AADE-02-DFWM-HO-27

Design of a Solids Control System for Venezuela Heavy Oil Drilling

David Beardmore, Phillips Petroleum Company; James Headley, ChevronTexaco; Terry Johnson and Ronnie Threadgill, Petrolera Ameriven; and J.D. Thomason, Halliburton

Abstract

A solids control system was designed for a new-build rig contracted to drill horizontal wells in Venezuela's Faja Region, the heavy oil belt near the Orinoco River. Previous operators had experienced significant problems with: 1) shaker screen blinding by the sticky oil, 2) centrifugal pump erosion and cavitation, 3) the resulting poor hydrocyclone performance and 4) inability to maintain low mud weights. The 8.5 inch horizontal holes are drilled through unconsolidated sands at instantaneous rates up to 2000 ft/hr, which puts a heavy load on the solids control equipment. The main goals of the solids control system design were to remove the high sand loading, and allow for high ROP's without slowing down drilling progress.

A solids control system was designed that met these goals. The pad rig is designed to move from well to well on a pad in 2 hours. The entire mud system moves with the rig. The system was designed with high flow line shaker capacity and high desanding capacity.

Introduction

The Hamaca Project is operated by Petrolera Ameriven, a joint venture between ChevronTexaco, PDVSA and Phillips, to produce, process, transport and upgrade 190,000 bbls per day of 8.5 degree API extra heavy crude oil. The project is located in the Orinoco Faja in Venezuela (Figures 1 and 2). Other similar projects are also operating in the Faja.

The fully integrated process will require the drilling of horizontal wells to exploit the extra heavy crude oil. The wells will be equipped with progressive cavity pumps that lift the oil to surface where it is blended with lighter diluent to allow movement of the fluid to a field-processing center. After separation of gas and water, the diluted crude is shipped approximately 150 miles north to the Jose Industrial complex where it will be upgraded for marketing to international buyers.

Development production started in October 2001 and will continue until the upgrader construction is completed in December 2003. During this early production period, light crude is blended with the extra heavy crude oil and is sold as a 16 degree API blended production. Production rate in December, 2001, was as high as 30,000 bbls of extra heavy crude oil per day, with a plateau rate of about 60,000 bbls per day expected to be achieved in the second half of 2002, subject to OPEC quotas.

In the Faja, horizontal wells are typically drilled from multi-well pads to intersect the three major heavy oil sand units that exist from 2100 feet to 3100 feet TVD (see Figure 3). Reservoir characteristics include: 28-40% porosity, 3-30 Darcies permeability, and 40-250 feet of net pay.

Well/Pad Design

A wellbore schematic (Figure 4) shows that there are two main hole sections of concern in a typical well. A 12-1/4 inch intermediate hole section is drilled from the surface casing shoe at about 900 feet down to a kick-off-point, where a curve is built to 90 degrees in the target sand. A 200 foot tangent section is included at about 65 degrees for placement of the progressive cavity pump. The first 500-800 feet of this section is reactive shale, followed by alternating sands and shales to TD, where 9-5/8 inch casing is set.

The 8-1/2 inch horizontal production section is typically 5000 feet long. Several different well designs are used: single laterals, multilaterals, and "fishbones". In single lateral wells, a 7 inch slotted liner is run to TD, and a progressive cavity pump is run on 5-1/2 inch tubing to the tangent section of the curve at 65 degrees. In multilateral wells, two 5000 foot laterals are joined by a Level 4 (cemented) junction. Fishbones are wells that have a main "trunk" well, with several +/-1600 foot side laterals drilled from the main trunk. In fishbone wells, the slotted liner is run through the main trunk with the laterals off of the trunk left open hole. There may be as many as six fishbone laterals in a single well.

All the drilling locations for the pads are dry locations ("closed-loop"). No earthen pits are allowed on location. The pads are paved to minimize mud during the wet season and dust in the dry season.

Other Operator Experience

When the Hamaca project was begun, there were already three operators working on heavy oil developments in the Faja: Petrozuata, Sincor, and Cerro Negro. Before the Hamaca project was started, these operations were visited to help determine current best practices and problems that needed to be addressed.

