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Integrated Approach for Optimized Techniques in Rig and Boat Cleaning Operations

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Abstract

Pit cleaning is a mundane but essential part of drilling. Because of the ever-higher requirements of drilling and completion fluids, elimination of carry-over contamination is increasingly important. The value of pit cleaning can also be expressed in negative values: when drilling operations are stopped because a pit is not ready or a boat cannot be loaded, lost time can quickly ring up thousands of dollars of rig downtime. The choice of cleaning methods is not simply using the best cleaner. The values of time versus the investments in machines, personnel, chemical costs, and the costs of disposal must be also be considered.

Introduction

Drilling and completion fluids must be kept free of contamination by other fluids primarily because of environmental and performance requirements. For example, completion brines require optical clarity to prevent plugging the rock surfaces of the production zone. As little as 10 gallons of spud mud can throw 500 bbl of completion fluid off spec. In a 16-ft x 16-ft x 12-ft tank, this corresponds to a layer about 0.01-inch thick.

In a similar way, oil-based mud (OBM) can taint synthetic-based mud (SBM) meant for offshore use. US environmental regulations in the Gulf of Mexico require that SBM can only be formulated with a non-aqueous fluid (NAF) that meets biodegradation, toxicity and polyaromatic hydrocarbons (PAH) requirements. Further, SBM must be certifiable as free of formation fluids, generally crude oil, by a gas chromatography/mass spectrometry (GC/MS) test prior to shipment.

Contamination by diesel muds can cause the SBM to fail the GC/MS test. More importantly, because discharge of diesel-based mud or cuttings is banned, knowingly mixing diesel-containing fluids into dischargeable SBM will change the dischargeability status of the mud. Finally, water-based muds (WBM) and completion fluids are generally incompatible with SBM, resulting in a thick paste when mixed.

In order for water-based muds to be dischargeable, they must meet their own environmental requirements for toxicity and be free of oil as measured by the static sheen test. Contamination by diesel-based muds can cause failure of both tests.

Mud Residue Removal for Recovery or Disposal

Most cleaning systems optimize surfactant cleaning action with cleaning time. The choice of methods for cleaning mud tanks must also consider the value of recovered mud, the value of cleaning time and the costs of labor. Mud recovery not only reduces disposal cost but also can provide an important source of revenue. These economics must be determined for each location as mud costs, disposal costs, and labor costs vary widely. Table 1 shows relative prices and costs of disposal in the Louisiana Gulf Coast.

It is estimated that boat tank residues in Gulf of Mexico vessels are about 35 bbl per tank. Many boats will have two to four tanks in SBM service, representing up to 140 bbl if residues are near mud quality. In this market, SBM recovery appears quite attractive. However, the strict environmental and performance requirements for SBM means great care must be taken to assure the recovered mud will be acceptable without extensive analytical and toxicity testing or extensive reconditioning.

Rheology and other properties should also be at or near typical mud properties to assure proper blending back into the mud pool. Historically, SBM sent out to the rigs have been 9.0 to 10 lb/gal. These are weighted up during drilling and returned as 14- to 17-lb/gal fluids. However, recent increased upper-hole usage is resulting in lighter fluids coming back to shore. Typical mud properties for IO-based SBM are shown in Table 2.

Beyond tank design, the next step to good mud residue recovery is maintaining good mud up to the time of return. Good suspension properties and goods solids control mean fewer residues of better quality. In rig tanks, low shear zones pick up static beds of settled barite and larger cuttings particles. In boat transport, the continual motion of the tank enhances this particle sag by breaking suspending gels. Rough seas, such as seen in North Sea, are particularly effective in this regard resulting in boat tank residues that are often hard-packed beds of nearly solid barite.

Even when not hard packed, the residue's solids-enrichment makes for very high plastic viscosity — indeed, that's why the residue remains in the tank instead of being pumped away. Highly packed beds become dilatent, displaying increasing viscosity with increasing shear. Fluidizing these beds for removal is made difficult by the stiffness of the bed which makes it resistant to hydraulic mixing with the low-viscosity wash agents. The tightly packed solids in the bed also resist thinning because of capillary suction; in order to introduce fluid, you have to pull apart solids embedded in a viscous matrix.

