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Cementing Solutions
Plug and Abandonment (P&A) Project

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Abstract

The Rocky Mountain Oilfield Testing Center (RMOTC) has recently completed a plug and abandonment (P&A) test of three (3) wellbores with Cementing Solutions of Houston, Texas. The Plug and Abandonment (P&A) test utilized two (2) generations of equipment on two (2) separate occasions. The primary intent was to reduce P&A costs on shallow to medium depth wells for the independent operator.

Introduction

The Rocky Mountain Oilfield Testing Center (RMOTC) has completed a Plug and Abandonment (P&A) Program at the Naval Petroleum Reserve No. 3. The Naval Petroleum Reserve No. 3 (NPR-3), also known as Teapot Dome Oil Field, is located thirty-five (35) miles north of Casper, Wyoming (See Figure 1). The initial selection was for a five (5) well program. The first well experienced mechanical problems upon the initial attempt of plugging and was deemed unsuitable for testing. The fifth well based on experience gained from the initial plugging operations was also deemed unsuitable for testing based on it's larger casing size and openhole interval.

Background

The development of the Teapot Dome Oil Field began in the 1920's with several of the earliest wells drilled. After the ARAB Oil Embargo of 1973, NPR-3 was opened up for full development beginning in 1976. To date over one-thousand (1000) wells have been drilled over the ten-thousand (10,000) acre field. Many of the wells drilled in the late 1970's and early 1980's have become uneconomic requiring the wellbores to be plugged and abandoned (P&A). The Department of Energy, as owner and operator of the field, has had an active P&A Program during the life of the field. The wells selected for testing were initially planned to be P&A during the course of the year.

Selection of Wellbores

The wellbores selected from the P&A Program were identified based on the needs of the testing partner; Cementing Solutions, depth of the wells, and casing sizes. A mix of casing sizes from 4-1/2” casing to 8-5/8” were identified. Appendix B details the selected wellbores and pertinent information.

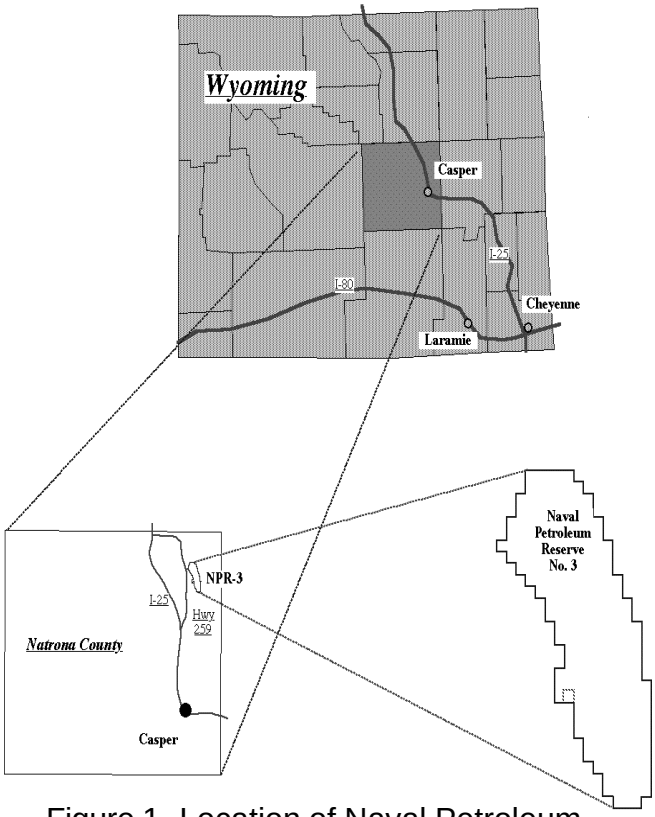


Figure 1. Location of Naval Petroleum Reserve No. 3.

The wells selected for testing were 27-S-3, 23-S-35, 23-S-2, 18-SX-11, and 77-SX-11. Two (2) of the five (5) wells selected, 77-SX-11 and 18-Sx-11, were later found to be unsuitable.

Well 27-S-3

Well 27-S-3 was drilled in late 1978 after the reserve was opened for full development. The well was completed in the Shannon formation which is the shallowest producing horizon at Teapot Dome. The well was produced from early 1979 to early 1993. Cumulative oil production was 7,644 barrels of oil and 52,216 barrels of water. Early production rates were only about three (3) barrels of oil per day (BOPD). The production rate at shut-in was less than two-tenths (0.2) BOPD. The well was uneconomic at this point. See Figure 2.