Each of these operators use pad drilling rigs, which are rigs that are designed to move quickly from well to well on a multi-well pad. These rigs use stationary mud processing systems (see Figure 5) that are connected to the mobile rig by flexible umbilicals. The flow line shakers and one mud tank (sand trap plus one compartment) move with the rig. The mud is pumped from this pit through an umbilical to a stationary tank where the fluid is processed by various hydrocyclones, mud cleaners, and centrifuges to clean the mud. The clean mud is pumped back to the rig through umbilicals.

Simple fresh water-based mud is typically used in the 12-1/4 inch intermediate section. Hole cleaning in the curve is the main concern, and xanthan biopolymers are used to enhance hole cleaning.

There were basically two different drill-in fluid systems in use in the Faja for drilling the 8-1/2 inch section. One is a very typical water-based drill-in fluid with xanthan biopolymer for rheology control, starch for fluid loss control, calcium carbonate for bridging, and biocide. The other system is solids-free: simply xanthan biopolymer and biocide.

Problems encountered by the earlier drillers in the Faja heavy oil wells include:

- Shaker screen blinding by the viscous, heavy oil that leads to high mud losses over the shakers and the requirement to run coarse screens (20 to 40 mesh) on the shakers. Prescreening with scalping shakers did not help appreciably. In most cases both sets of screens would blind with the sticky oil. The screen blinding problem was fought by spraying the screens with mineral or synthetic oil, but mainly coarse screens were being run.
- The use of the coarse screens increases the load on downstream solids removal equipment (desanders and desilters) and can lead to cone overloading, rope discharge from the cones and inefficient cone operation. Poor cone performance can make it difficult to control mud weights and result in high dilution rates and increased waste volumes.
- Since the normal rig used a stationary mud processing system, mud is transferred from the shaker tank to the mud processing system with centrifugal pumps. Problems encountered with this approach included: maintaining prime on the transfer pumps due to the gas content of the mud and wear on the pumps due to cavitation and the high sand loading in the fluid.
- Although gas cut mud was often encountered, attempts to use degassers usually failed due to plugging with the sticky heavy oil and the high sand loading. Degassers were generally not used by the other Faja operators.
- Differential sticking is at times a problem in the long productive sand intervals drilled. Maintaining a low mud weight is critical.
- Rates of penetration (ROP) can be quite high in the sands. In order to maintain directional control, the instantaneous ROPs can be greater than 2000 feet per hour. The mud system and the mud handling and solids removal equipment should be capable of handling solids generated at those high rates that may arrive at the surface as slugs of heavily sand-laden mud.
- High dilution rates can result in high trucking costs and logistical problems when handling waste mud and solids at a central site.

Mud Equipment / Waste Management System Design

The first rig on the Hamaca project was to be a newly built rig, which offered the rare opportunity to design and build a rig mud system from the ground up.

The rig selected was a Precision Drilling pad rig that includes a mud system designed such that the entire mud processing system moves on roller mats as the rig is moved (see Figure 6). This eliminates the necessity to move sand-laden mud from the shaker tank (that moves along with the pad rig) to stationary mud processing pits. As mentioned previously, the pumping of the sand-laden mud had been a source of problems for other operators in the Faja. This design improvement eliminated the transfer pumps and the attendant gas locking and wear problems.

The drilling fluids formulations to be used on the wells were as follows:

- Surface hole: native mud
- Build section: native mud in the first few hundred feet, converted to XC polymer and starch mud in the lower sections for directional control
- Horizontal section: drill-in fluid of XC polymer, biocide and preserved starch. No calcium carbonate is used in order to keep the mud weights low.

Fluid properties for the three sections are shown in Table 1.

The mud equipment system designed included everything between the bell nipple and the mud pumps, as well as the waste handling system. The assumption was that this rig would be used for several years so almost any reasonable investment in mud equipment would be paid back many fold. In addition, the system was somewhat over-designed, as it is easier to remove a piece of equipment than to add one. The design process focussed on the horizontal sections as that is where the most challenging solids removal situations would occur.

The system was designed according to accepted oilfield practice for efficient and effective solids removal from drilling fluids[1, 2, 3].

