's synthetic-base system that uses an ester as its base liquid. ECOGREEN systems are tightly emulsified and can be engineered to have a low fluid loss. Temperature stability is less than that of either NOVAPLUS or NOVATEC systems. Applications for the ECOGREEN system should not exceed 300°F (149°C). The drilling properties are similar to those for conventional (diesel or mineral oil) invert systems with the exception of the Plastic Viscosity (PV) that typically runs higher in ECOGREEN systems than for conventional invert systems with comparable densities and oil/water ratios.

$CaCl_2$ brine is recommended for the internal phase. The most common concentration of $CaCl_2$ brine is 25% by weight, which has a density of 10.3 lb/gal (1.23 SG). Higher concentrations of $CaCl_2$ brine can be used but the $CaCl_2$ concentration should not exceed saturation, which is 40% by weight. To be on the safe side, the $CaCl_2$% concentration should stay below 35% by weight. At concentrations above this, the internal phase can become destabilized and severe problems may occur with the system.

The products for the ECOGREEN system are listed in Table 5 followed by a brief description.

- ECOGREEN B is the ester-base liquid for the ECOGREEN system. Depending on its origin (an ester derived from vegetable oils such as palm or coconut or from fish oils), the actual name and technical information may vary accordingly. The variations in physical properties between different types of esters will effect the final properties of the ECOGREEN system.
- ECOGREEN P is the primary emulsifier for the ECOGREEN system. ECOGREEN P can be used alone to form tight water in ester emulsions but is particularly effective when used in conjunction with ECOGREEN S. It provides emulsification, wetting and contributes to the HTHP fluid-loss control of the ECOGREEN system. ECOGREEN P is a liquid and does not contain hydrocarbon solvents.
- ECOGREEN S is a blend of surfactants and is used as the secondary emulsifier and primary wetting agent for the ECOGREEN system. ECOGREEN S is an integral part of the ECOGREEN system and should be used in conjunction with ECOGREEN P when preparing fresh drilling fluid. The properties of ECOGREEN S assist in the dispersion and suspension of solids for better rheological control. It contributes to HTHP fluid-loss control in the ECOGREEN system. It is a liquid and does not contain hydrocarbon solvents.

Additive	Function	Concentration
ECOGREEN B	Continuous phase	70 - 95% vol, liquid phase
Freshwater	Water phase	5 - 30% vol, liquid phase
$CaCl_2$	Salinity, water phase	15 - 30% wt water phase
ECOGREEN VIS	Viscosifier	3 - 10 lb/bbl (9 - 30 kg/m^3)
ECOGREEN P	Primary emulsifier	3 - 12 lb/bbl (9 - 36 kg/m^3)
ECOGREEN S	Secondary emulsifier/ wetting agent	1 - 4 lb/bbl (3 - 12 kg/m^3)
ECOGREEN FP	Fluid-loss control	1 - 4 lb/bbl (3 - 12 kg/m^3)
Lime	Alkalinity control	4 - 6 lb/bbl (11- 23 kg/m^3)

TABLE 5: ECOGREEN system additives.

- ECOGREEN FP is used as a fluid-loss-control additive for the ECOGREEN system. It is specially designed to complement the emulsifiers of the ECOGREEN system to provide tight HTHP fluid-loss control at low product concentration. Used in conjunction with other ECOGREEN emulsifiers and ECOGREEN VIS, ECOGREEN FP will assist in increasing rheology.
- ECOGREEN VIS is an organophilic clay specially designed to yield in the ECOGREEN system. ECOGREEN VIS will provide viscosity and suspension of weight material.

ECOGREEN FORMULATION CHART BARITE (25% BY WT $CaCl_2$ BRINE: 96% SALT PURITY)

Table 6 lists generalized formulations based on typical drilling demands that dictate that lower mud densities can have higher water contents, or that higher densities require higher synthetic contents. Depending on mud density, SWR, required fluid properties or thermal stability, the amount of emulsifier, wetting agent, fluid-loss-control additive and viscosifier will vary. For instance, a 9 lb/gal (1.08 SG) 90:10 synthetic/water ratio ECOGREEN system would require more viscosifier and less wetting agent than shown in the chart below. As always, pilot testing is recommended prior to action taken at the rig.

