AADE-04-DF-HO-27

Preventing Differential Sticking and Mud Losses in Highly Depleted Sands

Alain Bachelot, Jean Ricaud, Gerard Arquey TOTAL E&P USA; Saddok Benaissa, Baker Hughes INTEQ

This paper was prepared for presentation at the AADE 2004 Drilling Fluids Conference, held at the Radisson Astrodome in Houston, Texas, April 6-7, 2004. This conference was sponsored by the Houston Chapter of the American Association of Drilling Engineers. The information presented in this paper does not reflect any position, claim or endorsement made or implied by the American Association of Drilling Engineers, their officers or members. Questions concerning the content of this paper should be directed to the individuals listed as author/s of this work.

Abstract

Drilling through depleted sands can result in a multitude of problems, such as lost returns, differential sticking, difficulty logging and the inability to reach the target depth. Often solving lost circulation can be difficult and costly as a result of non-productive time.

Remedies to cure losses are diverse and sometimes misapplied, possibly complicating the problem. Additionally, differential sticking zones can have a direct implication on the selection of casing points and jeopardize the architecture of the well. When the thief zone is severely depleted, problem-solving approaches such as cement plugs, squeezes, expandable liner and casing-while-drilling are used but can be costly and not always successful.

The use of fluid management techniques, team efforts and proper engineering has lead to the development of an innovative approach as an alternative to standard methods. This approach prevents the problems and avoids the complex processes of curing mud losses or stuck pipe. This new preventative approach with water-based mud has been applied in several different fields while drilling through highly depleted sands. This methodology has proven to be very successful in preventing differential sticking, mud losses, and differential sticking.

Introduction

Lost circulation has plagued drilling operations for years. Generally the types of formations that are prone to lost returns are cavernous and vugular, naturally occurring or induced fractures, unconsolidated sands, highly permeable and highly depleted sands. Well known lost circulation techniques such as bridging, gelling and cementing are typically used to cure the lost circulation problem, but have had varying degrees of success. These remedies are diverse and can sometimes complicate the problems associated with lost returns. Often attempts to cure lost circulation can be difficult and costly, especially when considering the associated non-productive time.

This paper highlights a case study using an innovative approach to prevent, rather than to cure, lost circulation when drilling through a series of highly depleted sands. This approach helps avoid the complex processes of curing drilling fluid losses. This new preventative approach with water-based mud has been applied in several different fields, while drilling through a series of highly depleted sands. These applications have reduced mud losses and have proven to be successful in preventing differential sticking. A newly developed deformable sealant (DS) is added at a 2 to 3% vol. to improve conventional water based mud used in the area.

Although operationally successful in the wells discussed, mud losses and pipe sticking continue to occur in some instances. Drilling fluid design, drilling engineering and geomechanics must be continually evaluated to push the drilling efficiency when drilling through depleted sands.

The DS sealing additive is a component of a newly developed High Performance Water Based Mud (HPWBM). Additional details and case histories about the HPWBM system can found in AADE-04-HO-14.

Field Description and Geological Setting

Several small gas fields, located in Hidalgo and Starr counties in South Texas are operated by TOTAL E&P USA. Table 1 outlines the general well profiles in each field. The main reservoirs are in the deeper sections of the wells and are generally depleted. Several highly depleted, tight and low permeability sands are present throughout the entire well. These 10 to 150 millidarcy permeability sands can be exposed to as much as 8,000 psi differential pressure. These series of highly depleted sands present drilling challenges when trying to reach deeper reservoir targets. Hydrostatic pressure to control over-pressured shale varies from field to field and can be as high as 14,000 psi, requiring an 18.5 lb/gal mud density.

This area has a complex subsurface geology, with extensive faulting in the deeper sections. A sequence of stacked sands separated by shale and lateral fault barriers are typical of the stratigraphic column of the area. Figure 1 indicates a typical pressure regime in these fields in south Texas.