The system design needed to account for the following needs and concerns:

- The main goal of the mud equipment and waste handling system is to maintain fluid properties and minimize waste haul off without slowing down the drilling process.
- The dry locations require haul off of drilled cuttings and waste mud. The system design needs to strive for minimum of haul off by yielding cuttings in as dry a state as possible and for a minimum of mud dumping and dilution to maintain properties. These goals will help minimize costs by minimizing waste volumes (cuttings and mud) that require trucking and disposal.
- With the dry location, no sand trap (settling pit) would be used in the mud handling system.
- Use a pad rig with a fully mobile mud system to eliminate the use of transfer pumps that caused problems for other operators.
- With the fairly coarse sand to be drilled, the shale shakers can be the heart of the system. However, if screen blinding is a problem and coarse screens are required, then a great deal of the sand cuttings will pass through the screens.
- If coarse screens are necessary, then the hydrocylones will become the heart of the system. Sufficient capacity will be required to process the sand at expected drilling rates without overloading.
- The low mud weight requirements and dry discharge requirements necessitate that the cones be operated as efficiently as possible and that the cone underflow be centrifuged.

Figure 7 is a conceptual drawing of the mud processing system.

The pit system was designed to have sufficient compartments for sequential, full flow processing through shakers, desanders, a desilting mud cleaner, and centrifuges.

The rig contractor insisted on having a sand trap (settling pit) in the system for rig marketability reasons (Figure 7, compartment #1). The mud ditch system on the tanks was designed to bypass the sand trap since it cannot be used on the dry location.

The system was designed with four linear motion shakers on the flow line. A four-way splitter was installed to provide even feed to all shakers. The splitter also included a cement bypass line to take contaminated mud to disposal. High-pressure washers were installed on the pits to help clean the screens during connections. Other operators were using two or three shakers. Even with the coarse screens, the shakers were often overloaded with solids, especially following periods of high ROP.

The additional shakers were specified in an attempt to be able to handle the large volumes of sand often encountered. In addition, it was hoped that more screen area would still allow for somewhat finer screens to be run even if screen blinding by the heavy oil was encountered.

As none of the other operators in the Faja were using degassers, no degasser was built into this system.

Considering the possibility that coarse screens (20-40 mesh) might be run on the shakers, there needed to be sufficient hydrocyclones in the system to carry the load when fast ROPs were encountered. For this reason, four 10-inch desander cones were designed into the system. The desander cones were divided into two pairs of two cones each with a dedicated centrifugal pump to serve each pair. These two cone units are operated in parallel. These two units have the combined capacity to treat 2000 gpm of fluid when both pairs of desander cones are in operation. The two pumps were chosen to give the system some flexibility, to be able to run only one pair of desander cones if the sand loadings were not high. In addition, feeding four desander cones from one centrifugal pump can be problematic.

The first tank compartment used is the desander suction compartment (#2 in Figure 7). Compartment #2 takes the flow from under the shakers. The two desander pumps take suction from this compartment and feed the two sets of desander cones. The desander overflow (cleaned mud) is discharged into compartment #3. The relatively dry desander cone discards are discharged to the solids tanks.

Backing up the desander units is a desilting mud cleaner with 20 four-inch desilter cones. These cones are mounted over a full size linear motion shaker, the same type of unit used on the flow line. This bank of desilter cones is fed by a dedicated centrifugal pump. The pump takes suction from compartment #3 (the desilter suction compartment). The cone overflow (clean mud) discharges into compartment #5. The cone underflows are screened by the linear motion shaker. The screen overs are discarded. The screen underflow is routed to compartment #4, which is a catch tank to hold the material for further processing by the centrifuge.

Decanting centrifuges for solids removal are the last step in the solids removal process. The centrifuge takes suction from compartment #4. This is the catch tank for the screen unders from the desilting mud cleaner. This catch tank is equalized with compartment #5, the desilter returns compartment. The centrifuge is fed at a rate greater than the desilting mud cleaner supplies screen unders. The differential is made up by drawing mud into the catch tank from compartment #5. Thus the centrifuge is also taking some suction from the active system.

