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A REVIEW OF PERFORMANCE OF MULTI-ZONE WELLS IN THE WILMINGTON FIELD, CALIFORNIA

By Carlton Beal, Richfield Oil Corporation
and
Read Winterburn, Union Pacific Railroad Co.

Pacific Coast District
Division of Production
American Petroleum Institute
Los Angeles, California

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By Carlton Beal[x] and Read Winterburn[xx]

ABSTRACT

A review has been made of 249 multi-zone wells originally completed in the Ranger, Upper, and Lower Terminal Zones, Wilmington Field, California. This group of wells includes about one-fifth of the present producing wells in the field and about ninety per cent of all the original Multi-Zone completions. Of these wells, forty-seven were equipped to produce separately from three zones, with the balance - or 202 - equipped to produce from two zones. Although the field has been producing for only about seven years, almost forty per cent of the wells have had to be repaired, after producing only 3.2 years, principally because of bad casing and tubing, water encroachment, and cessation of natural flow. All of the original multi-zone wells were completed flowing; of these, forty-two per cent are now pumping. Not one of the Multi-Zone pumping wells is equipped for simultaneous production of two or more zones separately by artificial lift because of mechanical difficulties such as sand production, corrosion of flow strings and packers, and large volume water production. In effect, over forty-five per cent of the original Multi-Zone wells in the field are operated at the present time so that they are single or combination zone wells. Conclusions are that multi-zone development in the Wilmington Field has not been justified except where surface locations are limited and in those cases where an advantage will be gained in a competitive area.

GENERAL DESCRIPTION OF FIELD

The producing horizons in the Wilmington Field comprise a maximum thickness of about 3000 feet divided into six zones, each of which is made up of alternating sands and shales. The field is divided into five separate fault blocks. The zones within these fault blocks (or in some cases combinations of two or three zones) are treated as fourteen separate pools for allocation purposes. The zones differ in oil gravity, physical characteristics of the sand, and productive area.

Horizons Produced in Most Multi-Zone Wells: The horizons that are produced in most multi-zone wells are the Ranger, Upper Terminal, and Lower Terminal Zones on each of the Fault Blocks previously described.(1) (2) Figure 1 shows an electric log of these zones and their characteristics. The oil sands are of generally high permeability (300 to 1000 Md) and high porosity. They are usually soft and unconsolidated, frequently causing sand trouble and cutting out of liners and tubing strings. Original formation pressure in all zones was roughly equal to the hydrostatic head measured from the surface. Originally these zones were saturated with oil and gas in solution and initially produced with gas/oil ratios as low as 200 - 400 cubic feet per barrel. Now,

[x] Development Engineer, Richfield Oil Corporation, Los Angeles, California
[xx] Chief Development Engineer, Union Pacific Railroad Company, Los Angeles, Calif.

in the course of partial depletion, they have increased to 800 - 1500 cubic feet per barrel. Well ratios have reached values in excess of 10,000 cubic feet per barrel in secondary gas caps. Most of the reservoirs in each of the five fault blocks have produced as depletion type pools with frequent instances of local water encroachment near the productive limits of each pool.

TYPES AND CLASSIFICATION OF MULTI-ZONE COMPLETIONS

Definitions: A "multi-zone" well is one that is mechanically equipped to produce two or more zones simultaneously through separate flow strings without commingling the oil. A "combination" well is one that produces simultaneously from more than one zone, causing the commingling of oil within the well bore. A "single zone" well is one that is perforated opposite only one zone and produces from this zone.

Classification of Multi-Zone Wells: Several authors [1][4][5] have described methods of producing "dual" zone (two zones only) wells by means of various types of packer installations. Corey[3] has provided a general description of several types of multi-zone completions in the Wilmington Field, and has described, in general, some of the advantages and disadvantages involved in this type of zone development. For the purpose of analysis, the multi-zone wells in the field have been divided into five general classes, as illustrated in Figure 2. These classifications are based on the location of cemented casing with regard to perforated intervals, flow strings and packer arrangements used to effect zonal segregation. The classes are described below:

Class I — Wells originally equipped with tubing packers set opposite a cemented blank section to obtain zonal separation.

Class II — Wells that were originally equipped with a tubing packer set on a tubing collar located in a cemented section between perforated intervals. These wells may or may not be equipped with casing packers.

Class III — Wells that were originally equipped with casing packers set on a swage in a cemented section between two perforated intervals to effect zonal separation. This class of wells may or may not be equipped with tubing packers.

Class IV — These wells are equipped with casing packers opposite cemented sections with or without tubing packers to effect zonal segregation.

Class V — This group of wells obtains zonal segregation by cementing two or more full strings of casing over perforated intervals. These wells are not equipped with tubing or casing packers.

Table I shows an analysis of 249 original multi-zone completions divided into the five classes. The original multi-zone wells comprised about 19.3% of the producing wells in the field. All of the wells that were included in the review originally produced from the Ranger and Terminal Zones or portions thereof and represent about 90% of all the original multi-zone completions in the field. Corey[3] states that in 1941 there were 264 multi-zone wells in the field which apparently include a small group of Tar - Ranger multi-zone wells.

The Table shows that 171 of the 249 multi-zone completions obtained zonal segregation by means of tubing hook-wall packer installations. These wells produced from two zones while 76 wells in Class II, III and IV obtained zonal segregation by installing casing packers. Of the 76 wells equipped with casing packers, 47 were equipped to produce separately from three zones. Only two wells (Class V) isolated producing zones without the use of tubing or casing packers. Included in the Class I group of multi-zone wells are two unique completions equipped with a dual tubing head which made possible fluid production from two zones through a string of 2" tubing along side a 2" string set on a packer. Also in Class I are two Lower Terminal Zone wells that subsequently developed excessively high gas/oil ratios due to secondary gas cap accumulation in the Terminal Zone and have been deepened to the underlying Union Pacific Zone and completed as dual zone wells.

DEVELOPMENT BY MULTI-ZONE WELLS

In considering the use of multi-zone completions in development programs, it is necessary to consider the three general circumstances in the field which led the operators to multi-zone development; namely, reduced development costs, competitive advantage, and isolation of running sand to obtain maximum oil capacity.

Reduced Development Costs: In some areas dual zone completions were used in the Upper and Lower Terminal Zones on a spacing which was considered adequate for each zone with the principal object of reducing development costs. The oil allocation practice was to give separate oil quotas to the Upper and Lower Terminal Pools and to produce only one zone at a time in each well. The well capacities were sufficient to thus produce the pool allotments determined on a basis of reservoir performance from each of the two zones and, since most of the wells are still capable of flowing from either zone, distribution of withdrawals is readily controlled. In these circumstances simultaneous production of any well from the separate zones has not been necessary and facilities for separate gauging have not been installed.