The well had 4-1/2” 10.5 lbs/ft casing set at 549 feet below ground level. The conductor pipe was 8-5/8” 24 lbs/ft set at 40 feet. The well had been perforated from 403 – 447 feet and from 483 – 509 feet.

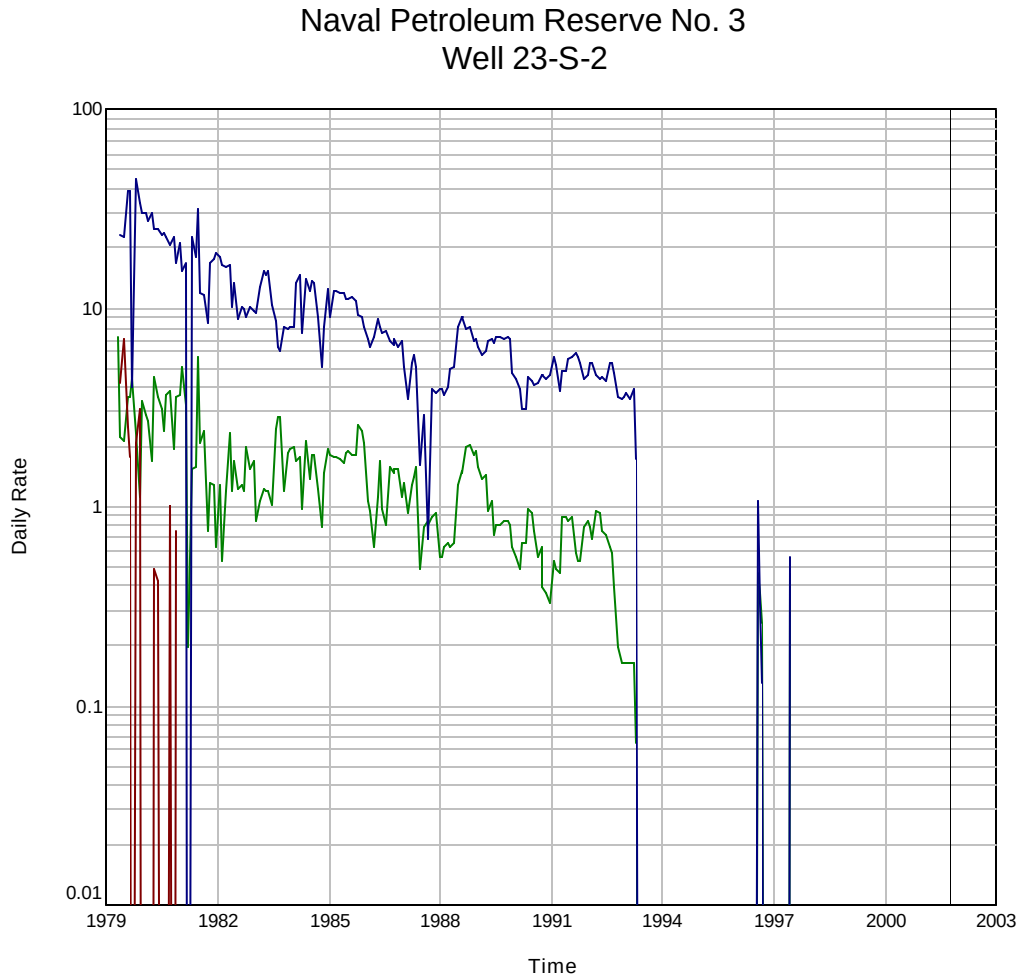


Figure 2. Production history for well 23-S-2.

Well 23-S-2

Well 23-S-2 was drilled in July 1962. There was an early Shannon drilling program in the late 1950's and early 1960's to protect the Naval Petroleum Reserve from drainage by an offset operator on the east side. The well was completed in the Shannon formation. The well was produced from late 1962 to mid 1966. After this time period, production was very intermittent till mid-1976 when the reserve was opened up for full development. Cumulative oil production was 31,875 barrels of oil and 4,380 barrels of water. The early 1960's production rates were over 50 barrels of oil per day (BOPD). The production rate at shut-in was less than one-tenth (0.1) BOPD making the well uneconomic. See Figure 3.