This arrangement of centrifuging on the desilter screen unders allows the centrifuge to process more of the larger particles in the mud system. The desilter cones concentrate the larger particles into a stream for the centrifuge to process and more solids are removed from the system. If the centrifuge operated only on the active system, most of the larger particles separated by the mud cleaner would go back into the mud stream and bypass the centrifuge (which does not process the full flow of the mud stream).

An additional centrifuge that was specified to act as a backup to both the mud system centrifuge and the dewatering centrifuge is, in fact, used most of the time on the active system. Thus there are normally two centrifuges processing on the mud stream.

The mud stream then overflows from compartment #5 into the suction pit (compartment #6). Compartment #7 is used as a reserve pit for drilling fluid. Compartment #8 is the slugging pit.

The processing pits and suction and reserve pits were mechanically agitated (except the unused sand trap). The compartments contain baffles designed after the recommendations found in API RP-13C[4] to help minimize any settling that may try to occur in the compartments.

Adjustable equalizers were installed between all the compartments. All these equalizers are intended to be run as bottom equalizers between all compartments except the overflow from the desilter discharge compartment (#5) to the rig suction pit (#6).

A three-compartment 300-barrel premix pit with a shear pump to effectively shear the polymer is also part of the mud equipment system. This premix tank also moves along with the rig. The compartments are stirred with mechanical agitators and mud guns. The tank bottoms also contain baffling to aid in mixing and help prevent dead areas in the compartments when mixing the viscous fluids.

The waste handling design calls for all waste liquid mud or other liquid wastes (other than cement contaminated fluids) to be dewatered. These liquids, which have to pass local contaminant limits, are to be reused in the mud or are to be land-applied at the rig site.

Solids, mainly drill cuttings, were to be collected from the linear shakers and desanders in one tank and from the mud cleaner and mud centrifuges in another tank. Originally these pits were to be V-bottom auger tanks that would mix the collected cuttings with drying diluent soil. The diluted solids would then be augered directly into waiting dump trucks for hauling to a central site, again to be used as base material for pad construction. A separate small pit would catch the dewatering unit solids discharge. This small volume would also be used as pad base material.

One company, Halliburton, supplied mud services, solids control services, and waste handling services to allow better coordination of these three interdependent operations.

Discussion of Mud Processing System Performance

Two rigs of this design have been drilling at Hamaca. As of the end of 2001, Petrolera Ameriven has drilled 168,000 feet of 12-1/4 inch hole (build sections) and 516,000 feet of 8-1/2 inch hole (production sections) on six pads. In general, the mud system worked as designed, and the drilling process was only rarely slowed by problems with the surface mud equipment system.

The first problem that was encountered was unexpectedly severe gumbo in the first 500 feet of 12-1/4 inch hole. This had not been reported often by the other operators. This caused flowline plugging, flow splitter plugging, and screen blinding. The problem was largely avoided by changing the drill out mud from a hole-cleaning rheology to simply water. The gumbo was dispersed by the water, and plugging problems were reduced. By the time the gumbo zone was passed, it had created a clay-laden native mud, which was used successfully in the rest of the section after treatment.

The auger flights in the auger tanks were also easily packed off by the sticky gumbo clay that was drilled in the upper 12-1/4 inch hole. This resulted in the need to shut down the augers and clean them out. To avoid this, the auger tanks were replaced by simple four-sided rectangular tanks. A backhoe is used to move the dried cuttings from the tanks to the dump trucks.

With the large screen area of four flow line shakers, it was found that 84 or 110 mesh screens can be run without appreciable mud loss in both the intermediate and production hole sections. This is in contrast to the other operators who typically run 20 to 40 mesh screens on two or three flow line shakers. It is not known if the improved operation of the shakers is due to less sticky crude oil at Hamaca or to the larger screen area.

Solids control technicians are required to watch the shakers at all times. Screens are washed with high-pressure water spray on connections, and occasional overloading of the shakers must be managed.

Due to the relatively large size of the formation sand grains, a large majority of drilled solids are taken out by the shakers. Consequently, it has been found that only one set of desanders needs to be run.