These effects can be demonstrated in simple test to simulate the formation of a settled bed from synthetic-based mud. A 250-mL quantity of 16-lb/gal synthetic-based mud is centrifuged at 1,050 g-force for one hour. The liquid mud is poured off, leaving a settled bed, mostly of barite. The centrifuge bottle is refilled with water, and the blade of a Fann laboratory mixer positioned 1½ in. above the bed. Controlling speed by a rheostat, the water is stirred for 5 minutes, and the fluidized barite is poured off. As shown in Fig. 1, essentially none of the bed is lost at a 25% setting, while 50% is lost at rheostat setting of 50%. Higher settings fluidize more, but even a 100% setting cannot liquefy the entire bed.

The sudden change in bed removal seen between the 25 and 50% settings is characteristic of plastic deformation of the bed at the yield-stress point. The bed behaves as a solid until the applied shear reaches the yield point, similar to the disruption of filter cakes.[1] Very little of the settled material is removed until the hydraulic shear applied by the wash fluid overcomes the plastic viscosity of the bed. At that shear and higher, the bed behaves as a fluid disperses into the wash liquid.

Also shown in Fig. 1, the use of surfactants shown to be effective in cleaning up the liquid mud have very little effect on liquefying the bed. They become effective once the bed is hydraulically dispersed, preventing the redeposition of the material onto the walls of the container.

As discussed above, the residues remaining in the tank are often very thick and require amendment with fresh synthetic and other mud components. These poor properties can be further degraded by the cleaning methods. Free use of water, particularly with surfactants, can result in a large increase in plastic viscosity. For example, sediment collected with pressure washer may be diluted 100% with wash water. Table 3 shows the resulting viscosity places the mud well off spec. If this mud is to be reclaimed, an additional 0.83 bbl of base NAF and several pounds of emulsifiers, wetting agents, and lime are required to bring the fluid to a 65/35 synthetic/water ratio with proper rheology.

To avoid water contamination, residues can be removed by mechanical means. Crudest, but easiest to implement, is to do the testing needed for confined space entry, and then send in a crew with buckets and shovels. Pumps lowered into the tank can also be effective for flowable deposits and wash water, but often are not able to pump of thick residues.

Vacuum clean-out by vacuum truck or stationary vacuum unit has significant advantages. The high-velocity air stream at the nozzle not only pulls up the residue, but it carries the residue along to the collection box. Unlike a typical diaphragm or centrifugal pump at the same elevation, the air stream to the vacuum pump can lift materials to above their suction head pressure. This ability is lost if the air velocity is allowed to drop by picking up too much material or kinking the hose. A typical vacuum setup for a self-draining tank is shown in Fig. 2. In less ideal tank geometries, a flexible line can be dropped to the bottom of the tank, or manually directed.

If it is uneconomical to reclaim the residue and it is soft enough to respond to hydraulic shear, the tank mixers and hydraulics may be used to flush the residue from the tank using water, water with surfactants, or solvent. WBM residues are often dispersible in water if the barite fraction is low. .

OBM or SBM residues, on the other hand, are very difficult to flush with water, and a surfactant is usually required. Solvents may be used if they are safe to handle in the situation, thinning the mud and clearing at least the lighter components. All these methods are subject to dropping barite as the residues are dispersed into the flush liquids. Heavily settled beds may be completely resistant to flushing if the surface shear is not high enough. Where effective, a large amount of water or solvent must be used. This is not a problem where water can be taken in and discharged without treatment. In many locations the fluid must be at least made oil-free before discharge, and the cost and complexity of treatment generally increases with each additional requirement. Solvents have their own disposal issues. One use is recycle to make fresh mud if the chemicals are compatible.

Rig-tank flushing with seawater may be most applicable to offshore tanks holding aqueous fluids suitable for discharge. Tanks are usually cleaned frequently, and the sediments may not be as hard-packed as boat-tank sediments. Yet the time lost to flushing is more often a direct contributor to rig downtime than the time spent cleaning boat tanks. The boats are run between changes and the rig cleaned at the change.