SWR → (Mud Weight)	**70:30 (9 - 11 lb/gal)**	**80:20 (12 - 14 lb/gal)**	**90:10 (15 - 17 lb/gal)**
ECOGREEN P	8 – 10 lb/bbl	10 - 12 lb/bbl	10 - 12 lb/bbl
ECOGREEN S	2 - 4 lb/bbl	3 - 5 lb/bbl	4 - 6 lb/bbl
ECOGREEN FP	1 - 2 lb/bbl	2 - 3 lb/bbl	2 - 3 lb/bbl
Lime	3 -4 lb/bbl	3 - 4 lb/bbl	3 - 4 lb/bbl
ECOGREEN VIS	2 - 6 lb/bbl	2 - 6 lb/bbl	2 - 6 lb/bbl

Synthetic:Water Ratio	**Mud Weight (lb/gal)**	**ECOGREEN B (bbl)**	**Water (bbl)**	**$CaCl_2$ (lb/bbl)**	**M-I BAR (lb/bbl)**
70:30	9	0.618	0.276	34.0	41.8
	10	0.593	0.266	32.8	96.3
	11	0.568	0.255	31.4	150.7
80:20	12	0.612	0.162	20.0	220.0
	13	0.583	0.155	19.1	273.4
	14	0.555	0.148	18.2	327.1
90:10	15	0.592	0.70	8.6	393.8
	16	0.560	0.66	8.2	446.9
	17	0.528	0.63	7.8	500.0

NOTE: 1 lb/bbl = 2.85 kg/m^3.

Table 6: ECOGREEN system formulations.

Mixing Procedure

It is essential that contamination with diesel or mineral oil be avoided.

It is essential that contamination with diesel or mineral oil be avoided. Any oil contamination could prevent synthetic-base mud from complying with local environmental regulations and thus prohibit the discharge of cuttings associated with the use of this fluid. Therefore, all diesel and other petroleum oil lines must be isolated, and the pits and mixing lines cleaned out. In addition, precautions must be taken to ensure that no losses occur. Precautionary procedures for the handling of the synthetic-base mud should be implemented to ensure losses are kept to a minimum.

The mixing procedure is as follows:

1. Prior to mixing the synthetic-base mud, mix the $CaCl_2$ brine in a separate pit.
2. Fill the mixing pit with the required volume of synthetic-base fluid.
3. Add the viscosifier with maximum possible shear applied.
4. Add the lime, if required, and shear the system for 15 to 20 min.
5. Add the primary and secondary emulsifier and mix for 15 to 20 min.
6. Add the wetting agent.
7. Slowly add the $CaCl_2$ brine over a period of 20 to 30 min and continue mixing for as long as practical.
8. Add the fluid-loss additive.
9. Add the barite to weight up the drilling fluid to the desired density.
10. Add rheology modifier, if needed.
11. Continue to mix for at least one more hour, and then make a full mud check.

NOTE: The final rheology and HTHP fluid-loss properties, as for oil-base muds, will not be achieved until the mud is exposed to temperature and shear as it is circulated through the well. Consequently, the final adjustments of these properties should not be made until the system has stabilized over several circulations.

Maintenance

The general maintenance and treatment of any of M-I's synthetic-base systems is similar to that of conventional oil-base muds, including product treatment and fluid property adjustment. Please refer to the Non-Aqueous Emulsions chapter for further details on properties, maintenance and treatments.

ECOGREEN NOTES

1. The ECOGREEN system will not tolerate H_2S or acid gas due to the nature of the base ester. Acids will hydrolyze or break down esters to form alcohols and fatty acids (see Synthetic Chemistry section which follows). ECOGREEN should not be used if H_2S contamination is anticipated.
2. Caution must be exercised when displacing the ECOGREEN system with cement. Cross-contamination should be avoided to prevent problems with either the ECOGREEN fluid or the cement itself. Sufficient spacer volume is a must.

Testing

Field test procedures for synthetic-base muds are the same as those for conventional invert systems (see Chapter 3, Testing). Acceptable mud properties are somewhat dependent on the base fluid and may vary from one to another.

There is one additional test, however, that may be requested when discharging a synthetic-base system. This is the retort analysis of the retention of synthetic-base mud on cuttings. This test is used to monitor the amount of synthetic-base mud discharged on the cuttings. It may be required for environmental compliance, mud management or Integrated Fluids Engineering (IFE) purposes. Remember that synthetic-base systems are expensive and any unnecessary waste can be costly. Different areas may have their own limits or protocols for the amount of synthetic-base fluids on cuttings and the method of determining this amount. Make sure you are familiar with the local protocol when required. The API RP-13B-2 test procedure, "Oil and Water Content from Cuttings for Percentage Greater than 10%," method is given at the end of this section.

Calculations

The calculations for M-I's synthetic-base mud systems are the same as those for conventional diesel or mineral-oil-base muds. Information regarding the Specific Gravity (SG) of the particular synthetic-base fluid (i.e. IOC1618, NOVATEC B or ECOGREEN B), can be found on the Material Safety Data Sheet (MSDS). A list of general SG ranges for internal olefins, linear alpha olefins, esters and other base fluids are provided in the chemistry section of this chapter. Calculations that are covered in Chapter 11 on Non-Aqueous Emulsions include:

- Solids analysis.
- Alkalinity and lime content.
- Salinity and activity.
- Adjustment to oil/water ratio.
- Adjustment to salt concentration.