This geological setting makes it difficult to predict the rate of depletion in the sands to be drilled, especially in deeper intervals. The severity of depletion of these sands increases the risk of mud losses and differential sticking. The increased potential for differential sticking often has a direct impact on the selection of casing points and can jeopardize the architecture of the well. Typical pore pressure – fracture gradient distribution in the McAllen field shows a considerable degree of depletion. Sand formations depleted to as low as 350 psi have been drilled.

The numerous faults present in the deeper formations often act as permeability barriers to the pressured sand reservoirs. All of these variables affect the pressure distribution throughout the entire well profile and make it very difficult to predict pressure in the sandstone formations from well to well.

Excessive drilling cost has been experienced in the past in these fields. This has been a result of the high differential between the hydrostatic pressure and the depleted sand formation pressure, bringing about lost circulation and associated differential sticking. When the thief zone is severely depleted, problem solving approaches such as cement plugs, squeezes, expandable liner and casing while drilling can be costly solutions. The use of the DS additive was investigated and successfully applied to the drilling operation.

Mechanical Stability and Well Planning

Drilling successfully through these series of depleted sands often requires a delicate balance between mechanical shale stability and controlling hydraulic fracturing. Planning a directional well through a series of highly depleted sands separated by overpressure shale presents significant technical challenges

These depleted sands have low permeability and small pore sizes and require a special sealant to provide an adequate bridging of the sands pore throats opening. Another US operator conducted an extensive study on series of depleted sands typically encountered in South Texas. Figure 2 indicates typical permeability distribution of the sand sections that are frequently encountered in South Texas fields. These low permeabilities range from 0.1 to 150 mD and require a special sealing material to provide adequate bridging. Figure 3 shows that most conventional lost circulation material are too large and, therefore, could be ineffective to bridge the low permeability sands. It is possible that these large size LCM materials also could be harmful to the fluid system because they contribute to the thickness of the filter cake and create a potential for pipe sticking. Numerous types of LCM have been used with different degree of success. These conventional materials are often the standard approach to cure lost circulation. However, when it comes to lost returns prevention in depleted sand, they may be ineffective.

Drilling Fluid Design

An inhibitive water base mud with a low fluid loss was selected to maximize the shale inhibition and minimize the filtrate invasion in the depleted sands. The DS is added to the drilling fluid prior to drilling the troublesome, depleted sand formations. The concentration of the sealing agent varies from 2 to 3% by volume. The degree of depletion, permeability and pore throat sizes of the depleted sand may result in the use of smaller or larger concentrations. Refer to Table 2 for typical field mud properties from mud program.

The innovative sealing agent is a liquid insoluble modified polymer that has excellent sealing characteristics. It is designated to reduce pore pressure transmission by bridging the pore throats in low permeability sands and shale micro-fractures. It is water insoluble and highly dispersible in fresh to saturated salt water base mud. Because of its characteristics, DS can bridge very small pores and reduce the fluid losses of water base mud in the low permeability depleted sand formations. This is especially important since other lost circulation materials might not work effectively. DS is also dispersible in oil, so it is compatible with lubricants and rate of penetration enhancement additives.

Bridging and Sealing Mechanism

Because DS is designed using deformable colloidal particles it will bridge at the borehole interface of low permeability sandstone formations. This bridge not only contributes to the external filter quality but also creates an internal filter cake. Figure 4 represents results of lab testing showing an internal mud cake formed inside a 50 mD disk by a water based mud containing 3% DS.

These bridging and sealing characteristics will help protect the formation where lost circulation may be encountered. This increased bridging appears to enhance rock strength, as well. It accomplishes this by increasing the formation fracture initiation pressure limit. By increasing the fracture initiation limit, the initial pore pressure fracture window is increased. This rock strength enhancement will allow the depleted sand to be drilled with the appropriate high mud weight mud required to control inter-bedded pressured shale, while potentially reducing mud losses in the depleted sand formations. The internal filtercake resulting from this bridging material results in a rapid reduction in differential pressure between the depleted formation and the fluid hydrostatic head. Figure 5 is a schematic of the effect of DS on high permeability external and low permeability internal filter cake with relation to differential pressure sticking.