Flushing sediments from rig tanks holding SBM is not only technically more difficult but also more regulated. Under the new permit[2] in the US Gulf of Mexico, pit cleanout residue after use of SBMs must be included in the calculations used to determine compliance with base fluid retention-on-cuttings limitations. One of the options for the limitation is the use of a default value of 75 bbl of residue to be averaged over the mass of the discharge of the synthetic intervals. In many cases this will not be significant impact on the well average. However, in some cases the extra mass of base fluid discharge may be the difference between compliance and non-compliance for the entire well. In those cases, efficient contained pit cleaning may be a significant benefit to the operation.

To deal with hard-to-flush sediments, jet washing is used to get more shear with less fluid. Jet nozzles deliver high shear in the form of a jet of liquid, created by squirting the wash liquid through a nozzle at high pressure. In tanks designed for cleaning, these can be fixed nozzles positioned to spray all the surfaces in the tank. This system is recommended for mudpits in offshore rigs where pre-installed combination of jet nozzles and mixing impellers will reduce considerably cleaning time and increase the effectiveness of chemistry added for final removal of solids from walls and corners.

More flexible systems use automatic nozzles that systematically move the jet to cover the areas to be cleaned. In tanks that contain settled beds, a nozzle that can be set to concentrate its jet onto the residue is the most efficient. Fig. 3 shows a commercially available nozzle that accomplishes this.

In many cases, however, the residue must be removed by direct mechanical means. Crews are usually sent into the tanks to physically remove the settled beds. Shovels, pickaxes and pikes are among the mechanical tools used to break up the bed. High pressure (10,000 psi) jet nozzles can also be used to break up settled beds of barite. Once fractured, the beds are removed by bucket or vacuum pickup.

Tank Washing

Removal of the residue is all that many cleaning operations require. When more cleaning is required, jet nozzles provide a very fast and entry-less way to deliver a final clean to properly designed tanks. A surfactant can aid the cleaning of areas that the spray cannot reach directly. As before, most tanks in current service are not optimized for cleaning, and further measures must be taken to assure total cleaning. For example, many Gulf of Mexico workboat tanks have interior baffles, extraneous pipes, and gun lines that create a “catacomb” of obstructions. Several boats have tanks constructed by topping the tank with closely spaced I-beams running the width of the tank, supporting the deck above — and hiding lots of mud.

When jet nozzles cannot reach the entire tank, manual entry is used to direct cleaning action onto the shadowed areas. While robots have been used, their expense and poor service factor make them uneconomical for most applications.

Beyond the standard testing required for entering confined spaces, there are several other health and safety considerations. Cleaning tanks containing non-aqueous fluids is cited as a high inhalation exposure hazard task.[2] To quote the Canadian Petroleum Safety Council:

> “Airborne mist will have a more immediate impact on the respiratory system than vapor and may cause inflammation of the lung tissues, lipoid granuloma formation and lipoid pneumonia… Mechanically atomized fluid may contain small amounts of heavier hydrocarbons or other chemicals in the drilling fluid that would not otherwise vaporize.”

All tank cleaning must be done with proper protection and ventilation. Exposure to surfactants are must also be considered in managing the risk.

Once properly protected, crews can clean the tank with fire hoses and brushes, low-pressure washers (<2000 psi), and high (>5000 psi) pressure washers with or without surfactant. Fire hoses and brushes take a long time, and consume a great amount of water. Low-pressure washers are effective in removing soil from tank surfaces, removing the need for brushing. With the increased hydraulic power comes some hazard to personnel, and crews must be trained in safe use of the wands and pumps. It is important to note that the 2,000 psi exists only at the orifice of the pressure-washing wand. When directed as a fan or other spread pattern, the energy is quickly diluted to safe levels. Indeed, part of the training is teaching the crew the optimum cleaning distance between nozzle and surface.

