STUDY ON THE CEMENT IN THE PROCESS OF CEMENTING FOR OIL WELL

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Abstract: *cement is the main material used cementing oil wells, which directly affects of cementation or cementing, in the last years has occurred many problems in a number of oil wells. As studies of the Montara well blowout 2009 and gulf of México 2010 showed that one of the main contributing factors to the failure was the substandard cementing cement. Design was reported to be the third most concerning technology gap for the cementing operations. Also a similar survey of the HPHT professionals that had been conducted two years earlier in the 2010 HPHT. Wells Summit reported that the cement Design as the biggest technology gaps for cementing oil wells operation, so this paper covers the functions of oil well cement, the API classification and properties of dry cement also provides a review of some of the best practices and case studies in the area of HPHT cementing. It also examines some crucial problems in HPHT cementing and provides some Recommendations.*
Keywords: *cement, cementation, Well High Pressure high, Temperature (HPHT) API.*

ИССЛЕДОВАНИЕ ЦЕМЕНТА В ПРОЦЕССЕ ЦЕМЕНТИРОВАНИЯ НЕФТЯНЫХ СКВАЖИН

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Аннотация: *цемент является основным используемым материалом для цементирования нефтяных скважин. Соответственно от качества цемента напрямую зависит и качество создаваемых цементных конструкций. Исследования, проведенные в результате прорыва скважины в Монтара (в 2009 г.) и в заливе Мехико (в 2010 г.), показали, что одним из основных факторов, которые привели к разрушению, был некачественный цемент. Согласно результатам опроса специалистов HPHT, который был проведен в 2010 году, третий по значимости фактор, приводящий к разрывам цементных конструкций, - это ошибки при проектировании цементной конструкции и нарушение технологического процесса. В данной статье исследованы функции цемента для нефтяных скважин, рассмотрены важнейшие проблемы цементирования HPHT, изучена классификация API и свойств сухого цемента, а также приведен обзор лучших практик и тематических исследований в области цементирования HPHT.*
Ключевые слова: *цемент, цементирование, температура.*

Introduction: Cementing is the process of mixing and pumping cement slurry down to fill the annular space behind the pipe. When setting, the cement will establish a bond between the pipe and the formation. Unlike oil and gas wells, the casings in geothermal wells are usually fully cemented back to the surface. Portland cement is the most type used cement. The American petroleum institute (API) classifies cement to 8 types according properties. Cementing mixtures is made by cement with water and additives. The additives are mixed with cement slurry to alter the properties of both the slurry and the hardened cement [1]. The success and long life of well cementation requires the utilization of high-grade steel casing strings with special threaded couplings and temperature-stabilized cementing compositions. Hydraulic sealing must be established the cement and the casing and between the cement and the formation This requirement makes the primary cementing operation important for the performance of the well Geothermal wells are drilled in areas with hot water or steam and because of the hostile condition special planning is necessary to ensure the integrity of the well. When primary cementing is not well executed due to poor planning [1].

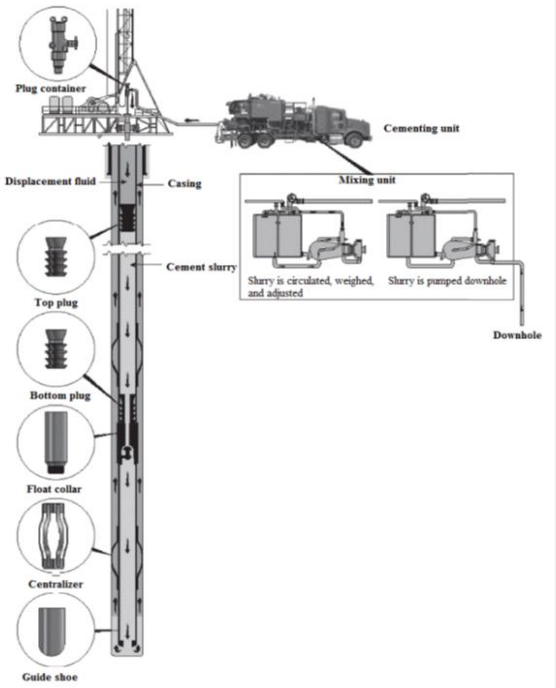

Fig. 1. Typical cementing process (API, 2009) [2]

In general, there are five steps in designing a successful cement placement:

a) Analyzing the well conditions: reviewing objectives for the well before designing placement techniques and cement slurry to meet the needs for the life of the well;

b) Determining slurry composition and laboratory tests;

c) Determining slurry volume to be pumped, using the necessary equipment to blend, mix and pump slurry into the annulus, establishing backup and contingency procedures;

d) Monitoring the cement placement in real time: comparisons made with the first step and change simpleminded where necessary;

e) Post-job evaluation of result Cementing operation is [2] continuous process as shown in Figure 1 (API 2009).

