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Comparison of GTL Synthetic versus Diesel Muds in Permian Drilling Operations

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Abstract

For over fifty years diesel has been widely used as the base fluid for oil muds in Texas. Synthetic gas-to-liquids (GTL) base fluid is an alternative to diesel and has been used in Asia for over twenty years.

GTL is a synthetic product produced from natural gas using the Fischer-Tropsch process. This odorless and clear fluid has a low viscosity, high flashpoint, high aniline point and negligible aromatics.

In this study onshore drilling operations performance and worker health of GTL versus diesel based muds are compared.

All wells were drilled in the Wolfcamp formation located in the Permian Basin of West Texas. To maintain well to well consistency, the drilling program retained the same drilling rig, crews, bit, footage, fluid contractor, tools and directional driller. The field trial data indicated an overall drilling improvement for GTL over diesel mud.

Worker health analysis showed lower total hydrocarbons (THC) and dermal exposure for rig workers using GTL over diesel mud.

Also, laboratory and field bioremediation studies of GTL cuttings showed a rapid TPH reduction.

Introduction

Synthetic iso-paraffin GTL base fluid is a product of natural gas. The natural gas is reacted with oxygen to make syngas, which is fed through a Fischer-Tropsch reaction process to create GTL products. The GTL base fluid produced has a narrow range of physical and chemical properties that yields stable operational performance and safe working conditions. Such properties include low odor, low viscosity, low volatility, high flashpoint, high aniline point and negligible sulfur and aromatics. GTL base fluid with these properties is an excellent choice for the replacement for diesel oil in drilling muds.

GTL base fluids have been used for more than 20 years in the Asia, Middle East, African and South American markets in land and offshore drilling operations. It is now available in the US and has been used for land drilling operations for over three years.

The objective of this study is to compare the drilling performance, worker welfare, and environmental impact of GTL-based and diesel-based muds in onshore drilling operations. The horizontal or unconventional wells that were compared in this field trial were all drilled in the Wolfcamp formation, same lease and same year, located in the Permian Basin of West Texas.

The study method used for the field trial minimized the many variables in the drilling process. Therefore, consistency was maintained in the type of formation, bit size (6.125 in.), bit type (PDC), lateral length (~4,200 ft), solids control equipment (SCE), drilling rig and crews, drilling fluid supplier, and directional drilling contractor. This consistency allowed for the direct comparison of the performance of GTL-based and diesel-based drilling muds.

In this field trial, four GTL-based wells were drilled and compared to four diesel-based wells drilled. The GTL field trial fluids were formulated to match the properties of the previous diesel fluids. Wells 1 through 3 had a fluid profile density of 12.0 over 13.0 pounds per gallon (ppg) and an oil-to-water ratio (OWR) of 80/20. The OWR for Well 4 was changed to 75/25 to maximize the benefit of GTL's properties.

Key parameters measured during the trial included rate of penetration (ROP), operational fluid consumption, worker safety and bioremediation of cuttings.

GTL Base Fluid Properties

The synthetic nature of GTL base fluid gives it a narrow range of physical and chemical property specifications that contribute to consistent ease of application in drilling fluid design.

Table 1 compares the physical properties of GTL and diesel fluids. The 185 °F (85 °C) flash point of the GTL base fluid is higher than the typical diesel 141 °F (60.5 °C) flash point. The higher flash point of GTL base fluid improves handling and safety at the well site. The GTL base fluid is synthetic material made up of approximately 20% linear and 80% branched paraffin. This synthetic fluid provides lubricity properties that are superior to mineral oils and diesel.[1]

Important environmental and human safety properties of GTL base fluid for land operations verses diesel are aromatics content, aniline point, sulfur content and benzene, toluene, ethylbenzene, and xylene (BTEX) content. In terms of aromatics GTL typically has approximately 200 ppm versus diesel at > 30,000 ppm (> 30 wt. %), which greatly improves

Table 1: GTL Base Oil versus Diesel Oil Physical Properties

Property	Diesel Oil	GTL Base	GTL Advantages
Flash point, °C	60 – 75	85	Improved safety
Aromatics, ppm wt	30,000-60,000	200	Lower toxicity, Improved worker safety
BTEX, ppm	400-2,500	ND	Lower toxicity, Improved worker safety
Density, 60 °F	0.80-0.85	0.78-0.79	Lower mud density
Viscosity, cSt, 40 °C	1.9-4.1	<2.8	Fast, consistent drilling
Pour point, °C	-12	-24	Improved performance in harsh environments
Aniline point, °C	61	94	Improved elastomer compatibility

**ND – non-detectable, limit 2 ppm; BTEX – benzene, toluene, ethylbenzene and xylene*

the working environment. Clean GTL base fluid has no measurable BTEX, which means that the level of carcinogenic benzene is negligible.[2] The high quantity of odorous components and volatile organic compounds in diesel contributes to air emissions, which creates personal hazard and risk to the workers who handle the fluid.

