New Lightweight Fluids for Underbalanced Drilling

by

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INTRODUCTION

The production of oil and gas in the USA is declining rapidly because the economics of many onshore fields are marginal due to high drilling costs and low well productivity. New reserves are located primarily in deep water where drilling costs are high and new technology must be developed.

As a result, there is a need for techniques to significantly reduce drilling costs to allow economical development of deep water reservoirs, and to increase well productivity by reducing formation damage during drilling and completion operations. These problems are addressed on this DOE project.

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OBJECTIVE

The objective of this project is to develop a new lightweight drilling fluid additive that will significantly reduce underbalanced and deep water drilling costs, and reduce formation damage during drilling and completion operations.

APPROACH

The approach being taken is to utilize hollow glass microspheres to reduce the density of drilling fluids and overcome major problems encountered with current air/mist/foam drilling systems. The Russians initially used these microspheres in the 1970s to overcome severe lost circulation problems in the Ural mountains. This project consists of transferring the Russian technology to the USA and utilizing microspheres currently manufactured by 3M to reduce underbalanced drilling costs.

PROJECT DESCRIPTION

Hollow glass spheres manufactured by 3M are added in volumetric concentrations up to 50 percent to reduce the density of drilling and completion fluids. For example, adding 50 percent microspheres to an 8.5 ppg mud, reduces its density to 5.84 ppg without the addition of air (**Figure 1**).