The mud cleaner, which is a 20-cone desilter above a linear shaker, was not performing efficiently at first. The head provided by the centrifugal pump at the feed header was too low. Rather than change the pump impeller or speed to increase the feed head, four of the desilter cones were blanked off in an attempt to reduce flow and increase feed head. This action resulted in increased head at the feed header and improved the cone discharge. It was found that 16 cones provided sufficient treatment capacity to maintain the mud in excellent condition.

It has also been found that running a slightly coarser screen on the mud cleaner, a 150 mesh instead of a 210 mesh, is advantageous. With coarser screens, the desilter cone bottoms can be opened up to make a finer cut, discharging more liquid and removing more solids. The additional solids that pass through the screen are easily removed by the centrifuges.

Two centrifuges are fed from compartment #4, which catches the mud cleaner screen underflow and receives additional clean mud from the desilter discharge compartment (#5). With these two units processing concentrated solids from the mud cleaner, it has been found that mud weights of 8.5 to 8.6 ppg can be maintained without dilution. These centrifuges tend to discharge little solids when drilling pure pay sand, but they discharge a large amount of solids when a clay is drilled in the intermediate hole, or when a shale is encountered in the production hole.

All of the compartment equalizers in the system were build as adjustable equalizers. When bottom equalization is required, the adjustable equalizer pipe is simply laid on the bottom of the tank. The adjustable equalizers are 12 inch diameter. It was found that when both desanders are running, the equalizer is not big enough to transfer 2000 gpm from the desander discharge tank back into the desander suction tank upstream. A hole was cut between these two processing compartments at the bottom of the tank to allow for increased flowback.

Using a volume balance approach, taking into account the fluid volumes at the beginning and end of the hole sections, volumes of water and mud added to the system, and all fluids removed from the system, solids removal efficiencies have been calculated. Removal efficiencies of 85-89% were obtained for the surface and intermediate sections. Removal efficiencies of around 95% were obtained for the production hole sections.

With this mud equipment system, it has been found that liquid waste generation has been minimized. The large majority of liquid mud that is sent to dewatering is the mud in the pits at the end of the intermediate hole. This clay-laden mud is unsuitable to begin drilling the gumbo section at the beginning of the next intermediate hole. (Note that the rig drills all the intermediate holes on a pad, and then turns around and drills all the production holes on the pad.) The production hole drill-in fluid is retained at the end of each well and used to begin drilling the next production section. Virtually no dewatering is done on the production hole. Much of the clear water produced by the dewatering unit is recycled back into the mud system, the rest is land-applied at the rig site.

Conclusions

The following points summarize the improved operations that Ameriven has implemented at their Hamaca development in Venezuela's Faja heavy oil region:

1) The mud equipment system designed for Hamaca has met the goal of not slowing the drilling process.
2) The mud equipment system produces low-weight mud without the need for dumping and dilution, which has minimized waste volumes.
3) The fact that the entire mud system moves with the rig removed transfer problems that other operators faced with sand-laden mud.
4) The added shale shaker capacity has allowed finer screens to be run, and consequently, more solids to be removed at the shakers.
5) The additional desander capacity helps ensure that the cones will not be overloaded if coarse screens have to be run on the shakers.
6) Improved effectiveness was achieved for the centrifuges by feeding them concentrated solids from the mud cleaner underflow.

Acknowledgments

The authors would like to thank Ameriven, Phillips, and ChevronTexaco for permission to publish this paper.

Special thanks go to Ameriven drilling personnel Ken Gunn, Steve Cassidy, Neal Kebert, Tom Sanders, Mark Amundson, Ricardo Groenke, Tim Ponsetti, Gerard Hebert, Gale Terry, Lynn Holifield, Rafael Nava, Ernesto Gomez, Antonio Hernandez, Tim O'Connell, Rusty Penny, Hector Caicedo, and Don Wojciechowski. The authors also wish to thank Halliburton and the following Baroid personnel: Martin Wayman, Tommy Burns, Gonzalo Bernal, Keith Browning, Iain Davidson and Matt Woodman. Thanks also to Precision Drilling International's Tim Braun and David Hobbs.

