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DRILLING AND TESTING OPERATIONS FOR PROJECT GASBUGGY

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ABSTRACT

This paper deals with mechanics of drilling and testing of the Gasbuggy site wells in the pre-shot and post-shot program. The information obtained from pre-shot well drilling and production testing of GB-1 and GB-2 wells confirmed the test site acceptability. The drilling discussion outlines the hole size, casing program, mud and gas drilling requirements, hydrological testing, coring, natural gas flow measurement and logging program.

Hydrological testing of water-bearing strata above the Pictured Cliffs zone was performed to determine the quantity and quality of mobile water that might affect the experiment. The natural gas flow and shut-in well test data obtained while drilling and following completion of each well are presented. The mechanics of emplacement hole drilling, casing, loading and stemming for shot containment are discussed.

Following the detonation of the device on December 10, 1967 the re-entry into the emplacement hole for preliminary sampling and chimney height determination is described. Post-shot pressure build-up data and gas sampling procedures are described. The re-entry drilling into GB-2R is described and the latest available test data relative to the flow rates and pressure data are presented.

INTRODUCTION

Project Gasbuggy moved from a four-year planning stage to the site confirmation stage immediately following the signing of a contract by the Atomic Energy Commission, the Department of the Interior, and El Paso Natural Gas Company for the jointly sponsored project on January 31, 1967. Obtaining test site confirmation was the first order of business and the first well, GB-1, was spudded on February 11, 1967.

The purpose of GB-1 was (1) to evaluate the water-bearing strata above the Pictured Cliffs zone for quantity and quality, (2) to evaluate the natural gas flow and shut-in pressure data of the objective Pictured Cliffs reservoir and (3) to obtain formation properties for reservoir evaluation of the gas-bearing Pictured Cliffs zone and associated formations.

A producing Pictured Cliffs well drilled in 1956 was located 330 feet from the proposed GB-1 location. This well, the San Juan 29-4 Unit No. 10, was drilled and completed with 9-5/8-inch surface casing set at 124 feet, 5-1/2-inch production casing set in a mud-drilled 8-3/4-inch hole through the Pictured Cliffs formation to 4203 feet. The well was selectively perforated, sand-water fractured and completed with 2-inch tubing. The well's calculated open flow at the end of a three-hour blow down through a 3/4-inch choke was 1400 Mcfd. The initial deliverability to the pipeline was 60 Mcfd at 50 percent of the wellhead shut-in pressure. The original bottom hole pressure was calculated to be 1230 psig at 4156 feet with a reservoir temperature of 130° F. This well produced 81,854 Mcf from initial production in 1957 to the time it was shut in during October, 1967.

GB-1 WELL PROGRAM

The drilling program for GB-1 consisted of setting 13-3/8-inch surface casing at 502 feet. A conventional 12-1/4-inch hole was mud-drilled to a depth 45 feet above the Ojo Alamo formation. From this point diamond coring with an 8-3/4-inch by 5-1/4-inch core bit was initiated and the upper portion of the Ojo Alamo was cored and swab tested under a packer to determine the rate of water entry. The lower portion of the Ojo Alamo was also cored and similarly tested. Results of each test indicated a low mobility water factor and a water quality not suitable for domestic use.

Coring was continued to the casing point above the Fruitland formation and after the cored hole was reamed 9-5/8-inch casing was run and cemented at 3755 feet. Full hole 8-3/4-inch by 5-1/4-inch coring with gas circulation was initiated immediately below the casing to the top of the Pictured Cliffs where the core hole size was reduced to 6-1/4-inch and continued to the well's total depth of 4320 feet, or 120 feet into the Lewis shale. A total of 870 feet of continuous coring was performed with a core recovery of 98 percent. Throughout the gas coring operation natural gas flow gauges were recorded at each drill pipe connection and when the core barrel was pulled. Figure 1 illustrates the natural gas flow data secured during the coring operation.

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A short duration, 18-hour, pressure build-up test was conducted when coring reached the top of the Pictured Cliffs. A natural gas flow rate of 100 Mcfd was measured for the Fruitland zone immediately prior to shutting in the well.

At total depth the cored interval was reamed to 8-3/4-inches. A series of dry hole logs, directional surveys, borehole photos and packer flow meter surveys were completed prior to running the 2-inch production tubing. Flow testing was resumed following a seven-day shut-in period with an isochronal type test being conducted with six-hour flow periods at rates of 90, 440, 275, and 146 Mcfd.

