UBD and Beyond: Aphron Drilling Fluids for Depleted Zones

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Abstract

With many of the easily accessible reserves exploited, the industry today has no choice, but to explore new and ever more challenging frontiers. At the same time, there is a pressing need to maximize the already discovered production potential in mature fields. Production from these fields has played a major role in meeting the world's energy needs, and today holds the potential to further bridge the supply gap. .

However, years of producing oil and gas has subsequently drawn down the reservoir pressure of these mature fields. Consequently, many of these structures worldwide are severely depleted – in some instances the depletion is so severe that continued development is economically unfeasible. Many of these fields still hold abundant hydrocarbons, but the eventual production of these trapped reserves require infill drilling or workover to adequately exploit the field. In others, drilling deeper for new production is necessary, and combined with the ability to preserve the present zone for continued production, can improve field economics.

When depletion draws down the pore pressure in what is typically a sand of other porous and permeable zone it becomes vulnerable to invasion from fluids used in drilling, workover, or completion. This results when the borehole pressure exerted by the hydrostatic column, plus the circulating pressure of the fluid, exceeds the pore pressure and the associated force required to push the fluid into the zone. Depending on the severity of the overbalance, invasion may be in the form of filtrate, seepage of fluid and solids, or complete loss of circulation. All of this damages the production zone while seepage and lost circulation require remediation before drilling can continue. This type of remediation usually involves adding solids as seepage control or bridging agents, thereby creating additional, and sometimes permanent, damage.

Aphron fluids are being used successfully in many severely depleted areas. In some cases, these fluids were applied after UBD was unsuccessfully attempted. This paper discusses some of these applications and describes how these fluids have enabled continued drilling in these mature fields. The aphron fluids were successful in preventing lost circulation and invasion while providing total well control and safety. Borehole stability was maintained and conditions for all drilling operations were excellent at all times. Wireline logging and coring operations were carried out with no problems. Directional tools functioned well, with no problems drilling directional or horizontal wells.

The authors will describe the aphron technology, which basically comprises small bubbles with unique properties, stabilized in a specially viscosified fluid. They also will explain the mechanisms by which they can balance borehole with formation, and the potential for expanded use as an important tool in drilling technology.

Introduction

There are many reservoirs where the pore pressure is drawn down below 1,000 psi with some even as low 500 psi. It is not uncommon to calculate a pore pressure of 2.0 lb/gal or less in these highly permeable zones. In order to understand the severity of the problem, the minimum density of most unweighted drilling and workover fluids is 8.5 lb/gal for water-base muds (WBM) and about 7.0 lb/gal for oil-base muds (OBM). It is easy to see where the borehole pressures can exceed pore pressure by several thousand psi, and to understand how it can become virtually impossible to drill these zones at all, not to mention the severe damage that occurs in the attempt.

The use of underbalanced drilling (UBD) techniques has been used extensively for drilling these highly depleted reservoirs. This technique utilizes gas or air to reduce drilling and workover fluid density to the point that it is less than formation pore pressure. Many times the zone is allowed to produce as it is drilled, and the movement of fluids is away from the formation. However, the costs associated with planning, equipment, and services is high, and well control issues can cause safety concerns, especially when toxic gases, such as H_2S are present. In addition, borehole instability is a problem in cases where underbalanced conditions can lead to collapse of the wall. Formation damage also can result during some operations where the well must be killed, thus putting pressure back into the zone and causing invasion. Even during stripping operations, borehole pressures will build up and may cause severe damage.

Benefits, disadvantages of UBD

Also known as "air", "gas", or "low head" drilling, UBD is a technique in which the more common circulating fluids, water or mud, are replaced by highly compressible air or gas. The air or gas performs most of the same functions as a drilling mud, such as. cooling the bit and cleaning the hole. Applicability of "air" drilling can be limited to a specific set of lithological and pore pressure conditions. Where it is applicable, significant savings of rig time and money can be achieved with these drilling techniques

Currently, it is estimated that 10% of all wells drilled in the US employ air or low-head drilling techniques. Owing to the significant cost savings and a growing comfort level of operators using air drilling techniques, there is a trend toward increasing this percentage. Offshoots of air and gas drilling are the use of mist, stable foam, and aerated mud, which generally are applied in increasingly difficult or wet environments. Even though they are more complex, they retain many of the benefits of straight air drilling, including:

1. Higher penetration rates, leading to less drilling time and lower costs.
2. Minimal damage to producing formations.
3. Ability to analyze formation productivity while drilling.
4. Ability to produce hydrocarbons while drilling.
5. Minimization of lost circulation.
6. More footage drilled per bit.

