AADE 01-NC-HO-49

Preventing Formation Impairment with a MicronAire™ Drilling Fluid System

Brent Warren, Kevin King, Garrett Browne and Colin Mann, all with Q'Max Solutions Inc.

Abstract

Invasion of drilling fluid particles into formations has long been recognized as a major cause of impairment in a number of reservoirs throughout the world. Prevention of particle invasion is virtually impossible, but minimization of the invasion can be achieved through the use of bridging systems. Bridging particles have invariably been solid in nature and have included a wide variety of materials such as carbonates, sized salts, resins and cellulose fibers.

The micronized drilling fluid described here uses air as the bridging particle. The air is entrained in a viscous bentonite based fluid, thus lowering the mud hydrostatic head and decreasing fluid or filtrate invasion. Under circulating conditions, the air particles are compressed in the mud column due to hydrostatic pressures. When the fluid contacts the lower pressured formation, one of two mechanisms can take place. The air particles may expand in size and seal off the pore throats directly, or the compressed air particles themselves may form a direct bridge on the formation face. This "air bridge" is then easily removed at the end of the well by flowback or circulating a clear fluid downhole.

This paper describes the MicronAire™ Drilling Fluid System and gives examples of the success of the system in a wide variety of reservoirs, from three Darcy unconsolidated oilsands to very tight low pressure gas bearing sands.

Introduction

The minimization, or ideally the prevention of formation damage is a fundamental step in the drilling process. Many previous works have dealt with the the loss of production due to formation damage[1-3], impairment mechanisms[4-10] and remediation of damage.[11-20] Minimizing the formation damage done to a well and/or the efficient removal of that damage is of prime importance in all drilling processes.

When drilling a well, the drilling fluid is the first material to contact the wellbore formations. The drilling fluid therefore plays a primary role in determining the type of damage and the extent to which the producing formations are impaired. Depending upon the type of fluid used, damage can be caused or can be prevented. Ideally the drilling fluid will prevent damage to the hydrocarbon bearing zones during the drilling phase and will allow for the flow of hydrocarbons during the production phase.

Drilling fluid formulations have evolved over the years to prevent formation damage.[21-24] Bridging systems are one of the most common methods used in drilling fluids to minimize invasion of mud solids and filtrates. A bridging system works by using properly sized additives, in combination with filtration control agents (such as celluloses and starches) to bridge pore throats (Figure 1). The ideal bridge will prevent invasion of solids/whole mud, and will minimize filtrate loss, into the producing formation. To be an desirable bridge, the removal of that bridge during production phase of the well should be straightforward.

Bridging with Air Particles

Bridging particles added to drilling fluids have been primarily restricted to solid materials. The variety of solids used are selected for their size distribution, shape, acid solubility, hydrocarbon solubilty, etc.. Some of the more common materials include calcium carbonates, celluloses, resins and salts.

Brookey, in 1998, described the use of air particles as bridging agents.[25] The air particles, or "Aphrons" as he termed them, provide a unique bridging material. Using air particles to form a bridge provides unusual and unique properties, including:

- Size range of sub-micron to 100 microns
- Highly stable
- Deformable to fit into various pore throats and pores
- Easily generated and in large abundance
- Air bridge is easily removed

Figure 2 shows a stabilized air particle enclosed in a protective barrier. Figure 3 provides a depiction of how these air particles form a bridge in a typical drilling situation. The air particles are circulated in the annular space and then find their way into the formation due to the difference in pressures, the mud circulating pressure being higher than the pore pressure. The size of the air particles also change because of the pressure differential. During circulation with a higher overbalance pressure, the air particles are “small”. When the small air particles enter the lower pressured reservoir, the air particles swell to equilibrate to the new pressure regime. With the ability to inject a large number of small air particles into a small area, and with the increase in size of those same particles, the pore area becomes filled with the bridging air molecules.

Chemistry/Rheology of Micronized Air System

In typical circulating drilling fluids, the two components are liquid (water and/or oil) and solids (added or from wellbore). Air is not a standard component of these type of fluids, and if present is usually not a desirable agent. Air entrainment in water-based fluids often leads to corrosion or foaming problems if not addressed.

On the other end of the spectrum, foam drilling fluids have a very high percentage of air and a minimal amount of water. The air in foam fluids is not designed to be entrained in the water carrier and will break out over time. In addition, the air in foam tends to coalesce and form larger air particles.

In a micronized drilling fluid, the air is entrained in the fluid and is designed so that the air particles are discrete and do not coalesce. To achieve those properties of air stability, two important components must be designed in the drilling fluid:

- Presence of a surfactant
- Minimum low-shear rate drilling fluid viscosity (LSRV)

The surfactant is needed in the drilling fluid in order to entrain the air particles and to keep the particles discrete. An effective surfactant will allow the air to stay in the drilling fluid while circulating, when acting as a bridge in the wellbore and while passing through solids control equipment on surface.

The concentration of air within the MicronAire^{TM} drilling fluid is also controlled by the concentration of surfactant. In general, the amount of air in the fluid is limited by the amount of surfactant added to the mud system.

