MORROW SANDSTONE WELL COMPLETION PRACTICES

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INTRODUCTION

Comprised chiefly of alternate beds of shale and sandstone, the Morrow sand members are the object of an intense search for natural gas in the Southwest. (Refer to Fig. 1 showing area map.) The Morrow Formation is Early Pennsylvanian in age and is found at depths ranging from about 7000 ft to 15,000 ft in southeastern New Mexico. Out of the 37 active wells in Eddy County reported in late January, only one well was not a scheduled Morrow test. Spurred on by the incentive of fair prices for "new" gas, reserves are steadily being developed in the Morrow in spite of the problems associated with drilling and completion.

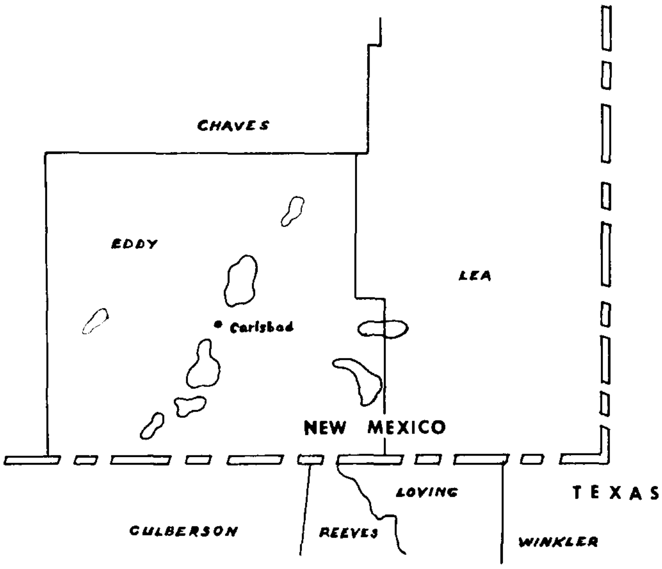


FIG. 1—AREA MAP

Before the economical incentive appeared in 1972, a high risk factor associated with Morrow drilling prospects severely limited activity. The stratigraphic accumulations of Morrow gas were quite difficult to identify, and the economics of 19-cent gas from wells known to be costly and troublesome were not appealing. Contributing to the risk factor were certain operational hazards. Wells drilled as offsets to discoveries frequently resulted in dry or abandoned tests. Often, completed well potentials were disappointing, when compared to the drillstem test indications. Conventional stimulation attempts usually produced lowered deliverabilities. It became increasingly evident that the Morrow sands were highly susceptible to damage caused by exposure to liquids from practically every source.

The Morrow damage susceptibility has been recognized by many well completion engineers as a most significant challenge. Various techniques have been employed to overcome this damage. Generally speaking, the successful Morrow completion design includes engineered drilling and cementing procedures complementary to specialized perforating and stimulation methods.

THE MORROW COMPLETION

Petroleum engineering texts commonly introduce the topic of well completions at the point when production casing is set. For the Morrow well completion, and possibly for other pay zones exhibiting a peculiar sensitive nature, the drilling processes must be included in completion planning. Factors that influence completion efficiency to be considered in this case are drilling mechanics, casing programs, drilling fluids, drillstem testing and cementing. Obviously, the perforating and stimulation programs deserve priority for discussion.

DRILLING PROGRAMS

Field studies indicate that Morrow zones have been damaged while being drilled. This is due in part to the abnormal gradient encountered above the Morrow (Fig. 2), sometimes requiring heavier muds. The Morrow exhibits a 0.44 psi/ft gradient near Carlsbad. An example casing program is shown in Fig. 2. Where practical to do so, mud programs have been modified to improve protection for the sensitive sands.[1] Lengthy circulation, with the Morrow exposed, increases the degree of invasion by mud filtrate.[2,3] Some operators have elected not to drillstem test, relying on electric logs and a specialized perforating procedure (discussed later). It is probable that severe mud damage occurs when the test packers are released. This likely is due to the mud-shock effect resulting in extreme spurt loss and mud invasion.[4,5]