The calculation related to the amount of synthetic-base mud retained on drill cuttings is provided at the end of this chapter.

Chemistry of Synthetics

The basic chemistry... dictates the physical properties, technical limitations and environmental fate and effect of each base fluid.

A quick review of the chemistry of the synthetic-base materials is important to the understanding of some of their applications and limitations. The basic chemistry of these materials dictates the physical properties, technical limitations and environmental fate and effect of each base fluid.

FIRST-GENERATION BASE LIQUIDS — PAOS, ESTERS, ETHERS AND ACETALS

Generalized structures of these first-generation products are shown in Figure 1 with their relevant physical properties given in Table 7.

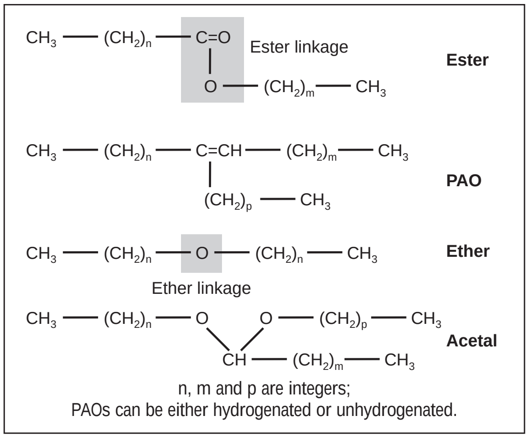


Figure 1: Structure of first-generation synthetics.

Esters, ethers and acetals contain oxygen in their structures.

Esters, ethers and acetals contain oxygen in their structures. This common feature does not equate to common reaction paths either chemically or biologically. In the ester molecule, the two oxygens create an active carbon site that is susceptible to attack by either acidic or basic reactants. The result would be a degradation of the ester to give the corresponding alcohol and carboxylic acid. It is this breakdown process that affords the ester-type SBM such a rapid biodegradation rate in both laboratory tests and seabed conditions.

In a drilling situation, concerns regarding the use of esters would focus around high-temperature applications, cement contamination and acid-gas influx. Esters can be chemically designed by adjusting the alkyl side chains R_1 and R_2 (i.e. n, m and p are optimized as in Figure 1) to have greater thermal stability and to be more resistant to acid or base hydrolysis. The trick would be to balance these aspects of an ester compound with the physical properties suitable for using the fluid as a drilling mud. Although the ester molecule is not associated with any aromatic type structure, esters have a low aniline point and have been implicated in the failure of elastomers.

The oxygen in the ether does not sufficiently activate the carbons surrounding it to make them readily susceptible to attack from acids or bases. This factor, combined with its molecular weight and the degree of branching in its carbon skeleton, contributes to the ether-type SBM's slow degradation rate. The ether SBM has, however, a high hydrolytic stability and does not suffer some of the technical limitations associated with the esters.

Although the acetal-base material is a *gem*-diether, its reactivity is somewhat different from that of the ether. Like the

Typical Properties	PAO	Ester	Ether	Acetal
Density (SG)	0.80	0.85	0.83	0.84
Viscosity at 40°C (cSt)*	5.0 - 6.0	5.0 - 6.0	6.0	3.5
Flash point (°C)	>150	>150	>160	>135
Pour point (°C)	<-55	<-15	<-40	<-60
Aniline point (°C)	108	25	40	—

*cSt = centi-Stokes = cP ÷ SG.

Table 7: Typical properties for first-generation synthetic-base liquids.

ether, it does exhibit high-temperature hydrolytic stability under basic conditions typical of invert-type drilling fluids. Acidic conditions, however, result in hydrolysis of the acetal to its base components, alcohol (2 moles) and aldehyde (1 mole). The R_1 and R_2 hydrocarbon side chains must be optimized to obtain a proper balance of physical properties as a drilling fluid and chemical reactivity for technical and environmental requirements.

PAOs are synthetic hydrocarbons formed from LAOs...

PAOs are synthetic hydrocarbons formed from LAOs (see next section). PAOs are either branched alkenes (unhydrogenated) or branched alkanes (hydrogenated). The term PAO is a generic one that refers to both the hydrogenated or non-hydrogenated materials. PAOs exhibit low pour points because of their highly branched nature. This branching, however, causes their rate of degradation to be much slower than more linear hydrocarbons such as LAOs, IOs or LPs. Unlike esters, ethers and acetals, PAOs do not contain oxygen and thus are stable to high temperatures, high alkalinity, acid gases and other chemical contaminants.