A minimum low-shear rate viscosity of the drilling fluid is also required as part of the fluid package. The drilling fluid requires good LSRV to keep the air particles from escaping out the fluid on surface. In practice, an LSRV of greater than 50,000 cps on a Brookfield at 0.5 rpm is the mininum rheology required to keep the air particles within the drilling fluid system. Ideally, a 100,000 cps Brookfield viscosity will keep all air particles entrained and will keep the drilling fluid density at a consistent and predictable value.

The drilling fluid composition is key to being able to achieve LSRV and therefore the entrainment of the air particles. Brookey employed high yield stress, shear thinning polymer(s) in order to achieve the required rheology and to ensure that the air particles are self-contained.[25]

The MicronAire^{TM} system achieves the requisite LSRV by using bentonite cross linked with an inorganic polymer. Examples of typical rheologies achieved with this base fluid are presented in Table 1. Note that the LSRV as measured by the Brookfield is often greater than those demonstrated with polymer mud make-up. The bentonite – inorganic polymer combination displays excellent shear-thinning capabilities. A specialized surfactant is used in the system in order to stabilize the air particle network without a disruption in the LSRV of the fluid. While costs can vary depending upon fluid requirements, pricing, etc., the MicronAire^{TM} system is approximately 50% of the cost of a polymer based Aphron system.

Density Ranges

Incorporation of stable air particles into a drilling fluid will obviously lower the density of the fluid. The reduction in drilling fluid density is directly related to the concentration of surfactant contained in the fluid. In laboratory conditions it is possible to obtain stable drilling fluid densities, under no pressure, as low as 700 kg/m^3 (5.8 ppg). Field applications have taken the system to as low as 800 kg/m^3 (6.7 ppg) density, although it is more common to run the densities in the range of 900-950 kg/m^3 (7.5 – 7.9 ppg). Drilling fluids with mud weights under 800 kg/m^3 tend to jack the mud pumps severely.

Air is a compressible material when subjected to pressure. Measurement of MicronAire^{TM} fluid density on surface will be less than the actual downhole density due to compression of the air within the fluid. While exact depth vs. density curves have not been established, an acutal downhole pressure device used on a well showed that a 900 kg/m^3 density surface mud weighed 950 kg/m^3 at a 700 meter depth (2300 feet).

One of the interesting aspects of a drilling fluid containing air particles is that the fluid density need not be restricted to densities less than 1000 kg/m3 (8.3 ppg).

The air particles may be entrained in weighted fluids containing common weighting agents such as barite, calcium carbonate, hematite, etc.. Therefore, the MicronAire fluid is applicable for use in higher pressure wells.

Potential Uses

MicronAire fluids have a number of potential applications in the wellbore. The list below presents some of the more common applications of an air bridging drilling fluid.

- *Surface lost circulation:* Recommended for problems where normal drilling fluid hydrostatic pressure leads to hydraulically induced fracturing. Low drilling fluid densities will minimize the chances of the fracturing mechanism. Air particles can also act as unconventional lost circulation materials, however, their effectiveness is limited to small lost circulation passages where an air bridge can be established.
- *Pay Zone lost circulation/formation impairment:* This use for MicronAire^{TM} fluid is one of the major applications, especially in formations which are water sensitive. As stated previously, the air particle bridge readily forms in the pore throats to prevent further whole mud/solids invasion and to minimize filtrate invasion. The unique combination of surfactant and LSRV fluid allow the air particles to pack closely, yet remain discrete.
- *Full time Underbalanced Drilling:* In theory, the MicronAire^{TM} system could be used for uninterrupted underbalanced drilling, provided certain requirements are met. The downhole fluid density (which will be greater than the surface density), needs to be less than the formation pressure for the system to be truly underbalanced.
- *ROP Enhancement:* Rate-of-Penetration will be enhanced in air particle drilling fluids where weighting agents are not required and where solids concentrations are less than 5%. The ROP increase is due to the lower hydrostatic pressure in the mud column and the resulting lower chip hold down pressure at the bit. No ROP increase will be realized in a weighted MicronAire fluid since the chip-hold down pressure of a MicronAire^{TM} and competitive fluids will be similar.

Field Examples

The MicronAire^{TM} system has been used in a variety of situations, from surface holes and vertical/horizontal payzones, from low permeability tight gas sands to heavy oil unconsolidated sands. The following field case examples will highlight some of the applications for air particle bridging systems.

1. *Tight Low Permeability Gas Sandstone*

Thunder Energy has drilled a number of wells into a low permeability, underpressured tight gas sandstones in west central Alberta (Figure 4). The dirty sandstones, known as the Basal Belly River and Edmonton sands, with average permeabilty and porosity of 1-20 mD and 3-4 %, respectively were previously drilled with simple bentonite based gel-chemical systems. Wells drilled with the gel-chemical mud typically do not produce back without a fracturing treatment. The suspected damage mechanism is swelling of the bentonitic clays in the small, tight pore throats and a subsequent reduction in overall Belly River and Edmonton sands permeability.