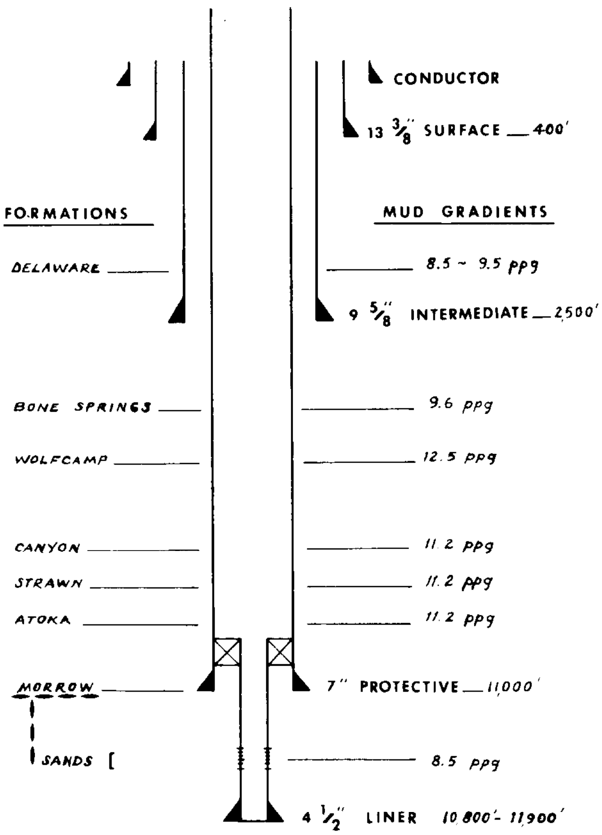


FIG. 2—S. CARLSBAD CASING PROGRAM

Many operators have discontinued the use of fresh-water-base muds. Improved penetration rates and shale control have resulted from the use of clear water, potash brine and more recently, potassium chloride-polymer systems.[1] Use of polymer fluid has reduced formation damage, particularly where the mud density was maintained near the balance point of the Morrow.

CEMENTING

In earlier times, operators tended to overlook the damage potential existing during the normal course of a primary cement job. Mechanics of placement and simple economics were the usual concern. Operators have begun the practice of multiple-stage procedures to eliminate long cement columns. Low water-loss premium slurries are being mixed and some operators are adding potassium chloride to the mixing water as an extra precaution against filtrate damage.

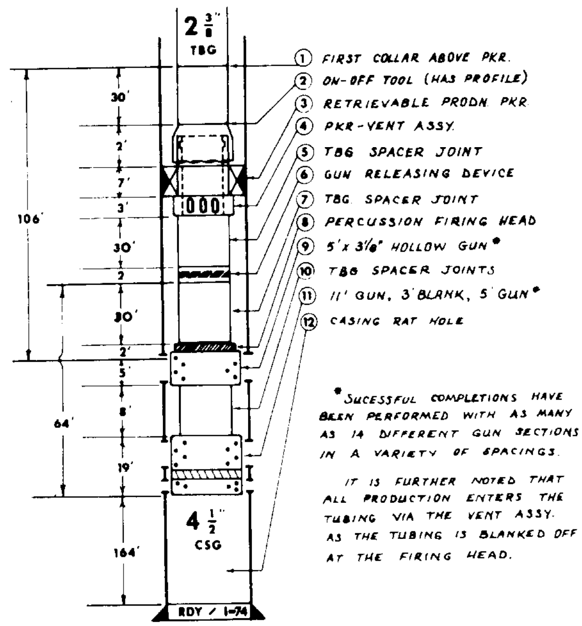
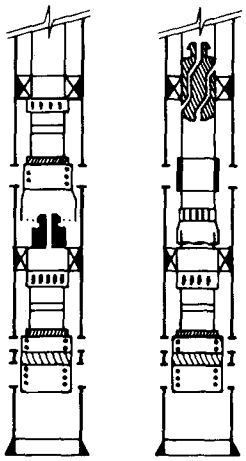


FIG. 3—DETAILED TUBING CONVEYED JOB

STIMULATION

Standard acid and frac treatments were generally disappointing. Hydrochloric acid and mud acid jobs failed to clean up the perforations. Numerous treatments consisted entirely of two percent potassium chloride water. Super-thick gelled water fracs and some gelled oil fracs were performed. Most of these treatments appeared to produce water-blocks or emulsions.