Ethylene is the monomer... in this process to oligomerize or form LAOs.

Even though esters, ethers and acetal are also produced via a synthetic process, their starting materials are more expensive then ethylene. This increased cost for raw materials, combined with the different manufacturing process results in a more expensive base fluid for these materials.

SECOND-GENERATION BASE LIQUIDS — IOs, LAOs AND LPs

The general structure of an internal olefin, a linear alpha olefin and a linear paraffin are represented in Figure 2.

$CH_3 — (CH_2)_n — CH = CH_2$ **LAO**

$CH_3 — (CH_2)_n — CH = CH_2 — (CH_2)_n — CH_3$ **IO**

$CH_3 — (CH_2)_n — CH_3$ **LP**

Figure 2: Structure of second-generation synthetics.

These molecules, like PAOs, contain only carbon and hydrogen. They are often referred to as *synthetic hydrocarbons* when they are derived strictly from a synthetic process as opposed to ones that involve refining of a petroleum distillate. Typical physical properties for IOs, LAOs and LPs are shown in Table 8.

The poly-alpha olefins, internal or isomerized olefins and linear alpha olefins are essentially from the same chemical family - *olefins*. They are all manufactured from pure ethylene (see Figure 3). Ethylene is the monomer (building block) in this process to oligomerize or form LAOs. Oligomerization is polymerization to a low molecular weight product. With the proper heat and catalysts, this process can be carried further, linking the oligomers into branched molecules (PAOs). When two identical oligomers react to form a molecule, the process is called *dimerization*. Likewise, if three identical oligomers are linked together, the process is called *trimerization*. IOs are synthesized by isomerizing LAOs (isomerization changes a molecule's structure but not its atomic

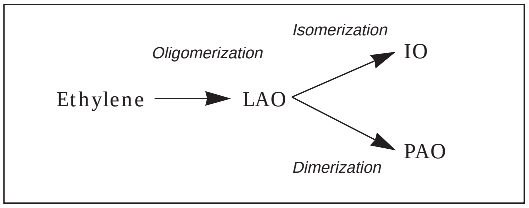
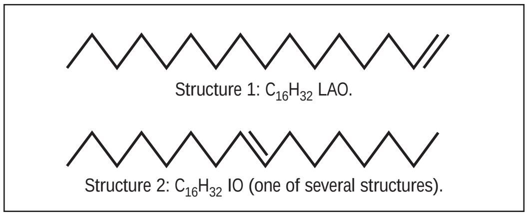


Figure 3: Relationships of LAOs, IOs and PAOs.

Typical Properties	LP	LAO	IO
Density (SG)	0.77	0.77 - 0.79	0.77 - 0.79
Viscosity at 40°C (cSt)	1.75 - 2.5	2.1 - 3.1	3.1
Flash point (°C)	>90°	113° - 146°	137°
Pour point (°C)	-10°	-12° - +3°	-24°
Aniline point (°C)	>93°	~94°	~94°

Table 8: Typical properties for second-generation synthetic-base liquids.


Structure 1: $C_{16}H_{32}$ LAO.

Structure 2: $C_{16}H_{32}$ IO (one of several structures).

Figure 4: Structural difference between IO and LAO.

...the pour point of the IO is lower than the pour point of the LAO.

composition). Likewise, PAOs are made by dimerizing or trimerizing LAOs.

After the LAO, IO or PAO materials are formed, they are distilled to isolate particular molecular weight ranges based on the total carbon number. For instance, LAOs range in molecular weights from approximately 112 (C_8H_{16}) to 260 ($C_{20}H_{40}$). This mixture of LAOs is distilled to give distinct cuts of an individual LAO or blends of LAOs. Therefore, the term LAO $C_{14}C_{16}$ is a blend of $C_{14}H_{28}$ and $C_{16}H_{32}$ LAOs. Likewise, the $C_{16}C_{18}$ LAO is a blend of $C_{16}H_{32}$ and $C_{18}H_{36}$ LAOs.

The IO material is formed by heating the LAO with a catalyst. Isomerization of a compound means that only the structure of the material is changed and not its molecular weight. Therefore the $C_{16}C_{18}$ LAO is converted to a $C_{16}C_{18}$ IO with the same proportion of $C_{16}H_{32}$ and $C_{18}H_{36}$ materials. LAOs and isomerized or internal olefins are very similar in both chemistry and structure. The structural difference between the IO and LAO products is that the double bond is in the terminal or alpha position in the LAO (Structure 1), while in the IO (Structure 2) the double bond is between two internal carbon atoms.

This structural variation results in differences in physical properties between the LAO and IO materials of identical molecular weights. The biggest difference is seen with respect to the pour point (see Table 9). The internal double bond of the IO gives rise to additional structural isomers (cis and trans) that do not allow the molecules of the IO to pack together as uniformly upon cooling. Therefore, the pour point of the IO is lower than the pour point of the LAO.