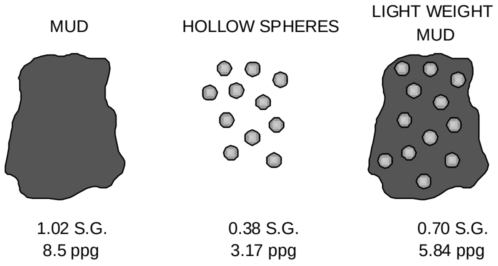

Fig. 1. Lightweight HGS Mud

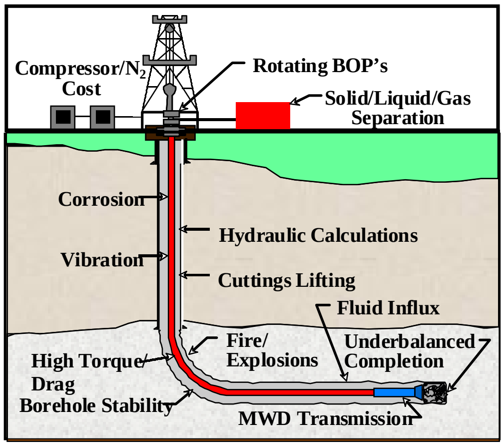

Fig. 2. Hole Problems with Aerated Drilling Fluids

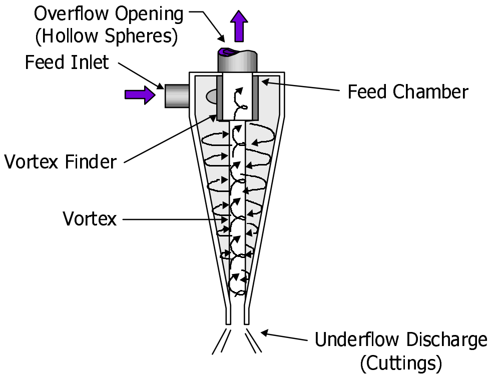

Fig. 3. Oilfield Hydrocyclone

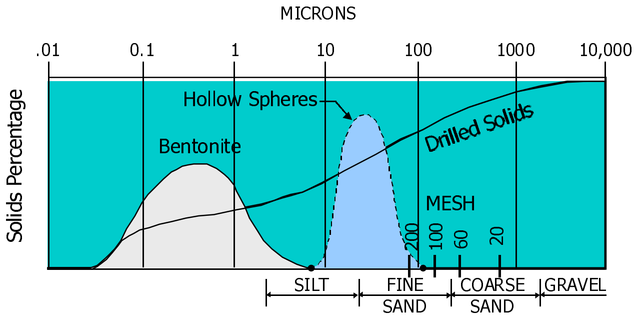

Fig. 4. Solids in Unweighted Water-Base Drilling Mud

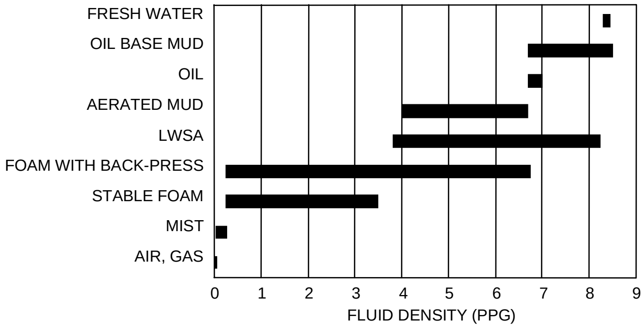

Fig. 5. Drilling Fluid Density

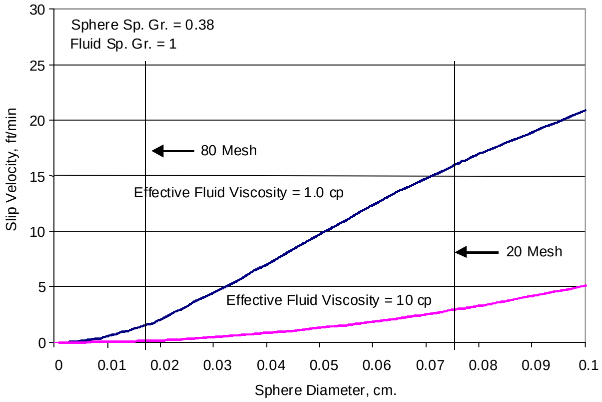

Fig. 6. Sphere Slip Velocity vs. Fluid Density

The microspheres are chemically inert and incompressible and therefore overcome many of the problems encountered with aerated fluids including corrosion, high compressor costs, drill string vibrations, excessive torque and drag, downhole fires, poor hole cleaning, and the inability to use mud pulse MWDs as shown in **Figure 2**.

When a well is completed, the microspheres can be removed with conventional mud solids handling equipment and used in subsequent wells, thus significantly reducing sphere costs. The simplest way to remove the spheres is to dilute water-base muds with water and allow the spheres to float to the top of the mud tank where they can be easily recovered.

Laboratory and field tests showed that the microspheres can also be effectively removed from the mud using drilling rig hydrocyclones. In this case, the heavier rock cuttings came out the underflow at the bottom of the cone and the microspheres came out the overflow (**Figure 3**).

The diameters of commercial hollow glass S38 spheres range from 8 to 125 microns, allowing these spheres to pass through 20- to 80-mesh screens (762 to 177 microns) typically used on oilfield shale shakers (**Figure 4**).

The microspheres have small diameters because they are typically used as fillers in paints, glues and other materials to reduce manufacturing costs. Because of their small diameter, oilfield shale shakers cannot be used to remove the spheres from the mud when they return to the surface. Larger diameter spheres (e.g., 1 mm diameter and larger) are needed in applications where the spheres must be removed from the mud during each circulation (e.g., riserless drilling) so they can be screened out of the mud by conventional oilfield shale shakers.