References

1. Handbooks 1 through 11, IADC Mud Equipment Manual, International Association of Drilling Contractors, Gulf Publishing Co., Houston, Texas (1982-1985)
2. "The Ormsby Method of Solids Control in Drilling Fluids", George Ormsby, Stonewall Associates, Inc. (1982).
3. "Practical Solids Control", Cagle Oilfield Services Inc., W.S. Cagle.
4. API RP 13C, Drilling Fluid Processing Systems Evaluation, Second Edition, American Petroleum Institute, Washington, D.C. (March 1996).

Table 1

Typical Mud Properties

Hole Size, In	Depth (MD)	MW, ppg	Mud Type	FV, sec	PV	YP	pH	Fluid Loss, cc/30 min
17.5"	0-900'	8.4-8.8	Water/Native Mud	25-35	-	-	-	No Control
12.25"	900-1500'	8.4-8.7	Water/Native Mud	25-35	2-6	2-8	9.0-10.0	No Control
12.25"	1500-3900'	8.5-9.2	XC/PAC/Starch/Cr-Free Lignosulfonate	30-45	10-15	12-18	8.5-9.5	7-12
8.5"	3900-9000'	8.5-8.7	XC/Starch/Biocide	36-45	6-9	15-25	8.5-9.5	6-10

Figure 1.
Venezuelan Faja - Heavy Oil Belt

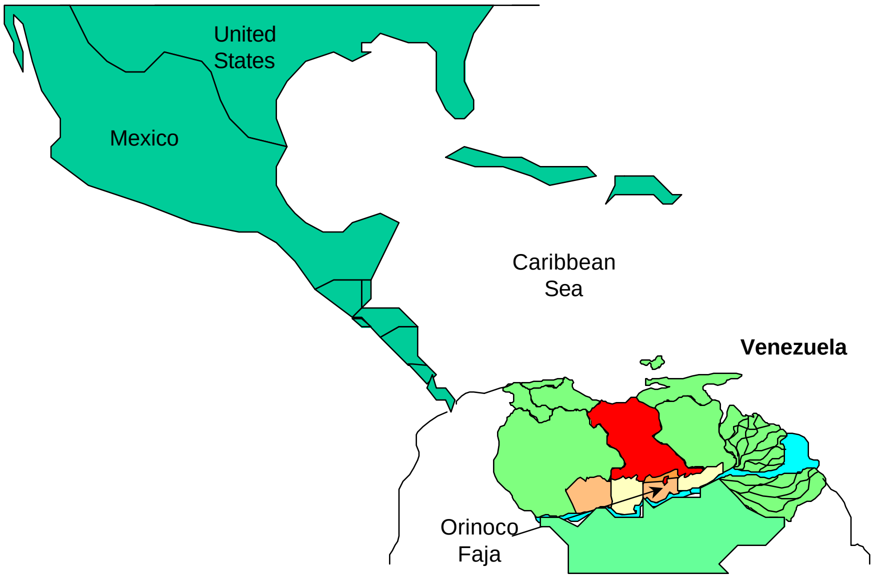

Figure 2.