The lower density of GTL versus many diesel oils allows for the formulation of lower-density drilling fluids. The lower kinematic viscosity of GTL base fluid allows for a wider range of rheological drilling mud profiles, which is often used to increase ROP performance and decrease the equivalent circulating density.[3]

Aniline point is a means to measure the aromatic content of fluids.[4] It is important for showing the compatibility of a fluid with elastomers. A higher aniline point indicates a lower aromatic content and better elastomer compatibility. GTL's aniline point of 94 °C indicates lower aromatic content than diesel oil with an aniline point of 61 °C. Therefore, better elastomer compatibility is expected with GTL. This translates into less non-productive time (NPT) due to elastomer failure and lowers drilling costs.

Comparison of Figure 1 and Figure 2 show the difference in the number and types of constituents in diesel oil and GTL fluids using a two-dimensional gas chromatography analysis (GCxGC).[5] In the GCxGC technique, the effluent from a GC column is collected rapidly and then injected into a second column. The second column allows for further differentiation of components eluting from the first column.

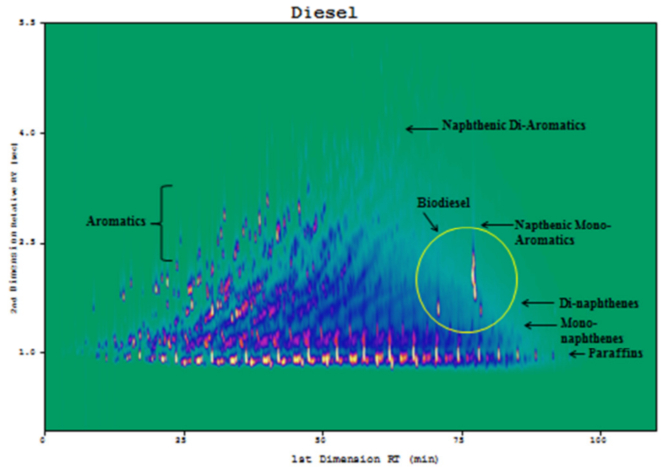

Figure 1: Diesel oil (low sulfur)

As seen for diesel oil in Figure 1, the peaks in the first GC trace are divided into other components. The GC traces extend past the first collected peaks and move horizontally up the chart. Diesel oil is a refined product that contains many types of molecules, including linear paraffin, branched paraffin, various aromatic, aromatic naphthenics, naphthenes, and others. The number of molecular types and isomers are shown by the many peaks observed.

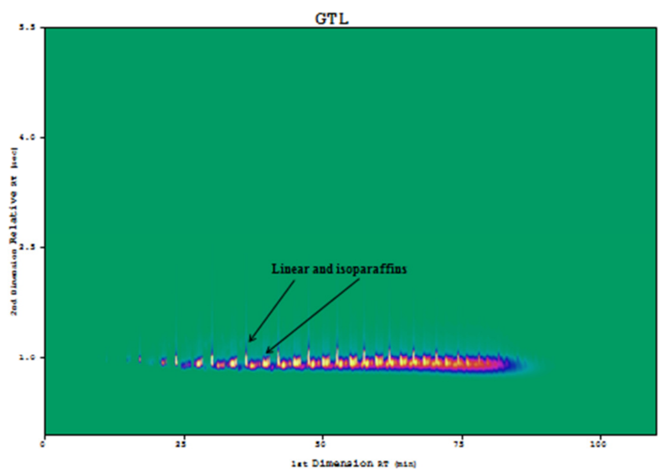

Figure 2: Synthetic GTL paraffin (linear and branched)

Figure 2 shows a synthetic GTL base fluid. It has only the tall thin narrow peaks associated with linear paraffins and the smaller and broader peaks of the branched paraffins present in this material. It does not contain the many different types of non-paraffinic compounds and aromatics found in products refined from crude oil. It is manufactured in a way that minimizes the formation of aromatic compounds.

Objectives and Methodology

This paper will highlight the drilling performance and cost-effectiveness of using synthetic GTL base fluid compared to diesel base fluid in unconventional land operations in Texas. It is based on an approach that measures drilling performance, environmental advantages, and health and safety benefits. The performance comparison will show that GTL base fluid is an economically viable option for US land operations.