Surfactants aid in this cleaning, but play a secondary role of preventing redeposition. In a test of surfactant power, three 25-bbl MPT tanks were manually cleaned with low-pressure washers. All the tanks had carried the same mud-contaminated $ZnBr_2$ completion brine, and had about 1 in. of sediment. A different surfactant was used to clean each tank. As shown in Table 4, the time and volume of water needed was consistent from tank to tank, reflecting the time needed to directly spray each surface. Interestingly, the crew refused to clean a fourth tank using only water because in their experience the soil splashed from one surface deposited on previously cleaned areas, requiring several passes to clear the tank.

High-pressure nozzles provide even more cleaning power, but at a greater risk of hydraulic damage and injury. While, as with low-pressure washers, the mechanical energy is quickly dissipated by fan nozzles, the greater danger of direct impact at the nozzle requires better training and inherently safer equipment including wands too long to touch the operator’s foot. The higher pressures require less water to deliver the same cleaning force, and less water is incorporated into collected muds.

Surfactants for Tank Washing

The choice of surfactants is dictated by performance and cost. The primary function of the surfactant is to emulsify and suspend the hydrophilic portions of the tank residues after they have been mechanically displaced from the surface of the tank. The desired performance is the elimination of re-deposition of soil onto adjacent clean surfaces.

More aggressive surfactants containing strong surface-wetting agents can actually displace the mud residues with the very low shear of streaming down the walls, providing for cleaning in areas not directly impacted by spray. Weighing against these desired outcomes are the potential for personnel exposure, potential environmental exposure, the cost of application, and generally negative impacts on wash water reclamation.

Cleaning-performance criteria are established by empirical testing in the field and in the lab. One quick test we use is a simple bottle shake test. An equal weight of mud and sand are mixed, and hot-rolled briefly to assure complete wetting of the sand by the mud. Five grams of the mixture is placed in a clean glass bottle, and shaken to distribute it across the surface. A specific amount of wash solution of known concentration of surfactant is added, and the bottle shaken by hand. If the glass appears clean and the sand does not clump together, the surfactant is judged acceptable (Fig. 4). By varying the volume and concentration, one can also estimate the amount, and so the cost, of surfactant needed.

Generally speaking, it appears that the concentration of surfactant is less important than the ratio of surfactant to simulated residue. Fig. 5 shows the results of bottle tests done with a fixed amount of simulated residue and different volumes of cleaning solutions of several concentrations of the surfactants. As expected, at the same volume of cleaning solution, higher concentrations of surfactants cleaned better. A closer look reveals that the bottles that contained at least 1.5 g of surfactant were able to clean the mud satisfactorily regardless of water content over this range. This result is not too surprising in that to be “clean” there must enough surfactant to completely emulsify the NAF and water-wet the sand and bottle.

Recycle/reuse of wash waters is another important consideration. How clean in clean enough? The generation of large volumes of wash water implies higher disposal cost. In the US, pit washings are not exempt from RCRA, and their disposal is handled differently from exempt oil-field waste. Transferring contaminated fluids from offshore operations also represents a logistical problem. If the water is to be used as a flush system for tanks in continuous mud service, simple settling tanks are sufficient. Closed-loop systems for offshore tank cleaning require rapid turn-around to high-clarity water and so must include high volume clarifiers such as hydrocyclones and filters.

Surfactants can both complicate and facilitate this process. Because surfactants generally reduce the water used for cleaning, the size of the task is smaller. However, as the same surfactant can often produce stable emulsions, flocculation, and ultimately necessitate other treatments. Lab-scale testing finds 90+% recovery of surfactant wash waters can be accomplished with the use of chemical flocculants, settling, and centrifugation.

Eventually, the accumulation of salt from the various cleaned surfaces becomes the limiting step. As the salinity increases, the surfactants become less effective, as does the clarification chemistries.

When possible, this water should be reused in drilling fluid operations. Otherwise, if permitted, discharge of this spent water is the least expensive disposition. Paid disposal or reclamation by reverse osmosis cleanup are more expensive options.

It is the economics at each site that will in the end dictate the system to be used. Primary among these are the value of recovering the mud and the opportunity cost of cleaning time. Using just these two considerations, Table 5 provides a guide to cleanup methods based the net value of recovery (mud price + price of disposal) and time value ($/hr of downtime for cleaning).