Few advances were made in stimulation until the relative permeability and capillary pressure properties of the rock were reconsidered. Satisfactory programs were developed by The Western Company in early 1973. These procedures included the use of weak hydrochloric acid solutions containing surfactants and water-wetting agents. Nitrogen and carbon dioxide were emplaced with the stimulant and mixed in the flush. Thinly gelled solutions of these and similar ingredients have been successfully employed in fracturing work by Western, Dowell and Halliburton Services as well. It is to be noted, however, that many Morrow wells with good drillstem test records have failed to respond even to these newer techniques. This is often the case where the Morrow perforations are exposed to completion fluids.



A B

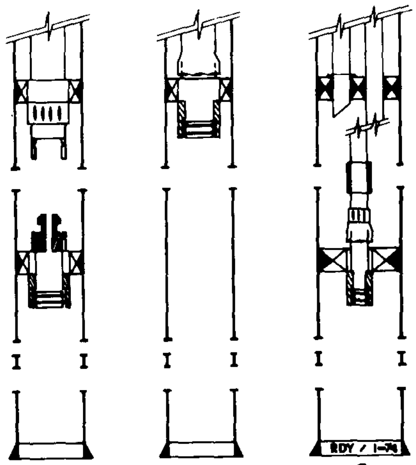
(A) DUAL TST: TBG CONVYD
(B) DUAL: X–O CHOKE

FIG. 4

PERFORATING THE MORROW

Due primarily to the uncertainty of pressure data, Morrow wells were initially perforated through the tubing after the tree was installed. This procedure proved unsatisfactory because of the usual need to spot acid and breakdown the formation. After pressure data became available in a given area, some wells were perforated through the casing before the tubing was run. In either case, further stimulation with increasingly larger volumes was often required.

In late 1970, a rather unique method of perforating Morrow wells began to evolve.[6] Designed purposely to simulate a drillstem test, hollow-gun carriers were lowered into a well on the production tubing, below a retrievable production packer. A wireline blanking plug was run in place so that after the packer was seated, the plug was removed. A go-devil was then dropped into the dry tubing, which fired the guns by striking a percussion-type firing mechanism. A natural completion was thusly accomplished, permitting



A B C

(A) DUAL TST: MX-ΔP_ EX·BP / RTR PLUG
(B) SINGLE: MX-ΔP_ EX·BP
(C) DUAL TBG: MX-ΔP / SET DOWN PKR

FIG. 5

the natural energy of the reservoir to expel fluids and particulate damage.