The continued operation of the two zones as separate reservoirs after cessation of natural flow will require conversion to single zone wells unless it is possible to overcome the several mechanical obstacles to application of special installations permitting artificial lift from the separate zones. If the wells are to be converted to single zone producers, additional development will be necessary to attain the originally intended well density. In this case the anticipated saving in development costs will not be realized.

Competitive Advantage: The second situation is that existing in several competitive areas in which both Upper and Lower Terminal Zones are productive where wells have been drilled to the closest allowable spacing. All wells in this area have been drilled to the base of the Lower Terminal Zone and perforated through both Upper and Lower Terminal sands. Well density on various properties usually ranges from one to three acres per well. Many of the wells are also perforated opposite the Ranger Zone sands which often have remained shut in behind a packer. Many operators have avoided placing the Ranger Zone on production in these wells because experience has shown that this zone often causes collapse of perforated casing as a result of excessive sand production. Immediate objectives of the operators in development by multi-zone completions were the competitive advantages to be gained from use of all available well locations to produce the most prolific zone and the most desirable oil while providing for eventual depletion of the remaining zones. Gun perforating for later depletion of these zones was not considered because of the sand problems which were encountered in producing through this type of perforation. The well density in these competitive areas is generally such that it will be possible eventually to convert wells to single zone wells and still have an adequate well density in each zone except on some small one or two well properties.

Isolation of Running Sand to Obtain Maximum Oil Capacity: In areas where the Lower Terminal is non-productive and the Ranger and Upper Terminal Zones are both productive of relatively heavy oil, the initial well capacities were below the potential required for top allotment. The majority of wells completed in such areas were perforated opposite both zones. The wells were completed as either combination wells or as Class I dual zone wells with a tubing packer set in a cemented blank section between Ranger and Terminal. The purpose of the latter type of completion was to reduce "sanding up" of the Terminal from the Ranger and occasionally to obtain a better oil gravity. However, soon after completion, it was found that the Ranger Zone was generally incapable of flowing through the annular space between the tubing and 8-5/8" casing or, if it flowed initially, it stopped soon after completion. Over eighty-five per cent of such wells have now been converted to combination wells producing Ranger and Terminal Zones together. For example, in one area noted for its sand trouble (Fault Block I) there were originally 27 Class I wells; 24 of these are now producing as combination Ranger-Terminal wells.

PERFORMANCE OF MULTI-ZONE WELLS

Effect of Allocation Methods on Use of Wells: Utilization of multi-zone completions for the accomplishment of the original purposes has been affected greatly by the method of allocation, the producing characteristics of the wells and the mechanical difficulties encountered. Well allotments prior to 1942 were based on oil potential with a uniform allotment to all wells having a potential in excess of a specified minimum. Under these circumstances wells received no benefit in allotment unless the productive capacity of the more prolific zone by itself was less than the minimum required for top allotment.

At locations where both Upper and Lower Terminal were productive, the productive capacities at the time of completion were generally such that either zone by itself had sufficient potential to earn top allotment.

Since early 1942, allocation has been made on the basis of individual zones in the various fault blocks with the pool allotment distributed to the wells by means of various allocation formulae. However, it has been the practice to allot a well oil production from only one zone at a time so that multi-zone wells have realized no benefit in allotment under the new system of allocation. At the present time most of the wells located in areas of comparatively low Terminal Zone productivity are receiving capacity allotments. These wells generally have perforations opposite both Ranger and Upper Terminal and are nearly all pumping as combination wells.

Selective Production: Selective production from multi-zone wells has proved useful in control of gas/oil ratios, water production and gravity of oil produced, and has been used by operators to gain competitive advantages in some areas. It has also been advantageous selectively to produce intervals of relatively low permeability after high head water had reached the wells in more permeable sands. In pools which receive separate allotments for Upper and Lower Terminal, selective production has permitted proper adjustment of pool withdrawal rates. Of 190 multi-zone wells reviewed, 46 have been changed from one zone to another to obtain optimum production.

A number of wells have been completed with cemented blank sections opposite shale members within the Upper and Lower Terminal, subdividing these zones into two or more subzones, any of which can be produced separately. Selective production from the lowermost interval when it will no longer flow through the tubing has been accomplished by pumping through tubing set on a packer. In eleven instances, upper perforated intervals have been produced separately after they ceased to flow in the annulus by placing a plug in the bottom of the tubing, perforating the tubing above the plug and flowing the upper zone. In other cases an intermediate perforated interval has been produced separately by placing a bridge in the cemented blank section at the base of the interval and producing through tubing set on a packer above the interval to be produced.

Cemented blank sections in multi-zone wells between perforated intervals have facilitated repair work, particularly scabbing and plugging operations designed to eliminate water sands from production. The "scabbing off" of water or gas intervals in all of the seven wells repaired by this method was successful at the time of recompletion.

Mechanical Difficulties: Numerous mechanical difficulties have developed in attempts to operate multi-zone wells. Some of the most prevalent of these are: (1) early cessation of flow from upper zones through the relatively large annular spacing between flow strings, (2) sanding up of upper zones, (3) collapse of casing caused by excessive sand production, (4) development of leaks between zones due to sand blasting, corrosion of flow strings or failure of packers and cement jobs, and (5) inability to lift adequate volumes of fluid when pumping through tubing set on a packer because of poor gas separation. The development of leaks between zones has permitted migration of fluid from one zone to another because of differential pressures developed by selective production. This has often permitted water from a wet interval to flood the sands around the well in other perforated intervals. Several instances have been found in multi-zone wells which have left the Ranger shut in behind a packer. A leaky cement job behind blank casing opposite the packer has been the source of water flooding of Ranger sands. One multi-zone well was redrilled into the Ranger after abandonment in the Terminal, because of a Ranger "water block".

To date, there has been no uniform procedure for repair work when wells reach the end of the flowing stage. Many revert to combination production of the Upper and Lower Terminal Zones, leaving the Ranger packed off behind a flow string; others continue to pump the lowermost zone through a tubing packer, while in a few cases the wells have been converted to single zone producers in an upper perforated interval after plugging the lower zones because of high water cut.