Conclusions

While surfactants can play a key role in delivering the needed performance, the choice of mud-tank cleaning system depends on many other factors. Mud value, risks of contamination, mud/surfactant interactions, costs of equipment, and time to clean, are among the most important.

Designing a batch or continous clarifying water system for reuse and recycling in pit-cleaning operations can reduce total volume of wastewater. This is a critical factor in offshore cleaning operations. Pre-installed jets nozzles in combination with mixer impellers, vacuum system, and a mobile chemical manifold will minimize cleaning time reducing rig stand-by and total volume of wastewater.

Where mud costs and environmental impacts are low, manual clean out with high volumes of water is a viable option. In environmentally sensitive areas like the US Gulf Coast or the North Sea, where mud and rig costs are high, well-planned tank cleaning with maximum recovery of mud is the cost-effective choice.

References

1. Cerasi, P., Ladva, H.K., and Soga, K.; “Measurement of the Mechanical Properties of Filter Cakes,” SPE 68948, SPE European Formation Damage Conference, The Hague, 21-22 May 2001.
2. US Environmental Protection Agency: “Final NDPES General Permit for New and Existing Sources and New Dischargers in the Offshore Subcategory of the Oil and Gas Extraction Category for the Western Portion of the

Outer Continental Shelf of the Gulf of Mexico", GMG290000, US EPA, 2/2002.
3. Canadian Petroleum Safety Council: "Industry Recommended Practice (IRP) Volume 14: Non Water Based Drilling and Completions Fluids," 14.1.3.1.7 High Exposure Areas And Tasks (2001) available online at http://www.psc.ca/irp_summary/irpvol_14.html.

Table 1- Relative Value of Drilling Fluids and Value of Recovery Gulf Coast, Louisiana, February 2002

Mud type	Approximate Relative Value, per barrel	Relative Value of 35-bbl residue	Relative Costs of Disposal	Net relative value of recovery, per tank
Synthetic-based	~18	~600	50	650
Oil-based mud	~6	~200	50	250
Water-based mud	1	35	50	85

Table 2 - Rheological and Other Properties Synthetic-Based Mud by Density

Property	10 lb/gal	14 lb/gal	17 lb/gal
PV (cP)	15-25	20-30	35-50
YP (lb/100 ft^2)	10-20	10-20	8-15
HTHP@250°F (mL)	<10	<6	<4
ES (V)	300-500	400-600	500-800
S/W ratios	65/35-75/25	70/30-80/20	80/20-90/10

Table 3 - Viscosity Increases with Mud Contamination by an Equal Volume of Wash Water Dial Readings at 150°F

Fann 35 rpm	Mud At 150°F	+ FW* at 150°F	+ FW + 1% Surf A	+ FW + 1% Surf B	+ FW + 1% Surf C
3	9	43	48.5	28	42.5
6	10	47	55	32	48
100	25	129	151.5	95	133
200	35	185	219	140	191.5
300	44	231	275	179	241
600	70	>300	>300	283	>300
*Equal volume of Freshwater or Freshwater containing 1% Surfactant					

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600	70	>300	>300	283	>300

*Equal volume of Freshwater or Freshwater containing 1% Surfactant

Table 4 -MPT Tank Cleaning Time and Volumes
Yard test performed at Swaco Envirocenter, Port Fourchon

	Cleaning Time (min)	Water Used (Gal)
Surfactant C	18	30
Surfactant 11	22	27
Surfactant 10	24	28

Table 5 - Decision Grid for Tank Cleaning

Clean to Mud Quality	**Low time value**	**High time value**
Low net value recovery	Fire hose and brushes, pump or vacuum out	Machine wash and vacuum or pump out
High net value recovery	Squeegee and vacuum or pump out, collect whole mud	High Pressure Wash and vacuum, collect diluted mud for recovery.
Clean to Completion Fluid Quality		
Low net value recovery	Pressure wash and vacuum or pump out	Machine wash, vacuum or pump out, hand clean obstructions
High net value recovery	Squeegee and vacuum, collect whole mud, hand pressure wash	Machine wash and vacuum, collect diluted mud for recovery, hand clean obstructions