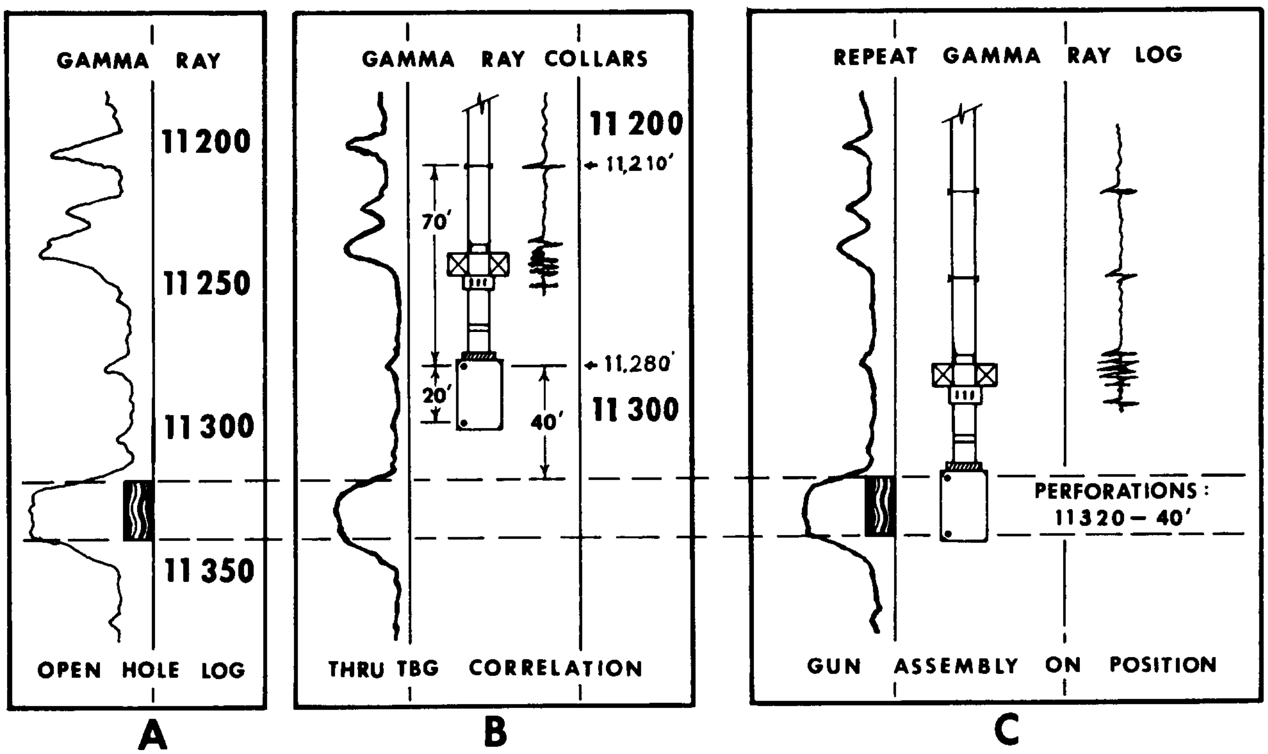
An example calculation of the kinetics set in motion by this technique in a typical South Carlsbad well is found in the Appendix at the conclusion of this paper. With a maximum differential pressure of 4938 psi, a force of 850 lb_f is released into the wellbore. The velocity of the gas traveling through the perforations was 1847 ft/sec (1259 mph), and the force and power available to unload each barrel of water are shown to be 4768 lb_f and 683 ft-lb/sec, respectively.

Vann Tool Co. is the developer of the foregoing process, which is commonly known as the "tubing conveyed perforating technique". Since 1970, over 100 completions have been performed, during which time the procedures and tools have continuously been refined. Blanking plugs are no longer required to convey the tubing into the well dry. The "packer actuated vent assembly" has been designed for this purpose. Shown in each of the well diagrams in Figs. 3, 4 and 5, this tool is run just below the retrievable production packer in the closed position. The vent assembly is opened by lowering the tubing after the packer has been positioned and seated. Compressed fluid pressure below the packer is thereby relieved and the well is in near-perforating condition. The next steps are to connect the wellhead and flowline and to drop the detonating bar down the tubing. The bar has a standard fishing neck and is easily removed. Experience has indicated that four shots per ft that penetrate a minimum distance of one well diameter approximate openhole completion results.[7]

It is important to illustrate the method employed to position the perforating guns in the tubing-conveyed method. After the guns are lowered to their approximate position by strapping the tubing, a through-tubing gamma ray-collar log is run. Since the gun and completion assembly were carefully measured on the surface, the precise distance between the top shot and a marker collar in the tubing above the packer is known. This marker collar is correlated to the openhole logs. The tubing is then either raised or lowered to place the top shot exactly on top of the interval to be perforated. This operation is illustrated in Fig. 6.

into the casing rat hole by running a Garrett shifting tool on wireline for the operation.