Controlled Variables

The Permian field trial consisted of 4 GTL-based wells (Wells 1-4) and four diesel wells (Wells 5-8) drilled in West Texas near Midland/Odessa. The wells were unconventional drilling operations in the same shale formation. The wells were drilled in the Wolfcamp regions to a measured depth of 15,000-ft to 16,000-ft with approximately 4,000 ft laterals under similar bottomhole conditions. The well selection for the GTL trial was not part of the controlled variables; instead, it followed the operations schedule. In order to guarantee a valid comparison, the diesel wells analyzed were selected on the basis of similar formation target, borehole size and lateral length. Also, to maintain consistency the same rig and crews were used along with the same fluids service company, directional driller, bit type and BHA. The trial used the same SCE, which were shakers only with a screen size range of 170-200 micron. The results of these eight wells were compared against each other.

The diesel wells chosen were drilled within 4 months of the start of the field trial using the same crews, directional company and mud contractor. As noted earlier, only the Oil Based Mud (OBM) section or lateral section of the well was used in the evaluation.

Table 2 shows the mud properties were consistent during the trial: plastic viscosity (PV), yield point (YP), OWR, low-gravity solids (LGS), density ppg, and emulsion stability as measured by electrical stability. Fluid properties performance was determined from analysis of the drilling fluid well recap report from the fluids contractor.

ROP Calculation

In considering ROP performance, one must take into account that all well's performance are measured differently. The drilling performance of a fluid in a well is measured in the drillers' community as the number of days from spud to rig down. In this field trial, the drilling fluid performance was measured by ROP from the start of the oil-based mud (OBM) section or lateral hole section to total depth (TD) drilled. The ROP was calculated using the time intervals for drilling without any NPT. In this analysis the key drilling parameters of sliding and rotational ROP measured in foot/hour were used to determine an overall ROP for the lateral section.

Drilling Methodology and Field Observations

The drilling rates for all wells were determined from the displacement of the WBM section with either diesel or GTL fluid to TD.

The first well in the field trial started with a new synthetic GTL system which had a density of 12.5 ppg with an OWR of 80/20. It was prepared at the drilling location using a portable low shear mixing plant. This demonstrates the versatility of GTL base fluid by preparing a drilling fluid on location. Technical recommendations for the GTL drilling mud were made by drilling mud company personnel. Rig personnel preparing the GTL drilling fluid compared it to a clear, high performance water base mud and expressed positive feedback regarding the absence of smell and cleaning requirements associated with diesel.

Table 2: Permian Well Average Mud Properties Analysis

Well	Fluid Type	Average Density, ppg	PV, cp	YP, lbs/ 100 ft2	LGS, % by vol	OWR	ES, volts
Well 1	GTL	12.8	21	14	2.9	79/21	1166
Well 2	GTL	12.6	18	16	1.7	79/21	694
Well 3	GTL	13.0	22	12	4.9	80/20	559
Well 4	GTL	12.4	18	13	3.75	77/23	585
Well 5	Diesel	12.9	20	14	2.8	77/23	750
Well 6	Diesel	12.5	17	10	4.3	79/21	726
Well 7	Diesel	12.8	21	13	5.1	79/21	485
Well 8	Diesel	12.7	19	12	5.3	75/25	527

Key: PV = plastic viscosity, YP = yield point, LGS = low-gravity solids, OWR = oil water ratio, ES = electrical stability

Drilling the lateral interval of Well 1, the LGS in the fluid increased to 2.6% by volume as compared to diesel muds at around 5% LGS. Well 1 drilled a horizontal section of more than 4,200 ft. MD ending with a 13.2 ppg mud density at TD. Well 1 drilled section with an ROP of 26.6 ft/hr which was comparable to the diesel comparison well in the same field.

Well 2 used the GTL mud from the first well with a density of 13.4 ppg. This mud was diluted with base fluid to a 12.5 ppg GTL synthetic drilling fluid with an OWR of 81/19 and LGS at 1.6% by volume. Well 2 drilled a horizontal section of about 4,200 ft. MD ending with a 13.0 ppg mud density, an OWR 79/21 and LGS of 1.3% by volume at TD. Well 2 drilled with an ROP of 45 ft/hr which was 14 ft/hr higher than the diesel comparison well.

Well 3 started with mud from the second well at a density of 13.0 ppg, again requiring dilution with GTL base fluid. Well 3 started with a 12.25 ppg GTL synthetic drilling fluid with an OWR of 79/21 and LGS of 3.8% by volume. Well 3 drilled a horizontal section of around 4,200 ft. MD ending with a 13.45 ppg mud density with an OWR of 81/19 and LGS of 6.8% by volume at TD. Well 3 drilled with an ROP of 45.3 ft/hr which was 14 ft/hr higher than the diesel comparison well in the same field.