The importance of cementing

The most important functions of a cement sheath between the casing and the formation are (Rabia, 1985):

a) to prevent the movement of liquid from one formation to another or from the

formations to the surface through the annulus

b) To holding the casing string in the well

c) To support the well-bore walls (in conjunction with the casing) to prevent collapse of formations

d) To prevent blowouts by forming a seal in the annulus

Cementing is also used to condition the well

a) To seal loss of circulation zones;

b) To stabilize weak zones (washouts, collapses);

c) To plug a well for abandonment or for repair;

d) To kick-off side tracking in an open hole or past a junk;

e) To plug a well temporarily before being re-cased

Cement. Its widely used plugging material is formulated as slurry of water and cement that is compositionally managed in terms of gallons (gal) of water or pounds (lb) of additives per 94-lb sack (sk) of cement. Cement used in plugging has improved significantly over the past few decades. The cement composition in the early days of the oil industry is similar to what is used today, but today's cement uses a number of additives that enhance the sealing of the cement in the wellbore (Ide et al., 2006). With the advances in well drilling technology and the types of wells being drilled and completed, the cementing technology has improved to allow for cementing of horizontal wells, high-pressure wells, high temperature wells, low-temperature wells, C_O2 wells, and other specialty applications [3]. There are many cement classes approved by the API. The differences between cements lie in distribution of the five basic compounds as table 1.

Cement type for high temperature or high pressure well. For the last 50 years, the most commonly used cements for thermal wells have been Portland cement, Silica-Lime system, and High-Alumina cement. Table 1 presents Cement class standard specification; some information were taken from Nelson 2006.

Classes A and B: These cements are generally cheaper than other classes of cement and can only be used at shallow depths where there are no special requirements

Class C: This cement has a high c3s content and so produces a high early strength

Table 1. Cement class standard specification

<table>
<tr><th>Class</th><th>Depth (ft.)</th><th>Temperature (°F)</th><th>Purpose</th><th>Properties</th></tr>
<tr><td>A</td><td>0 – 6,000</td><td>80 - 170</td><td>Use when special properties are not required.</td><td>O</td></tr>
<tr><td>B</td><td>0 – 6,000</td><td>80 - 170</td><td>Moderate or high sulfate resistance.</td><td>MSR and HSR</td></tr>
<tr><td>C</td><td>0 – 6,000</td><td>80 - 170</td><td>High early strength.</td><td>O, MSR, HSR</td></tr>
<tr><td>D</td><td>6,000 – 10,000</td><td>170 – 290</td><td>Retarder for use in deeper well (High temperatures & high pressure).</td><td rowspan="5">MSR and HSR</td></tr>
<tr><td>E</td><td>10,000 – 14,000</td><td>170 – 290</td><td>For high pressure and temperature</td></tr>
<tr><td>F</td><td>10,000 – 14,000</td><td>230 – 320</td><td>For extremely high pressure and high Temperature.</td></tr>
<tr><td>G</td><td>All depths</td><td></td><td rowspan="2">Basic well cement (improved slurry acceleration and retardation).</td></tr>
<tr><td>H</td><td>All depths</td><td></td></tr>
<tr><td>J</td><td>All depths</td><td>>230</td><td>For extremely high pressure and high temperature.</td><td>HSR</td></tr>
</table>

O: Ordinary, M: Medium, H: High, O: Ordinary, S: Sulfate, R: Resistance, E: Early, TT: Thickening time

Classes D, E and F: These are known as retarded cements due to a coarser grind, or the inclusion of organic retarders (lignosulphonates). Their increased cost must be justified by their ability to work satisfactorily in deep wells at higher temperatures and pressures

Class G and H: These are general-purpose cements, which are compatible with most additives and can be used over a wide range of temperature and pressure. Class G is the most common type of cement used in most areas.