The fluid density decreases as sphere concentration increases. **Figure 5** shows that microspheres can reduce the density of water from 8.34 ppg to 5.84 ppg, which will allow the microspheres to be used in most underbalanced wells.

If mud circulation is stopped, the spheres will float upward in the drilling fluid, with the upward velocity increasing with increased sphere diameter and fluid density, and with decreased fluid viscosity. **Figure 6** shows that the slip velocity of spheres will be on the order of 5 to 20 ft/min, which is small compared to the fluid annular velocities. This indicates that sphere flotation will not be a major problem.

One of the major advantages of underbalanced drilling is increased drilling rates. Drilling rates in sandstone, limestone and shale are typically reduced by 70 to 80 percent as the differential fluid pressure between the wellbore and formation fluids (p_b - p_f) increased from 0 to 1,000 psi (**Figure 7**). The microspheres can therefore significantly increase drilling rates by reducing wellbore pressures.

The S38 spheres will collapse if subjected to pressures in excess of 4,000 psi. The highest fluid pressure occurs at the bottom of the well due to the weight of the column of fluid in the well. When the fluid is circulating, the highest pressure exists inside the drill string, just above the drilling motor and bit.

The spheres will typically be used in lightweight muds weighing less than 7 ppg, in which case the S38 spheres can be used to depths of 8,000 to 11,000 feet (**Figure 8**). S60 spheres, which have collapse pressures of 10,000 psi, can be used to depths of 12,000 to 30,000 ft, but their higher specific gravity (0.60) will require higher sphere concentrations.