Even though UBD techniques can be highly beneficial, they also have limitations. These limitations may be due to obstacles that are known beforehand, those discovered during well planning, or those encountered during drilling or workover operations. It is important to emphasize that UBD is a technology that must be planned and applied carefully. A problem with UBD can become serious very quickly, and with costly results. Some limitations and points of concern with UBD applications are:

1. Potential for wet or unstable boreholes.
2. Unsuitable pore pressure regimes.
3. Significant drill string wear or corrosion.
4. No hydraulic dampening of drill string.
5. Potential for downhole fires (under specific conditions).
6. Potential formation damage due to invasion during certain operations or by imbibition.

Description and Function of Aphron Fluids

Aphrons in drilling fluids were first described as independent spheres with a gas or air core encapsulated by a multiple layer film.[1]. They were further described as non-coalescing and recirculateable so that they are useful as a conventional drilling, workover or completion fluid when stabilized in a uniquely viscosified system. This system is able to stop losses and prevent formation invasion. It was first described as an "at-balance system" where the density of the fluid was kept as near the formation pore pressure as possible. After a great deal of experience, it was shown that the aphron fluids prevented losses and invasion even when the borehole pressures, induced by equivalent circulating densities (ECD), greatly exceeded the formation pore pressure. Indeed, some of the case histories show no losses or damage even where differentials of several thousand psi existed.

Therefore, a new description of "at-balance drilling" is required. Ivan etal[2] expanded the description of the aphron system as one that creates an "energized environment". Since the aphrons are compressible and store energy as they are pumped downhole, this energy is available to be released as the aphrons enter formation openings. Ivan further describes the "meniscus wrapping theory" and the importance of "Laplace Pressure". This means the energy is not only stored in individual aphrons, but also is applied to the larger aggregates which form as the aphrons are crowded into a formation opening. This allows the formation of a "micro-environment" in the formation openings where external Laplace forces increase dramatically along with the Low Shear-Rate Viscosity (LSRV). The energy stored in this micro-environment is able to absorb and mitigate the borehole pressure until it is put "at-balance" with the formation pore pressure. Further, this at-balance condition seems to be able to adjust and absorb the borehole pressure changes to compensate for normal operations, including connections, trips and other activities. Those operations cause surge and swab, but usually do not affect the at-balance condition.

Another interesting feature of the aphron system is its unique lack of wetting. The water used in the formulation is bound so that it is not readily available to the "thirsty" rock which, in conventional fluids, is taken up through capillary forces and is a form of imbibition. This imbibition can take place even in UBD operations and is described by Bennion[3, 4] as a serious cause of formation damage even in underbalanced conditions. The Capillary Suction Test (CST) is a reliable method of testing the tendency of a fluid to allow capillary movement or imbibition. Most drilling fluids take only minutes to move through the test medium, while inhibitive fluids may take a few hours. Repeated tests of the aphron fluid show no movement even after seven days[5].

Growcock etal[6] further describes the application of aphrons in water-based fluids and the use of polyphrons in oils, oil-based mud, synthetic-based muds and other non-aqueous fluids. Both aphrons and polyphrons function in a similar way in their respective fluid formulations.

These systems cause a solids-free, mostly air or gas barrier, to be placed temporarily along the borehole openings as the zone is drilled. Experience has shown that this temporary barrier is readily removed on completion by relieving the borehole pressure and allowing the energized environment to move out. Any residue left is minor, not tenacious, and is easily removed by the produced formation fluids.

Lake Maracaibo Depleted field Application

Ramirez etal[7] describes the application of the aphron fluids in a nine-well project in the Lagomar area of Lake Maracaibo. This application followed a recent group of seven wells that were drilled using aerated fluids and UBD techniques In the pre-aphron wells an intermediate string was set to the top of the La Rosa formation in order to isolate the normal pressure zone.

Even with aerated mud, severe lost circulation was experienced. Shale bodies were present in certain of the sands that caused borehole instability problems. Cementing was unsatisfactory, because of lost circulation, formation damage and poor cementation of the zone of interest. Furthermore, the operator experienced difficulty in running wireline logs.

This is contrasted with the experience of the aphron-drilled project. The nine wells were drilled without problems. No lost circulation or borehole instability was observed even though RFT logs showed borehole density as high as 9.3 lb/gal while formation equivalent gradients were as low as 2.4 lb/gal.

Many of the wells were cored, all with good results and core recovery averaged over 90%. Wireline logs, MWD and LWD were used with no problems. Borehole conditions and inhibitive capabilities of the system proved excellent. For this reason, the last five wells in the program were drilled without intermediate casing resulting in a significant savings. This was done even though the shale and claystone sections are highly reactive.

Another remarkable experience is that the cementing results were improved so much that the operator was able to increase the slurry density from “lite” cements to 11.5-12.5 lb/gal. Returns remained complete throughout cementing, improving the quality of cement jobs and the interpretation of the bond logs.

To date, nearly 100 wells have been drilled in Venezuela using the micro-bubbles aphron system.