Three wells were drilled with the MicronAire^{TM} system with the expectation of limiting invasion of water and thus being able to produce the wells without undergoing a fracture job. Table 2 shows the production results and drilling fluid costs of the MicronAire^{TM} system compared to either water or a gel-chemical fluid. As can be seen from the data, the drilling fluid costs with the MicronAire^{TM} system were approximately twice that of a gel-chemical fluid, but production values were increased with these air-bridged fluid wells. Previously, all wells in the area required a frac job, each averaging a cost of approximately $ 30,000 (Cdn) per well. A frac job was initiated on only one of the three wells drilled with MicronAire^{TM} system as compared to three of the four offset wells. Gas production rates over the first three months of the wells were generally higher than the offset wells, although there is some variability in the quality of the reservoir itself. Note that the 1-14 well did not have a commercially viable Basal Belly River zone. The production and cost data are also shown in Figure 5.

2. *High Permeability Heavy Oil Sand*

Oil sands in eastern Alberta typically have poor matrix strength and permeabilities averaging 2-3 Darcy. As a result, lost circulation of drilling fluid into the wellbore is a commonplace occurrence. While the drilling fluid normally doesn’t damage the production of the heavy oil, costs are incurred from the additional fluid used on the well, as well as the costs and time of production lost recovering the drilling fluid prior to producing oil. The reservoir is relatively homogeneous but is subject to large wormholes where significant volumes of fluids are lost.

Wascana Energy used the MicronAire^{TM} system in hopes of limiting lost circulation and decreasing the down time prior to producing the oil. The area of interest is shown in (Figure 6). Table 3 shows the productions from wells over their first four months and indicates the success seen with the air bridge drilling fluid. The oil production from the MicronAire wells was twice that of the offset gel chem wells in the first month and from 1.5 to 1.8 times greater during the last 4 months. Although not reflected in the Table, the onset of production with the MicronAire driled wells was significantly faster than the gel chem drilled wells.

Conclusions

- Bridging systems designed with air as the bridging agent are extremely effective in preventing formation impairment.
- "Air bridges" prevent the loss of whole mud and solids to formation, and severely limit the amount of filtrate lost.
- Air bridges are effective in preventing losses of fluid into mild-moderate lost circulation zones.
- The MicronAire^{TM} system is effective in a wide variety of formation types from tight gas sandstones to unconsolidated oil sands to carbonates.
- The cross-linked bentonite carrier fluid for the air-particles provides excellent LSRV properties. The combination of the base fluid and surfactant can provide drilling fluid densities as low as 700 kg/m^3. Common MicronAire^{TM} densities are 900-975 kg/m^3.

Nomenclature

LSRV=low shear rate viscosity
ROP = drilling rate of penetration
ppg = pounds per gallon
cps = centipoise
n' = power law index (Herschel-Bulkley)
K' = Consistency Index (Herschel-Bulkley)

Acknowledgments

The authors would like to thank Thunder Energy and Wascana Energy for their help in providing production and cost data, as well as the opportunity to use the air-bridging system in their wells. We would also like to thank the management of Q'Max for allowing the information to presented at this conference.

References

1. Jiao, D. and Sharma M.: "Mud Induced Formation Damage in Fractured Reservoirs," SPE Paper No. 30107, presented at the 1995 European Formation Damage Conference, The Hague, Netherlands, May 15-16.
2. Bennion, D.B., Bietz, R.F, Thomas, F.B.: "Formation Damage and Horizontal Wells – A Productivity Killer ?", SPE Paper No. 37138, presented at the 1996 International Conference on Horizontal Well Technology, Calgary, Canada, Nov 18-20.
3. Tague, J.R.: "Optimizing Production in Fields with Multiple Formation Damage Mechanisms" SPE Paper No. 58745, presented at the 2000 SPE Formation Damage Control Symposium, Lafayette, Louisiana, Feb 23-24.
4. Bennion, D.B., Cimolai, M., Bietz, R.F, Thomas, F.B.: "Reduction in the Productivity of Oil & Gas Reservoirs Due to Aqueous Phase Trapping", CIM Paper No. 93-24, presented at the 1993 Annual General Meeting of Petroelum Society of CIM, May 9-12.
5. Gruber, N.G. and Adair, K.L.: "New Laboratory Procedures for Evaluation of Drilling Induced Formation Damage and Horizontal Well Performance", Journal of Canadian Petroleum Technology, Vol. 34, No. 5, pp 27-32, 1995.
6. Bennion, D.B., Thomas, F.B. and Bennion, D.W.: "Effective Laboratory Coreflood Tests to Evaluate and Minimize Formation Damage in Horizontal Wells", Presented at 1991 International Conference on Horizontal Well Technology, Houston, Texas, Nov. 12-14.
7. Jiao, D. and Sharma, M.M.: "Formation Damage Due to Static and Dynamic Filtration of Water-Based Muds", SPE Paper No. 23823, Presented at the 1992 SPE Formation Damage Control Symposium, Lafayette, Louisiana, Feb 26-27.
8. Marx, C. and Rahman, S.S.: "Evaluation of Formation Damage Caused by Drilling Fluids Specifically in Pressure-Reduced Formation", SPE Paper No. 12494, Presented at the 1984 Formation Camage Control Symposium, Bakersfield, California, Feb 13-14.
9. Rao D.N. and Bassiouni Z.A.: "A New Technique to Confidently Characterize Wettabilty Alterations Induced by Drilling/Completion/Workover Fluids", Presented at the 2000 SPE/DOE Improved Oil Recovery Symposium, Tulsa, Oklahoma, April 3-6.
10. Longeron, D.G., Alfenore, J., Salehi, N., Saintpère, S.:"Experimental Approach to Characterize Drilling Mud Invasion, Formation Damage and Cleanup Efficiency in Horizontal Wells with Openhole Completions", SPE Paper No. 58737, presented at the 2000 SPE Formation Damage Control Symposium, Lafayette, Louisiana, Feb 23-24.
11. Byrom, T.G. and Coulter, G.R.: "Some Mechnaical Aspects of Formation Damage and Removal in Horizontal Wells:, SPE Paper No. 31145, presented at the 1996 SPE Formation Damage Control Symposium, Lafayette, Louisiana, Feb 14-15.
12. Jones, A.T. and Davies, D.R.: "Quantifying Acid Placement: The Key to Understanding Damage Removal in Horizontal Wells:, SPE Paper No. 31146, presented at the 1996 SPE Formation Damage Control Symposium, Lafayette, Louisiana, Feb 14-15.
13. Browne, S.V. and Smith, P.S.: "Mudcake Cleanup to