(a) Reasons for Remedial Work: The chief reasons for remedial work were bad liners, bad casing, water encroachment, cessation of natural flow and leaky tubing. Frequently, liners and tubing failure occurred concurrently with increase in water production owing to corrosion. Continued sand trouble often was the cause of eventual liner collapse. Corrosion and the setting up of differential pressures across packer installations and flow strings was the major cause for leaks. A notable fact is that 32 of the 194 wells reviewed experienced packer or flow string leaks. There were nine failures in 127 Class I wells - or only 7.1%, as compared to 28 failures in 67 casing packer (Class II, III & IV) wells - or 41.9%. These failures often necessitated reentering the multi-zone wells to replace the failure or removing the packers and flow strings completely and recompleting as combination wells.

(b) Types of Remedial Work Done: Of the 102 remedial jobs done on the 249 multi-zone wells, 32 required costly redrilling principally because of collapsed liners or casing and excessive sand trouble. Over 87% of the redrill work was done on Class I tubing packer wells.

(c) Use of Artificial Lift in Multi-Zone Wells; All of the original 249 multi-zone wells were flowing completions. Of these, 104 are now pumping and none is producing on gas lift. Of the original completions, 30 wells have now been repaired as single zone producers and 37 are combination zone producers. Of the 104 original multi-zone wells that are now pumping, 47 wells still maintain zonal segregation by means of casing or tubing packers. However, none of these is equipped to produce two or more zones simultaneously through separate flow strings by artificial lift so that for all practical purposes they are producing as single or combination wells, using the multi-zone installation for the purpose of selective production. Of the 47 multi-zone pumping wells, 19 are now pumping below tubing packers (Class I), 27 are pumping below various combinations of tubing and casing packers (Class II, III & IV), and one Class V well is pumping. Consequently, at least 114 wells, or 45.9%, of the original multi-zone completions are operated at the present time so that they are effectively single or combination zone wells.

Operators have apparently unanimously decided against employment of installations permitting simultaneous production of separate intervals by artificial lift because of the numerous mechanical difficulties previously cited; furthermore, in the case of the areas of more prolific Terminal Zone production well capacities from a single perforated interval are large. The fact that wells are never given oil allocation in more than one zone has also discouraged experimental work with multi-zone production by artificial lift.

SUMMARY AND CONCLUSIONS

Use of multi-zone completions has been useful in providing for development of several zones where limited surface locations are available and has afforded means of controlling gas/oil ratios, water production, oil gravity and pool production rates by selective production. In some wells repair work has been facilitated by the presence of cemented blank sections. In competitive areas operators have been able to gain advantages through selective production in this type of completion.

However, under conditions obtaining in the Wilmington Field it has been the general practice to revert to single or combination zone production at the end of the flowing life principally because of the many mechanical difficulties encountered which act as serious obstacles to multi-zone production by artificial lift. Leaks developing between zones, and production of wells as combination wells has led to non-uniform and undesirable combinations of zones in many of the wells under conditions which may eventually reduce oil recovery efficiency.

Considering the conditions that exist in the field, and assuming that it is desirable to develop and produce all zones simultaneously, it is concluded that development could have been more economically effected and the various zones more efficiently produced if uniform development had been accomplished by single wells to each zone (or in some areas to a combination of two zones) throughout each fault block. Wells drilled on this basis could be equipped with cemented blank sections if it were anticipated that selective production of a zonal subdivision might eventually become necessary. As far as obtaining the maximum economic recovery from the field is concerned, the competitive advantages gained by most of the operators who have completed multi-zone wells have not contributed to over-all recovery efficiency and greater recovery might have resulted from single zone development using cemented blank sections where necessary to control production. It is emphasized that conclusions in regard to Wilmington are in no way intended to reflect on decisions to use multi-zone completions in other fields where mechanical problems are less serious, drilling more expensive, and recovery from individual zones relatively low.

ACKNOWLEDGMENTS

The authors extend their appreciation to the operators in the Wilmington Field for providing the data used in this report.

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TABLE I

ANALYSIS OF MULTI-ZONE WELL COMPLETIONS IN THE RANGER & TERMINAL ZONES, WILMINGTON FIELD

AS OF SEPT. 1944

	Class of Completion - See Figures 2A & 2B					
	I	II	III	IV	V	Total All Classes
I ORIGINALLY COMPLETED MULTI-ZONE WELLS (1)	171	35 (3)	26 (3)	15 (3)	2	249 (2)
II PRESENT METHOD OF PRODUCTION						
1. Pumping	66	16	13	7	2	104
2. Flowing	105	19	13	8	0	145
III PRODUCING ZONES ALTERNATED TO OBTAIN OPTIMUM PRODUCTION						
1. Wells reviewed	125	26	24	13	2	190
2. Wells changed over from one zone to another	28	14	1	2	1	46
3. Wells never changed	97	12	23	11	1	144
IV EFFECTIVENESS OF SEPARATION						
1. Wells reviewed	127	30	24	13	0	194
2. Wells known to have had leaks in packers or flow strings	9	8	10	5	0	32
V WELLS IN WHICH REMEDIAL WORK HAS BEEN DONE	72	11	5	7	1	96
VI AVERAGE PRODUCING TIME OF REPAIRED WELLS FROM ORIGINAL COMPLETION TO FIRST REMEDIAL WORK, YEARS	3.2	4.3	2.8	4.0	1.2	3.2
VII NUMBER OF REMEDIAL JOBS DONE ON ORIGINAL MULTI-ZONE WELLS	77	12	5	7	1	102
1. Types of recompletions						
a. Multi-zone	23	2	1	5	0	31
b. Ranger zone only	11	2	2	0	1	16
c. Terminal zone only	10	2	2	0	0	14
d. Combination of more than one zone	32	4	0	1	0	37
e. Unclassified	1	2	0	1	0	4
2. Reasons for remedial work						
a. Bad liner or casing	23	1	1	1	0	26
b. Water encroachment	16	8	2	2	1	28
c. Well stopped flowing	17	1	2	0	0	20
d. Tubing went bad	5	0	0	1	0	6
e. Sand trouble	7	0	0	0	0	7
f. High gas-oil ratio	7	0	0	0	0	7
g. Miscellaneous	3	2	0	3	0	8
3. Types of remedial work done						
a. Redrilled	28	0	1	2	1	32
b. Packer pulled	20	1	0	3	0	24
c. Plug	9	3	3	1	0	16
d. Scab off water or gas	5	2	0	0	0	7
e. Plug and perforate tubing above tubing packer	6	4	1	0	0	11
f. Repair hole in tubing string with tubing patch	3	2	0	1	0	6
g. Redrill and redeepen to another zone	2	0	0	0	0	2
h. Miscellaneous	4	0	0	0	0	4