Class H has coarser grind than Class G and gives better retarding properties in deeper wells [6]. Other types of cement not covered by the API specification include:

- Pozmix cement. This is formed by mixing Portland cement with pozzolan (ground volcanic ash) and 2% bentonite. This is a very durable cement. Pozmix cement is less expensive than most other types of cement;
- Gypsum cement. This is formed by mixing Portland cement with gypsum. These cements have a high early strength and can be used for remedial work. They expand on setting and deteriorate in the presence of water;
- Diesel oil cement. This is a mixture of one of the basic cement classes (A, B, G, H) with diesel oil or kerosene with a surfactant. These cements have unlimited setting times and will only set in the presence of water. Consequently, they are often used to seal off water producing zones where they absorb and set to form a dense, hard cement [4, 5].

Portland cement chemistry:

Portland cement is a calcium silicate material; most of its components are tricalcium silicate (C_3S) and dicalcium silicate (C_2S). With the addition of water, tricalcium and dicalcium silicate hydrate to form a gelatinous calcium silicate hydrate called “CSH phase” which is an early hydration product and excellent binding material at well temperatures less than 230°F (110°C). In high temperature, “CHS phase” decreases the compressive strength and increases the permeability of the set cement. Swayze (1954) describes this phenomenon as Strength Retrogression. At temperatures above 230°F, conventional Portland cement system results in a significant loss of compressive strength within one month. The main problem is a serious permeability increase; within one month, the water permeability's of the normal density class G cement were 10-100 times higher than the recommended limit (0.1 mD). High-density Class H permeability was barely acceptable. The Compressive strength and permeability behavior of Portland cement at an elevated temperature are presented in Figure.

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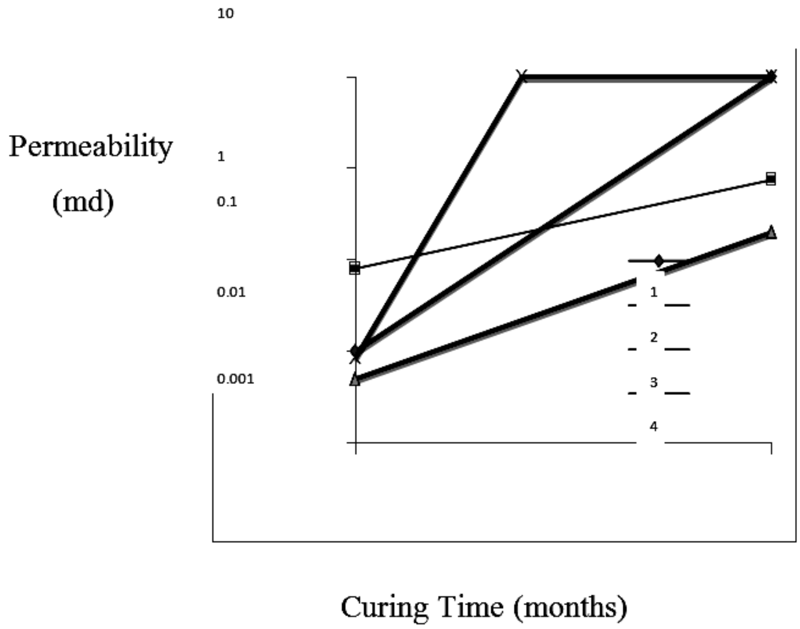

Fig. 2. Ppermeability behavior of Portland cement at elevated temperature (Nelson and Eliers, 1985)

1 = N density Class G
2 = N density Class G
3 =H density Class H
4 = L density extended cement

Strength retrogression can be prevented by reducing the bulk lime with a silica ratio (Menzel, 1935) cement could be replaced partially by fine silica sand or silica flour. At 230°F, we must put average 40% silica BWOC will reduce cement silica ratio and at this level, to berm rite, which preserves high compressive strength and low permeability is formed[6].

High Alumina Cement

It is used because it can withstand wide ranging temperature fluctuations. Figure 3shows the effect of curing temperature high alumina cement extended to 70% crushed firebrick (Heindl and Post, 1954). From 1,022°F to1, 742°F, recrystallization occurs. The strength and durability of high alumina cement between 440°F to1830°F are controlled by the initial water to cement ratio. The amount of added water to prepare slurry should be minimum; at least 50% of the solids should be cement. Dispersant is helpful for pump ability of the slurry.