Field Application

The difficulties encountered when drilling through depleted formations, to reach deeper objectives required optimization of drilling practices and drilling fluid design. The project drivers for the South Texas fields are numerous. Some of these drivers include:

- The operator’s goal is to drill these wells at, or below, the predicted drilling days curve, with lower well costs.
- Drilling occurs through complex geology, in a highly faulted area.

- Drilling takes place through highly depleted formations, which vary from well to well.
- There is a narrow pore pressure-fracture window, with a high potential for mud losses.
- The high differential pressure creates a risk of differential sticking.
- Complex casing designs are often required to meet the production objective.
- History has demonstrated numerous difficulties logging and running liners.
- Hole stability must be maintained in the reactive and often pressured shale sections
- Water-based mud is desired for environmental reasons. Fluid densities range to a maximum of 18.5 lb/gal.
- To meet the drilling goals mud associated NPT must be continually reduced, by minimizing mud losses, stuck pipe, and hole reaming.

Case History 1

Technical background & project objectives:

When drilling the 9½" and 6½" intervals, a series of depleted sand sections were to be drilled. Some of these sandstone formations were expected to have an extremely low depletion pressures. Differential pressure as high as 8,000 psi is often observed in these fields.

It was planned to use the DS in conventional water-based mud to eliminate differential sticking, severe losses and logging problems that had plagued the operator on offset wells. The DS was to be added in a concentration of 3 % by volume. This concentration was to be maintained throughout the 12 ¼", 9 ½" and the 6 ½" intervals.

Project results

On the first two wells, all sections were successfully drilled without any differential sticking or mud losses in the depleted sands. All logging runs were made without incident. A reduction of several days in rig time was achieved, compared offset wells, by reducing downtime related to differential sticking, mud losses and logging problems. This reduction in drilling days and cost was achieved with improvements to basic water based mud used previously in the McAllen field. This was considered a major improvement because differential sticking, mud losses and, most importantly, logging problems had occurred on most wells drilled by the operator in this field.

Case history 2

Technical background & project objectives

Severe losses and logging problems had plagued the operator on offset wells. Several depleted sand formations were planned to be drilled in the 14¾" intervals of these wells. The adjacent shale required a 13 lb/gal mud weight for stability control. The objective of the addition of DS to the water-based mud used in this field was part of the plan to reduce non-productive time (NPT). The DS was used to eliminate the mud losses while drilling the depleted sand sections by adding at a concentration of 3% by volume while drilling above the first depleted sand. The flexibility in allowing the DS to be added to the drilling fluid while drilling aided in reducing operating costs.

Project results

The 9½" and the 6½" sections were successfully drilled without any mud losses or differential sticking problems in the depleted sands. Most importantly, logging problems were not observed in these wells.

Future Work

While operationally successful in the wells discussed, mud losses and pipe sticking have occurred in some instances even with this new sealing/bridging additive. Drilling fluid design, drilling engineering and geomechanics must be continually evaluated to push the drilling efficiency envelope when drilling through depleted sands. Initial work on the inter-relationship between the drilling fluid design and geomechanics is presently being conducted. It is envisaged that a consistent geomechanics model will be fully developed as an engineering tool. This tool could be used to define the operational limits of various mud weights with proper drilling fluids design. Such a model would enable a consistent and focused approach on the design of drilling fluid in order to effectively mitigate massive fluid losses and differential sticking associated with drilling through severely depleted sands or in narrow margin environments. It is also envisaged that the approach will be eventually be applied to oil based mud drilling.