New Mexico Low Pressure H_2S Gas Carbonate Application

Kinchen etal[8] describes the application of the aphron system in a low-pressure carbonate reservoir in the Indian Basin field of New Mexico. This experience involves drilling through the Upper Pennsylvanian section in the Cisco dolomite. Seven wells were drilled with the aphron system after nine previous wells which were drilled with various techniques including UDB.

The Cisco dolomite is highly vugular, with fracture permeability. Figure 1 shows a formation imagery log with large openings with of more than three feet across. Figure 2 shows core samples of the Cisco. The large openings in combination with low formation pressures (1.1 to 2.8 lb/gal) present a difficult drilling challenge where lost circulation and resulting formation damage is severe.

Table 1 shows the various techniques employed to drill the 16 wells covered in this paper. Four were drilled using conventional drilling fluids with lost circulation material (LCM), two were drilled using a combination of conventional fluids/LCM and drilling “blind”, or without returns, three were drilled with UBD with air or air/mist, and seven were drilled with the aphron fluids. As the table shows, production is spotty in the field, with good wells and poorer wells in each category of drilling technique. Remarkably, the cleanup and time to production of the aphron drilled wells was much faster. All these wells reached peak production in a few days while two actually reached peak in four days. This was in contrast to the other wells which typically took at least two months to reach their peak, while some produced on an incline for several months. This resulted in an enormous reduction in completion costs, and expedited return-in-investment (ROI).

Other significant factors were the successful cementing results. Even with two-stage cementing, the conventionally drilled wells experienced significant lost circulation during pumping and required extensive remediation. The aphron drilled wells had full returns throughout cementing with greatly improved coverage across the zone permitting selective perforation during completion. Owing to the control of lost circulation and support of the fluid column, intrusion of dangerous H_2S was prevented. A corrosion monitoring program showed very low corrosion rates even in the severe environment. The aphron system has certain scavenging and buffering characteristics that minimize corrosion even in the presence of acid gases.

North Sea Trapped Reserves Application

Donaldson etal[9] describes the application of the aphron system as a tool to access trapped reserves in a highly depleted reservoir in the North Sea. White etal[10] describes the evaluation and the technology behind the application. Table 2 shows the well schematic illustrating the difficulty of the operation.

In this application, the producing reservoir was depleted from 366 to 50 bar. The trapped reservoir, with virgin pressures, lay beneath this depleted producing zone. The trapped reservoir contained limited reserves, so it was necessary to reach it by a low-cost deepening project. An additional challenge was to preserve the existing reservoir for continued production. Small hole sizes precluded the possibility of a liner to isolate this reservoir, so a novel approach was designed to spot a specially designed aphron fluid pill treated with sized $CaCO_3$ to protect the zone during the deepening project. This was designed to open the zone for future production.

Further complicating the project was the existence of the claystone layer with imbedded sand lenses. In order to preserve shale stability, it would be necessary to preserve the on-balance situation without fracturing the upper reservoir. Since the sand lenses were potentially virgin pressure, the possibility of well control had to be considered. This led to a simulation well yard test where the aphron system was subjected to a well control situation and put on choke. From that test, procedures for well control with the fluid were designed.

To assess the effectiveness of the aphron pill in protecting the existing reservoir, a 50-bbl aphron fluid pill formulated with 75-lb/bbl sized $CaCO_3$ was placed across the perforations. After the pill was placed, a pressure limit test of 58 bar surface pressure (11.25 lb/gal equivalent mud weight) was conducted.

Afterwards, the milling and drilling deeper operation was carried out without losses or problems to a final depth of 11,650 ft (MD). Further, no completion damage to the existing reservoir was experienced.

Mexico Mature Field Workover Application

Rea etal[11] described the application of the aphron fluid for workover operations in three wells in the Poza Rica field of eastern Mexico. Three wells in the Tajin area were remediated and re-completed with mechanical pumps. Because of their tight features, these wells were fractured during their initial completion to optimize production. This fractured area causes frequent lost circulation to the depleted sands, constant gas influxes, and high potential for taking kicks.

The procedure for working over each of these wells consisted of displacing the aphron fluid at the top of cement plugs which covered the perforations across the depleted sands.
After the displacement, the cement plug was drilled providing communication with a lower-pressure set of perforations. In one well, two cement plugs were drilled, providing even more communication with perforations across a low-pressure zone. In all cases the re-completion was accomplished with no losses and no operational problems despite the high pressure differential of the fluid and the fractured nature of the reservoir. Tables 3a, b, c show the schematics of the well re-completions.

Results and Conclusions

As illustrated in the case histories, the fluid can be used to drill low-pressure reservoirs where UBD was unsuccessful. In many of these cases, coring and use of MWD and LWD were accomplished with no problems. Many were drilled with normally pressured zones were combined with those of low pressure and drilled together in the same interval. In most cases, problems were reduced or eliminated, days on well were reduced, completions and time to production were minimized, while in some instances, casing strings were eliminated.