The well had 4-1/2" 9.5 lbs/ft casing set at 670 feet below ground level. The conductor pipe was 8-5/8" set at 12 feet. The well had been perforated from 542 – 560 feet and from 625 – 636 feet. The perforating system was with 1/2" bullets common to that era.

Naval Petroleum Reserve No. 3
Well 23-S-35

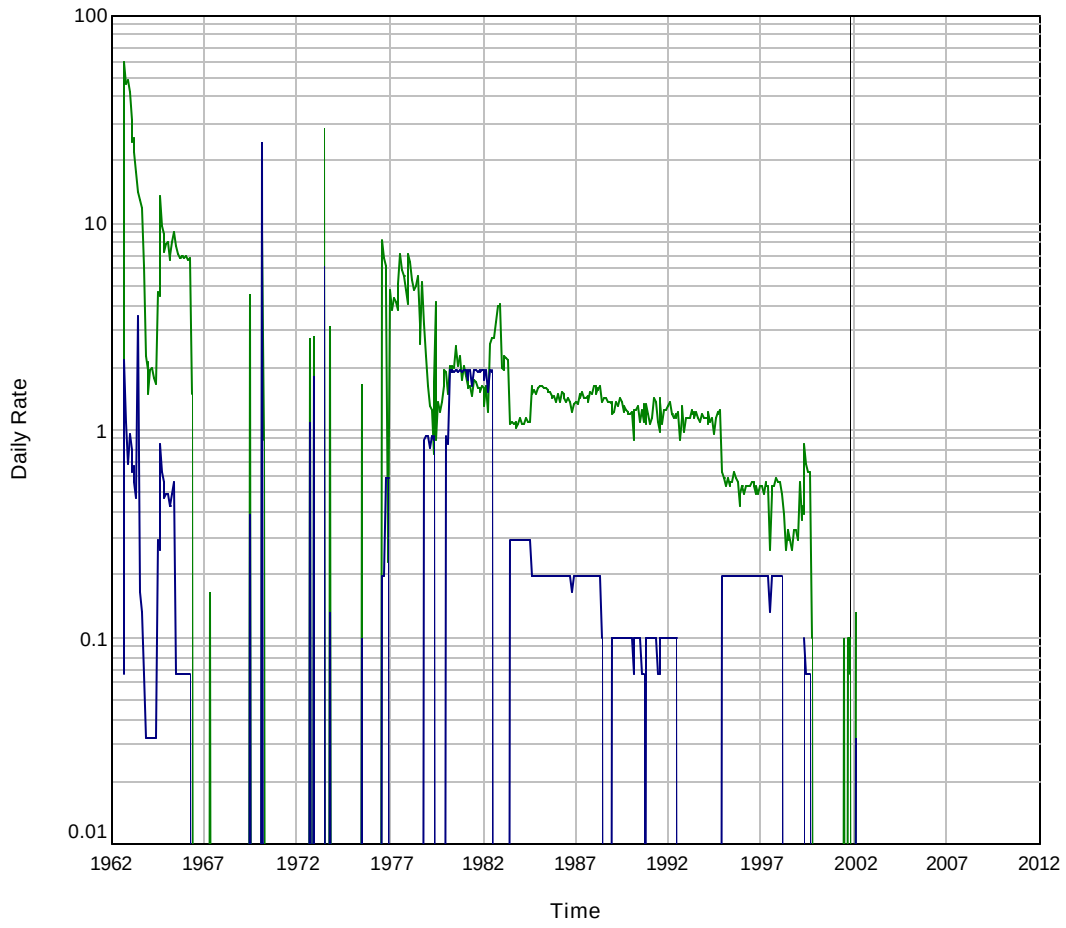


Figure 3. Production history for well 23-S-35.

Well 23-S-35

Well 23-S-35 was drilled in September, 1994 as a shale exploration target. Casing was set through the Shannon and cemented with 188 sacks of cement. The well was then deepened to 2672 feet with no significant oil or gas shows. The well was plugged back to 976 feet in late September and re-completed in the Shannon formation in October, 1994. Due to the offset waterflood on the eastside operator in the 1960's, the well only produced water upon completion. The well was subsequently shut-in and placed on dormant status See Figure 4.