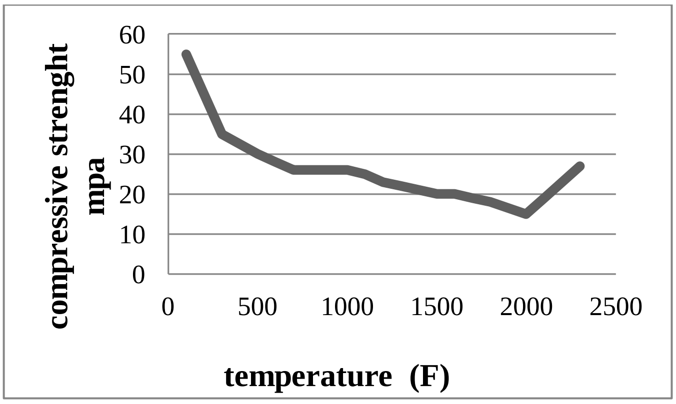

Fig. 3. Compressive Strength of High Alumina Cement crushed firebrick concrete after 4 months exposure from 68°F to 2,190°F (Heindl and Post, 1954)

Silica sand should not be used for temperatures exceeding 572°F because of the change in the crystalline structure; thermal expansion is relatively eventually disrupt the cement. The most commonly high at these temperatures and thermal cycling could used extender for high alumina cement is crushed alum inosilicate firebrick. Other suitable materials include calcined bauxite, certain fly ashes diatomaceous earth, and perlite aluminate phase. Since it is not widely used, currently class J cement is not in the API cement list, however, it’s still used mainly for geothermal well applications. Similar cement known as belite silica cement has been used in high temperature wells cementing (Bulatov, 1985). It’s very useful because addition of silica is not required and retarder is not necessary for circulating temperatures less than 300°F. Cement silica ratio of class J cement is adjusted and obtained upon curing [7, 8, 9].

Properties of Cement

The main properties required of cement slurry are summarized below

Compressive Strength

To support the casing string a compressive strength of 500 psi is generally thought to be adequate. This includes a generous factor of safety. The casing shoe should not be drilled out until this strength has been attained. This is referred to as 'waiting on cement' (WOC). The development of compressive strength is a function of several variables including temperature, pressure, amount of mixwater added and elapsed time since mixing. With proper accelerators added the WOC time may be reduced to 3-6 hours.

Table 2. Compressive Strength of Cement [6]

Temperature(F)	Pressure(PSI)	Typical compressive strength (psi) at 24 hours				
		Class A & B Portland	High early strength class C	API class G	API class H	Retarded class D,E,F
60	0	615	780	440	325	-
80	0	1470	1870	1185	1065	-
95	800	2085	2015	2540	2110	-
110	1600	2925	2705	2915	2525	-
140	3000	5050	3650	4200	3160	3045
170	3000	5925	3710	4830	4480	4150
200	3000	-	-	5110	4570	4775

Thickening Time (pumpability)

This is the time during which the cement slurry can be pumped and displaced into the annulus (i.e., the slurry is pumpable during this time). The slurry should have sufficient thickening time to allow for mixing, pumping and displacement before the cement sets and hardens in the annulus. Generally 2-3 hours thickening time is enough, including a safety factor to allow for delays and interruptions in the cementing operation [10].

Table 3. Cement Thickening Times [6]

Depth (ft)	Static Temp F	HIGH PRESSURE THICKENING TIME (hr)				
		Class A & B Portland	High early strength class C	API class G	API class H	Retarded class D,E,F
2000	110	4	3	3	3.9	-
4000	140	3.5	2.5	2.5	3.25	4
6000	170	2.5	2	2.1	2	4
8000	200	1.6	1.75	1.75	1.65	4

Slurry Density

The standard slurry densities, may have to be altered to meet requirements (e.g., a low strength formation may not be able to support the hydrostatic pressure of a cement whose density is around 15 pp). The density can be altered by changing the amount of mixwater or by using certain additives. Most slurry densities vary between 11-18.5 pp.