Well 4 started with the mud from the third well at a density of 13.5 ppg and mud weight was cut to 11.5 ppg, with an 80/20 OWR and LGS of 3.3% by volume. The horizontal section was drilled to TD ending with a fluid density of 13.4 ppg, with an OWR 76/24 and LGS at 4.0% by volume. Well 4 drilled with an ROP of 44.4 ft/hr.

All four GTL wells exhibited stable mud properties throughout the drilling operations. The GTL average mud weights were slightly higher than the diesel muds due to changes in formation pressure gradients. This higher density generally would be expected to result in a slightly lower ROP but this was not the case with the GTL wells.

All GTL wells landed the 4.5-in. production liner to TD without any issues. Some diesel wells required a reamer run to smooth out the well bore.

No elastomer failures with downhole equipment were reported by the directional company personnel when using GTL muds. The high aniline point of GTL fluid helps reduce elastomer failure. The MWD tool used Viton O-rings and the integral stator part of the directional tools used hard rubber elastomer.[6]

Results

ROP

Table 3 and Table 4 were developed using data obtained from the Shell Competitive Analysis Group and the directional driller's final well report. Overall ROP was measured by including the sliding and rotational ROPs. This analysis does not include NPT.

GTL mud drilled faster in all wells with the exception of GTL Well 1 and diesel Well 8. This was unexpected for Well 1 since it was a fresh mud and started with low solids loading. The lower performance could be attributed to lack of crew familiarity with the new mud system and/or changes in the directional driller's mode of operations.

Table 4 compares ROP performance across the eight wells. As depicted in Table 4, when comparing all GTL and diesel wells (total of eight wells), the foot per hour average showed a 9.5% improvement in ROP using GTL based mud versus diesel mud.

The best comparison of wells is GTL Wells 2 and 3 versus diesel Well 6. These wells were drilled in sight of each other in the same field using the same rig. In this case, the GTL mud had a 30.5% ROP improvement over the diesel mud.

Fluid Consumption

Fluid consumption in this report is based on a mass balance calculation of all fluids consumed by SCE and other miscellaneous fluid consumptions on the rig. These do not include downhole losses. Fluid consumption is aggregated only for the synthetic- or oil-based intervals, not the water-based sections.

Table 3: ROP Performance Comparison

Well Name	Type	OBM Addition, ft	Overall ft/hr	Sliding ft/hr	Rotating ft/hr
Well 1	GTL	4205	26.6	9.1	34.8
Well 2	GTL	4199	45.2	10.7	57.8
Well 3	GTL	4122	45.3	19.2	49.3
Well 4	GTL	4436	44.4	18.2	64.4
Well 5	Diesel	4076	29.5	10.0	41.9
Well 6	Diesel	4650	31.4	9.1	55.0
Well 7	Diesel	4152	38.4	7.1	50.5
Well 8	Diesel	4446	48.1	16.1	57.2

As earlier mentioned, the well comparisons had similar fluid densities and properties. The SCE included two rig shakers with screens using 170- to 200-mesh screens in the horizontal sections.

Table 4: ROP Foot/Hour for Sliding and Rotating Drilling Comparison

ROP, foot/hour average			
Well/Fluid	**GTL**	**Diesel**	**Improvement**
All Wells	40.4	36.9	9.5%
GTL Wells 2 and 3 vs. Diesel Well 6	45.2	31.4	30.5%

Mud recap reports showed that significant fluid consumption reductions were realized at the shaker from the improved recovery of the GTL fluid vs the diesel fluid. This was attributed to the lower base fluid kinematic viscosity compared to diesel.

Figure 3 shows the overall fluid consumption in barrels per well.

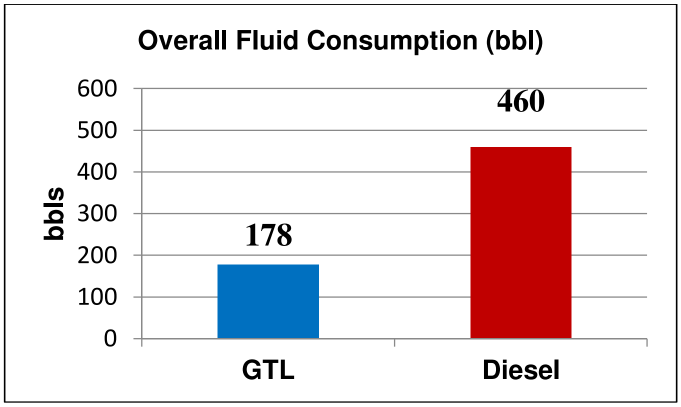

Figure 3: Overall fluid consumption

Industrial Hygiene Assessment

Methodology

Shell Upstream Americas engaged a contractor to conduct a study to determine inhalation and dermal worker exposure during GTL and diesel well drilling operations. A total of 34 workers across the following four job classes at three locations were assessed for inhalation and dermal hydrocarbon exposure:

- Floor hand
- Pit man
- Driller
- Mud engineer.