After a review of the data obtained during the drilling and the initial testing of GB-1 the technical representatives of the participating organizations recommended, and secured, site acceptability.

GB-2 WELL PROGRAM

Immediately after site acceptance the GB-2 well was commenced to confirm the continuity of data obtained from GB-1. The well was located 470 feet from GB-1 and 300 feet from the proposed emplacement hole location. The relative well locations are shown in Figure 2.

Surface 9-5/8-inch casing was set at 496 feet, and an 8-3/4-inch hole was mud-drilled through the Ojo Alamo formation where a hydrological swab test was conducted in a similar manner as employed in GB-1. Drilling was resumed to the casing point at the Fruitland-Pictured Cliffs contact where 7-inch casing was run and cemented at 3920 feet.

Below the casing a 6-1/4-inch by 3-1/2-inch gas coring program was pursued to total depth of 4260 feet. Mud or water entry, attributed to drilling the naturally fractured upper Pictured Cliffs with mud prior to running casing, necessitated remedial cement squeeze operations at the casing seat after reaching 4046 feet before successful gas coring could be accomplished to total depth. As in GB-1, natural gas gauges were taken with each drill pipe connection and trip with the core barrel. The flow rates ranged from 4 to 43 Mcfd in the cored interval. Three hundred forty feet were cored with a 92 percent core recovery.

A series of dry hole logs, directional surveys, borehole camera, packer flow meter and bottom hole fluid sampler runs and surveys preceded the landing of 2-inch production tubing, completing the well.

PRE-SHOT TESTING

A shut-in pressure build-up test of GB-2 was initiated and continued for nine weeks before the well was blown, without restriction, for eight days to a rate approaching stabilization at 4 Mcfd. The well was again shut in and pressure build up recorded until the hole was mudded up, wet hole logging completed and the well stemmed for shot containment.

A second GB-1 isochronal type test was initiated after drilling GB-2 and was conducted using six-hour flow intervals at rates of 415, 264, 148 and 75 Mcfd, with the last rate being continued for 30 days.¹ A third flow test was later made in which the well was produced at regulated surface rates to achieve a constant reservoir volume withdrawal. The surface rate was regulated from 738 Mcfd initially to 94 Mcfd at the conclusion of the 6-day period.

Figure 3 shows the wellhead pressures of GB-1 and San Juan 29-4 Unit No. 10 and the interference recorded between these wells. Immediately prior to final logging and stemming for shot containment the GB-1 well was produced through a 3/4-inch choke for five days. The rate was measured at 447 Mcfd at the end of three hours and 35 Mcfd at the end of the five days. Pressure interference between GB-1 and GB-2 was not observed during this period.

THE EMPLACEMENT HOLE

The drilling of GB-E, the nuclear device emplacement hole, was started on June 25, 1967. A dry hole digger was employed prior to assembling the drilling rig to set 30-inch surface casing at 49 feet. A 13-3/4-inch pilot hole was drilled to a depth of 4350 feet and subsequently reamed from a 13-3/4-inch to 28-inch hole diameter employing both platform reamers and conventional pilot and string reamers. Specially fabricated casing of 20-inch O. D. was run to a depth of 4324 feet. The pipe was cemented in a conventional oil field manner in three stages. The first stage employed float shoe, float collar and a baffle collar arrangement, while the second stage was placed through a cement collar at 3550 feet. The third stage used a cement collar at 1800 feet. In excess of 19,000 cubic feet of cement slurry was used in cementing. The 20-inch casing was designed to prevent collapse, assuming that the casing would be dry at the time of device emplacement. Reinforcing bands were added at 5 and 6 foot intervals on the bottom 1460 feet of the casing to achieve the desired collapse design factor.

The 20-inch casing from the surface to 2400 feet weighed 130 pounds per foot with a wall thickness of .64 inch. The balance of the casing weighed 160 pounds per foot with a wall thickness of .77 inch. While cementing, the stage collar at 3550 feet was not closed and later permitted Ojo Alamo water to leak into the casing. It was decided to run the device with water in the casing rather than risk squeeze cementing the stage collar ports.

The nuclear device canister, shown in Figure 4, was moved over the emplacement hole with a crane and later lowered into the 20-inch cased hole on 7-inch casing. The firing cable is shown extending from above the canister and running over the rounded crutch which was used to prevent damage to the cable.