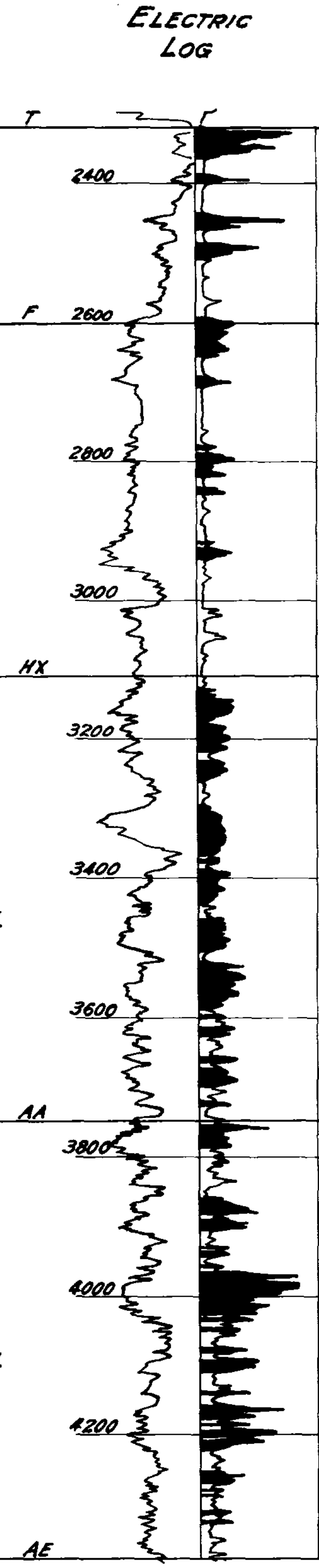
(1) In Ranger and Terminal zones only, which represent approximately 90% of the multi-zone completions in the field. A small number of multi-zone Tar-Ranger wells are not included in this review.

(2) Represents 19.3% of the producing wells in the field.

(3) Of the 76 class II, III and IV wells, 47 were equipped to produce separately from 3 zones.

FIGURE 1

THE PRODUCING ZONES IN MOST MULTI-ZONE WELLS
WILMINGTON FIELD



Zone	Zone Thickness (FT.)	Percent Sand (%)	Oil Gravity (°A-P-I)
TAR	250-400	40	12-15
RANGER	400-600	15-30	12-15
UPPER TERMINAL	400-600	50-70	14-25
LOWER TERMINAL	700	50-70	26-31

Figure 2A

Classification of Multi-Zone Wells, Wilmington Field

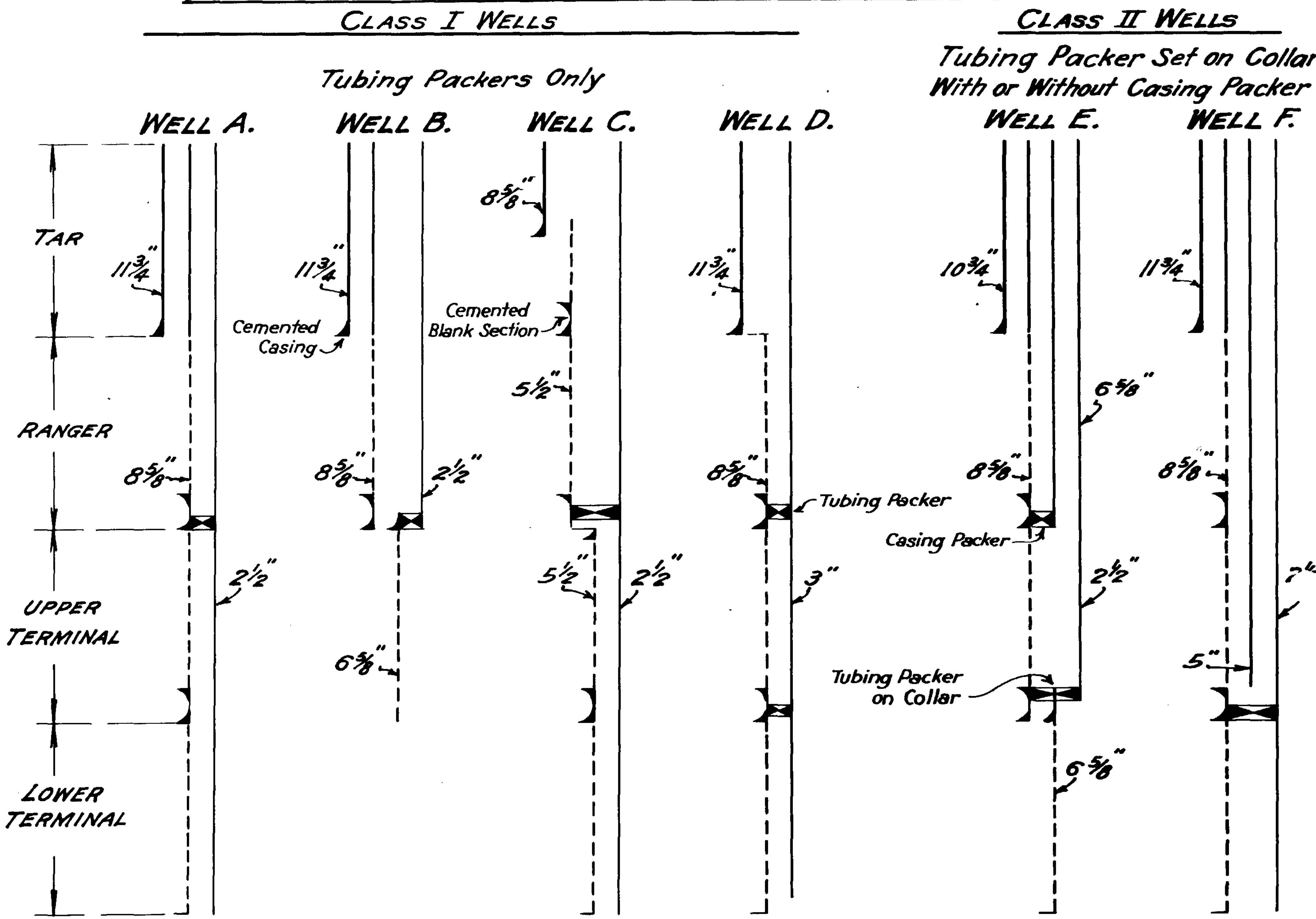
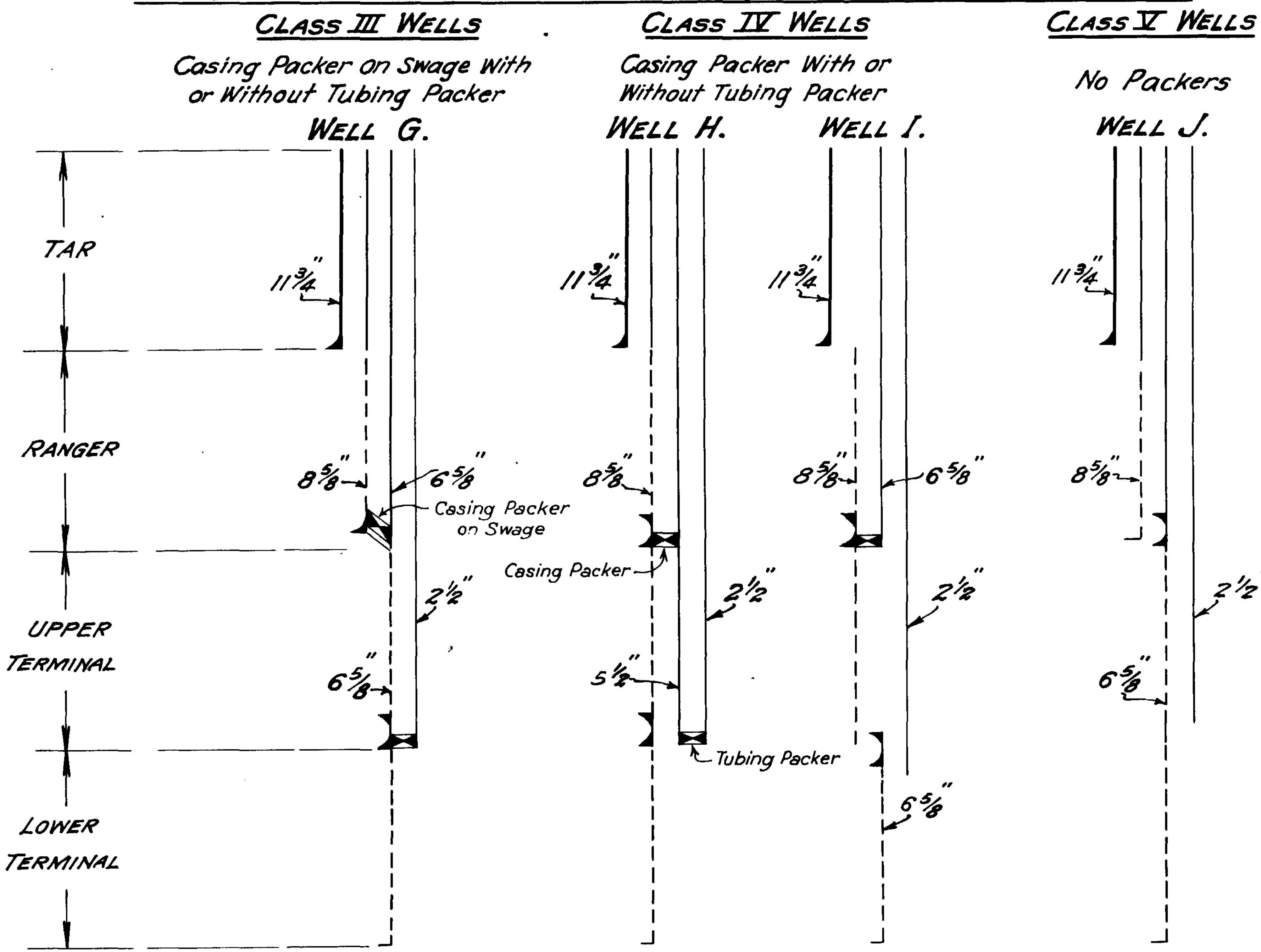