Enhance Prodcutivity of High-Angle Wells”, SPE Paper No. 27350, presented at the 1994 SPE Formation Damage Control Symposium, Lafayette, Louisiana, Feb 7-10.

14. Frick, T.P. and Economides, M.J., “Horizontal well Damage Characterization and Removal”, SPE Paper No. 21795, Presented at the 1991 Western Regional Meeting, Long Beach, California, Mar 20-22.
15. Goode, D.L., Berry, S.D., Stacy, A.L.: “Aqueous-Based Remedial Treatment for Reservoirs Damaged by Oil-Phase Drilling Muds”, SPE Paper No. 12501, Presented at the 1984 Formation Camage Control Symposium, Bakersfield, California, Feb 13-14.
16. Bennion, D.B., Thomas, F.B. Bennion, D.W., Bietz, R.F.: “Fluid Design to Minimize Invasive Damage in Horizontal Wells”, Journal of Canadian Petroleum Technology, Vol. 35, No. 9, pp 45-52, 1996
17. Lacewell, J.L. and Burnett, D.B.: “Correlating Good Well Design, Drilling and Cleanup Practices with High Well Productivity”, SPE Paper No. 64580, Presented at the 2000 SPE/Petroleum Society of CIM International Conference on Horizontal Well Technology, Calgary, Canada, Nov. 6-8.
18. Kamath, J. and Laroche C., “Laboratory Based Evaluation of Gas Well Deliverability Loss Due to Waterblocking”, SPE Paper No. 63161, Presented at the 2000 SPE Annual Technical Conference and Exhibition, Dallas, Texas, Oct 1-4.
19. Way, P.W., Howard, P., Johnson, A.: “Jetting Clean-Up of Formation Damage Caused by the Drilling Process”, SPE Paper No. 62799, Presented at the 2000 IADC/SPE Asia Pacific Drilling Technology, Kuala Lumpur, Malaysia, Sept. 11-13.
20. Luyster, M. R.,. Monroe, T.D, Ali, S.A.: “Factors Affecting the Performance of Enzyme Breakers for Removal of Xanthan-Based Filter Cakes”, SPE Paper No. 58749, presented at the 2000 SPE Formation Damage Control Symposium, Lafayette, Louisiana, Feb 23-24.
21. Gaurina-Medjimurec, N., Steiner, I., Simon, K., Matanovic, D. “Avoidance of Formation Damage by Application of Proper Drill-In Fluid (A Case Study of a Mature Field)”, SPE Paper No. 65185, Presented at the 2000 SPE European Petroleum Conference, Paris, France, Oct. 24-25.
22. Davison, J.M., Jones, M., Shuchart, C.E., Gerard C.: “Oil-Based Muds for Reservoir Drilling: their Performance and Cleanup Characteristics”, SPE Paper No. 58749, presented at the 2000 SPE Formation Damage Control Symposium, Lafayette, Louisiana, Feb 23-24.
23. Dick, M.A., Heinz, T.J., Svoboda, F., Aston, M.: “Optimizing the Selection of Bridging Particles for Reservoir Drilling Fluids”, ”, SPE Paper No. 58793, presented at the 2000 SPE Formation Damage Control Symposium, Lafayette, Louisiana, Feb 23-24.
24. Patel, A.D. and Growcock, F.: “Reversible Invert Emulsion Drilling Fluids: Controlling Wettability and Minimizing Formation Damage”, SPE Paper No. 54764, presented at the 1999 European Formation Damage Conference, The Hague, Netherlands, May 31-June 1.
25. Brookey, T.: “Micro-Bubles”: New Aphron Drill-In Fluid Technique Reduces Formation Damage in Horizontal Wells”, SPE Paper No. 39589, presented at the 1998 SPE Formation Damage Control Symposium, Lafayette, Louisiana, Feb 18-19.