One joint of the 7-inch casing, noted in Figure 5, was made up on the top of the canister and lowered into the hole. After skidding the rig over the emplacement hole the device was lowered on the 7-inch casing to a depth

of 4240 feet. Some 13 cables to the device and various instruments were supported with clamps between the centralizer blades positioned on every other casing joint and were taped to the casing to minimize damage while lowering.

STEMMING OPERATIONS

The slotted joints of casing were run at predetermined depths to permit placement of the cement used for the stemming operation. Tubing was run inside the 7-inch casing and the cement mixture pumped through these slots to fill the annulus between the 7-inch and 20-inch casing. Three stages of cement were placed from 4228 feet to 3000 feet, 10/80 mesh sand was placed from 3000 feet to 2500 feet, cement from 2500 feet to 1500 feet, and sand to within 50 feet of the surface. A chemical grout of 750 gallons was pumped into the top 50 feet of the 20-inch casing.

Figure 6 diagrams the stemming of GB-E, GB-2, San Juan 29-4 Unit No. 10, and the placing of instruments and stemming of GB-1 following the completion of preshot production testing and the mudding up of the dry hole sections for wet hole logs and surveys. GB-1 was equipped with instruments and stemmed in the same operation. The instruments and cables were attached to 1520 feet of 2-3/8-inch fiberglass tubing and lowered into the hole to 4250 feet on conventional steel tubing. Cement was pumped through the tubing string into the open hole section and the 9-5/8-inch by 2-3/8-inch tubing annulus from 4250 feet to 3000 feet. Drilling mud stemmed the balance of the hole to the surface.

The San Juan 29-4 Unit No. 10 was stemmed by the use of sand placed in the bottom of the hole opposite the perforated intervals and a bridge plug set above the sand at 3880 feet. Cement was then placed from the bridge plug to 2940 feet and the balance of the casing was filled with mud to the surface. GB-2 was stemmed with cement from 4220 feet to 3000 feet and the balance of the hole was filled with drilling mud.

OFFSET WELL PERFORMANCE

Prior to detonation, the seven gas wells within a 1-1/4-mile radius of ground zero were shut in for pressure build-up study. Shortly before detonation, bottom hole pressure bombs were placed in three of these wells and surface pressure recording instruments were placed on three other wells. The charts from these recording instruments only indicated a fluctuation of the stylus at the time ground shock reached each instrument and the rate of pressure build-up in each well remained apparently unaltered at the time of the detonation and thereafter. No physical damage was found to have occurred to any of the field wells or their surface equipment.

RE-ENTRY OPERATIONS

Re-entry drilling operations were initiated in the emplacement hole on December 13, following the detonation

on December 10, 1967.² The program consisted of drilling out the sand and cement used to contain the explosive inside the 7-inch casing. Gas was used as the circulating fluid to a depth of 3300 feet, but was changed to a treated water when the cement became sufficiently moist to preclude further gas drilling. It was determined that water was entering the wellbore through the 20-inch stage collar at a depth of 3550 feet. The rate of influx water was determined to be two cubic feet per hour.

At a depth of 3858 feet a six-foot void was encountered and circulation was lost. No radioactivity was encountered. The fluid level was determined to be standing at a depth of 1750 feet from the surface. Drilling was resumed without the establishment of circulation and on January 10, 1968 a nine-foot void was encountered at a depth of 3907 feet. The bit appeared to have encountered metal at a depth of 3916 feet and drilling operations were discontinued. Shortly thereafter radioactive Xenon gas was detected at the surface and the wellhead pressure increased to 833 psi. The drill pipe utilized to drill down to this depth was stripped out of the hole and 2-1/2-inch tubing was landed at 3792 feet through a production packer set at 3786 feet. A diagram of the completed re-entry wells, GB-ER and GB-2RS, is shown in Figure 7.

Small volumes of gas were taken from the well in order that the gas samples could be collected for laboratory analysis. Pressure measurements were made during these short flow intervals.²

Re-entry drilling into the Gasbuggy No. 2 well was initiated in June, 1968. During the re-entry operations it was found that the well could not be entered to the total depth due to obstructions in the casing at 3704 feet and 3812 feet. A window was milled in the casing at 3691 feet and a sidetrack hole was gas-drilled to a new total depth of 4600 feet. During this re-entry drilling operation, gas flow measurements were made each time drill pipe connections and trips were made. Production tubing was landed in the uncased hole at 4224 feet after logging and survey operations were completed. Figure 8 illustrates the gas flow data secured while drilling the post-shot sidetrack hole and also shows a comparison of pre-shot flow measurements obtained from GB-2.