In many cases, the aphron fluids made coring possible. Hole conditions were excellent for obtaining good quality wireline logs, while MWD and LWD performed well in the system. Hole washout and enlargement was negligible providing a near-gauge hole in all cases. Borehole stability was excellent, even in areas where highly reactive clays and shales were drilled. In most cases, losses were prevented or minimized even when borehole pressure differential vs. formation pore pressure was very high.

Cementing results were excellent, demonstrating full returns during cementing, putting a reliable cement column across the depleted zones. Cement bonds results were very good with no instance of cementing failure even in the vugular, highly fractured reservoirs.

Completions were simplified with rapid cleanup. In some cases, peak production was accomplished in a few days in areas where wells historically were slow to clean up when drilled conventionally, or even with UBD in some cases.

Where UBD is advantageous it can be useful and is a proven tool for advancing drilling technology. It has some advantages that no other fluid can match, such as high penetration rates and the ability to produce while drilling. In certain cases, it is non-damaging.

When UBD fails or cannot be applied due to the circumstances of the project, it is necessary to go beyond UBD with aphron systems being likely solutions.

References:

1. Brookey, T. “Microbubbles, New Aphron Drill-In Fluid Technique Reduces Formation Damage”, SPE Paper No. 39589 presented at the International Symposium on Formation damage held in Lafayette, LA, (February 18-19, 1998).

2. Ivan, C., Growcock, F., Friedheim, J., “Chemical and Physical Characterization of Aphron-Based Drilling Fluids”, SPE Paper No. 77445 presented at the SPE Annual Technical Conference and Exhibition held in San Antonio, TX, (29 September-2 October, 2002).

3. Bennion, D.B., Thomas, F.B.: Underbalanced Drilling of Horizontal wells: Does It Really Eliminate Formation Damage?”, SPE 27352, SPE Intl. Symposium on Formation Damage Control, Lafayette, LA, 1994.02.7-10.

4. Bennion, D.B., Thomas, F.B., Bietz, R.F., and Bennion, D.W.: “Underbalanced Drilling: Praises and Perils,” SPE Drilling and Completion, December, 1998, pp. 214-222.

5. Laboratory Testing Report of Micro-Bubble Aphron Fluids, PDVSA, 1998.

6. Growcock, F., Simon, G., Khan, A., “Application of Aphrons and Polyphrons in Drilling Fluids” SPE Paper No. 80208 presented at the 19th SPE International Symposium on Oilfield Chemistry, (5-8 February, 2003).

7. Ramirez, F., Greaves, R., Montilva, J., "Experience Using Microbubbles-Aphron Drilling Fluid in Mature Reservoirs of Lake Maracaibo", SPE Paper No. 73710 presented at the International Symposium and Exhibition on Formation Damage Control held in Lafayette, LA, (20-21 February, 2002).

8. Kinchen, D., Peavy, M., Brookey, T., Rhodes, D., "Case History: Drilling Techniques Used in Successful Redevelopment of Low Pressure H2S Gas Carbonate Formation", SPE Paper No. 67743 presented at the SPE/IADC Drilling Conference held in Amsterdam, The Netherlands, (27 February-1 March 2001).

9. Donaldson , S., van de Weijer, T., Chesters, A., White, C., "A Novel Approach to Access Trapped Reserves below Highly Depleted Reservoirs", SPE Paper No. 79865 presented at the SPE/IADC Drilling Conference held in Amsterdam, The Netherlands, (19-21 February, 2003).

10. White, C., Chesters, A., Ivan, C. and Norris, R., "Aphron-Based Drilling Fluid: Novel Technology for Drilling Depleted Formations in the North Sea", SPE Paper No. 79840 presented at the SPE/IADC Drilling Conference held in Amsterdam, The Netherlands, (19-21 February, 2003).

11. Rea, A, Cuellar Alvis, Paiuk, B., Climaco, J, Vallejo, M., Leon, E. and Inojosa, J., "Application of Aphrons Technology in Drilling Depleted Mature Fields", SPE Paper No. 81082 presented at the SPE Latin American and Caribbean Petroleum Engineering Conference held in Port-of-Spain, Trinidad, West Indies, (27-30 April, 2003).

12. "Dynamics of Rock-Chip Removal", M.R. Wells-Amoco Production Co. SPE paper # 14218, June 1989.

13. "Underbalanced Drilling to Avoid Formation Damage". Paul Francis, Petroleum Development Oman, Bart van der Linden Shell EP Technology and Applied Research.

14. "Analytical Techniques for Recognizing Water Sensitive Reservoir Rocks", Charles H. Hewitt. SPE Paper # 594. Presented at the SPE Regional meeting in Denver, Colorado on May 27-28,1963.