Water Loss

The setting process is the result of a dehydration reaction. If water is lost from the cement slurry before it reaches its intended position its pumpability will decrease and water sensitive formations may be adversely affected. The amount of water loss that can be tolerated depends on the type of cement job, for example:

- Squeeze cementing requires a low water loss since the cement must be squeezed before the filter cake builds up and blocks the perforations;
- Primary cementing is not so critically dependent on fluid loss. The amount of fluid loss from a particular slurry should be determined from a pilot test. Under standard laboratory conditions (1000 psi filter pressure, with 325 mesh) a slurry for a squeeze job should give a fluid loss of 50-200 cc. For a primary cement job 250-400 cc is adequate.

Corrosion Resistance

Formation water contains certain corrosive elements, which may cause deterioration of the cement. Two commonly found compounds are sodium sulphate and magnesium sulphate. These will react with lime and c3s to form large crystals of calcium sulphoaluminate. These crystals expand and cause cracks to develop in the cement structure. Lowering the C3A content of the cement increases the sulphate resistance. For high sulphate resistant cement the c3A content should be 0-3% [11, 12].

Recommendations for a Good Cementing

Most of the failure in cementation oil wells caused by cement to this should improve the performance of the mix either by adding improved chemicals or study the production of cement with high specifications Based on the survey in HPHT Summit, cement design is one of the HPHT technology gaps that should be given high attention. In the design phase, increase of temperature will decrease plastic viscosity and yield viscosity To overcome the strength retrogression problem, when the static temperature exceeds 230°F silica by weight of cement should be added to Portland cement. For temperatures exceeding 750°F, HAC is more suitable than Portland cement. Silica in HAC should not be used as an extender for temperatures exceeding 570°F mixing of silica sand, silica flour, hematite manganese tetroxide with expansion additives showed the good performance.

References in English / Список литературы на английском языке

1. *Evans K.B.* Geothermal Resource Development P.O. Box 785. Naivasha, KENYA, 2011. P. 7.
2. *Bourgoyne A.T., Millheim K.K., Chenevert M.E., Young F.S.* Applied drilling engineering (2-nd printing). Society of Petroleum Engineers. Richardson. Texas, 1991. P. 508.
3. Hydraulic fracturing operations. Well construction and integrity guidelines (1-st edition). [Electronic resource]: API Publishing Services, Washington, 2009. P.32 URL: http://www.energyindepth.org/wp-content/uploads/2009/03/API-HF.pdf./ (date of access: 01.05.2017).
4. *Prisca S., Amani M.* International Journal of Engineering and Applied Sciences. [Electronic resource]: EAAS & ARF. Texas A&M University, Qatar, 2012. P. 24. URL: www.eaas journal.org./ (date of access 11.04.2017)
5. Paper № 2-25 Plugging and abandonment of oil and gas wells. [Electronic resource]: Prepared by the Technology Subgroup of the Operations & Environment Task Group. URL: www.npc.org./ (date of access: 10.04.2017)
6. *Khafaji A., Al-Humaidi A.A.* New Cement Developed for High-Temperature Sidetrack// SPE 2006: Annual Technical Conference and Exhibition held (San Antonio, Texas, U.S.A, 24-27 September 2006). SPE, № 102596, 2006.
7. *Al-Yami A.S., Nasr-El-Din H.A., Al-Humaidi A.* An Innovative Cement Formula to Prevent Gas Migration Problems in HP//HT Wells. SPE 2009: International Symposium on Oilfield Chemistry held (Woodlands, Texas, 8 October 2009). SPE. № 120885. 2009.
8. *Al-Yami A.S., Nasr-El-Din, Jennings, Khafaji A., Al-Humaidi A.* New Cement System Developed for Sidetrack Drilling//SPE 2008: Oil and Gas Technical Conference and Exhibition held (Indian, Mumbai, 4-6 March 2008). SPE, № 113092. 2008.
9. *Amani M., Al-Jubouri M., Shadravan A.* Comparative Study of Using Oil-Based Mud versus Water-Based Mud in HPHT Fields//Advances in Petroleum Exploration and Development, DOI:10.3968/j.aped.1925543820120402.98,2012. Vol. 4. № 2. P. 18-27.
10. Special considerations in cementing high-pressure high temperature well [Electronic resource]: International Journal of Engineering and Applied Sciences, 2013. Vol. 1, № 4. P. 120-146. URL: http://www.slb.com/~/media/Files/cementing/product _sheets/cemstress.pdf./ (date of access: 26.12.2012).
11. Pennsylvania’s Plan for Addressing Problem Abandoned Wells and Orphaned Wells. DEP Document № 550-0800-001. [Electronic resource]: Pennsylvania Department of Environmental Protection. Bureau of Oil and Gas Management, April 2010. P. 4. URL: http://www.elibrary.dep.state.pa.us/dsweb/Get/Version-48262/550-0800-001.pdf./ (date of access: 04.04.2012).
12. Primary and remedial cementing guidelines. Drilling and Completion Committee. Alberta. Canada, 1995. P. 17.