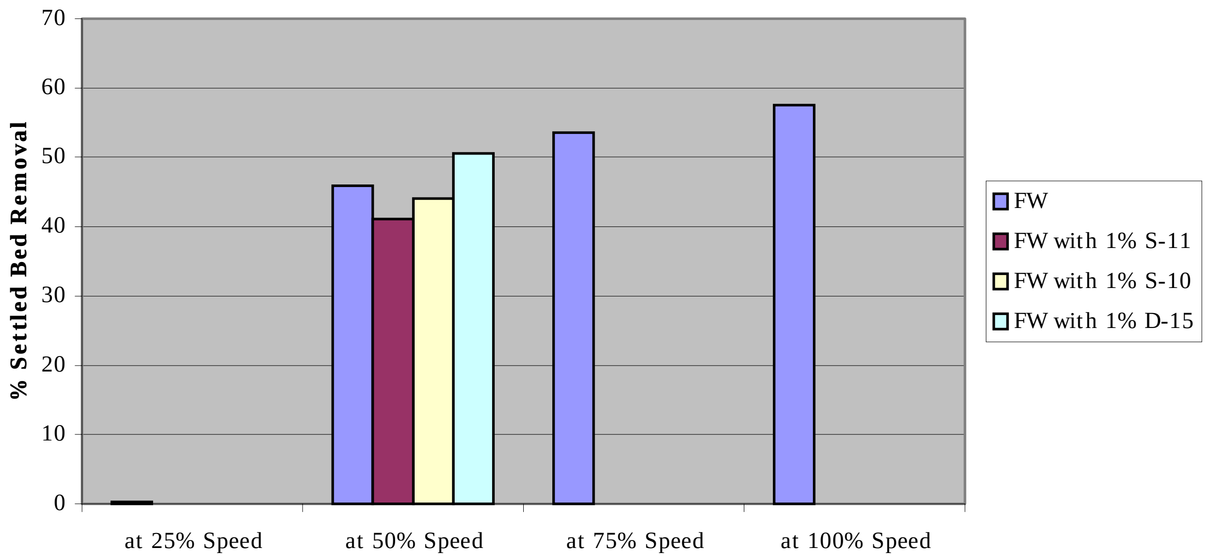

Fig. 1 – Hydraulic shear better than surfactant at removing settled beds.