15. "New Applications For Underbalanced Drilling Equipment", Charles R. "Rick" Stone SPE and Larry A. Cress SPE. SPE/IADC # 37679 1997 SPE/IADC Drilling Conference held in Amsterdam, the Netherlands March 4-6, 1997.

16. "Case Histories of Design and Implementation Of Underbalanced Wells", David R. Giffin, William Lyons. SPE #55606. Presented at the SPE Regional Meeting. Gillette, Wyoming 15-18 May 1999

17. "Minimum Gas Flow Rate for Continuous Liquid Removal in Gas Wells", Meshach Ike LLobl and Chi U. Ikoku. SPE # 10170. Presented at the 56th Annual Fall Technical Conference and Exhibition in San Antonio, Texas. October 5-7, 1981.

18. "High Pressure Flammability of Drilling Mud/Condensate/Sour Gas Mixtures in De-Oxygenated Air for Use in Under Balanced Drilling Operations".

Fig. 1 Formation Imagery log

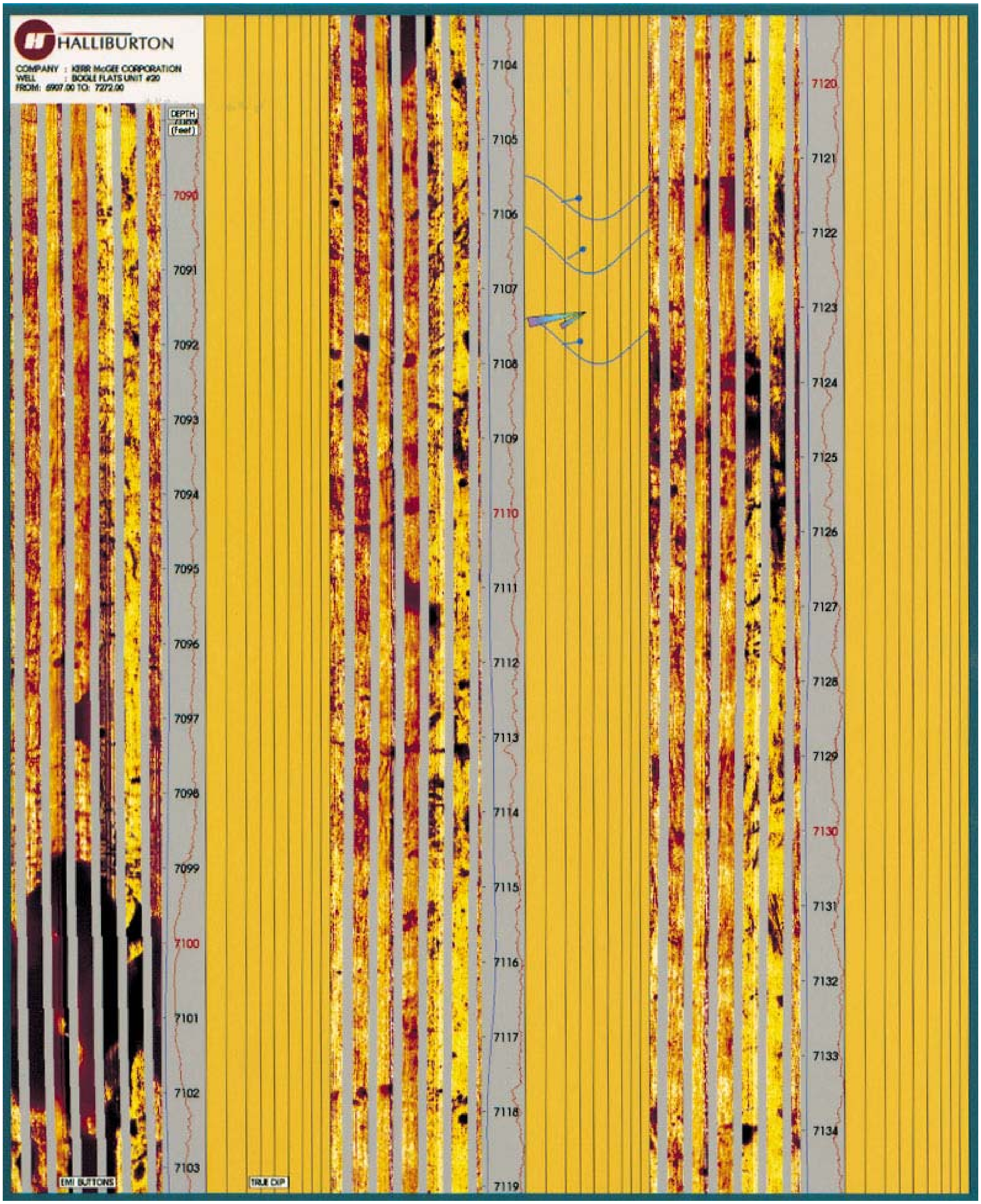

Fig. 2 Core Samples

Table 1 – Indian Basin, New Mexico field experience

Water Based Mud with Lost Circulation Material

well	Stimulation			Production Rate			Production
	date	size, gals	type	gas, mmcfpd	oil , bopd	water, bwpd	method
Conoco St. #2	06/21/95	1680	15% neat	1430	0	0	flowing
	06/27/95	4300	15% foam	3418	8	9	flowing
	02/20/96	10000	15%foam	6775	14	5	flowing
Bogle Flats #11	07/17/95	7000	15%	4300	9	205	flowing
Bright Fed #2	07/30/95	20000	foam 15%	210	0	200	flowing
	03/08/96	20000	foam 15%	trace	0	200	swab
	05/04/98	33250	15%	170	0	234	sub