FIGURE 28

CLASSIFICATION OF MULTI-ZONE WELLS, WILMINGTON FIELD-Cont.



sentative of the number of dual wells now producing in these three states.

● **Dual completion presents problems.** The dual type well presents problems during completion and production that are not encountered with single formation wells. Drilling, running casing, and cementing dual wells present no problems other than those encountered in drilling deep single pay wells. The well becomes a dual type after the casing has been perforated opposite the two pays selected. Common completion practice is to control hydrostatically the pays while running the tubing and tubing-casing type packer.

Many makes and several types of packers are used in dual wells. In many cases packers used in dual wells are the same casing-tubing packers used in single zone wells to seal the casing-tubing annulus from the pay section.

● **Duals require sub-surface equipment.** In completing and producing a dual type well, however, it is necessary that equipment be used that will permit placing the tubing in communication with the casing-tubing annulus at will. This communication is required to relieve the upper pay of hydrostatic heads after the tubing has been run and the packer set.

The upper pay is ordinarily brought in by circulating or swabbing the tubing. Also, this communication is required, if it is desired to subject the upper pay to hydrostatic heads and control after the pay is brought in.

Several makes of packers are designed to permit placing the tubing and tubing-casing annulus in communication by moving the tubing to open either circulation holes or valves. These packers generally perform satisfactorily so long as the tubing and component parts of the packer remain free to move and no foreign matter lodges in the seat to prevent re-closing.

● **Dual packers have to withstand pressure differentials.** Another service requirement of packers used in dual wells is to withstand variable pressure differentials between the two pay zones. Frequently the pays produce with much different pressures opposite the formations and thereby subject the packer to very low or very high differential pressures. It follows that the sealing elements of the packer should be designed to withstand these pressure differentials, however small or great, from either direction.

Further, the design of the packer should be such that there will be no movement of the packer up or down the hole because of pressure differentials. Some packers utilize much of the weight of the tubing to hold them in place. This tends to crook the tubing in the casing, and in some wells has made the installation and removal of production equipment within the tubing difficult.

Fig. 1 shows a packer that was specially designed to meet problems encountered in dually completed wells. A pressure differential from either above or below this packer tends to lock it more securely in the casing. Pressure applied from above the packer will transmit a

TABLE 3

Locale and extent of dually completed oil and gas wells in Texas.