Olefins are thermally stable and tolerate contamination well. They are unaffected by high alkalinity from drilling cement, and additions of lime for treatment of acid gases will not affect them. They are unaffected by salt and anhydrite. Olefins will not hydrate clays or cause them to swell.

...to adjust the base fluid composition to obtain the suitable flow properties of an SBM, lower-molecular-weight LPs must be blended together.

The linear paraffin materials share similar chemistries to the LAO and IO products except that they contain no double bonds and their carbon backbone, like the LAO, is essentially linear. The LPs are classified alkanes (without double bonds) vs. LAOs and IOs, which are alkenes (with double bonds). The absence of the double bond and the linearity of the molecule in an LP will raise the pour point and kinematic viscosity relative to an LAO or IO containing the same number of carbon atoms. Therefore, to adjust the base fluid composition to obtain the suitable flow properties of an SBM, lower-molecular-weight LPs must be blended together. These lower-molecular-weight LPs affect other properties such as flash point and vapors as well as environmental characteristics such as toxicity and biodegradation.

Linear paraffins can be manufactured by either a purely synthetic route or by a multistep refinery process that includes hydrocracking and the use of molecular-sieve separation.

Material	Viscosity at 40°C (cSt)	Flash Point (°C)	Pour Point (°C)
LAO $C_{16}C_{18}$	3.1	146	+3
IO $C_{16}C_{18}$	3.1	137	-24
LAO $C_{14}C_{16}$	2.1	114	-12

Table 9: Physical properties of LAO- and IO-base liquids.

Environmental Health and Safety Issues

The chemistry of the synthetic-base fluid such as molecular weight or structure has direct affect on the toxicity of the SBM.

The regulatory restrictions regarding the discharge into the sea of drill cuttings coated with a particular synthetic-base mud have determined which types of SBMs are marketed and sold in a particular area. These restrictions are typically linked to environmental assessment tests that can be grouped as those pertaining to toxicity, biodegradation, bioaccumulation and seabed impact. General principles of environmental science are covered in greater detail in the Health, Safety & Environmental chapter. This section will provide a brief overview on how these principles drive the synthetic market.

Toxicity is determined by tests on living organisms. Different regulatory bodies and governments use different organisms and test protocols for determining toxicity. The response to a substance varies from organism to organism, therefore the toxicity and acceptability of each material may vary from one country to another. Toxicity is generally reported as the concentration of a substance that will produce a specified mortality rate in the test organism after a specified period of time. This number is referred to as the LC_{50}, or the Lethal Concentration (LC) to cause a 50% mortality of the population of a specific organism.

Some countries require that more than one organism be tested to determine acceptability of a given mud system. For example, the North Sea countries (Norway, Holland, Denmark and the UK) require three species to be tested — an algae, a herbivore and a sediment reworker. The chemistry of the synthetic-base fluid such as molecular weight or structure has direct affect on the toxicity of the SBM. Toxicity issues are also balanced with other factors such as biodegradation and bioaccumulation to assess overall environmental acceptability.

Biodegradation tests are usually made under both aerobic (with oxygen) and anaerobic (without oxygen) conditions to determine how rapidly a substance will degrade. Large cuttings piles that do not degrade are a serious environmental concern in some discharge environments. Biodegradation tests are used to estimate how long a substance will persist or last in the environment before breaking down. Rapid degradation of substances is generally considered to be desirable. However, substances that undergo rapid aerobic degradation can deplete oxygen from the area around the discharge and create a toxic effect.

The chemistry of the synthetic-base fluid, such as molecular weight or structure, has a direct effect on the biodegradation (both aerobic and anaerobic) of the SBM. There are numerous test protocols for both aerobic and anaerobic biodegradation testing and some caution must be taken when comparing results between test methods. Some countries require biodegradation testing for approval of SBMs. Check with your local M-I representative or contact M-I's environmental department for details on local compliance.

Bioaccumulation tests determine if a substance collects in the tissues of organisms that are exposed to it or in the tissues of predatory species that feed on organisms exposed to the substance. Nontoxic levels of a substance in the environment can reach toxic levels in tissues if it accumulates. Bioaccumulation of a substance is of concern to personnel exposed to the substance and also for the potential threat it presents if the substance accumulates in the tissue of organisms used for food. The chemistry of the synthetic-base fluid, such as molecular weight or structure, has direct affect on the bioaccumulation of the SBM.