	07/14/00	90000	30Q foam	433	0	338	sub

Mist/Air Drill Open Hole Wells

well	Stimulation			Production Rate			Production
	date	size, gals	type	gas, mmcfpd	oil , bopd	water, bwpd	method
Bogle Flats #13	03/21/96	5000	15% foam	2677	3	8	flowing
	05/11/96	10000	15% foam	5034	13	2	flowing
Bogle Flats #14	04/26/96	9000	15% foam	1597	0	30	flowing
Bright Fed # 3	05/14/96	none	15% neat	0	0	0	swab
	06/20/96	10000	15% foam	648	0	260	pump
	10/20/99	20000	15% foam	305	0	211	sub
	11/24/99	107500	15% foam	0	0	0	collapsed hole

Dry Drill wells with LCM

well	Stimulation			Production Rate			Production
	date	size, gals	type	gas, mmcfpd	oil , bopd	water, bwpd	method
Bogle Flats #20	05/19/99	0	none	0	0	40	swab
	05/26/99	10000	15% foam	120	0	0	flowing
	06/04/99	20000	15% foam	1200	0	2169	sub
WIBU #1Y	03/28/00	62500	15% foam	2700	0	3207	sub

Aphron Drilling Fluid Wells

well	Stimulation			Production Rate			Production
	date	size, gals	type	gas, mmcfpd	oil , bopd	water, bwpd	method
Lowe State #4	07/11/99	35000	15% neat	702	0	831	sub
	08/25/99	30000	20% foam	1174	8	2386	sub
Lowe State # 5	07/29/00	40000	15% neat	4215	5	2417	sub
Conoco State #6	04/11/00	0	none	4014	0	1551	sub
Bogle Flats #21	06/04/00	40000	15% foam	250	0	553	sub
Conoco State #7	07/23/00	60000	15% foam	893	0	2315	sub
WIBU #5	09/14/00	10200	15% PPI	533	0	388	sub
Federal 28 #2	Waiting for facilities and pipeline construction.						