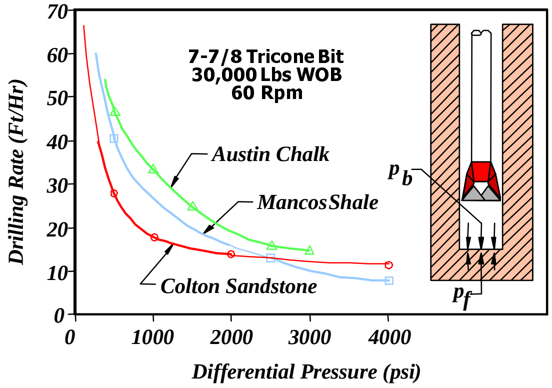

Fig. 7. Differential Pressure and Drilling Rate

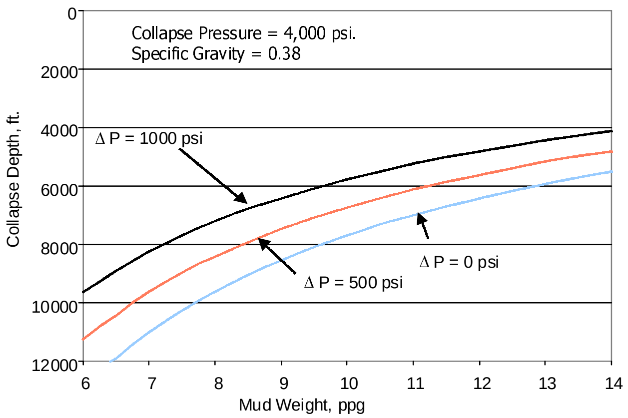

Fig. 8. S38 Hollow Sphere Collapse Depth

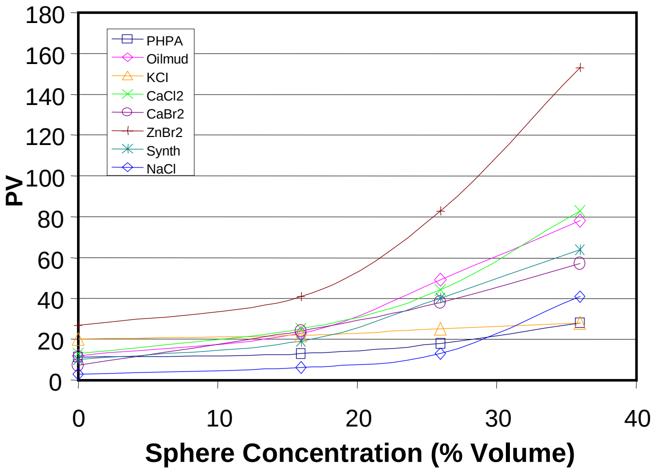

Fig. 9. PV vs. % Sphere Concentration

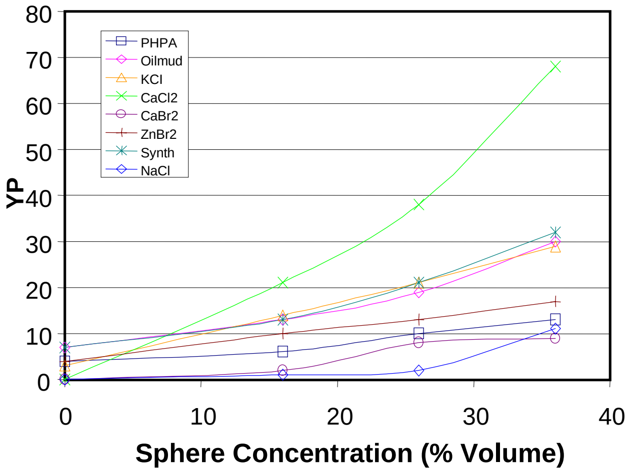

Fig. 10. YP vs. % Sphere Concentration

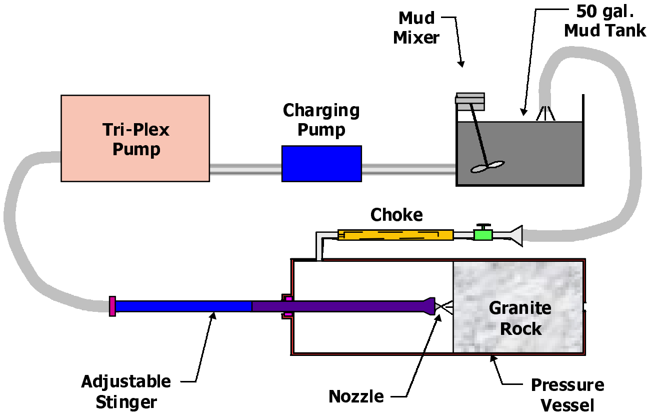

Fig. 11. HGS Breakage Test Flow Loop

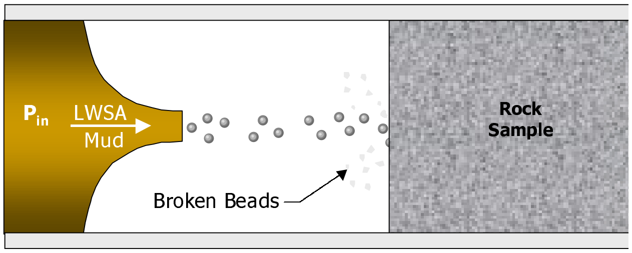

Fig. 12. HGS Spheres Impacting Rock

PROJECT ACCOMPLISHMENTS

Laboratory tests showed that fluid rheology with the microspheres is within an acceptable range at sphere concentrations of 30 to 50 percent provided the drill solid concentrations are kept low (**Figures 9** and **10**).

Laboratory tests showed that the microspheres were not damaged by conventional mud pumps or rig mud handling equipment. Laboratory tests were conducted at the Drilling Research Center (DRC) in Houston, Texas, to determine if the microspheres will break when they exit bit nozzles and impact the rock (**Figures 11** and **12**). These tests showed that with proper nozzle selection and standoff, sphere breakage can be minimized once malformed spheres (typically 5 to 10 percent) break during their initial pass through the nozzles.

Drilling tests were conducted in the DRC high-pressure drilling stand to determine the effect of the microspheres on drilling rate (**Figure 13**). This drilling stand simulates deep oil-well drilling by applying higher fluid pressure in the wellbore than in the formation ($P_w > P_f$) to create a differential pressure across the hole bottom (**Figure 14**).

Drilling rates with and without the microspheres were identical with no differential pressure applied. With differential pressures of 750 and 1,500 psi, the microspheres reduced drilling rates slightly in three of the four tests, possibly due to reduced jet impact and increased chip hold-down effects (**Figures 15** and **16**).