Conclusions

Field case histories indicate that drilling mud losses associated with severely depleted tight sands can be reduced with the use of a newly developed DS product. Several conclusive benefits were observed with the addition of this bridging/sealing agent. With a better understanding of the sands pore bridging properties and the use of an internal mud cake approach, highly depleted tight sands can be drilled successfully and economically. Some of the successes accomplished are:

- Improved drilling curve
- Reduced drilling days
- Stable and gauge hole
- Improvement on mud losses
- Reduction in Total NPT
- Establishing a learning curve

Acknowledgement

The authors wish to thank TOTAL E&P USA and Baker Hughes INTEQ for permission to publish this paper. The work, test protocol, discussions and comments provided by staff from both companies were very much appreciated. Special thanks Mike Knight with Dominion Exploration for giving us permission to publish field data on Wilcox permeability and pore throat size; Cecil Hernandez and Ron Miller for their effort and support.

References

1. Ali, A.; Kallo, C. L.; Singh, U. B., “Preventing lost circulation in severely depleted unconsolidated sandstone reservoirs”, paper SPE/IADC 21917, Amsterdam, March 1991.
2. Benaissa, S.; P. Isambourg, P. ; Ottesen, S. ; Marti, J. “ Down-Hole Simulation Cell for Measurement of Lubricity and Differential Pressure Sticking, paper SPE/IADC 52816, Amsterdam, Feb. 1999.
3. Dewar, J.; Halkett, D., Procedures Control Total Mud Losses While Drilling in Deep Water”’ Oil & Gas Journal, Nov. 1993.
4. Dryer, G.; Gani, S. R.; Gauantt, G. “Innovative Perforation Techniques Show Promising Results in Problematic Deep Depleted Sands”, SPE/IADC 47807, Jakarta, Sept 1998.
5. Jones, J. F., “Successfully Managing Drilling-Fluids Losses in Multiple, Highly Depleted Sands”, paper OTC 13107, Houston, April 2001.
6. Kurochkin, B., “Clay/latex mixture stops lost circulation in large carbonate fractures”, Oil & Gas Journal, August 1995.
7. McGill, M.; Seaton, S.; Valenziano, R.; Bruner, S.; Golden, J., “Drilling Severely Depleted Sands in the Gulf of Mexico: The Benefits of Cloud Point Glycols”, SPE/ATC 38571, San Antonio, Oct. 1997.
8. Monroy, R.; Mandujano, H; Tejeda, J.; Solis, E.; Rueda, F., “Pemex control lost circulation in South Mexico”, Oil & Gas Journal, Aug. 1999.

SPE/IADC 67735, Amsterdam, Feb. 2001.

9. Nahm, J. J.; Romero, R. N.; Wyant, R. E.; Hale, A. A.; Briggs B. R.; Smith, T. R.; Lombardi M. A.; Keedy, C. R., “Universal Fluid: A Drilling Fluid to Reduce Lost Circulation and Improve Cementing”, SPE/IADC 27448, Dallas, Feb. 1994.
10. Rojas, J. C.; Bern P. A.; Fitzgerald, B. L.; Modi, S.; Bezant, P. N., “Minimising Down Hole Losses”, SPE/IADC 39398, Dallas, March 1998.
11. Singh, B.; Emery, N., “Fracture-Gradient Predictions in Depleted Sands in the Gulf Coast Sedimentary Basin”, AAPG Memoir 76, p. 125-129, 2002.
12. Sweatman, R.; Faul, R.; Ballew, C., “New Solutions for Subsalt-Well Lost Circulation and Optimized Primary Cementing”, SPE/ATC 56499, Houston, Oct. 1999.
13. Tare, U. A.; Whitfill, D. L.; Mody, F. K, “Drilling Fluid Losses and Gains: Case Histories and Practical Solutions”, SPE/ATC 71368, Sept. 2001.
14. Verret, R. J., “Innovative Lost Circulation Squeeze – Solution to Deep Water Losses”, AADE 04, Houston, April 2002.