Table 2 – Well Schematic

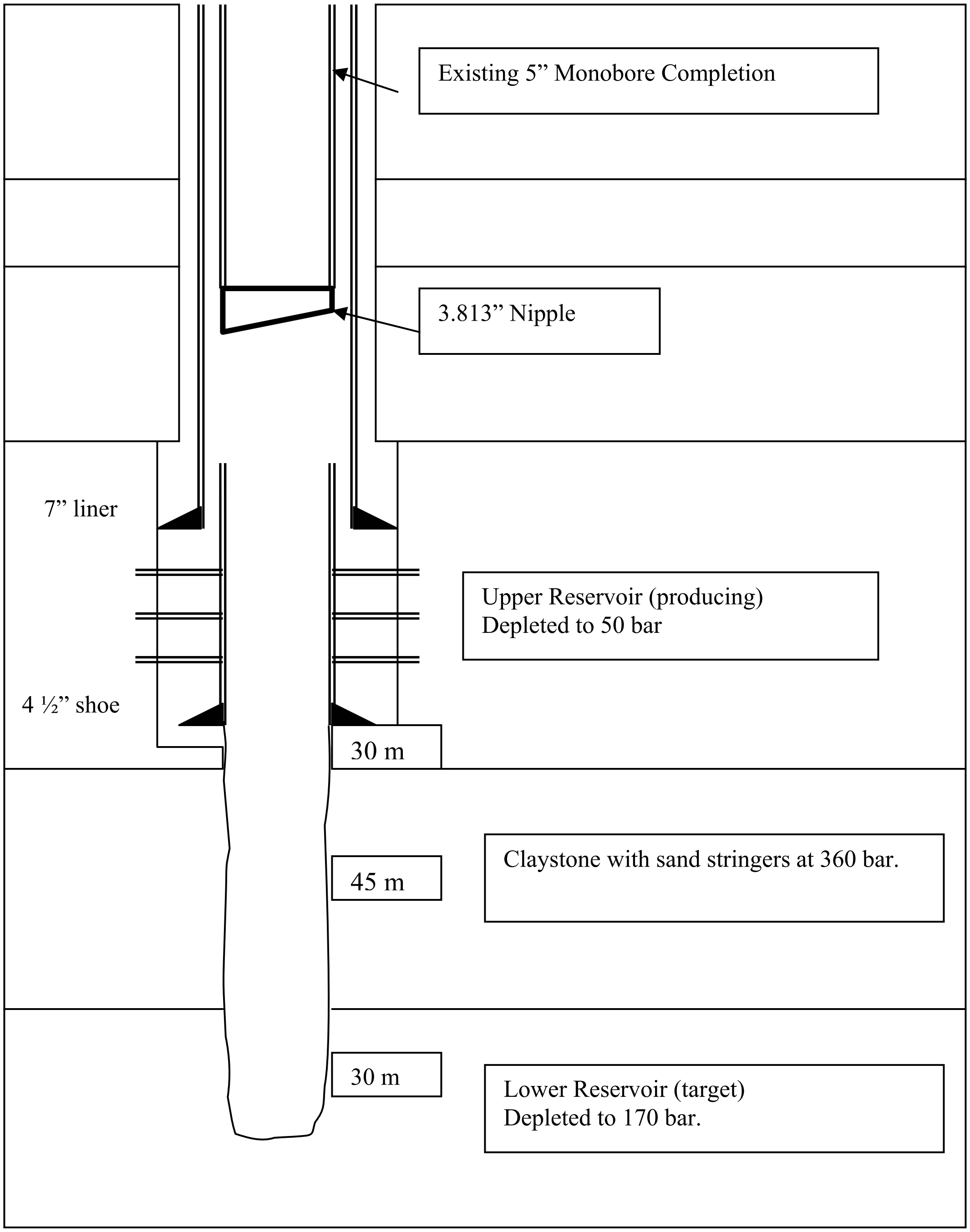

Table 3a – Tajin re-completions

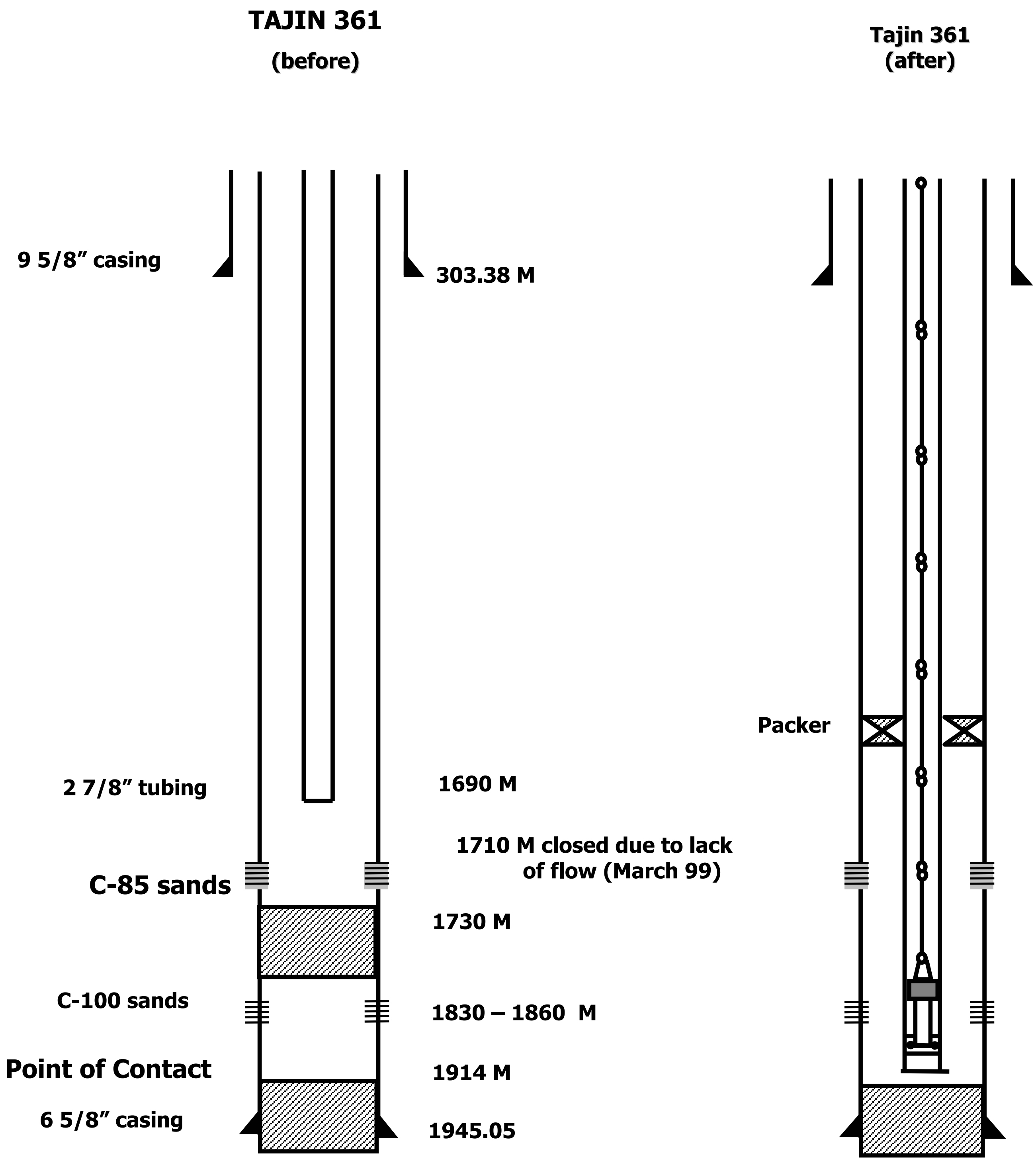