A series of formation damage tests was conducted with the microspheres in Berea sandstone cores using the formation damage test apparatus shown in **Figure 17**. Results showed that the microspheres can significantly reduce formation damage. These tests showed that the microspheres (8 to 100 microns) form a tight filter cake and cause less formation damage than water-base muds without spheres (**Figure 18**).

With water-base fluids, the microspheres produced no permanent damage whereas without the microspheres, the fluid produced 45% permanent damage around the wellbore (**Figure 19**). With oil-base and synthetic fluids, the microspheres had no effect on formation damage.

This shows that the microspheres have potential to significantly increase oil and gas flow from wells drilled and completed with water-base fluids. This phenomenon will be studied in more detail in the next phase of this project.

Two field tests were successfully conducted with microsphere muds in Mobil wells in Kern County, California, in September 1996. **Figure 20** shows the mud pit system used in these 1,700-ft Mobil wells. Two to four hundred barrels of mud containing 10 to 20 percent microspheres were used on these wells. These field tests showed that the microspheres can be easily mixed into the mud and that the rheological properties of the lightweight mud were similar to conventional muds. The success of these tests demonstrates the high potential of using microspheres for underbalanced drilling.

Another important application of these microspheres is for offshore riserless drilling.

A major problem with deep-water offshore drilling is that the pore and fracture pressure gradients are typically close together, making drilling very difficult (**Figure 21**). If the annulus pressure exceeds frac pressure, lost circulation will occur; if it falls below pore pressure, fluid influxes from the formation (“kicks”) will occur.