The THC (TWA and STEL) samples were taken using a Berufsgenossenschaftliches Institut fur Arbeitssicherheit (BIA) Sampler provided by Shell to collect mist and vapor phases.[7] BIA sampling method was validated by the lab using drilling fluids from the sampled sites.

BTEX/hexane/heptane, TWA samples were collected by using 3M 3500 passive organic vapor monitors. Benzene/xylene STEL samples were collected by using personal sampling pumps and charcoal tubes at a flow of 0.2 l/min.

The composition of bulk samples for all the fluids was analyzed at the lab. GC, validation and determination of THC, and calibration studies were carried out.

Semi-quantitative dermal exposure assessment (DREAM) was applied for studies in Occupational Hygiene and Epidemiology. This qualitative assessment uses the following parameters and ranges:

- Hazard/dermal toxicity ranking of the drilling fluid (scale 0 to 4) based on systemic toxicity from skin absorption from safety data sheet information, where 0 = minimal and 4 = significant
- Worker exposure of hands/arm/torso to hydrocarbons during individual tasks (scale 0 to 4), where 0 = minimal and 4 = long-term (>1 hour) exposure
- The overall semi-quantitative dermal risk ranking for each job class at each site is then the product of the Hazard Ranking multiplied by the Exposure Ranking.

Results

As depicted in Figure 4 and 5, TWA average exposures at diesel sites were higher than the GTL sites, with the Pit Man job class and Mud Engineer having the highest exposure at the diesel sites. No significant difference in the TWA sample for Driller and Floor Hand job classes was detected.

There was no detectable BTEX inhalation exposure reported on GTL rigs. BTEX inhalation was detected for diesel rigs. The detected levels were well below the OSHA PEL and ACGIH TLV.

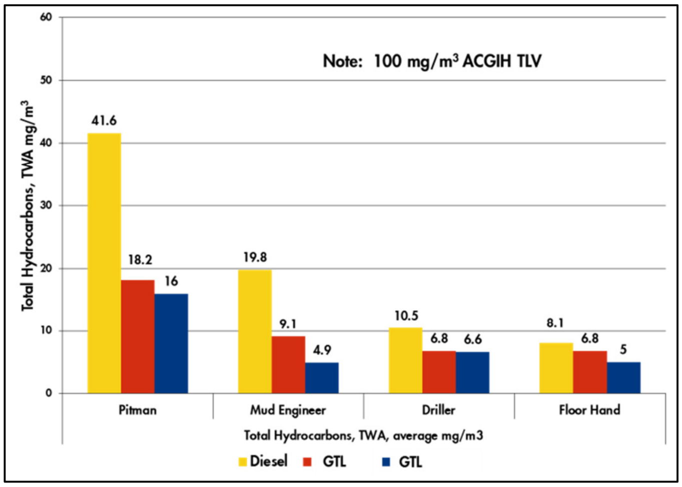

Figure 4: Inhalation exposure summary results – average 8 hours

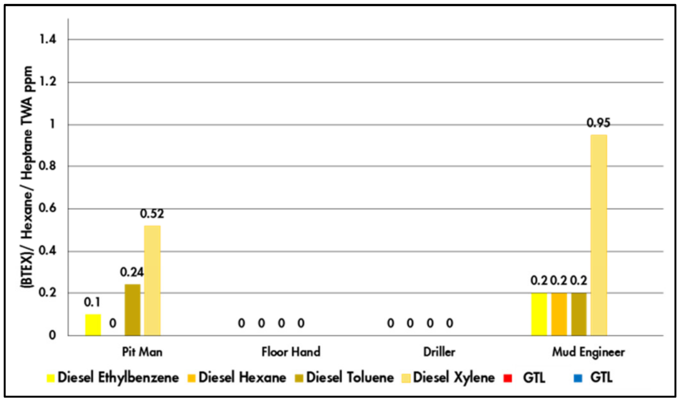

Figure 5: BTEX Inhalation exposure summary results – average 8 hours

Short-term (15 to 30 minutes) exposure also found that the Pit Man job class had the highest exposure at the diesel sites. The five STEL exposures at or above 100 mg/m^3 were incurred by the Mud Engineer while performing mud analysis at the laboratory, the Driller while working in the "Dog House," and Pit Man while he was washing the shakers (three samples).