Seabed studies are designed to determine the impact of SBM discharges on the sea floor. These studies can include the presence or residue of any SBM and assessment of the organisms that live on the seabed itself. Physical properties such as grain size, oxygen content and salinity of water may also be measured. These studies measure the combined effect of toxicity, biodegradation and bioaccumulation in a particular discharge environment. Factors such as current, water depth and seabed conditions play a big role in what happens to SBM discharges in a particular area.

Factors such as current, water depth and seabed conditions play a big role in what happens to SBM discharges in a particular area.

Other tests are used to address regional environmental concerns. For example, the *static sheen test* is designed to prevent oil contamination in drilling fluids. More sophisticated analytical techniques such as Gas Chromatograph/Mass Spectroscopy (GC/MS) or Ultraviolet (UV) techniques may be used to perform the same function.

The primary point with regard to environmental issues and health and safety concerns as they relate to SBMs is that they are fundamental to the ability to utilize a particular type of synthetic-base system in an area. Environmental issues will continue to play a very important role in the development of synthetic-base muds. Short-term marketing issues will be driven by regulatory compliance while long-term usage will be driven by environmental impact.

HEALTH AND SAFETY FOR SYNTHETIC-BASE MUDS

The hazards involved with using SBMs

Like all chemicals, SBMs can be health hazards if handled improperly. The synthetic liquids used to make SBMs are less toxic and less irritating than the oils used in oil-base muds. However, SBMs are difficult to remove from the skin, and contain some irritating chemicals such as calcium chloride and lime. This means that SBMs can be quite irritating to the skin and eyes if certain precautions are not taken. Likewise, mist and vapor from SBMs, especially in the area around the shakers, can be irritating to the respiratory system.

Self-protection when using SBMs

GENERAL PRECAUTIONS

- Always have the Material Safety Data Sheets (MSDSs) available on location for all materials that are being handled. Read and follow all instructions on the MSDSs.
- Avoid unnecessary contact with the mud.
- Wipe mud from skin as soon as possible, and wash with soap.
- If mud soaks through clothing, change and wash as soon as possible.
- Use good personal hygiene, washing thoroughly after each tour.
- SBM is very slippery. Keep decks and stairs clean.

Personal Protective Equipment (PPE) recommendations

For jobs that require significant contact with the mud use the following procedures and PPE. Always follow manufacturer's instructions when using PPE.

- **Skin.** The most commonly reported health problem associated with handling SBMs is dermatitis or skin irritation. The following four-step regimen is designed to prevent dermatitis when handling SBMs and to relieve minor irritation. If left untreated, minor skin irritation can progress and result in intense itching and blisters which are susceptible to infection. Cases of severe dermatitis, especially if infection is suspected, should be referred to a physician immediately.
  - **Protection.** In addition to the protective clothing and equipment mentioned below, before any potential contact with exposed skin, apply barrier cream to areas of skin that can

not be covered by some other form of PPE. Use a silicon-base cream or one specifically designed to protect against oil-base hazards.

- **Cleaning.** Use a soap designed to remove oil and grease from skin, such as the waterless soap preparations used by mechanics. Do not wash skin with diesel or rig wash.
- **Reconditioning.** To prevent chafed, cracked skin apply a reconditioning skin lotion to replace the moisture and natural oils lost by frequent washing.
- **Relief.** If necessary, use over-the-counter hydrocortisone cream to relieve minor irritation. Follow instructions and precautions provided by the manufacturer.
- **Eyes.** Use chemical splash goggles.
- **Body.** Use impermeable clothing such as Tyvek® disposable coveralls in warm weather or slicker suits in cold weather.
- **Hands.** Use impermeable gloves made of nitrile, neoprene or equivalent.
- **Feet.** Wear impermeable boots made of neoprene, urethane/vinyl or equivalent.
- **Respiratory.** Use a NIOSH-approved P95 half-mask disposable or reusable particulate mask for mist/aerosol or use a NIOSH/MSHA-approved organic vapor respirator for vapors.

Laundering recommendations

Be sure that your clothes are clean before wearing them. For clothing that is heavily soiled with SBM this will require special laundering procedures. Laundering procedures must be adapted to available equipment and conditions, however, the following suggestions have been proven to be effective:

- Designate one washing machine for washing only muddy clothes. Clothing which is not soiled with SBM should be washed in a separate washing machine.
- Pre-soak muddy clothes 1 to 2 hr in a laundry detergent solution before laundering. This can be done in a container such as a clean 55-gal drum or large plastic trash can.
- Do not overload washers.
- Run muddy clothes through at least two wash cycles using hot water and regular laundry detergent. Additional cycles may be necessary for extremely muddy clothes. Each time the wash cycle is repeated, add more detergent.

Special Applications for Synthetic-Base Muds

Rigs that use synthetic-base muds should be fitted out with the same equipment as those using oil-base muds.