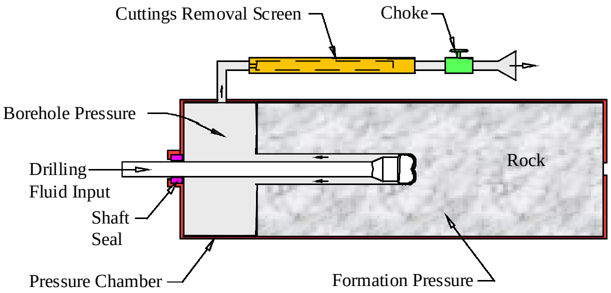

Fig. 13. DRC High Pressure Drilling Stand

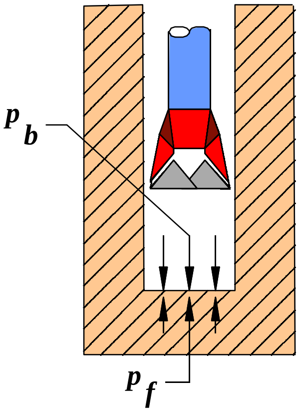

Fig. 14. Simulated Bottom Hole Conditions

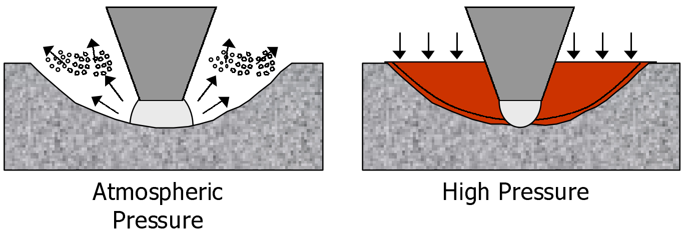

Fig. 15. Chip Hold-Down Effects

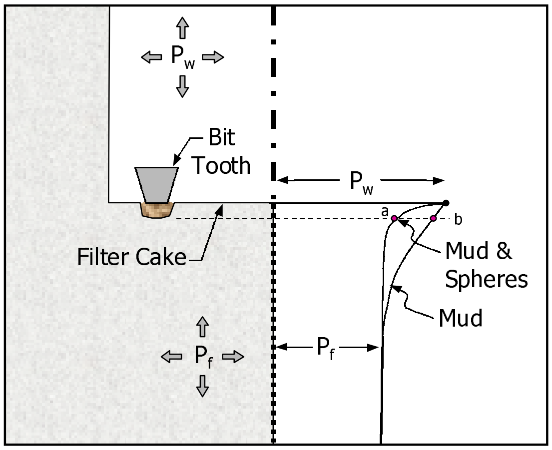

Fig. 16. Chip Hold-Down Pressure Gradients

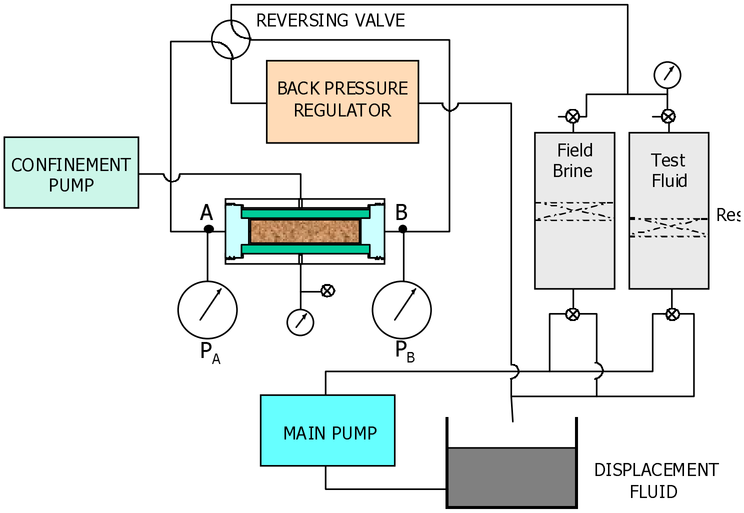

Fig. 17. Formation Damage Test Apparatus

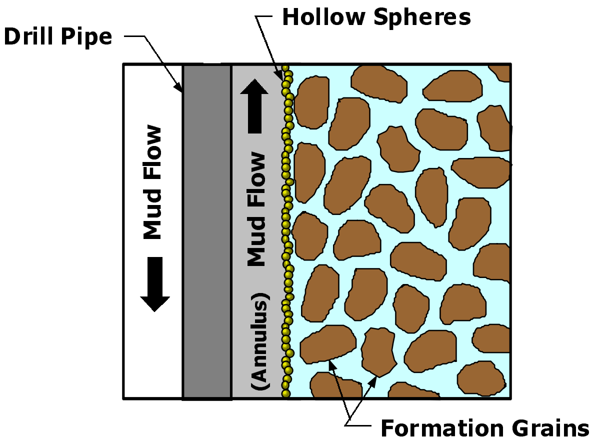

Fig. 18. Hollow Sphere Filter Cake

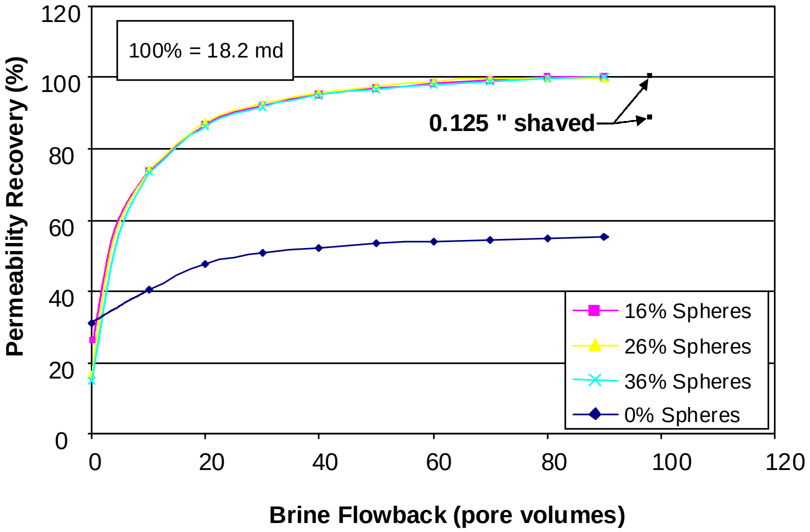

Fig. 19. Permeability Recovery with
PHPA Water-Base Drilling Fluid

Fig. 20. Golden State Drilling Rig Mud System

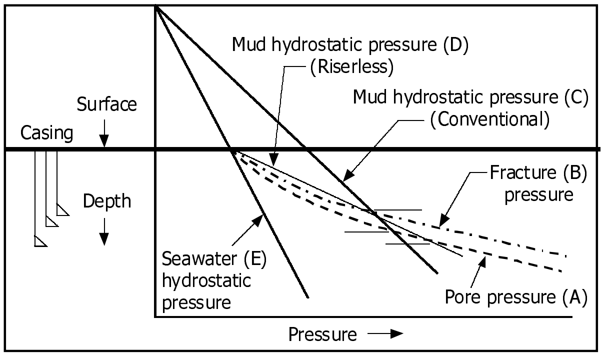

Fig. 21. Hydrostatic Gradients for Conventional and Riserless Drilling (Snyder, 1998)