Field	County	Number of permits granted by the Texas Railroad Commission through April 15, 1946			
		Dual oil	Dual gas	*Combination oil and gas	Total
Abell	Pecos	1	..	..	1
Agua Dulce	Nueces	20	35	11	66
Alice	Jim Wells	..	3	..	3
Angleton	Brazoria	..	3	..	3
Bedford	Andrews	1	..	..	1
Benavides	Duval	1	1	..	2
Bethany	Panola	..	3	..	3
Blanconia	Bee	..	..	5	5
Blucher	Jim Wells	2	1	..	3
Blue Lake	Brazoria	..	..	1	1
Bolt	Kimble	..	..	1	1
Bonnie View	Refugio	..	..	1	1
Brayton	Nueces	..	..	1	1
Burnell	Karnes	..	..	1	1
Cadena	Duval	3	..	..	3
Cameron	Starr	..	..	1	1
Carthage	Panola	3	42	3	48
Cayuga	Anderson	..	1	7	8
Chapel Hill	Smith	..	2	7	9
Chesterville	Colorado	..	1	..	1
Cold Springs	San Jacinto	..	..	2	2
Coletta Creek	Victoria	..	..	1	1
Columbus	Colorado	..	..	1	1
Conroe	Montgomery	2	..	..	2
Daboval	Wharton	..	..	1	1
Dickinson	Galveston	1	2	..	3
Dyersdale	Harris	..	..	1	1
East Longhorn	Duval	1	..	..	1
East White Point	San Patricio	11	..	..	11
Edna	Jackson	..	1	..	1
El Campo	Wharton	..	..	2	2
Embar	Andrews	1	..	..	1
Emperor	Winkler	..	..	2	2
Estes	Ward	..	..	1	1
Fig Ridge	Chambers	3	..	..	3
Fitzsimmons	Duval	..	..	1	1
Fort Stockton	Pecos	..	..	1	1
Francitas	Jackson	..	5	..	5
Gandy	Nueces	..	..	1	1
Garcia	Starr	20	..	..	20
Goebel	Live Oak	..	..	1	1
Green Branch	McMullin	..	..	1	1
Greta	Refugio	..	..	2	2
Hamman	Matagorda	..	..	1	1
Hardin	Liberty	..	1	1	2
Harmon	Jackson	..	..	1	1
Hendricks	Winkler	..	..	1	1
Hildreth	Montague	1	..	..	1
Hull	Liberty	1	..	..	1
Humble	Harris	1	..	..	1
Humble Light	Harris	..	..	1	1
Jim Ned	Coleman	..	..	1	1
Joyce Richardson	Harris	1	..	3	4
Katy	Waller	..	4	..	4
Kelsey	Brooks	3	..	..	3
Kermit	Winkler	..	..	1	1
Keystone	Winkler	..	..	1	1
LaBelle	Jefferson	..	..	1	1
LaGloria	Jim Wells	..	15	..	15
Lake Creek	Montgomery	..	7	1	8
LaRosa	Refugio	..	1	9	10
League City	Galveston	8	..	1	9
Livingston	Polk	2	..	..	2
Lolita	Jackson	1	..	4	5
Long Lake	Anderson	..	..	20	20
Lovell Lake	Jefferson	..	..	1	1
Magnolia City	Jim Wells	1	..	..	1
Maniposa	Brooks	..	..	1	1
Mascho	Andrews	..	..	1	1
Maurbro	Jackson	..	..	1	1
Mayo	Jackson	11	..	2	13
McFaddin	Victoria	..	2	1	3
Minnie Bock	Nueces	..	..	2	2
Murray	Young	1	..	..	1
R. Musquez Survey	Jackson	..	..	1	1
Needville	Fort Bend	5	..	2	7
New Hope	Franklin	33	..	..	33
New Refugio	Refugio	..	..	1	1
New Ulm Area	Colorado	..	1	..	1
North Houston	Harris	..	3	..	3
North Magnolia	Jim Wells	6	..	2	8
Odem	San Patricio	2	..	..	2
Old Ocean	Matagorda	17	..	..	17
Old Refugio	Refugio	..	..	1	1
Opelika	Henderson	..	1	1	2
Piedras Pintos	Duval	1	..	..	1
Pinehurst	Montgomery	1	1	..	2
Placedo	Victoria	13	..	1	14
Plymouth	San Patricio	..	..	1	1
Quinto Creek	Jim Wells	..	..	1	1
Reddin	Jones	25	..	..	25
Rodessa	Jefferson	1	..	..	1
Rooke	Refugio	2	..	..	2
Runge	Karnes	1	..	..	1
San Caja	McMullen	..	1	..	1
Sand Hills	Crane	4	..	..	4
San Salvador	Hidalgo	..	5	..	5
Sarco Creek	Goliad	..	1	..	1
Satsuma	Harris	..	..	6	6
Saxet	Nueces	1	..	2	3

*Indicates upper gas and lower oil, or vice versa, type completions.

Notes: (1) Gas-condensate pays are classed gas pays.
(2) Only dual wells with both pays productive are listed.

Mechanics and economics of dual completions

By **HUBERT C. LAIRD**

Otis Pressure Control, Inc.*

EXCLUSIVE

FROM the mechanical standpoint, dual completion of a well is largely an outgrowth of the practice of controlling ratios by blocking off a part of the gas-bearing portion situated above oil-bearing portion of a producing formation. Correctly placing the packer to admit the desired amount of gas into the tubing was often very difficult. The packer had to be reset several times in many instances before the desired results were obtained.

This difficulty led to the development of equipment that made it possible to admit the gas into the tubing at the desired rate from the annulus above a packer that was set near the gas-oil contact or opposite a break between the oil-gas sections of the pay. This type of completion was practiced in the Jefferson field in the latter part of 1935 or early in 1936, followed by its application in Rodessa and Hobbs. This type of completion received some publicity in September, 1936.†

With equipment available for the type of completion just described, it was a simple matter to set a packer between two separate formations and utilize the gas from an upper zone to produce oil from a lower zone. At the same time gas could be produced at the surface from the casing. Some of the earlier dual completions were of this type, that is, upper gas and lower oil.

● **Dual completions in California.** Due to the fact that many of the fields in California have from five to seven productive formations, California operators were among the first to dually complete. In 1939 approximately 100 wells were dually completed in the Montebello field alone. It is estimated that to date there have been more than 300 wells dually completed in California, including wells in the Long Beach Harbor, Paloma, Kettleman Hills, Coalinga, Riverdale, and other fields. These dual completions do not include wells in which more than one formation is produced from the well bore without maintaining separation.

Inasmuch as there is no state regulatory body in California having jurisdiction over the drilling and producing of oil and gas wells, some operators in that state produce a number of formations through a single bore without any attempt to separate one pay from another. Other operators in California, however, have recognized that it is to their advantage in some instances to maintain separation between the productive formations and have utilized the practice of dually completing. Due to sand conditions, however, some operators feel that dual completions are not desirable, because of difficulties encountered in pulling packers when large quantities of sand settle out in the annulus above them.