All STEL THC were found only on the charcoal tube. Results are depicted in Figure 6 and Figure 7.

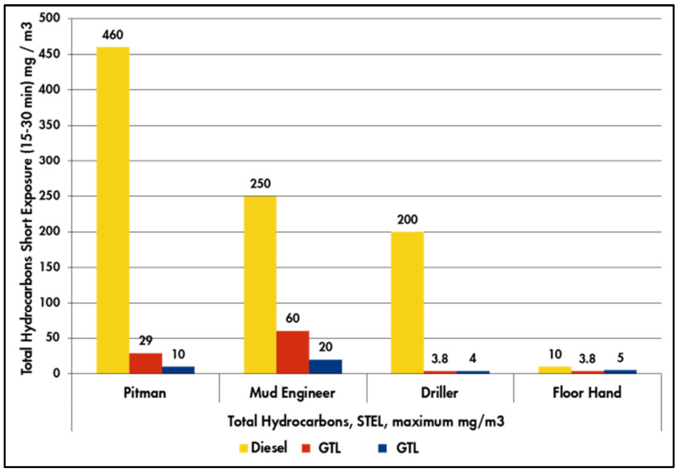

Figure 6: Inhalation exposure summary results – average 15- to 30-min exposure

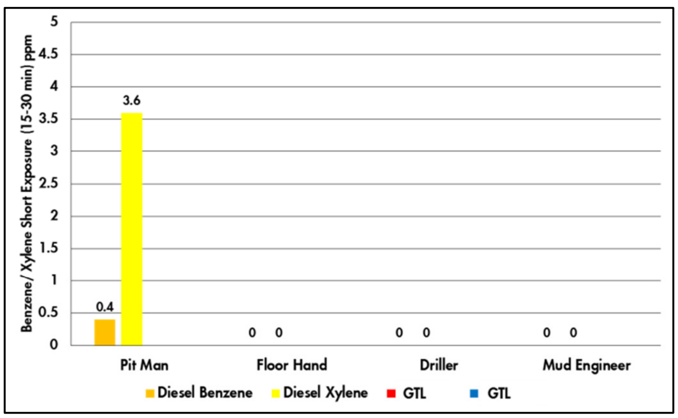

Figure 7: Inhalation exposure summary results – average 15- to 30-min exposure.

Qualitative dermal exposure of the workers to base fluids was determined using the dermal exposure assessment method (DREAM). This assessment is based on safety data sheet information. It gave diesel a Hazard/Dermal toxicity ranking of 4 and GTL of 1. Exposure time for these products was highest for the Pitman and Floor hand giving them the highest dermal exposure ranking of 4 during a shift. For diesel multiplying the hazard/toxicity and exposure time rankings (4 x 4) gives a dermal risk exposure for these jobs of 16 as seen in Figure 8. Dermal risk exposure of GTL for these same jobs was 4 (4 x 1). The mud engineer had a dermal risk ranking of 4 (4 x 1) for diesel and 1 (1 x 1) for GTL.

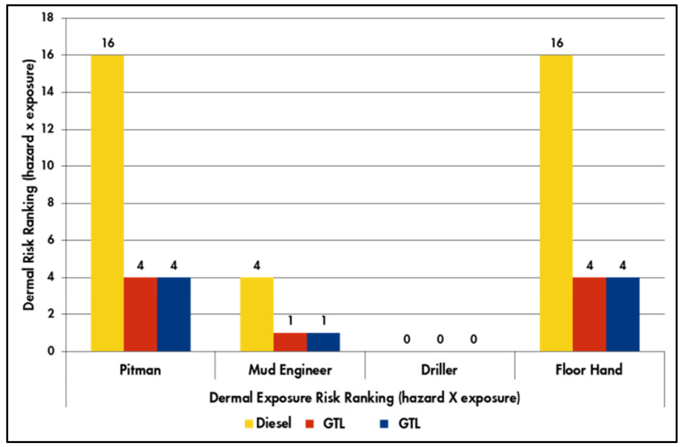

Figure 8: Dermal risk ranking

Industrial Hygiene Assessment Summary

As shown in Figure 5, the only inhalation exposure to BTEX/hexane/heptane detected was to the pit man and mud engineer at the diesel site. The only exposure to benzene/xylene STEL detected was to the Pit Man at the diesel site. The highest exposure at this site was created by washing the shaker. These exposures were well below the OSHA PEL and ACGIH TLV.

All GTL samples from the sites were less than Limit of Quantification and thus are considered not detectable.