Nomenclature

HPWBM = high performance water-based mud
WBM = water-based mud
OBM = oil-based mud
SBM = synthetic based mud
BHA = bottom hole assembly
PDC = polycrystalline diamond cutters
ECD = equivalent circulation density
ROP = drilling rate of penetration
TD = total depth
TVD = true vertical depth
ROB = rotating off-bottom
WOB = weight on bit
PSI = pressure, pounds/inch²
BETA = Baker Hughes Experimental Test Area
MWD = measurement while drilling
LWD = logging while drilling

Table1. General well profiles by field

Fields	Depth ft	Deviation	Max Mud WT lb/gal
A	12, 000	Vertical	13.0
B	16,000	42^o	18.5
C	15,000	10^o - 15^o	15.0
D	13,000	15^o - 20^o	18.5

Table 2. Typical field mud formulation and properties.

Products	Concentration
Bentonite	4-8 lb/bbl
Lignite	4-6 lb/bbl
Lignite – Resin	1-2 lb/bbl
Lignosulfonate	2-3 lb/bbl
Polymeric Deflocculant	0.05 -0.2 lb/bbl
Caustic Soda	1-1.5 lb/bbl
Sulfonated Asphalt	4-6 lb/bbl
Bio Polymer	0.05-.15 lb/bbl
Barite	To 18 ppg
Calcium Carbonate	1-2 lb/bbl
Lubricant	1-2 % by vol.
Mineral Oil	1-2% by vol.
DS	3-4% by vol.
Lime	As needed to treat CO2
Properties	
Density, lbm/gal	18.0
Depth, ft	14,000
Viscosity @ °F	120
600 rpm	113
300 rpm	63
200 rpm	44
100 rpm	23
6 rpm	6
3 rpm	5
Plastic Viscosity, cPs	50
Yield Point, lbf/100ft^2	13
Initial gel, lbf/100ft^2	5
10 min gel, lbf/100ft^2	11
30 min gel, lbf/100 ft^2	16
API filtration, mls/30 min	1.2
HTHP @300 F & 500 psi, mls/30 min	4.6
pH/Pm	10.7/2.9
Drill solids, %	3.2
ECD Bit	18.41