	Gel-chemical	**Polymer**	**MicronAire (medium weight)**	**MicronAire (low weight)**
Density (ppg)	**8.93**	**8.60**	**7.85**	**7.22**
Plastic Viscosity (cps)	**25**	**22**	**27**	**27**
Yield Point (cps)	**13**	**20**	**24**	**34**
10 sec. gel (cps)	**6**	**9**	**9**	**17**
10 min. gel (cps)	**24**	**16**	**24**	**26**
n’*	**0.83**	**0.72**	**0.73**	**0.70**
K’* lb-sec/100 ft^2	**0.92**	**1.95**	**2.21**	**2.79**
Brookfield cps @ 0.3 rpm (spindle)	**12,000**	**45,000**	**109,000**	**142,000**

*** - Herschel-Bulkley model**

Table 1: The Rheology of MicronAire^{TM} “Air-Bridging” Particles – Typical Properties

			1 MONTH PRODUCTION*		2 MONTH PRODUCTION*		3 MONTH PRODUCTION*	
WELL ID	**MUD TYPE**	**MUD COST $**	**gas**	**water**	**gas**	**water**	**gas**	**water**
07-06	MicronAire^{TM}	1639	9130	5.0	7220	0	6580	0
13-22	MicronAire^{TM}	4355	6970	28.3	2020	3.8	3750	4.4
01-14	MicronAire^{TM}	6853	not a commmercially viable production zone					
09-17	Water	530	25490	1.3	27010	0.6	30090	4.4
06-17	Water	610	3860	15.1	2370	2.5	1840	5.7
07-30	Gel Chem	1749	180	0	240	169	190	193
09-10	Gel Chem	2711	2740	8.8	2780	7.6	2360	12.0

*** Production is cumulative values from first onset of production. No oil is produced. Gas in cu.ft, water in bbl.**

Table 2: Thunder Energy Drilling and Production Results – MicronAire vs. Water or Gel-Chemical Muds in a Tight Belly River Gas Sandstone

		HEAVY OIL PRODUCTION (bbl/month)*			
WELL ID	**MUD TYPE**	**Month 1**	**Month 2**	**Month 3**	**Month 4**
14-07	MicronAire^{TM}	3720	4360	7670	6660
07-05	MicronAire^{TM}	2190	4240	6210	7300
08-05	MicronAire^{TM}	3940	5360	6570	8660
5A-09	MicronAire^{TM}	4270	5730	7180	7710
6A-04	MicronAire^{TM}	380	1450	1450	1520
06-08	MicronAire^{TM}	1610	590	830	900
13-07	MicronAire^{TM}	2890	4900	6680	8400
	AVERAGE	2714	3804	5227	5879
03-08	Gel Chem	820	860	1600	1180
14-05	Gel Chem	4410	7150	4210	4550
15-05	Gel Chem	820	1350	160	2000
16-05	Gel Chem	850	3000	5180	6090
02-04	Gel Chem	1120	680	730	790
06-27	Gel Chem	630	1110	2020	2340
10-05	Gel Chem	1750	3040	3950	4870
11-05	Gel Chem	730	3160	5080	5880
	AVERAGE	1391	2544	2866	3463

Table 3: Wascana Energy Oil Production Results in Luseland Field (36-25 W3) – MicronAire vs. Gel-Chemical Muds in an Unconsolidated Heavy Oil Sand

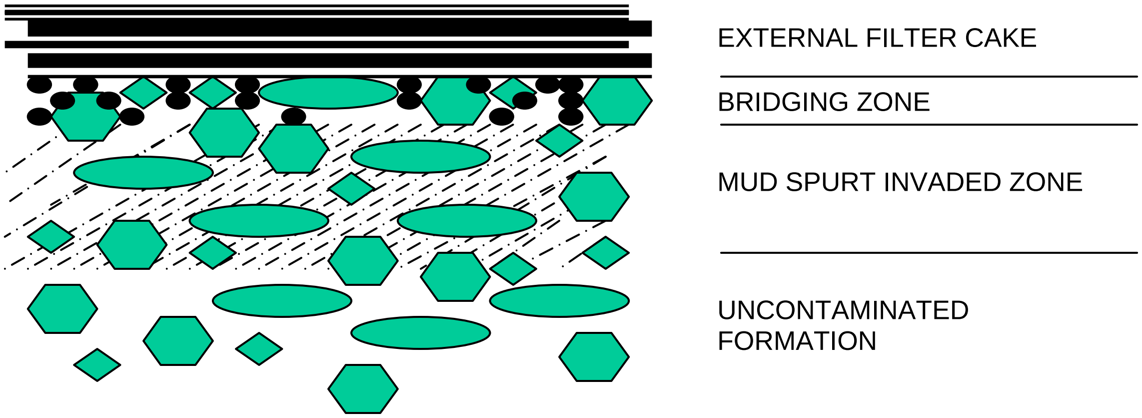


Figure. 1 - Typical Bridging Mechanism at Wellbore Wall.