Overall the dermal risk factor for GTL is reduced by a factor of 4 over diesel due to its lower Hazard/Dermal toxicity profile.

Worker Satisfaction Survey

An immediate assessment was administered during drilling activity of each well to all rig personnel, including day and night shifts. This included Company Man, Derrick Hand, Driller, Floor Hand, Motor Hand, Mud Engineer, Pit Hand, and Tool Pusher. A total of 35 surveys were completed using a simple selection form with a comments section; results are depicted in Figure 9. The survey results indicate that rig

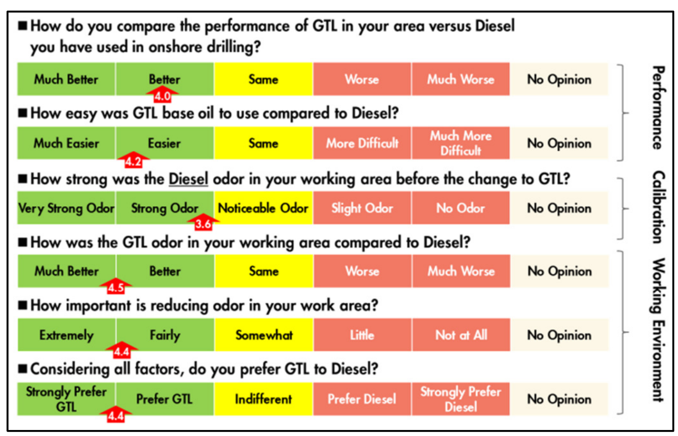

Figure 9: Worker satisfaction survey results

workers scored GTL muds higher than diesel oil muds in all categories of the survey, with a 4 or better score out of 5.

Bioremediation

The goal of the waste management study was to demonstrate the benefits of GTL base fluid in terms of no harm to environment.

The process of drill cuttings remediation in this study had to be simple and cost effective. The study also had to reflect an onsite operation. Most bio-remediation studies are performed in lab facilities, whereas, this project utilized an onsite test. These tests were conducted from March through May. The area experienced a heavy rain event during the trial period.[8]

A local environmental firm was selected because they had a good working relationship with the Texas Rail Road Commission and operators.

The GTL Well 4 in the Kermit area was selected for the bio remediation study. The remediation was conducted in a lined pit on the well pad with bio-piles as the remediation method of operation.

Remediation Methodology

To establish a baseline, the environmental firm collected samples from each of the remediation bio-piles for evaluation of TPH, chloride and moisture content prior to any treatment activities. During the testing, the pits were worked weekly for the first 30 days and the every other week for the next 45 days. A chain of custody of samples was maintained.

The lined pad was segregated into four quadrants. Each quadrant utilized fourteen cubic yards of GTL drill cuttings or cuttings/amendment for the study. In the environmental report these quadrants are designated as pits, hence the term "Pit Test." All four pits used an excavator to work the bio-piles to provide aeration for the degradation and remediation of the samples.

Samples were collected from each pile after 30 minutes of aeration. One set of samples from each pile was sent to a local 3rd party laboratory certified by the Texas Rail Road Commission for environmental analysis. The other set was kept by the environmental contractor. The TPH analysis was performed using the TX105 Extended Method.

Pit 1, contained only the fourteen cubic yards of GTL drill cuttings and served as the base case. No treatment was performed on the GTL drill cuttings. Aerobic biodegradation utilizing natural occurring microorganisms present in the environment was measured by following TPH levels.

The second pit, Pit 2, contained the fourteen cubic yards of GTL drill cuttings with forty two pounds of fertilizer added to the cuttings. The fertilizer was 32% by weight of Nitrogen.

The third pit, Pit 3, contained the fourteen cubic yards of GTL drill cuttings with the addition of a solvent product containing microbes which are used in the region for hydrocarbon spill remediation. Five gallons of the product were added to the fourteen cubic yards of cuttings.

The fourth pit, Pit 4, contained seven cubic yards of GTL drill cuttings with the addition of seven cubic yards of clean soil from the reserve pit area. The cuttings and soil were mixed in a 1:1 ratio of cuttings to soil, making the test material fourteen cubic yards.

These treatments were chosen to provide a blank with three treatments options to determine the best methodology. Chart 5 shows the result for all Pits. All Pit tests show TPH reduction. Some of this may have been from hydrocarbon evaporation. Pit 4 with added soil amendment was the only treatment showing significant TPH reduction.