Figure 1. Typical formation and pore pressure regime

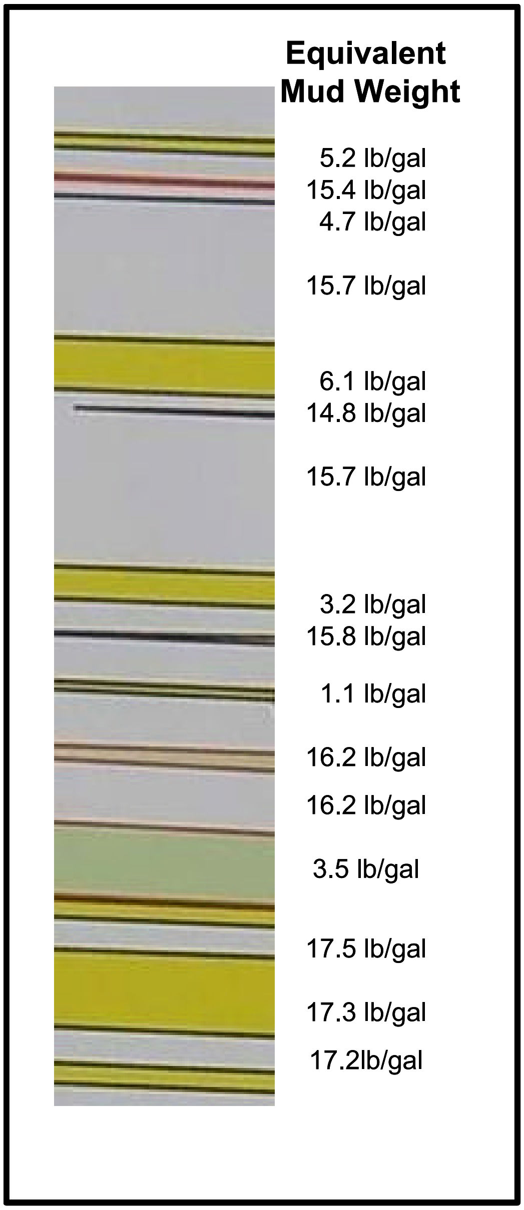

Figure 2. Permeability Distribution - Sand Formations