The well had 7" 20 lbs/ft casing set at 1,015 feet below ground level. The conductor pipe was 9-5/8" set at 55 feet. The well had been perforated from 828 – 858 feet and from 918 – 938 feet with four (4) shots per foot.

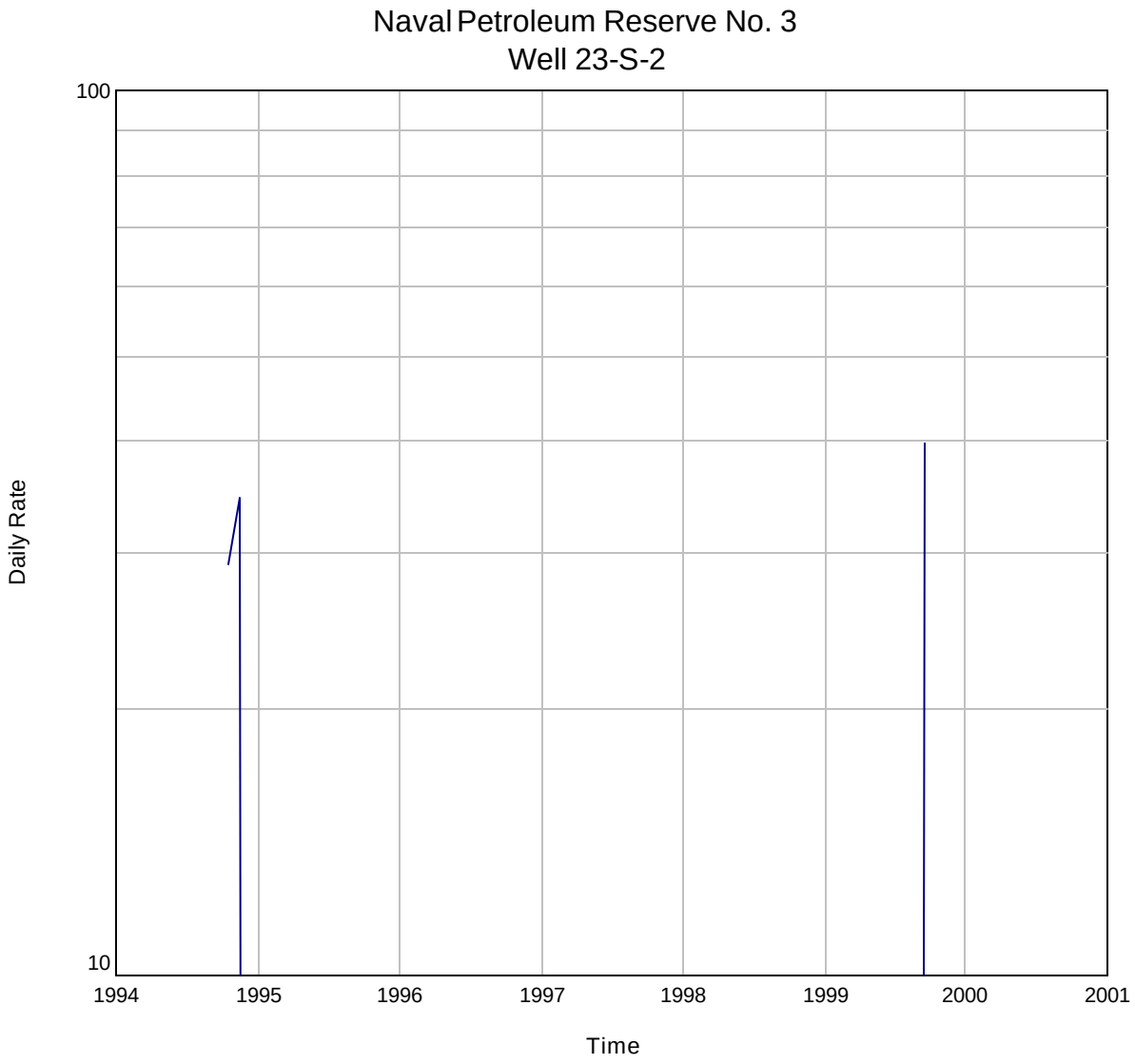


Figure 4. Production history of well 23-S-2.