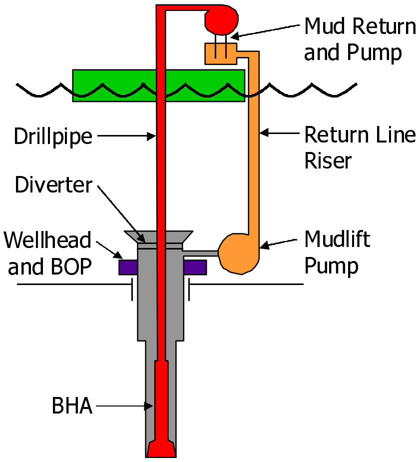

Fig. 22. Riserless Drilling System

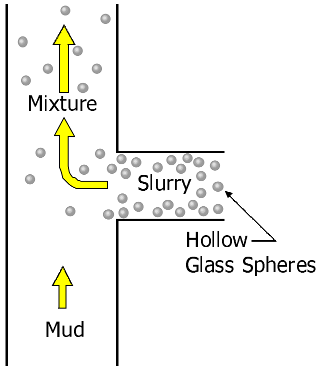

Fig. 23. Hollow Glass Sphere Technique

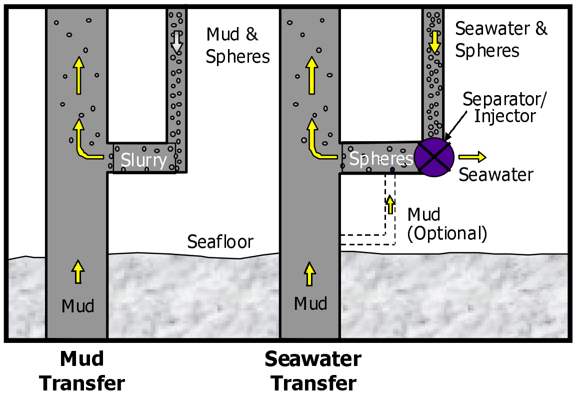

Fig. 24. Hollow Glass Sphere Injection Systems

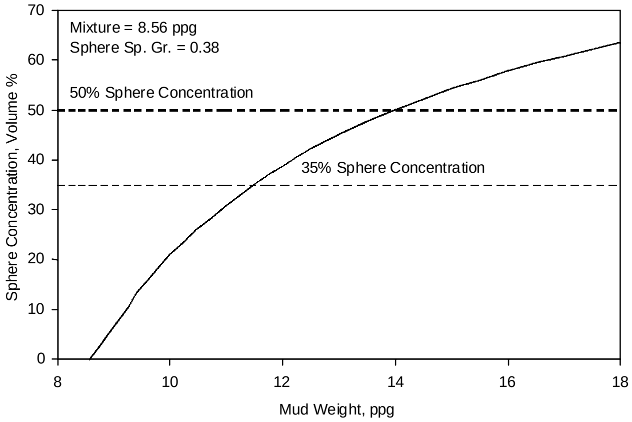

Fig. 25. Mud Weight vs. Sphere Concentration

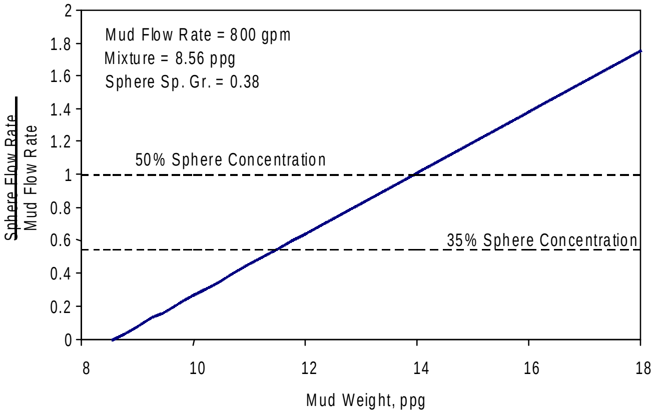

Fig. 26. Mud Weight vs. Sphere Concentration

With “riserless” drilling, a pump is used on the seafloor to reduce the wellbore annular pressure at the seafloor (**Figure 22**). With conventional riser drilling, the mud hydrostatic pressure gradient (C) is a straight line extending from the surface of the water whereas with a seafloor pump, the hydrostatic curve (D) is a straight line that extends from the sea floor. The flatter gradient with the seafloor pump allows a much greater vertical distance to be drilled between the pore and fracture gradient curves, significantly reducing the number of casing strings required. In an example well, riserless drilling reduced the number of casing strings from 8 to 5, saving $3 million since each casing string costs $1 million (Gault, 1996).

With this technique, the microspheres would be injected into the riser at the sea floor to reduce the density of the mud in the riser (**Figure 23**), eliminating the need for expensive and troublesome seafloor pumps.

Major advantages of the microspheres in this application are 1) they are chemically inert and incompressible, 2) they can be pumped with conventional mud pumps, and 3) they can be easily removed and recirculated at the surface.

The microspheres can be mixed with the mud at the surface and pumped to the sea floor as a slurry and injected directly into the riser, or pumped to the sea floor with seawater where they will be separated from the seawater using a sea-floor separator (screen) and injected into the riser using an injector (e.g., Moineau pump). Mud can be diverted from the annulus to the injector, if needed, to facilitate injecting the spheres into the riser (**Figure 24**).

The goal of riserless drilling is to reduce the effective mud weight to that of seawater (8.56 ppg). **Figure 25** shows that a sphere concentration of 18% reduces the density of a 10-ppg mud to that of seawater whereas a 52% sphere concentration is required with a 14-ppg mud. This shows that it is feasible to use microspheres as an alternative to riserless drilling for a wide range of mud weights.

Figure 26 shows that a sphere flow rate equal to the mud flow rate (i.e., 50% sphere concentration) will reduce the density of a 13.8 ppg mud to that of seawater (8.56 ppg), showing that the seawater transfer technique could be effective with most muds. The microspheres can be easily removed from the drilling mud and recirculated at the surface using conventional oilfield mud solids handling equipment.

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