The modified pressure implosion technique involves the use of an expendable bull plug and approaches a similar effect created by the tubing-conveyed route. This procedure is depicted in Fig. 5. When the casing rat hole is shallow, eliminating the use of the gun releasing device, the tubing can be run in dry, with the expendable plug positioned in the lower end of a vent assembly. The well may then be perforated through the tubing dry (some water cushion is suggested), and the formation pressure implodes as in the previous case. Through-tubing guns produce small, relatively shallow perforations and are not generally recommended in this case. More often, the well is



A. PERFORATIONS FROM OPEN HOLE LOGS ARE BASIS FOR TIE-IN LOG.
B. GUNS ARE STRAPPED INTO HOLE. KEY COLLAR LOCATED (11,210), T/SHOT (11,280).
C. LOWERED TBG PRECISELY 40' TO POSITION GUNS.

FIG. 6

In the event that fully opened tubing is required subsequent to the initial completion, a gun releasing device may be installed between the vent assembly and the firing head. This feature replaces the former, less reliable methods. During the developmental stages of the tubing-conveyed technique, tubing cutting and shear-pin collars had been employed. The guns may now be dropped

perforated through casing under a controlled hydrostatic condition before the tubing assembly is run. Then usually the wells come in when the packers are seated (opening the vent assembly). The small steel plug frequently is ejected to bottom as the vent shifts open. If not, a wireline probe or small "knock-out" bar similar to the detonating bar may be used to expel the plug.

ADVANTAGES OF THE TUBING-CONVEYED TECHNIQUE:

1. No completion fluids touch the pay sands.
2. Formation pressure apparently expels damaging materials.
3. This technique provides a high degree of accuracy and efficiency in perforating.
4. Pressure control equipment is not required.
5. The wells are completed and perforated simultaneously.
6. Results simulate drillstem tests and openhole completions.

CONVENTIONAL APPROACHES TO DIFFERENTIAL PERFORATING

Many completions are accomplished by utilizing modified conventional techniques. These are being done by swabbing load water prior to perforating. This has proven to be a hazardous approach, as the guns are often blown up the tubing, resulting in well problems. When casing guns are employed prior to running the tubing, the Morrow is subjected to the casing fluid.

SUMMARY AND CONCLUSIONS

A totally engineered program employing current and proven techniques enhances the success of Morrow well completions. Each aspect of the drilling and final completion should be carefully planned and directed.

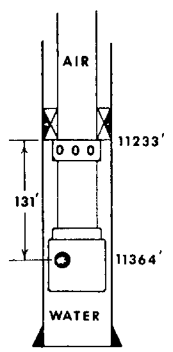
ACKNOWLEDGMENT

The author expresses his appreciation to Vann Tool Co. for the encouragement to publish this paper. He is also grateful for the opportunities provided by his previous employer, Midwest Oil Corp., to develop practical experience in the design and supervision of Morrow drilling, completion and stimulation procedures.

APPENDIX

KINETICS IN TUBING CONVEYED PERFORATING:

EXAMPLE CALCULATIONS:



A South Carlsbad well was perforated with 40, 0.42" holes using the tubing conveyed technique. Only 131' of water was in the well at detonation. The BHP was known to be 5000 psi (DST). The water surfaced in 3 mins, followed by black, muddy fluid. Gas surfaced after 4 mins. The well came in at 3 MMCFD on a 3/4" choke at 200 psi. Casing and tubing sizes were 4-1/2" and 2-3/8", respectively. The guns were 3-1/8" O.D.

1. What were the implosive forces that swept load water and mud through the perfs and out of the well?
2. How much velocity and energy were available for cleaning up the well?
3. What force was applied to unload the approximately 5 bbls of load water and muddy filtrate? How much work was done?