The remaining two (2) wells, 77-S-11 and 18-SX-11, both Shannon producers, had mechanical problems which prevented the wells from being plugged and abandoned. Well 77-S-11 had a hole in the casing at a shallow depth which was discovered while attempting the initial test. Well 18-SX-11 had an enlarged openhole section which would require a large volume of cement to be pumped. Both wells were discarded.

Regulations for Plug and Abandonment

The Department of Energy follows the State of Wyoming regulations (governing body Wyoming Oil and Gas Conservation Commission – WOGCC) on plug and abandonment of oil and gas wells. In general, the rules require the perforations to be isolated by squeeze cementing. In addition, the production casing must demonstrate mechanical integrity in a manner prescribed or approved by the

state. In addition, the state prohibits any substance not normally used in plugging operations to be placed in the wellbore at any time.

The Department of Energy has adopted the following procedures to meet the state requirements. Cement is bullheaded down the casing to the perforations and excess is used to enter the perforations. Depending upon casing size, the volume of cement may be between 45 – 100 sacks. For example, in 4-1/2" casing the calculated cement fill-up volume is over 500 feet in the casing using 45 sacks of cement. Some of the cement is pumped out the perforations into the depleted zone or propped fracture of the near wellbore.

The initial cement job is allowed to set-up or cure and then is tagged with a wireline unit to verify the top of the cement. The objective is to obtain at least 100 feet of cement over the top perforation. If the cement top is satisfactory then the casing is pressure tested to ensure mechanical integrity.

The well is considered to be plugged adequately and a surface plug of 100 feet is set by lowering a one (1) inch hose to 100 feet and circulating cement back to surface. The casing is cut-off three (3) feet below ground level and a dry hole marker is welded on the top. The State of Wyoming then inspects the site prior to any final reclamation.

Cementing Solutions

The objective behind the plug and abandonment test with Cementing Solutions and RMOTC was to demonstrate a more cost effective method of P&A for the small independent operator. The cost savings were anticipated due to lower equipment costs, reduced cement costs, and reduced labor costs.

Equipment costs

Normal P&A operations require several pieces of large equipment including a large cementing pump truck, a large bulk truck, a water supply truck, and personnel transport. Cementing Solutions intended to replace the large over-the-road equipment with a smaller trailer unit pulled by a pickup. The trailer included a water supply tank, a hydraulic pump supply, and a pump skid containing two (2) 1.5 bbl tanks feeding a small positive displacement pump. The unit was self contained with no additional equipment needed except a cement truck (Ready-Mix) to supply the cement to the 1.5 bbl tanks. The unit could be easily operated by two (2) operators or possibly by one (1) operator. See Figure 5 on following page.

Figure 5. Equipment configuration for Cementing Solutions P&A Process.

Cement Costs

The cost of cement is a large component of the total cost of cementing a wellbore. Various formulations of cement are utilized in the oil field. Oftentimes, the main objectives are to maximize the yield of the cement in terms of volume and minimize the cost. The State of Wyoming also requires that API class cement to be used. The State of Wyoming also has not allowed operators to use ready mix trucks to plug wells. WOGCC has previously only allowed cementing to occur by the pump and plug method as well as also prohibited the use of aggregate, such as rock or sand, in the cement.

Several of the above issues were serious enough that before the testing could begin at RMOTC, a meeting was held between WOGCC and RMOTC and representatives of Cementing Solutions. The items discussed during the meeting included the type of cement to be used, compressive strength of the cement, the use of a ready-mix truck for cement delivery, and the use of sand as an aggregate.

Cementing Solutions provided data on their proposed cement design which indicated sufficient compressive strength of their slurry. The type of cement to be used, Type 1, is similar to API Class A cement which the commission found to be acceptable. Halliburton also states this in their cementing handbook. The use of a ready-mix truck was discussed. In the past, the WOGCC has prohibited such practices because of the likely failure of cement jobs if the cement is simply poured down the casing without any pumping or plug displacement. Representatives from Cementing Solutions explained that the truck would simply be a delivery vehicle and a positive displacement pump and conventional displacement rubber plugs would be used in the operation. The details of the operation are therefore, not unlike, a conventional cementing job albeit with smaller equipment and pumps.