Due to the high cost of Synthetic-Base Muds (SBMs) and the severe consequences if an SBM is contaminated, there are special precautions and items with which the mud engineer needs to be familiar when using an SBM. These items relate to the rig, solids-control equipment, drilling practices and problems.

RIG MODIFICATIONS

Although synthetic-base fluids may be more environmentally acceptable than oil-base muds, the price of these fluids dictates that discharges of these fluids must be minimized. Rigs that use synthetic-base muds should be fitted out with the same equipment as those using oil-base muds. The rig should be modified as follows:

- Centrifugal pumps should have mechanical packing to prevent contaminating the system with fluid from the packing.
- Check the seals on mechanical equipment and replace any that might leak oil into the system.

- Plug off water and diesel lines to mud pits.
- Check BOP elastomers for compatibility with the base fluid.
- Pressure-test hoses that will be used to offload mud from boats.
- Check for leaks in the mud pits, ditches and gates.
- Shale dump lines:
  - Install seawater lines on each end of cuttings trough.
  - Shale chute should have a minimum ID of 16 in.
  - Should be free of obstructions with a minimum of turns.
  - Shunt line should extend 40 ft below the water surface.
- Mud pump liners and pistons should be continuously flooded with seawater.
- Synthetic-base-fluid holding tanks should be cleaned and dried out before usage.

SOLIDS-CONTROL EQUIPMENT

Design solids-control equipment to handle maximum flow and drilling rates.

- Shale shakers:
  - Screens should be washed with synthetic-base fluid instead of water or oil.
  - Primary/scalping: elliptical motion.
    - Processes flow from flow line.
    - Drier discharge than linear motion shakers.
    - Deck angle aids in handling heavy load of cuttings.
    - Reduces load for fine screen secondary shakers.
  - Secondary: linear motion.
    - Processes underflow from primary shakers to remove fine solids.
    - Use finest possible screens.
  - Discharge from shakers is normally 50 to 60% drilling fluid.
    - Expensive with synthetic-base fluids.
    - Excessive discharge to environment.
  - Drying shaker.
    - Used to process and dry cuttings from secondary shakers.
    - Reclaimed fluid contains high concentration of fine solids.
    - Centrifuge reclaimed fluid before returning it to the active system.
  - Rig should have enough shaker capacity so neither drilling nor flow rates are restricted by lack of shale shaker capacity.
  - At least 3 primary over 3 secondary shakers are needed for fast drilling in 12¼-in. or larger holes.
- Centrifuges.
  - A barite recovery and high-speed tandem unit are usually used.
    - High-speed unit processes overflow from barite recovery unit.
    - Discard all solids including barite.

DRILLING PRACTICES

- Drilling assemblies:
  - Minimize full-gauge stiff drilling assemblies.
  - Limit directional assemblies to collars and Measurement While Drilling (MWD) equipment needed to control direction.
  - Use spiral collars and heavy-weight drill pipe when possible to minimize wellbore contact.
- Drill to casing point with water-base mud.
- If possible, displace casing and drill out with seawater.
- Clean lines, pits, troughs and shale shaker possum bellies before putting synthetic-base mud in system.
- Displace seawater with synthetic-base mud and test surface casing with synthetic-base mud.
- Use unweighted SBM for drill ahead volume when drilling soft formations; use the largest jets available.

- Hole cleaning:
  - Minimize hydraulic diameter of annulus:
    - Use the largest drill pipe possible. Increases annular flow rates. Minimize pressure losses in the drillpipe.
    - Maintain >100 ft/min annular velocity if possible.
  - Maximize flow rate.
  - Monitor the cuttings load in the annulus.
  - Rotate and reciprocate the drill pipe when circulating in directional wells.
  - Pump the hole clean before tripping.
- Eliminate short trips.
  - Back ream out of each new hole section.
  - Circulate until the shakers are clean before tripping.

Synthetic-Base Mud Problems and Applications

PROBLEMS

- Gauge hole.
  - Minimize BHAs to the minimum required for directional control.
  - Limit the number and size of centralizers.
- Limit surge and swab pressures.
  - Use VIRTUAL HYDRAULICS.®
- Lost circulation.
  - Use higher margin between shoe tests and mud weights.
  - When losing returns, add LCM continuously while drilling.
  - Use M-I-X II,™ calcium carbonate, mica.
  - Do not use paper, cane fiber, wood fiber or cellophane.
- Kicks.
  - Gas solubility makes kick detection more difficult and critical than in a water-base mud.
  - Oil contamination in a synthetic-base system makes the mud unacceptable as a synthetic-base mud.
  - Salt water.
    - Additions of synthetic-base liquid to adjust synthetic/water ratio is expensive.
- Cementing practices.
  - Spacer selection critical, viscosity, chemistry.
  - Use water-base or waste mud to recover mud from behind casing.