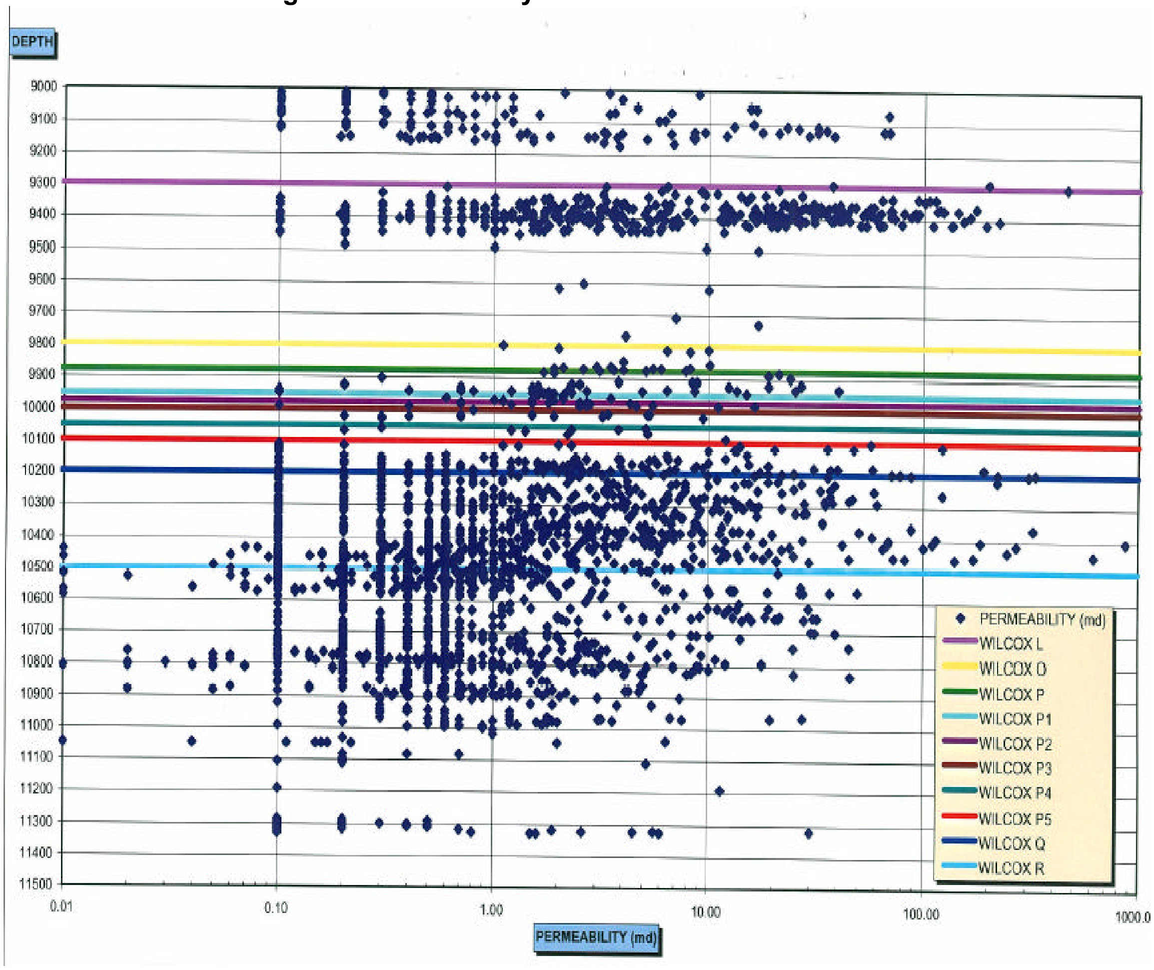

Figure 3. Particle Size Distribution - Sand Formations

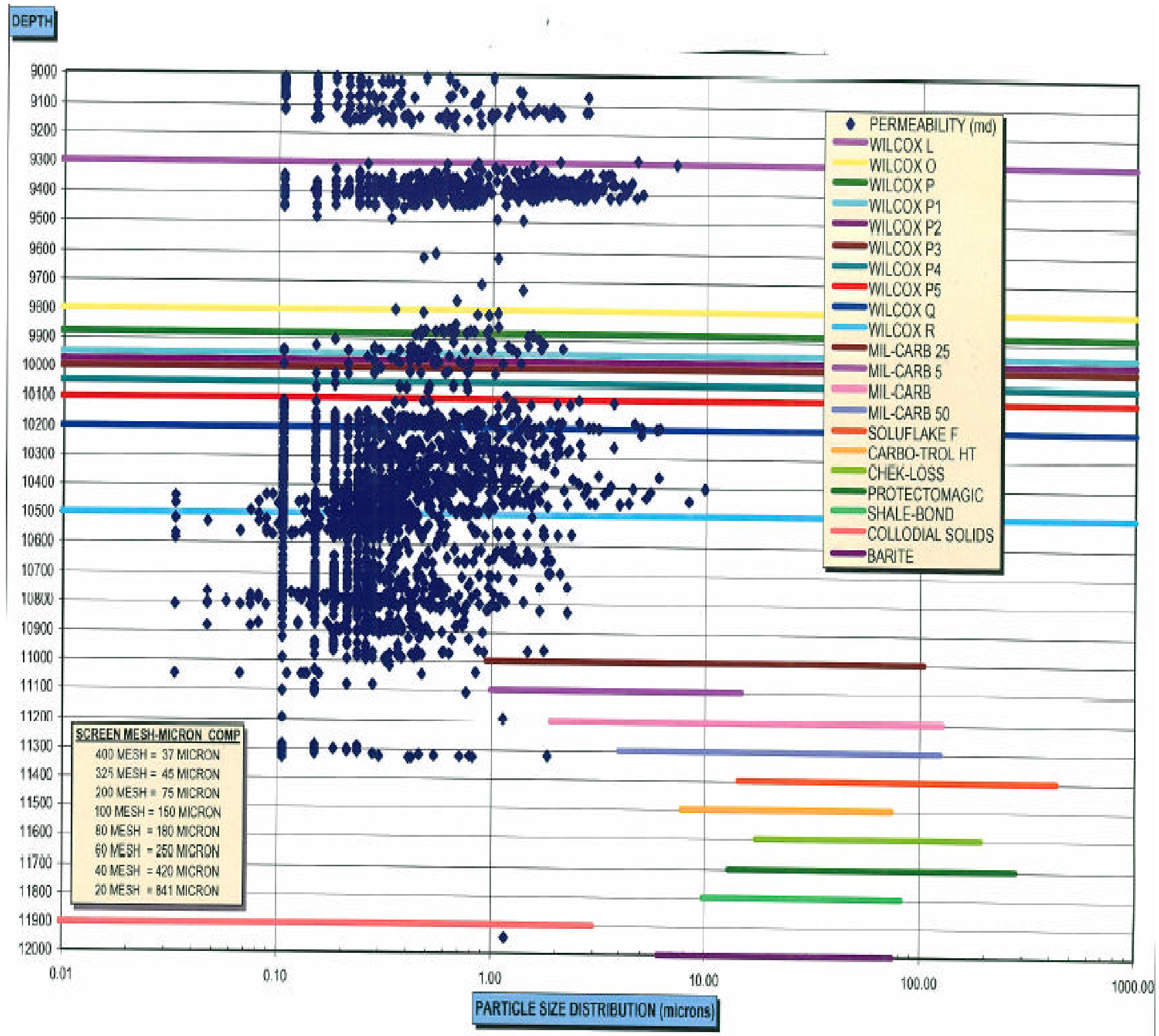

Figure 4. Internal Mud Cake