POST-SHOT TESTING

Production testing on the re-entry emplacement well, GB-ER, started on June 28, and consisted of producing the well at a rate of five million cubic feet per day for six days, shutting the well in one day for bottom hole pressure and temperature measurement, and resuming the five million cubic feet per day flow rate for five days. The well was then shut in briefly for bottom hole pressure and temperature measurement, then reopened at a rate of 0.75 million cubic feet per day for four days with bottom hole pressures and temperatures being measured. The well was then shut in for pressure build up measurements which are still continuing. Figure 9 relates the surface wellhead and bottom hole pressure data for this test series.

At the beginning of the test the surface wellhead pressure was 942 psig and the bottom hole pressure was 1067 psig with a temperature of 118° F. All of the bottom hole pressure and temperature measurements in the emplacement hole were made at a depth of 3790 feet. The normal Pictured Cliffs reservoir temperature at 4050 feet is 130° F. During the initial six-day flow period 28.93 MMcf of gas were produced. Just prior to the 24-hour shut-in period the flowing pressure was measured at 585 psig with a wellhead temperature of 146° F. At the beginning of the 24-hour shut-in period the wellhead pressure was recorded at 821 psig with a bottom hole pressure of 906 psig at 248° F. and at the end the wellhead pressure was recorded at 819 psig with a bottom hole pressure of 917 psig at 174° F. During the next 5-day flow period 25.13 MMcf of gas were produced with a flowing pressure measured at the end of the period of 328 psig and a flowing temperature of 153° F. The shut-in wellhead pressure at the end of this period was 709 psig with a bottom hole pressure of 780 psig and 247° F. During the next four days 2.98 MMcf of gas were produced with a flowing pressure at the end of the period of 575 psig at 84° F. The wellhead pressure one hour after closing the well was 718 psig with a bottom hole pressure of 798 psig at 227° F. The bottom hole pressure at the time the well was shut in was measured at 793 psig at 241° F. Twenty-four hours after discontinuing flow the wellhead pressure was measured at 723 psig at the time the bottom hole pressure was 814 psig at 174° F. After 52 days' pressure build up, on September 4, 1968, the wellhead pressure measured 812 psig with a bottom hole pressure of 916 psig at 118° F.

Figure 10 shows the recorded wellhead and bottom hole temperatures measured on GB-ER throughout this test period. The wellhead pressure curve is shown to relate the temperature curves with flow sequence.

During the flow tests conducted on GB-ER pressures were measured on GB-2RS which indicate communication existed between the two wells. Figure 11 relates the wellhead pressures measured on GB-ER and GB-2RS.

The three flow tests attempted in mid-July for GB-2RS were hindered by the apparent caving of the re-entry hole after tubing was run. Perforating the tubing from 4052 feet to 4062 feet failed to establish normal communication between the annulus and the tubing needed to obtain a representative test.

Figure 12 summarizes the results of the gas analyses obtained from GB-ER during the post-shot testing. The change in sample composition with production reflects a decrease in carbon dioxide and hydrogen while the methane and other hydrocarbons increased. This is interpreted as evidence of uncontaminated reservoir gas entry into the chimney.

No further flow tests have been conducted on the emplacement hole or the GB-2RS well but pressure build up data is being recorded at this time.

REFERENCES

1. Atkinson, Charles H. and Ward, Don C.: "Project Gasbuggy- Status Report", J. Pet. Tech., October, 1967, p. 1323.
2. Holzer, F. "Gasbuggy Preliminary Post-Shot Summary Report", Lawrence Radiation Laboratory, Report No. PNE 1003, January, 1968, pp. 9-12.

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GASBUGGY NO. I
NATURAL GAS FLOW RATES
WHILE CORE DRILLING

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

GASBUGGY STEMMING

Figure 6

POST SHOT RE-ENTRY

Figure 7

GASBUGGY NO. 2 R S NATURAL GAS FLOW RATES WHILE DRILLING

Figure 8

GASBUGGY ER

Figure 9

GASBUGGY ER

Figure 10

POST SHOT TESTS

Figure 11

GB-ER GAS ANALYSES WITH FLOW

Figure 12