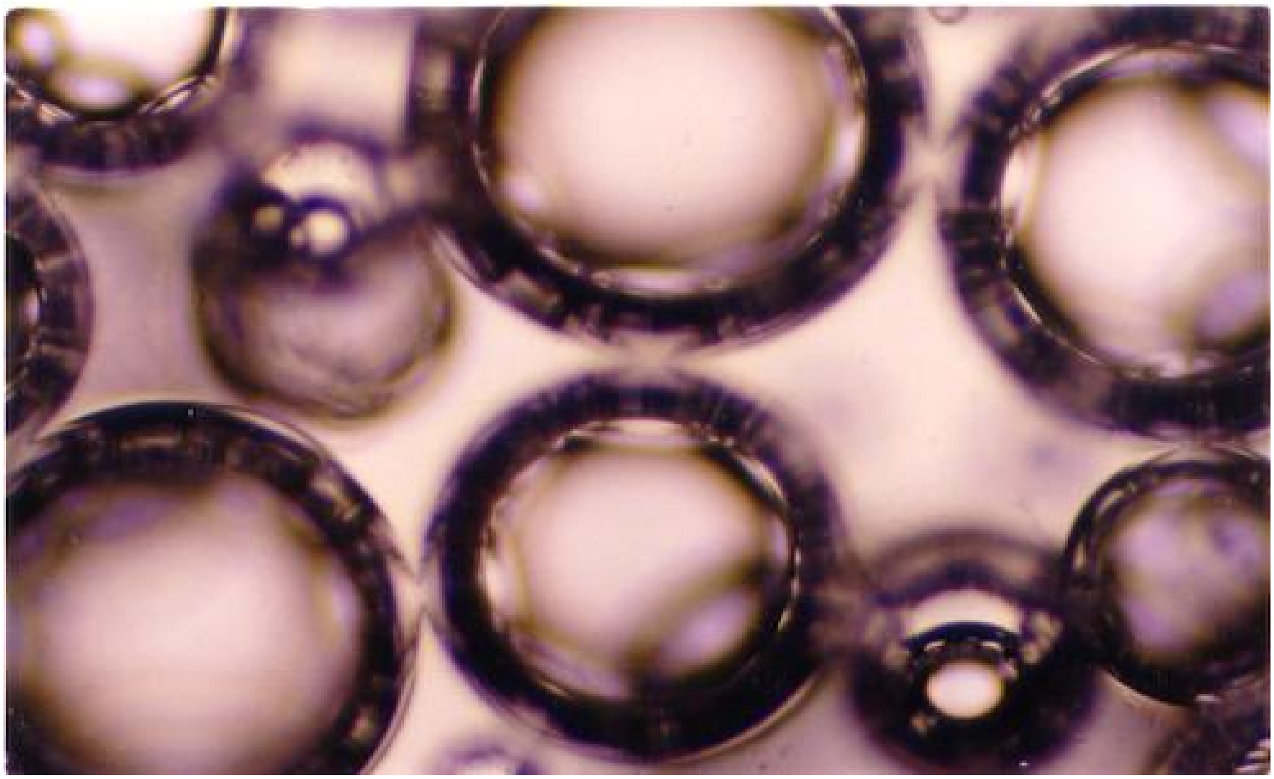


Figure. 2 - Air Bubbles with Outer Wall Shell

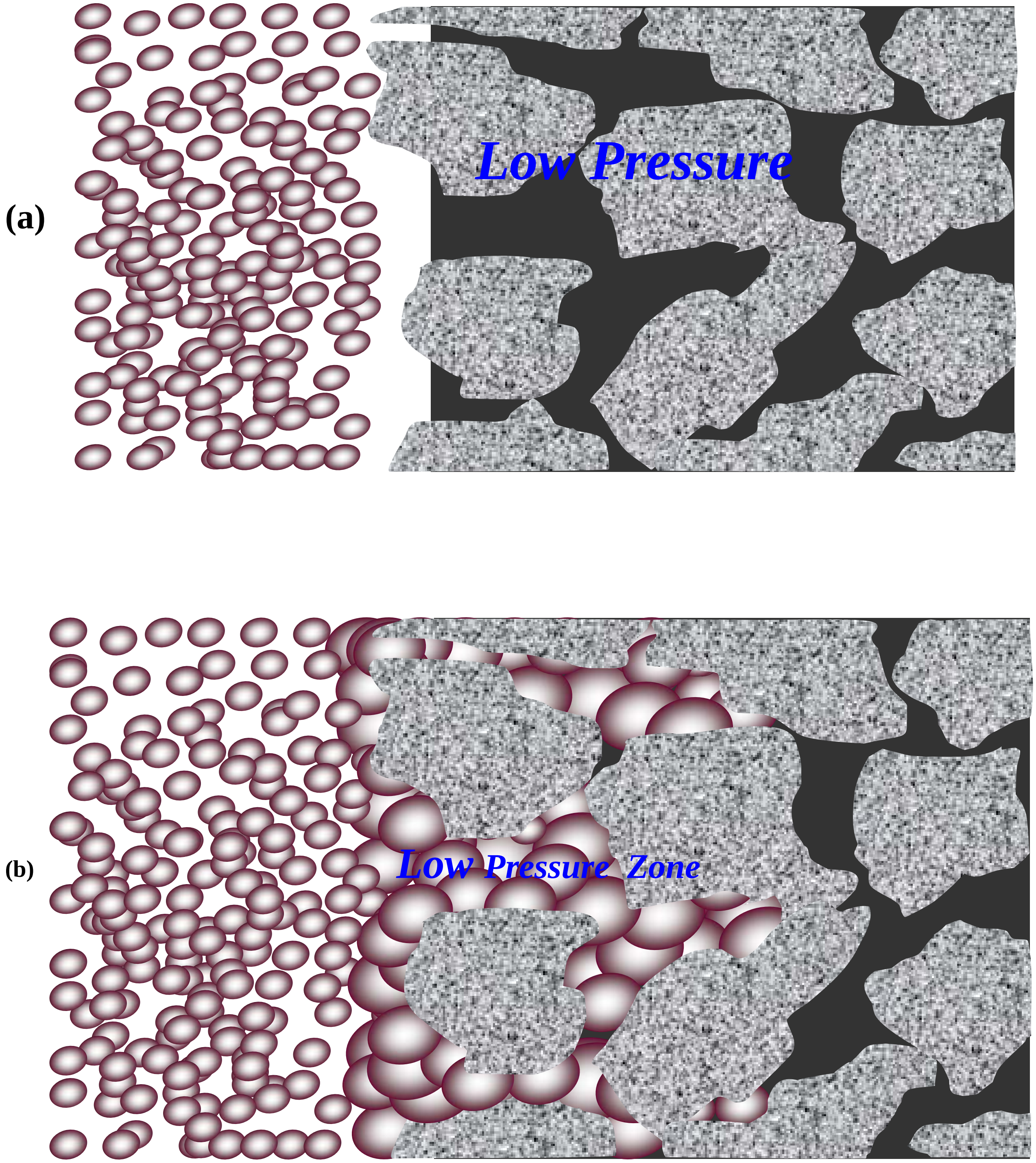


Figure. 3 - Conception of air bridging mechanism. (a) air