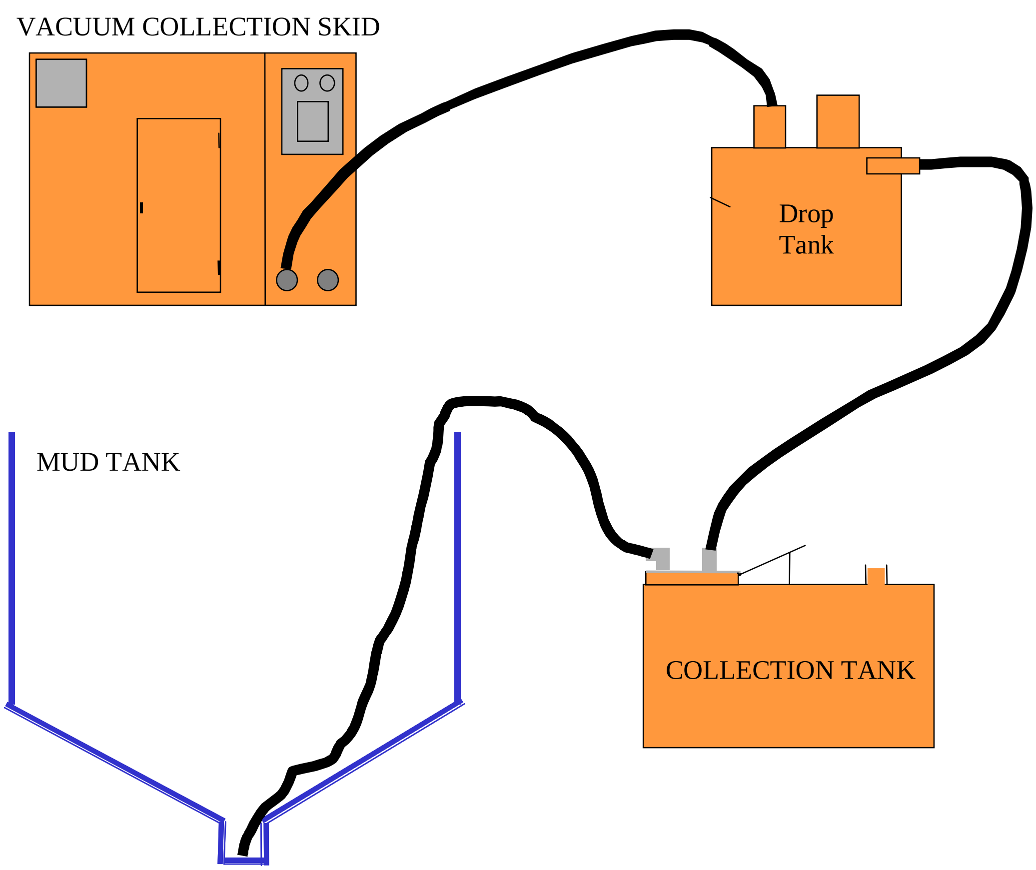

Fig. 2 - Typical Vacuum Collection System in Self-Draining Tank.

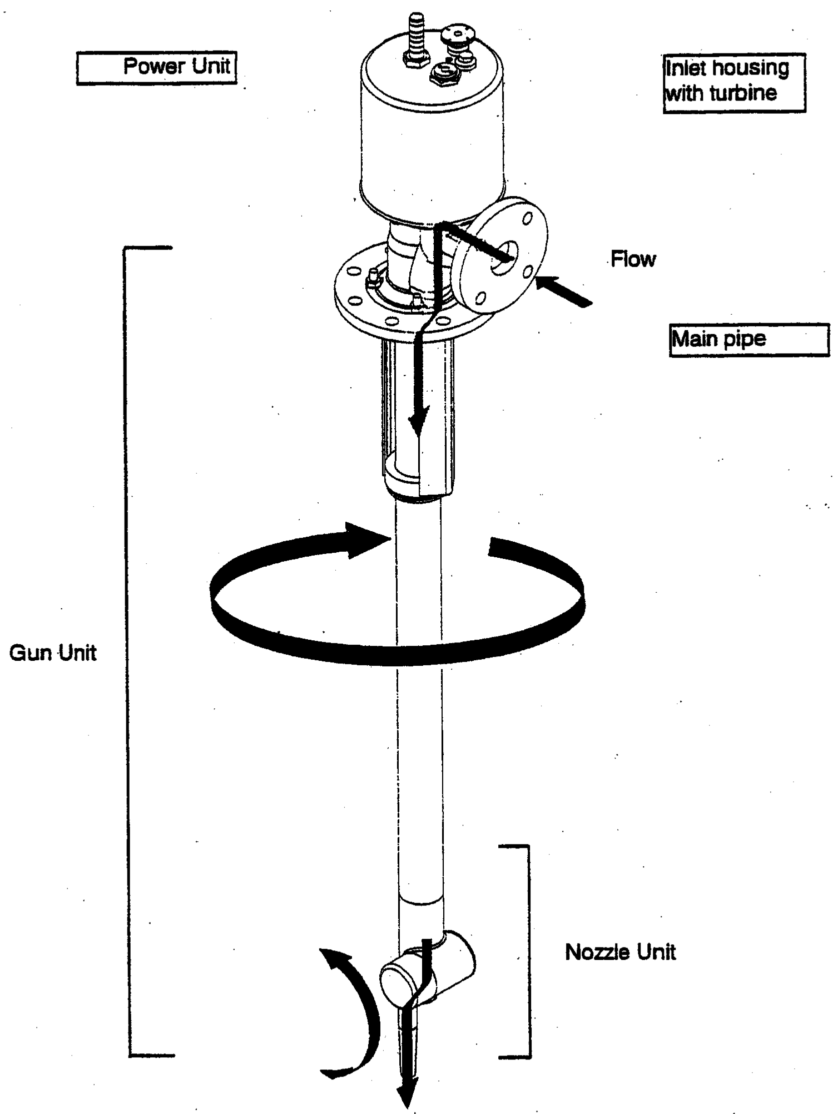

Fig. 3 - Programmable Jet Washer (courtesy Toftejorg Ab)