The use of sand in the slurry as an aggregate was also discussed. The concern is that the sand would settle out and perhaps leave a poor zone or column of cement possibly on top and bottom. The bottom of the column of cement might have a high concentration of sand and low cement content due to settling. The top of the cement column may also have poor strength characteristics as the sand settled lower.

Although not fully resolved at the time, the WOGCC allowed RMOTC to proceed ahead with the test under supervision of its field inspectors. Cement samples taken during the jobs showed no stratification or layering within the samples. The samples were also quite hard and dense after curing.

Based on the samples above as well as field and laboratory testing the applicability of the cement mixture as proposed by Cementing Solutions is believed to be consistent with current oil field practices.

Labor Costs

Labor is also a major expense of a P&A operation. It is not unusual to have three (3) or more cementing personnel on any given job. Based on the equipment that Cementing Solutions had proposed, labor savings could be significant. The trailer mounted unit could be operated by one (1) or possibly two (2) people reducing the total labor cost by 1/3 or more.

Job Design

Based on the selection of five (5) wells for the initial test, RMOTC and Cementing Solutions completed a cement design for each proposed well. The design was based on the following assumptions:

- The calculated volume of cement was estimated based on the depth of the last perforation, the depth of the first perforation, a 100 foot column of cement above the top perforation, and 150 foot surface plug.

- During bullheading cementing operations it is difficult or impossible to determine which perforation may take fluid. Even depleted formations, such as the Shannon, may have some low reservoir pressure left, perhaps 10 to 25 psi. If the well is left shut-in for an extended period of time, fluid (either oil or water) will build up in the casing as the pressure is equalized with the reservoir. For example, if a reservoir is abandoned at 50 psi, then it is likely a 100 feet water column will exist over the top perforation at plug and abandonment.

- The water or water/oil column has to be displaced back into the perforations as the cement is pumped in order to squeeze cement the perforations. The displacement of this fluid into the perforations has some additional difficulties. It is generally not known which perforation will

accept fluid. Some perforations may be partially plugged over the years with paraffin, scale, or other debris. In addition, some perforations may never have produced fluid which means that it is unlikely that they will accept fluid.

- In thin formations, such as 10 feet or less, the displacement of cement across the perforations is probably less of a concern than thicker formations. The Shannon has an additional difficulty due to the fact that it is a dual bench system (Upper and Lower Shannon). The Upper Shannon and Lower Shannon are separated by approximately 40 feet of shale.

In the design of the cement job, it was assumed that the greatest volume of cement would be utilized. That is, the lowest perforation would accept fluid and bullheading cement would reach this lowest perforation. The volume of cement required is then a function of the top and bottom perforation and a 100 foot column of cement above the top perforation.

The displacement volumes of water to place the cement at depth were calculated based on displacing the cement plug 100 feet above the top perforation. If the bottom perforation did not accept fluid then some volume of cement would leave the casing at a higher depth. The cement plug may end up higher than planned. In either case, the result would most likely be acceptable.

The perforations would be squeezed with cement and isolated from the casing. The casing could then be pressure tested for mechanical integrity after the top of the cement was verified. After the mechanical integrity test was complete, it was planned to set a 150 foot surface plug which exceeded the state requirement of 50 foot. The plug would be set with Cementing Solutions by swabbing down the fluid in the casing to 150 feet below surface and simply pumping sufficient cement to fill this void. At this point, the wellbore would be considered plugged with only the surface plate to welded to the top of the casing and buried, and the site reclaimed. For detailed calculations see Appendix A.

First Plugging Attempt

The first plugging operation was attempted on Well 27-S-3. Figure 6 showed the overall location of equipment and operation. The 4-1/2” casing has a grey plug launcher attached in the background. The Ready-Mix truck is shown delivering cement to the two (2) cement tubs located on the skid. The displacement water tank was filled with cold water to displace the cement plug.

After less than half a barrel of cement was pumped, the positive displacement pump on the skid stopped pumping. The case on the pump was removed several times to free the pump. Small fingernail size rocks were jamming the impellor of the pump. The P&A operation was terminated after repeated attempts to pump the cement.

The small amount of cement pumped was subsequently displaced by RMOTC's chemical truck to the bottom of the well. The displacement was necessary to prevent a plug being formed at a shallow depth where it would possibly have to be drilled out to allow further access to the perforations for further P&A operations.