● **Dual completions in the Mid-Continent.** For the last five years operators in the Mid-Continent and Gulf Coast areas have practiced dually completing oil and gas wells. Deeper drilling and the penetration of more than one economically productive pay with one well bore has induced many operators to dually complete. Critical shortages of steel and manpower coupled with urgent needs for oil during the war led to a much quicker adoption of the practice than could have been expected during normal times.

The State of Texas, because of its leading position in oil production, has the greatest number of such applications. Data from this State indicate how extensively and in which fields this type of completion has been used.

Table 1 presents a summary of such information showing the chronological progress of dually completing oil and gas wells in Texas. Table 2 shows the dual completions granted in the major fields, and Table 3 is a tabulation of the dual completions granted in all fields in Texas.

Table 4 shows that 63,098 oil and gas wells were completed in Texas, Louisiana, and Oklahoma since 1940 and that 1123 of these, or 1.78 per cent, were dual completions. Although most of the dual completions were in Texas, a slightly larger percentage of Louisiana's new wells were dually completed.

Louisiana had 153 dually completed wells. Most of these wells are of the dual oil type and are found in the Neale Hackberry, Pine Prairie, Lisbon, White Lake, and other fields. In Oklahoma approximately 50 wells have been dually completed. These are located in the Cement, Chickasha, New Garber, Pauls Valley, and West Moore fields.

The tables do not reflect the number of wells that have changed status due to the abandonment of one or more pays, as this data was not readily available. Due to the newness of production represented by dual wells, however, it is believed that the figures are fairly repre-

*Temple P. Hoffer, petroleum engineer, Otis Pressure Control, Inc., assisted in the preparation of this article.

†"Progress in Bottom Hole Choking," by H. C. Otis, *The Petroleum Engineer*, September, 1936.

TABLE 1

Chronological progress of dually completing oil and gas wells in Texas.

Period	Number of dual completion permits granted by the Texas Railroad Commission			
	Dual oil	Dual gas	*Combination oil and gas	Total
Year 1940	...	1	24	25
Year 1941	...	29	17	46
Year 1942	...	36	34	70
Year 1943	110	17	18	145
Year 1944	238	29	36	303
Year 1945	159	77	28	264
January 1 to April 15, 1946	41	10	16	67
Grand totals	548	199	173	920

*Indicates upper gas and lower oil, or vice versa, dual wells.

Notes: (1) In preparing the above table, gas-condensate pays were classed as gas pays.
(2) The above table includes only wells in which both pays are productive. Some 15 dual wells in which one or both pays are used for gas injection purposes are not listed.

TABLE 2

Summary of dually completed oil and gas wells in Texas.

Field	County	Number of permits granted by the Texas Railroad Commission through April 15, 1946			
		Dual oil	Dual gas	*Combination oil and gas	Total
Seeligson	Jim Wells	144	..	6	150
Stratton	Nueces	39	31	5	75
Agua Dulce	Nueces	20	35	11	66
Wimberly	Jones	60	..	..	60
Stowell	Jefferson	46	2	2	50
Carthage	Panola	3	42	3	48
New Hope	Franklin	33	..	..	33
Reddin	Jones	25	..	..	25
Garcia	Starr	20	..	..	20
West Ranch	Jackson	15	..	3	18
Old Ocean	Matagorda	17	..	..	17
Placedo	Victoria	13	..	1	14
Mayo	Jackson	11	..	2	13
Sheridan	Colorado	..	12	..	12
East White Point	San Patricio	11	..	..	11
LaRosa	Refugio	..	1	9	10
121 other fields		91	76	131	298
Grand totals		548	199	173	920

*Indicates upper gas and lower oil, or vice versa, type completions.

Notes: (1) Gas-condensate pays are classed gas pays.
(2) Only dual wells with both pays productive are listed.

Reprinted from THE PETROLEUM ENGINEER, *August, 1946*

TABLE 3 (Continued)—Locale and extent of dually completed oil and gas wells in Texas.

Field	County	Number of permits granted by the Texas Railroad Commission through April 15, 1946			
		Dual oil	Dual gas	*Combination oil and gas	Total
Sayles	Jones	1	..	..	1
Scott & Hopper	Brooks	.	..	1	1
Seeligson	Jim Wells	144	..	6	150
Sejita	Duval	..	..	3	3
Sheridan	Colorado	..	12	..	12
Silsbee	Hardin	.	..	1	1
South Caesar	Bee	2	..	1	3
South Esperson Dome	Liberty	.	..	1	1
Stowell	Jefferson	46	2	2	50
Stratton	Nueces	39	31	5	75
Sweden	Duval	1	..	..	1
Taft	San Patricio	..	..	1	1
Thomas Lockhart	Duval	.	1	1	2
Tijerina	Jim Wells	3	.	..	3
Von Blucher	Jim Wells	.	1	.	1
Wade City	Jim Wells	.	1	4	5
Ward	Ward	.	..	1	1
Washburn	LaSalle	4	.	3	7
Waskom	Harrison	.	1	1	2
Wasson	Gaines	4	..	.	4
Weiner	Winkler	.	..	1	1
West Beaumont	Jefferson	.	2	2	4
West Columbia	Brazoria	5	..		5
Westhoff	Jackson		1	.	1
West Port Neches	Orange		..	1	1
West Ranch	Jackson	15	..	3	18
Wheeler	Winkler	7	..	.	7
White & Baker	Pecos		..	1	1
White Creek	Live Oak		..	1	1
Willamar	Willacy	1	.	1	2
Williams	Coleman	2	.	..	2
Wilson	Jim Wells	.	1	..	1
Wimberly	Jones	60	..	..	60
Winnsboro	Wood	1	..	..	1
Woodsboro	Refugio	..	1	..	1
Unnamed field	Archer	..	1	..	1
Unnamed field	Hidalgo	..	1	..	1
Grand totals		548	199	173	920

*Indicates upper gas and lower oil, or vice versa, type completions.

Notes: (1) Gas-condensate pays are classed gas pays.
(2) Only dual wells with both pays productive are listed.

force from the upper packer element through the body of the packer to the slip mandrel, thence to the slips, and finally into the walls of the casing. Pressure from below will exert a downward force on the slip mandrel, because of the difference in areas of sections represented by the diameters of the polished collar and the outside of the main mandrel. This pressure locking feature permits the secure installation of the packer in the casing without applying any force from the tubing. If an operator wishes to support part of the weight of the tubing string on the packer, however, the packer is designed to stand it. In practice, the tubing is landed so that the polished collar is resting the desired amount on the slip mandrel.