Petrolera Ameriven Hamaca Development

Figure 3.
Typical Well Design for a Hamaca Pad - 14 wells

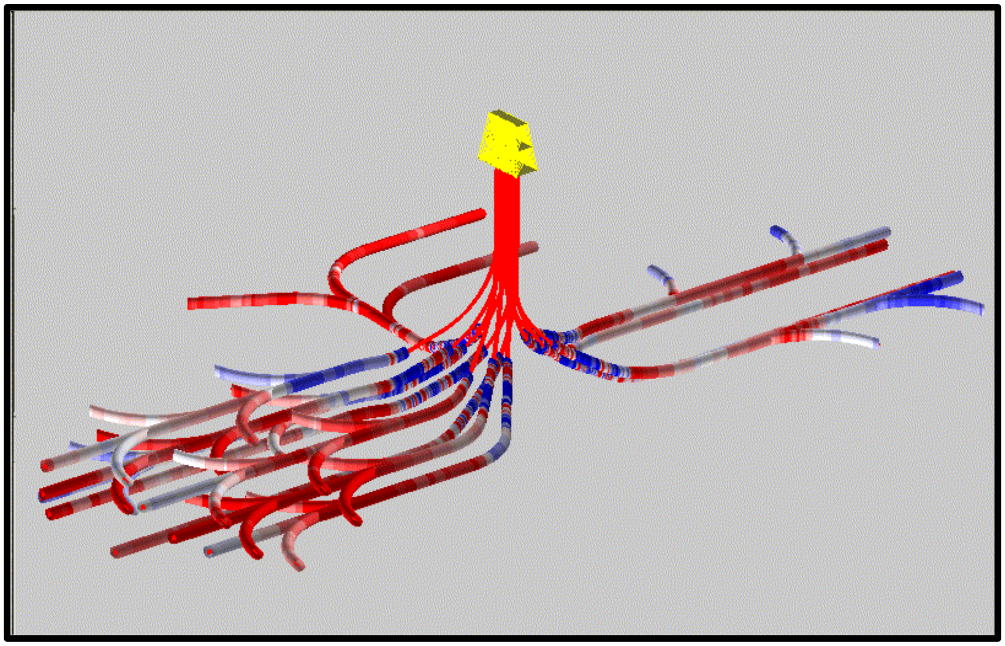

Figure 4.
Typical Hamaca Wellbore Diagram - Single Lateral

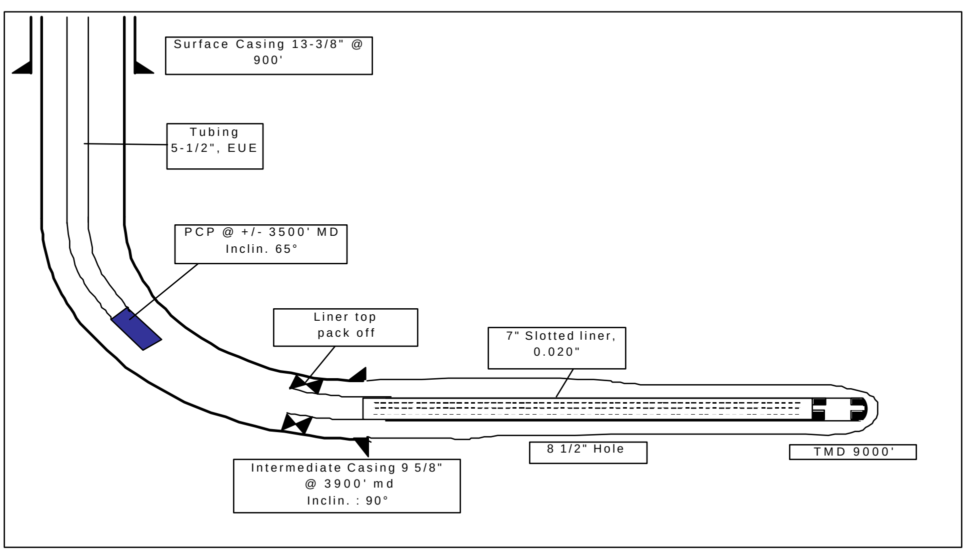

Figure 5.
Mobile Pad Rig with Stationary Mud Processing System

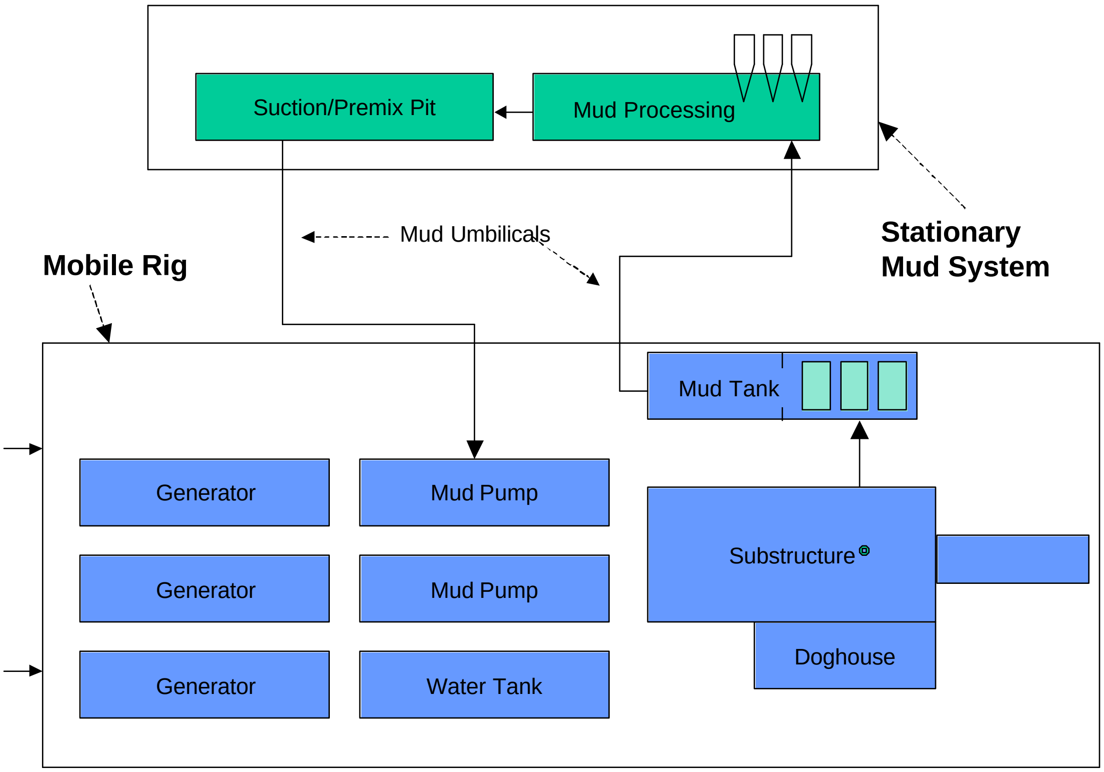

Figure 6.
Mobile Rig With Fully Mobile Mud System as Used at Hamaca

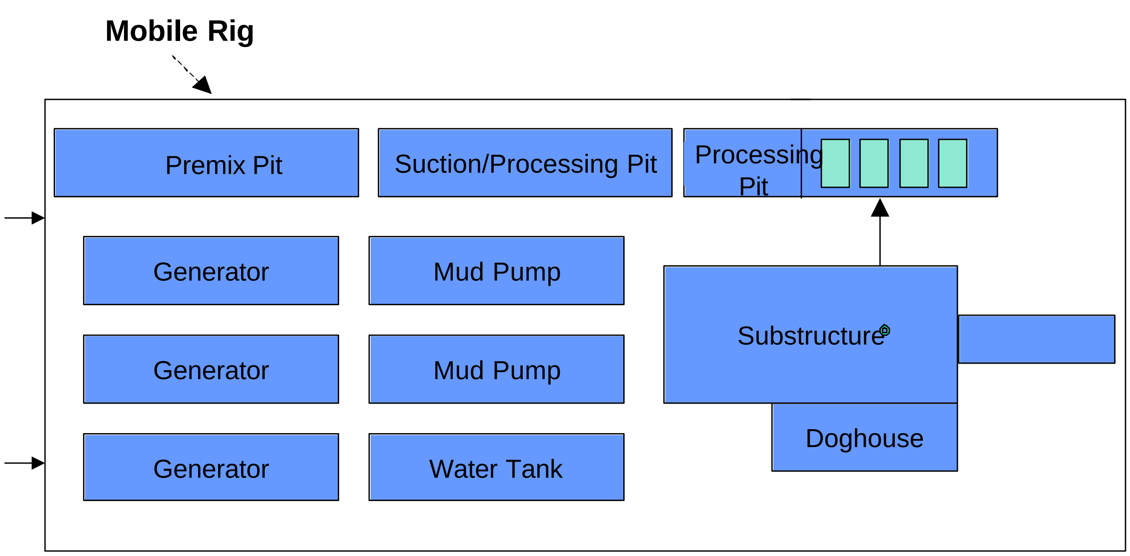

Figure 7.
Solids Removal System Design