Prior to commencing the testing at RMOTC, Cementing Solutions performed some very extensive tests on the local cementing company bulk mixture. The tests did not indicate the presence of small foreign particles (small rocks and pebbles) which were found to be in the Ready-Mix cement slurry delivered on-site by the local company. The presence of the small rocks and pebbles caused the positive displacement pump to become jammed and quit turning. After a visit to the local yard where the cement was mixed, it was apparent that quality control measures were not in place to prevent a small amount of foreign matter to be included in the cement slurry. The P&A test was temporarily suspended until further review could be completed.

Second Plugging Attempt

The second plugging operation was considerably more successful. The skid mounted pumping system was replaced by a single, commercial cement pump used on construction sites. This unit was also trailer mounted and pulled behind a pickup. The cement pumping unit had a unique swinging valve system activated by a small hydraulic ram which allowed the cement slurry to be pumped without any limitations on aggregate content. Small rocks or pebbles did not affect the pump due to its design and normal application.

Well 27-S-3

The first well attempted was a continuation of the initial test. Well 27-S-3 had cement at 377 feet from surface and the casing had been pressure tested to ensure mechanical integrity. Since the cement top was above the top perforation, the well would not accept fluid into the formation. RMOTC therefore swabbed the well down to the plug back total depth (PBTD) with only air left in the casing and no fluid.

The initial test of the equipment was simply to demonstrate that cement could be pumped down the casing from the Ready-Mix truck without incident before attempting other wells. The operation went as planned with the casing being completely filled with cement to the surface with no difficulties in pumping the ready mix cement. The State of Wyoming approved the procedure before commencing operation.

Well 23-S-2

After the first well was filled with cement the second well attempted was 23-S-2. This well went as planned during the cement pumping operation; however, during water displacement of the cement plug, the cement pump was unable to develop sufficient pressure with the lower viscosity water. Pump pressure, even upon shut-in, was less than 25 – 50 psi. The swinging valve was allowing the water to leak between the metal faces allowing the water to bleed off without developing pressure.

The RMOTC pressure truck was hooked up to well and the cement plug displaced. The following day the cement plug was tagged high and the casing would not pressure test. Apparently, a hole had existed in the casing at a higher depth which prevented the cement plug to be adequately placed. The casing was swabbed down and Cementing Solutions filled up the casing similar to 27-S-3.

Well 23-S-35

The third well attempted was 23-S-35 with larger 7” casing which was set deeper. The P&A operation went essentially as planned. The cement plug was pumped by Cementing Solutions and then displaced with the RMOTC pressure truck. The cement plug was tagged at 664 feet or 164 feet above the top perf and the casing pressured to 450 psi. The well was swabbed down to 150 feet from surface and topped off with cement pumped by Cementing Solutions.

Well 77-S-11

The last well attempted was 77-S-11; however, soon after cement pumping began circulation around the outside of the pipe occurred. This circulation to surface indicated another hole in the casing at a shallow depth. Cementing operations were halted and the cement was displaced out of the casing with water. Further remedial work would have to be performed before this well could be abandoned.

Well 18-S-11

No work was attempted on this well due to the larger size casing, large openhole section, and limited pumping rate of the single plunger pump.

Summary

Alternate cementing technology for plug and abandonment of shallow wells with smaller diameter casing was tested at RMOTC by Cementing Solutions with some degree of success. Cement samples, both field and laboratory, indicated that alternate mixtures of cement (Type 1) with sand aggregate may have some applicability in current oil field P&A operations. Cementing operations with smaller, well-designed equipment is possible. Quality control of the cement slurry in Ready-Mix trucks was insufficient at the local contractor to allow the first generation of equipment to be successfully tested. The second series of equipment utilized was able to pump the cement slurry successfully; however, the pump was unable to develop adequate displacement pressure using the lower viscosity water. This operational problem was overcome during the testing operation by using RMOTC's pressure truck. Unknown wellbore conditions, such as holes in casing, can adversely affect any cementing operation regardless of equipment used in the operation.