1. The forces are:

A. Differential pressure, p = BHP - (head of air + water head) (1)

$$p = 5000 \text{ psi} - \left[\frac{.0005 \text{ psi}}{\text{ft}}(11364') + \frac{.433 \text{ psi}}{\text{ft}}(131')\right]$$

$$p = 5000 - 62 = \underline{4,938 \text{ psi}}$$

B. Force = pressure x area of a perforation x no. of perforations/g (2)

$$F = \frac{4938 \text{ psi } (.785)\ (.42)^2\ (40)}{32.17} = 850 \text{ lb}_f$$

C. Acceleration through the perfs: a = f/m (3)

Where: a = acceleration of fluid through the perfs
m = mass of 1 bbl of water, slug.

Then: $$a = \frac{850 \text{ lb}_f}{62.4 \text{ lb} / 32.17 \text{ ft/sec}^2} = 438.2 \text{ ft/sec}^2$$

2. Bernoulli's equation in hydraulics is an energy equation describing the motion of fluid in steady-state, adiabatic, irreversible (no friction) flow along a streamline, where there is no shaft work.

A. For the fluid velocity in the well, at detonation, the equation is stated as: (4)

$$V_2 = \sqrt{\frac{2\,(p_1 - p_2)}{\rho\left[1 - (A_2/A_1)^2\right]}}$$

Where:
V_2 = velocity of water inside the casing, fps
p_1 = formation pressure (BHP), psf
p_2 = hydrostatic head inside well, psf
ρ = density of load water, 1.94 slug/ft^3
A_1 = cross-sectional area of perforations, ft^2
A_2 = cross-sectional area of flow inside casing, ft^2

Then: $$V_2 = \sqrt{\frac{2\ (4938) \text{ psi } (144) \text{ in}^2/\text{ft}^2}{1.94 \text{ lb sec}^2/\text{ft}^4\left[1 - \left(\frac{4.89 \text{ in}^2}{(40)(.138 \text{ in}^2)}\right)^2\right]}} = 1846.51 \text{ fps or } 1259 \text{ mph}$$

B. For a constant density fluid, $\bar{V}_1 \bar{A}_1 = \bar{V}_2 \bar{A}_2$, and $\bar{V}_2 = \bar{V}_1 (\bar{A}_1/\bar{A}_2)$ (5)

Where:
$\bar{V}_2$ = velocity of water in mouth of tubing, fps
$\bar{V}_1$ = velocity of water entering tubing, fps
$\bar{A}_1$ = cross-sectional area of gun - csg. annulus, ft^2
$\bar{A}_2$ = cross-sectional area of tubing, ft^2

Then: $$\bar{V}_2 = (1846.51)\frac{\text{ft}}{\text{sec}}\left(\frac{4.89 \text{ in}^2}{3.12 \text{ in}^2}\right)\left(\frac{144}{144}\right) = 2894 \text{ fps - or } 1973 \text{ mph.}$$

C. The force available to unload each bbl of water:

F = ma (3)

$$= 1 \text{ bbl} \times \frac{5.61 \text{ ft}^3}{\text{bbl}} \times \frac{62.4 \text{ lb sec}^2}{\text{ft}(32.17)\text{ft}} \quad (438.2)\ \frac{\text{ft}}{\text{sec}^2}$$

$F = 4768.4 \text{ lb}_f/$ bbl of water

D. The power potential for unloading the water:

$p = w\ (VA\ \rho/g)$ (6)

Where:
p = power available, ft lb$_f$/sec
w = weight of 1 bbl of water, lb
V = velocity of water, fps
A = tubing section, ft^2
ρ = water density, 1-94 slug/ft^3
g = standard gravity constant, 32.17 ft/sec^2

Then:
p = 350 (2894) (.0217/32.17)
p = 683 2 ft lb$_f$/sec, per bbl of water
H.P. = 1.242/bbl

3. The force to unload 5 bbls of (water):

A. $F = (4768.4)\ (5) = 23,842 \text{ lb}_f$ (2-C)

B. $$W = \frac{(683.2)\ \frac{\text{ft lb}_f}{\text{sec}}}{\text{bbl}} \times 5 \text{ bbl} \times 60 \text{ sec} = 204,960 \text{ ft lb}_f$$ (2-D)

C. H.P. = (1.242) (5) = 6.21 H.P.

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