Table 3b – Tajin re-completions

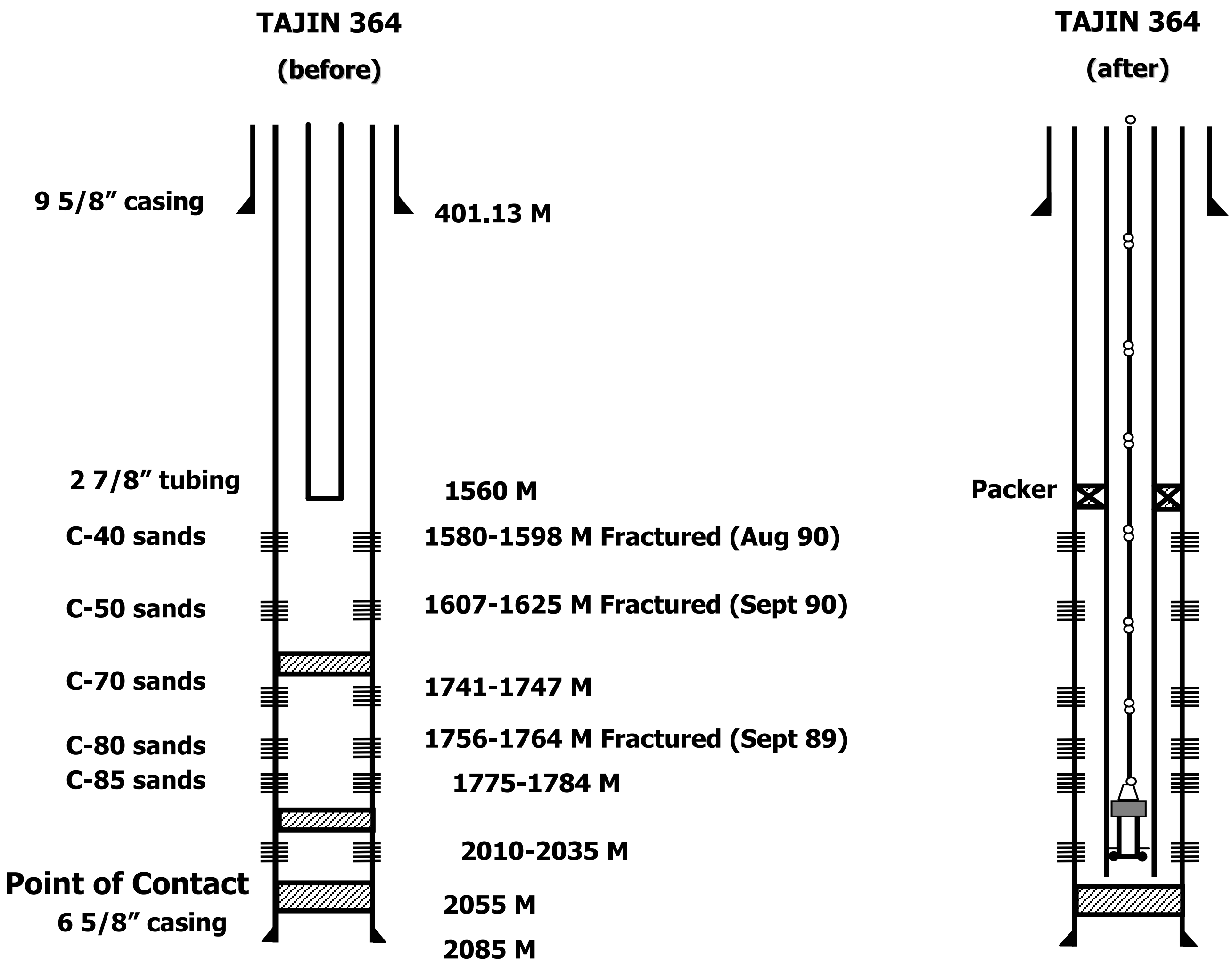

Table 3c – Tajin re-completions