References / Список литературы

1. *Эванс К.В.* Развитие геотермальных ресурсов. P.O. Box 785. Найваша, Кения, 2011. Стр. 7.
2. *Борджоне А.Т., Миллхейм К.К., Ченеверт М.Е., Юнг Ф.С.* Прикладная техника бурения (2-е издание). Общество инженеров-нефтяников. Ричардсон. Техас, 1991. Стр. 508.
3. Операции по гидравлическому разрыву. Рекомендации по строительству и целостности скважин (1-е издание). [Электронный ресурс]: Издательство API. Вашингтон, 2009. Стр. 32. Режим доступа: http://www.energyindepth.org/wp-content/uploads/2009/03/API-HF.pdf./ (дата обращения 01.05.2017).

4. *Приска С., Амани М.* Международный журнал инженерных и прикладных наук. [Электронный ресурс]. EAAS & ARF. Техасский университет A & M. Катар, 2012. Стр. 24. Режим доступа: www.eaas journal.org./ (дата обращения 11.04.2017).
5. Документ № 2-25 Закрепление и ликвидация нефтяных и газовых скважин. [Электронный ресурс]: Prepared by the Technology Subgroup of the Operations & Environment Task Group. Режим доступа: www.npc.org./ (дата обращения 10.04.2017).
6. *Кафаджи А., Ал-Хумайди А.А.* New Cement Developed for High-Temperature Sidetrack// SPE 2006: ежегодная техническая конференция и выставка (Сан-Антонио, Техас, США, 24-27 сентября 2006). SPE. № 102596, 2006.
7. *Аль-Ями А.С., Наср-Эль-Дин Х.А., Аль-Умаиди А.* An Innovative Cement Formula to Prevent Gas Migration Problems in HP // HT. SPE 2009: международный симпозиум по химии нефтяных месторождений (Вудлендс, Техас, 8 октября 2009). SPE. № 120885, 2009.
8. *Аль-Ями А.С., Наср-Эль-Дин, Дженнингс, Хафаджи А., Аль-Хумаиди А.* New Cement System Developed for Sidetrack Drilling // SPE 2008: Нефтегазовая техническая конференция и выставка (Индия, Мумбаи, 4-6 Марта 2008 года). SPE. № 113092, 2008.
9. *Амани М., Аль-Джубури М., Шадраван А.* Comparative Study of Using Oil-Based Mud versus Water-Based Mud in HPHT Fields Advances in Petroleum Exploration and Development. DOI:10.3968/j.aped.1925543820120402.98 7, 2012. Том 4. № 2. С. 18-27.
10. Special considerations in cementing high-pressure high temperature well. [Электронный ресурс]: International Journal of Engineering and Applied Sciences, 2013. Том № 1. № 4. С. 120-146. Режим доступа: http://www.slb.com/~/media/Files/cementing/product_sheets/cemstress.pdf./ (дата обращения 26.12.2012 г.).
11. План Пенсильвании для решения проблемы заброшенных скважин и сиротских скважин. Документ DEP № 550-0800-001. [Электронный ресурс]: Департамент охраны окружающей среды штата Пенсильвания. Бюро по управлению нефтью и газом, Апрель 2010. С. 4. Режим доступа: http://www.elibrary.dep.state.pa.us/dsweb/Get/Version-48262/550-0800-001.pdf./ (дата обращения 04.04.2017).
12. Основные принципы и рекомендации по цементированию. Комитет по бурению скважин. Альберта. Канада, 1995. Стр. 17.