APPLICATIONS

- **Good applications for synthetics.**
  - Development wells.
  - High-cost deepwater drilling.
  - Deviated wells.
    - Extended reach.
    - Horizontal.
    - Extreme azimuth changes.
  - Applications on rigs with limited torque, re-entries using workover rigs.
  - Offshore wells that typically use oil-base mud.
  - Exploratory wells with good offset data.
- **Poor applications for synthetics.**
  - High risk of lost circulation.
  - Wells where zero-discharge is required.
  - Routine exploratory wells without good offset data.

Test Procedure for Determining Oil (or Synthetic) and Water Content from Cuttings for Percentages Greater Than 10%

(After API Recommended Practice 13B-2(RP 13B-2) Appendix B)

DESCRIPTION

This procedure measures the amount of oil from cuttings generated during a drilling operation. It is a retort test which measures all oil and water released from a cuttings sample when heated in a calibrated and properly operating *Retort* instrument.

In this retort test a known *weight* of cuttings is heated in the retort chamber to vaporize the liquids associated with the sample. The oil and water vapors are then condensed, collected and measured in a precision, graduated receiver.

NOTE: Obtaining a representative sample requires special attention to the details of sample handling (location, method, frequency). The sampling procedure in a given area may be specified by local or governmental rules.

EQUIPMENT

The recommended retort instrument is a 50 cm^3 volume with an external heating jacket. The liquid receiver should be a 50 cm^3 graduated cylinder with 1 cm^3 graduations and ± 0.5 cm^3 precision.

NOTE: The receiver volume should be verified gravimetrically.

PROCEDURE

A. Clean and dry the retort assembly and condenser.

B. Pack the retort body with oil-free steel wool.

C. Apply lubricant/sealant to threads of retort cup and retort stem.

D. Weigh and record the total mass of the retort cup, lid and retort body with steel wool. This is mass (A), grams.

E. Collect a representative cuttings sample.

F. Partially fill the retort cup with cuttings and place the lid on the cup.

G. Screw the retort cup (with lid) onto the retort body, weigh and record the total mass. This is mass (B), grams.

H. Attach the condenser. Place the retort assembly into the heating jacket.

I. Weigh and record the mass of the clean and dry liquid receiver. This is mass (C), grams. Place the receiver below the condenser outlet.

J. Turn on the retort. Allow it to run a minimum of 1 hr at roughly 1,000°F (500°C).
NOTE: If solids boil over into receiver, the test must be rerun.

K. Remove the liquid receiver. Allow it to cool. Record the volume of water recovered. This is (V), cm^3.
NOTE: If an emulsion interface is present between the oil and water phases, heating the interface may break the emulsion.

L. Weigh and record the mass of the receiver and its liquid contents (oil plus water). This is mass (D), grams.

M. Turn off the retort. Remove the retort assembly and condenser from the heating jacket and allow them to cool. Remover the condenser.

N. Weigh and record the mass of the cooled retort assembly without the condenser. This is mass (E), grams.

O. Clean the retort assembly and condenser.

CALCULATIONS

A. Calculate the mass of oil from the cuttings as follows:

1. Mass of the wet cuttings sample (M_w) equals the mass of the cuttings and retort assembly prior to retorting (B) minus the mass of the cooled retorted cuttings and retort assembly (A).
   $M_w = B - A$
2. Mass of the dry retorted cuttings (M_d) equals the mass of the cooled retort assembly (E) minus the mass of the empty retort assembly (A).
   $M_d = E - A$
3. Mass of the oil (M_o) equals the mass of the liquid receiver with its contents (D) minus the sum of the mass of the dry receiver (C) and the mass of the water (V).
   $M_o = D - (C+V)$

NOTE: Assuming the density of the water is 1 g/cm^3*, the volume of water is equivalent to the mass of the water.*

B. Mass balance requirements:

The sum of M_d, M_o and V should be within 5% of the mass of the wet sample.

$$\frac{M_d + M_o + V}{M_w} = 0.95 \text{ to } 1.05$$

The procedure should be repeated if this requirement is not met.

C. Reporting oil from cuttings:

1. Mass of oil (g) per kg of *wet* cuttings sample
   $$= \frac{M_o}{M_w} \times 1{,}000$$
2. Mass of oil (g) per kg of *dry* retorted cuttings
   $$= \frac{M_o}{M_d} \times 1{,}000$$

NOTE: When reporting oil from cuttings in terms of the dry (retorted) cuttings, the oil content may be higher than that calculated from the wet cuttings sample due to interstitial water extracted during retorting. Also, a cutting containing a higher percentage of water than another cutting containing a lesser amount of water will appear to give a higher oil retention weight for the same reasons.