Appendix A

Cement Design Calculations

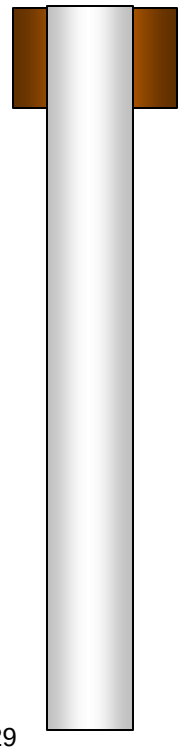
Cement Design Volumetrics

Casing/Hole Size	Casing Wt	Capacity			
13" openhole		0.1642	bbls/ft		
8-5/8"	24 lbs/ft	0.0636			
4-1/2"	9.5 lbs/ft	0.0162			
4-1/2"	10.5 lbs/ft	0.0159			
7"	20 lbs/ft	0.0404			
Well 18-SX-11		**Section Length**		**Section volume**	
8-5/8"@513					
Openhole 430 - 765		335	ft	68.8	bbls
100 ft in csg		100		6.4	
Total		435		75.1	bbls
Displace		330	ft	21.0	
Top Off		150	ft	9.5	
77-SX-11					
4-1/2" 9.5# @1164					
Perfs 1018 -1106		88	ft	1.4	
100 ft in csg		100		1.6	
Total		188		3.0	
Displace		918	ft	14.9	
Top Off		150	ft	2.4	
23-S-2					
4-1/2" 9.5# @675					
Perfs 542 - 636		94	ft	1.5	
100 ft in csg		100		1.6	
Total		194		3.1	
Displace		442	ft	7.2	
Top Off		150	ft	2.4	
27-S-3					
4-1/2" 10.5# @546		PBTD @377			
N/A Perfs		0	ft	0.0	
377 ft in csg		377		6.0	
Total		377		6.0	
Displace		0	ft	0.0	
Top Off		0	ft	0.0	
23-S-35					
7" 20# @1015					
Perfs 828-938		110	ft	4.4	
100 ft in csg		100		4.0	
Total		210		8.5	
Displace		728	ft	29.4	
Top Off		150	ft	6.1	

Appendix B

Wellbore Diagrams

Well 27-S-3
Date Spudded: 10/6/78
Production 4-3-79



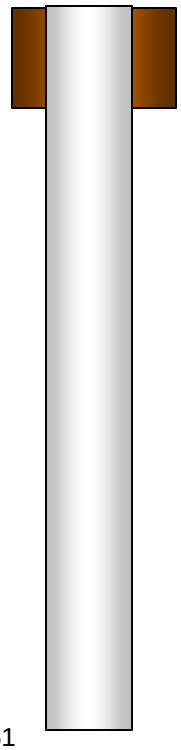
Conductor: 8-5/8" @ 40ft

4-1/2" 10.5# K-55 set at 549'
Cemented with 70 sks Type II with 10% NaCl &
90 sks Lite with 10% NaCl and 10#/sk Gilsonite

Perfs: 483' - 501' w/ 1SPF 10 shots
506 & 509 1 shot each
403' - 407' w/1SPF
421' & 423' 1 each; 432' & 434' 1 each
441' - 447' w/ 1 sp3f

PBTD: 529

Well 23-S-2
Date Spudded: July 16, 1962
Production 8/24/62



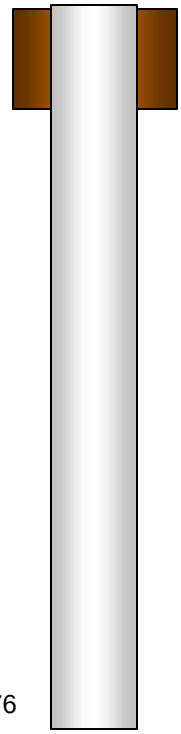
Conductor: 8-5/8" @ 12ft

4-1/2" 9.5# H-40 set at 675'
Cemented with 75 sks 4% Gel and Strata-Crete sks
Tailed with 25 sks Neat on bottom

Perfs: 542' - 560' with 54 shots
625' - 636' with 33 shots

PBTD: 651

Well 23-Sx-35
Date Spudded: 9/9/94
Production 10/13/94



Conductor: 9-5/8" @ 55ft
Cemented with 15 sks

7" 20# K55 set at 1015
Cemented with 188 sksClass G with 50:50 Pozlan
6.5 bbls of cement to surface

Perfs: 828' - 858' with 4spf
918' - 938' with 4 spf

PBTD: 976

References

Halliburton Publication. (1981), *Oil Well Cements and Cement Additive,*

Halliburton Cementing Tables, English/Metric Units, Technical Data, Sec. 203 pg. 3