Formed Inside 50 Md Disk WBM Containing 3% DS

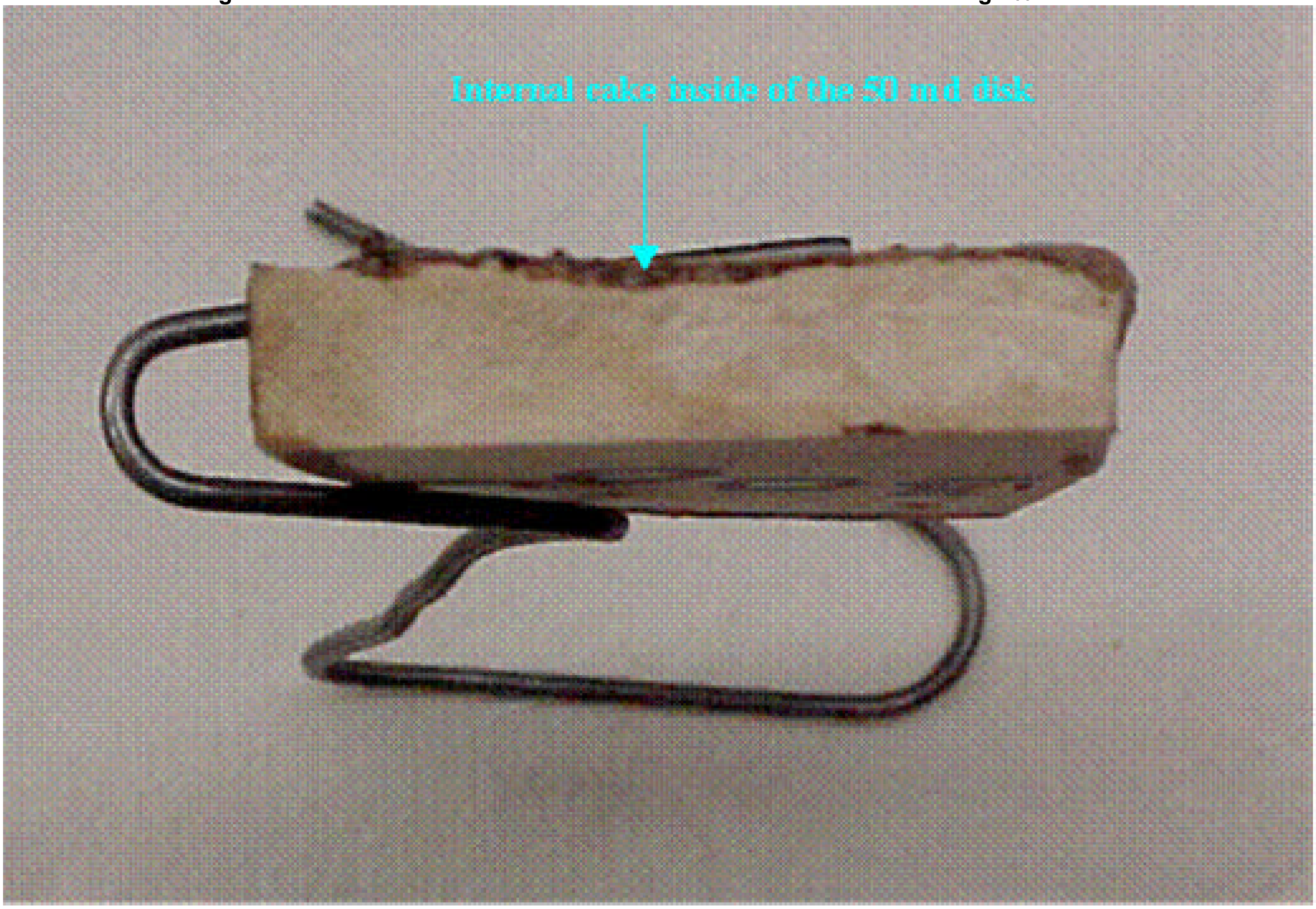

Figure 5. DS- External and Internal Mud Cake and Differential Sticking