particles in annular space, (b) bridge formed internally in pore spaces

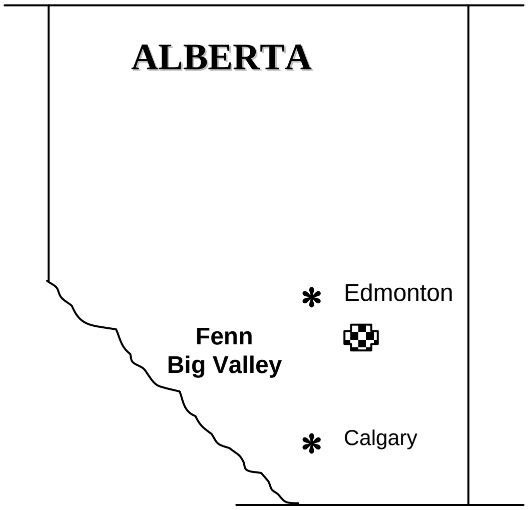
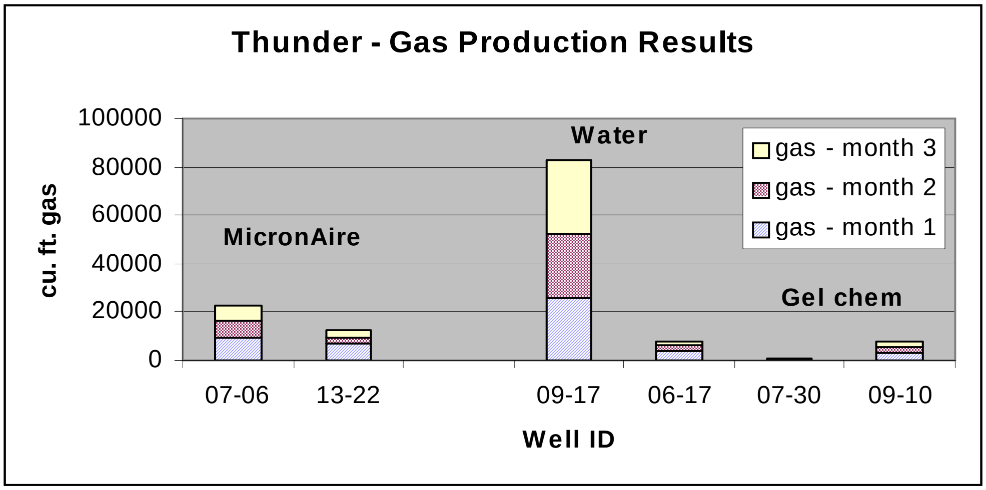
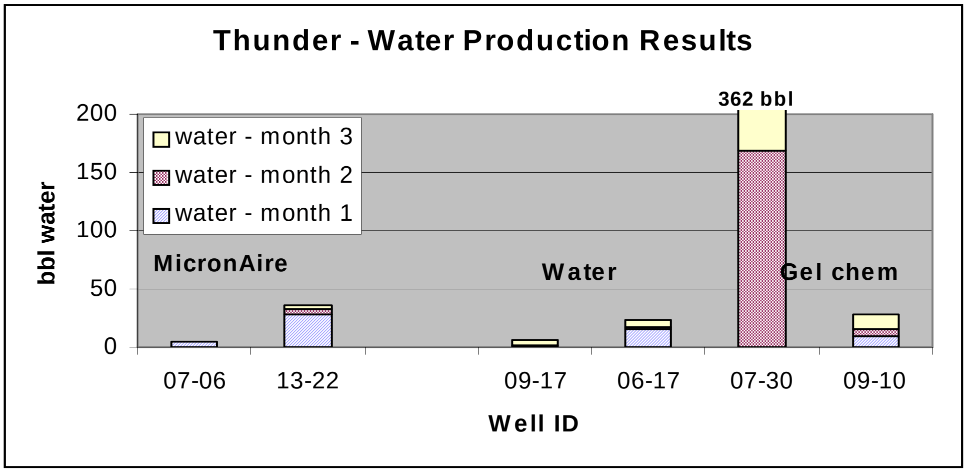