Figure 4. Cleaner Capacity Test. Using 5 grams of mud/sand mixture in each bottle, 30 mL of wash solution is applied with increasing surfactant concentration. From left to right, 1,2,3,4,5, 7.5 and 10 vol% surfactant is applied. 1% is not able to clean the mud off the glass. At 2,3,4, 5%, synthetic-wet sand remains. By 7.5% concentration, clean glass and no synthetic-wet sand remain. The 5% is marginally clean, 7.5 and higher are clean.

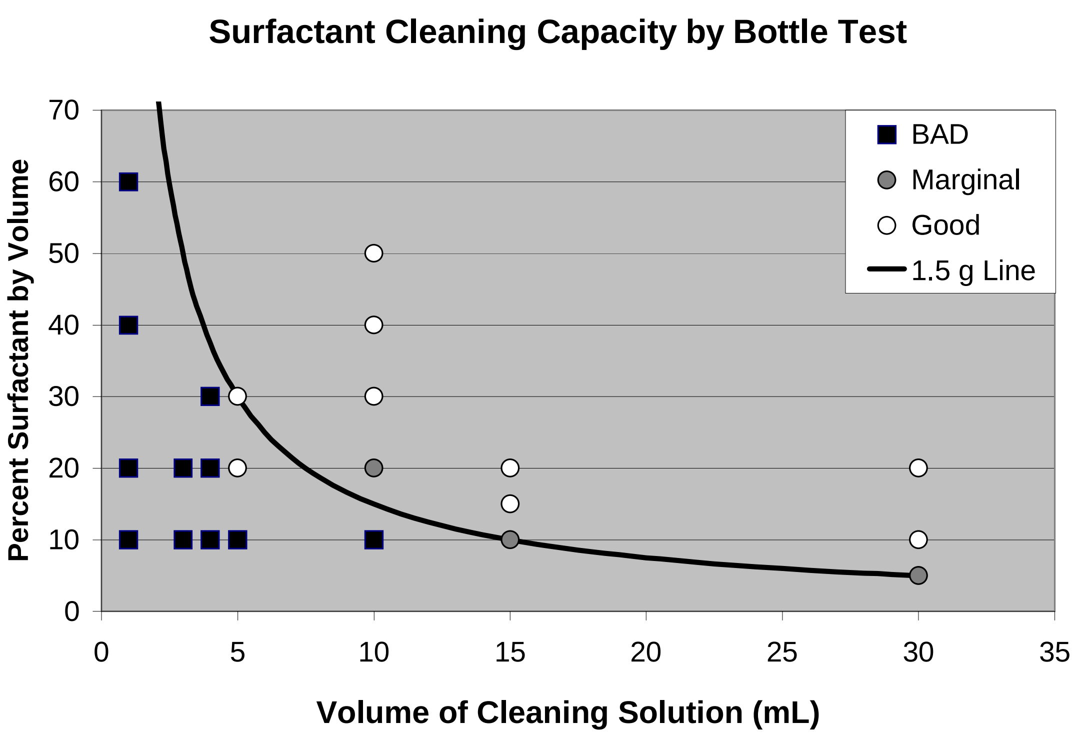

Figure 5. Surfactant Cleaning Capacity. Five grams of mud/sand mixture weighed into glass bottle, varying volumes and concentrations of surfactant A were added and shaken. Very clean bottles with water-wet sand are marked with open circles. Nearly clean or synthetic-wet sand are gray disks, and bottles with mud and sand clinging to the sides are marked as black squares. The curved line represents the product of volume and concentration corresponding to 1.5 g of surfactant in the bottle: points above the line have more surfactant, those below, less.