The best practice for remediation GTL base fluid cuttings is the blending of the cuttings with clean soil or another amendment such as wood chips or hay.[9] The TPH for the cuttings was reduced from 11.0% on cuttings to 1.3% TPH after two months. This result is consistent with other studies evaluating the remediation of GTL base fluid cuttings.[10,11]

Chart 5: TPH Results for Pit Tests

Pit Number	Day, TPH%		
	0	30	60
1	11.1	13.2	6.6
2	11.1	12.3	10.3
3	11.1	12.7	8.1
4	11.1	3.7	1.3

Table 6: TPH Results from Bio-pile Pit Tests 1-4

Pit 4 (1:1)	C6-C12, ppm	C12-C35, ppm	Total C6-C35, ppm	TPH
Start	22,400	88,800	111,200	11.0%
Initial Treatment	11,100	60,600	71,700	7.2%
1st week	11,700	74,900	86,600	8.6%
2nd week	10,100	69,300	79,400	7.9%
1 month	4,290	33,200	37,490	3.7%
2 months	1,380	11,800	13,180	1.3%

Data Evaluation

The Pit studies showed that addition of a soil amendment was necessary for measurable reduction in TPH. Pits 1-3 had no soil amendment added. Pit 2 had a fertilizer amendment and Pit 3 had a microbial amendment added. Pits 1-3 showed measurable TPH reduction but this was likely due to evaporation. Pit 4 was amended with an equal amount of soil to give a 1:1 ratio of soil to cuttings. As seen in Table 5, the initial TPH was reduced initially by about 40% from 11.0% to 7.2% by dilution with soil. After the two-month test duration the TPH was reduced to 1.3% by the bioremediation process, yielding an overall reduction in TPH of 88%.

As depicted in Table 6, the more readily bioavailable C6-C12 hydrocarbon bioremediated or evaporated faster with only 0.2% remaining. The majority (2.1%) of the remaining TPH is in the C12-C35 carbon number range. This result is consistent for all the bioremediation tests.

Conclusions

GTL base fluid for oilfield applications can reduce overall drilling costs compared to diesel drilling.

- GTL muds provided consistent fluid properties in all wells.
- GTL muds improve drilling ROP by 10 to 30% vs. diesel.
- GTL mud reduces fluid consumption versus diesel.
- Production liners for GTL wells were successfully set to TD without issues.
- There were no elastomer failures using GTL muds.

GTL base fluids for oilfield applications reduce occupational exposure versus diesel.

- Reduced exposure to aromatic vapour emissions.
- Virtually odourless and non-carcinogenic.
- Up to 50 times lower short-term (15 - 30 min) THC and up to 4 times lower during full-shift exposure (8 hours) with GTL base fluid.
- Reduced dermal exposure by a factor of 4 with GTL base fluids in the qualitative assessment.
- The workers highly preferred GTL over diesel in terms of performance, ease of use, and low odor.

Bioremediation

- Bioremediation was conducted on location using biopiles requiring minimal maintenance and using common field equipment.
- GTL cuttings bioremediate rapidly in biopiles.
- TPH reduced to <5% after 30 days and to 1.3% after sixty days.
- Best practice for biopile composition is to add soil amendment at 1:1 with cuttings versus soil.

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Nomenclature

ACGIH TLV = American Conference of Governmental Industrial Hygienists Threshold Limit Value
ASTM = American Society for Testing and Materials
BIA = Berufsgenossenschaftliches lnstitut fur Arbeitssicherheit
BTEX = Benzene, Toluene, Ethylbenzene and Xylene
Cp = Centipoise
DREAM = Semi-Quantitative Dermal Exposure Assessment
ES = Electrical Stability
Ft = foot
GC = Gas Chromatography
GTL = Gas To Liquids
HSE = Health, Safety and Environmental
KPI = Key Performance Indicators
LGS = Low Gravity Solids
LTMO = Low-Toxicity Mineral Oils
MD = Measured Depth
MWD = Measurement While Drilling
ND = Non-Detectable
NIOSH = National Institute of Occupational Safety and Health
NPT = Non-Productive Time
OBM = Oil-Based Mud
OCNS = Offshore Chemical Notification Scheme
OSHA PEL = Occupational Safety & Health Administration Permissible Exposure Limits
OWR = Oil-to-Water Ratio
PBZ = Personal Breathing Zone
Ppg = Pounds Per Gallon
ppm = Parts Per Million
PV = Plastic Viscosity
ROP = Rate of Penetration
SCE = Solids Control Equipment
STEL = Short-Term Exposure Level
TD = Total Depth
THC = Total Hydrocarbon
TIH = Trip in Hole
TOOH = Trip out of Hole
TPH = Total Petroleum Hydrocarbon
TWA = Time-Weighted Average
YP = Yield Point

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