Figure 4 - Thunder Energy Fenn – Big Valley Location (~ 100 miles southeast of Edmonton, Alberta)



(a)



(b)

Figure 5 - Thunder Energy Fenn - Big Valley (a) Gas Production and (b) Water Production for MicronAire^{TM} and Offset Wells.

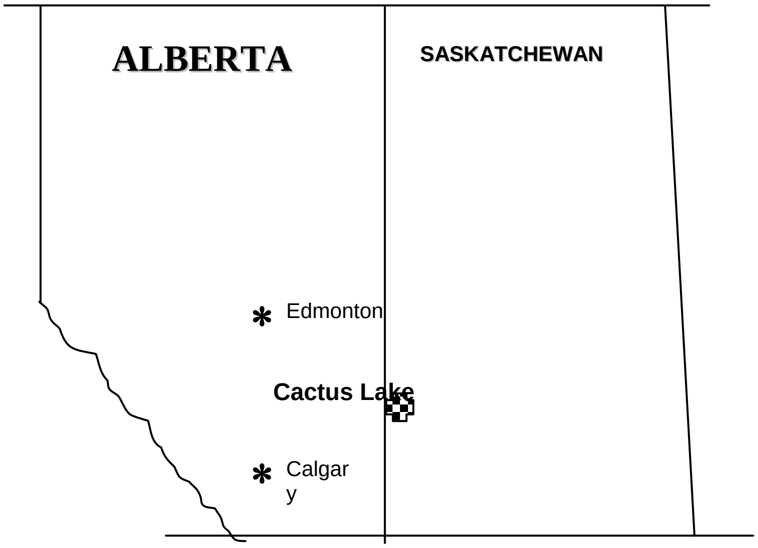


Figure 6 - Wascana Energy Cactus Lake Location (~ 160 miles East of Calgary, Alberta)

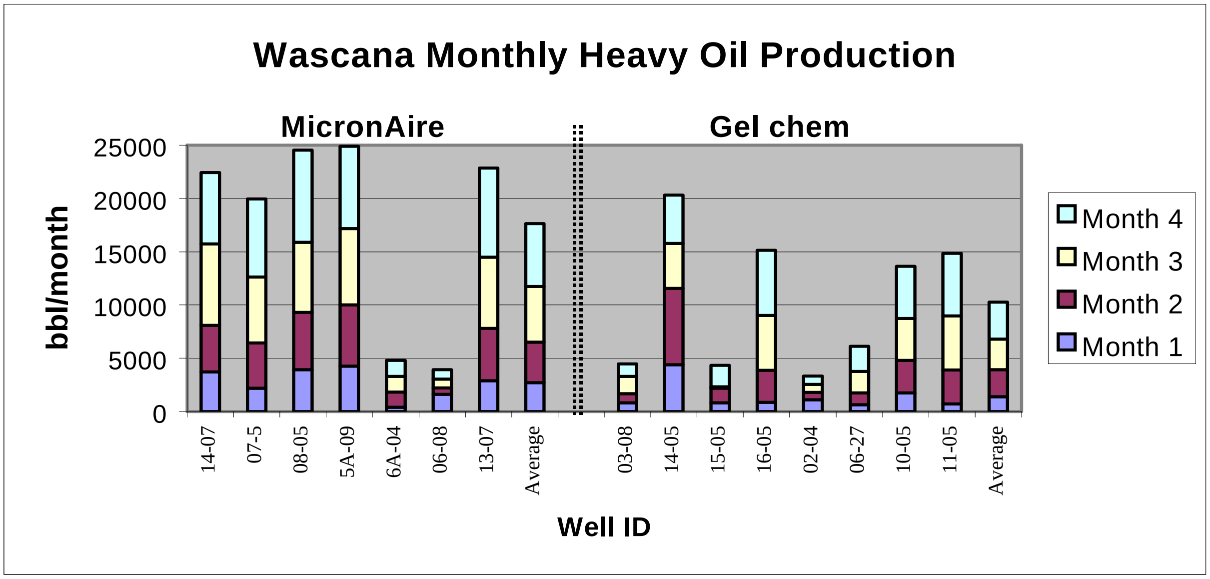


Figure 7 - Wascana Energy Cactus Lake Oil Production for MicronAire^{TM} and Offset Wells