The opposed-cup type packing elements are very effective in sealing against high and low pressure differentials. This packer also possesses a feature not found in all packers; that is, the only operation necessary to pull the packer is to pull up the tubing. Rotation of the tubing or feeling for J-slots is not necessary. This packer like some others is constructed with a by-pass for running, pulling, and, in the case of two-zone wells, washing in the well.

● **Removable subsurface equipment used in dual wells.** The necessity of placing the tubing in communication with the casing-tubing annulus during dual well completion operations has been stated. In order to open the annulus to the tubing by means of packers it is necessary to move the tubing. In production operations this is both time consuming and costly once the tubing has been landed and surface connections made. Efficient production of two-zone wells requires that equipment be used that will readily and positively open and close the tubing to the annulus. Removable subsurface equipment is being used to meet both completion and production problems.

Fig. 2 represents a bottom-hole choke that is installed and removed on a wire line. The side door choke assembly consists essentially of three parts; namely, the landing nipple, the side door choke, and the check valve. The landing nipple has four ports in the wall and is made up in the tubing string at the time the tubing is run. Whereas, the side door choke and check valve are run and pulled under pressure on an ordinary steel measuring line. The choke proper consists of a pack-off section and a locking device.

The packing is arranged so that flow around the pack-off section is prevented regardless of whether the greater pressure is from the upper or lower zone. The purpose of the check valve is to prevent flow from the upper zone, through the landing nipple, and into the lower zone. This equipment is ordinarily installed immediately above the packer in a two-zone well and has provided an effective means for operators of dual wells to perform the following completion and production operations.

1. Acidize either zone independently of the other.
2. Take pressures of each zone independently of the other, even though the upper zone possesses a higher formation pressure.
3. Kill the well by circulating through the side ports.
4. Circulate above and wash loose sticky packers that have to be pulled.

Fig. 3 shows an application of side door chokes to independently acidize zones in duel gas wells in the Carthage, Texas, gas field*. This application is considered unique, because the side door choke in conjunction with a second packer enabled the selective acidizing of certain sections of the lower pay zone.

● **Landing nipple used in testing packer setting.** Fig. 4 represents a type of landing nipple that is being used with the type of side door choke shown in Fig. 2. This nipple is equipped with a lead washer and washer support that will withstand excessive pressure differentials provided the higher pressure is applied on the annulus side of the nipple. If the higher pressure is applied inside the tubing, however, a very small differential will shear the lead washer and connect the tubing and annulus. Once the washer is sheared the nipple and choke function in the same relation as that shown in Fig. 2.

The main purpose of this tool is to expedite testing the packer for leakage. The packer is set and pressure applied immediately in the annulus. If the packer is not leaking, then pressure is applied inside the tubing and the side ports in the landing nipple opened for subsequent completion and production operations. The above procedure enables the operator to test the packer prior to bringing in the upper pay. If the packer is not sealing, the operator does not have to kill the well again to remove, re-run or re-set the packer.

● **Zones switched without removing choke.** Another type of side door choke that is being used successfully in certain areas permits switching either upper or lower pay into the tubing without removing the choke from the well. The assembly consists essentially of a landing nipple that is made up as a part of the tubing string, the side door choke, and a removable plug. The nipple contains two sets of side ports rather than the

*"Selective Acidizing Increases Well Capacity" by Paul L. Shelton and J. M. Clark, *The Petroleum Engineer*, May, 1946, Pg. 235.

TABLE 4—Number of oil and gas wells completed in three states by years.

Year	Texas	Louisiana	Oklahoma	Total
1940	9,775	1,704	1,747	13,226
1941	9,827	1,664	2,110	13,601
1942	4,688	879	1,159	6,726
1943	4,421	673	1,184	6,278
1944	5,696	786	1,791	8,273
1945	7,650	1,167	2,445	11,262
1946 (to May)	2,558	411	763	3,732
Totals	44,615	7,284	11,199	63,098
Dual completions	920*	153	50	1,123
Percentage of total	2.06	2.10	0.45	1.78

*The 920 dual completions in Texas were made in 137 fields by 159 operators.

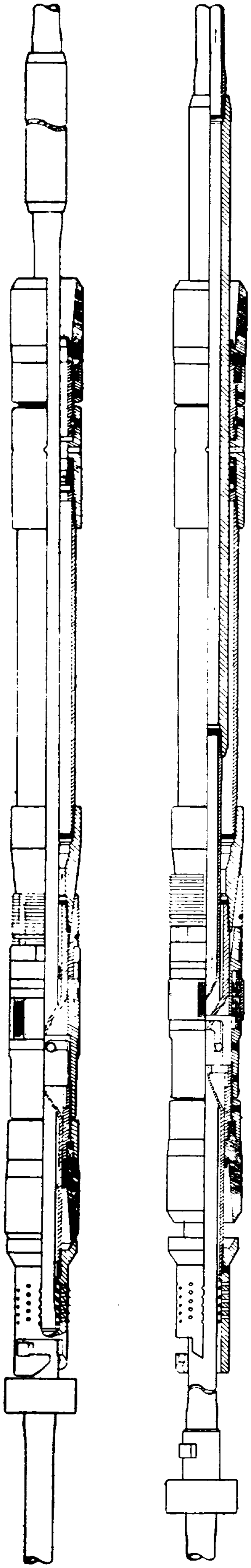


FIG. 1

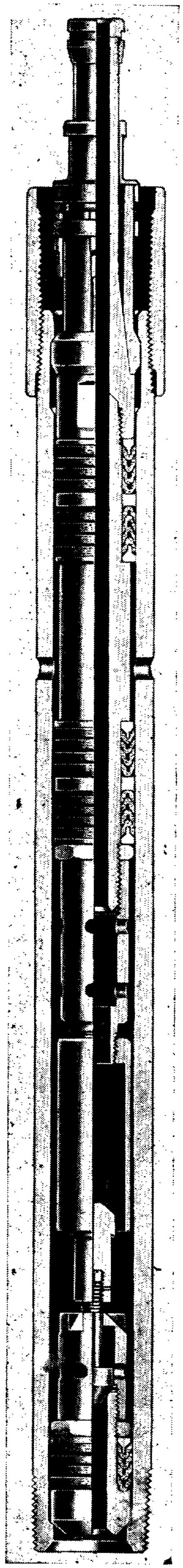


FIG. 2

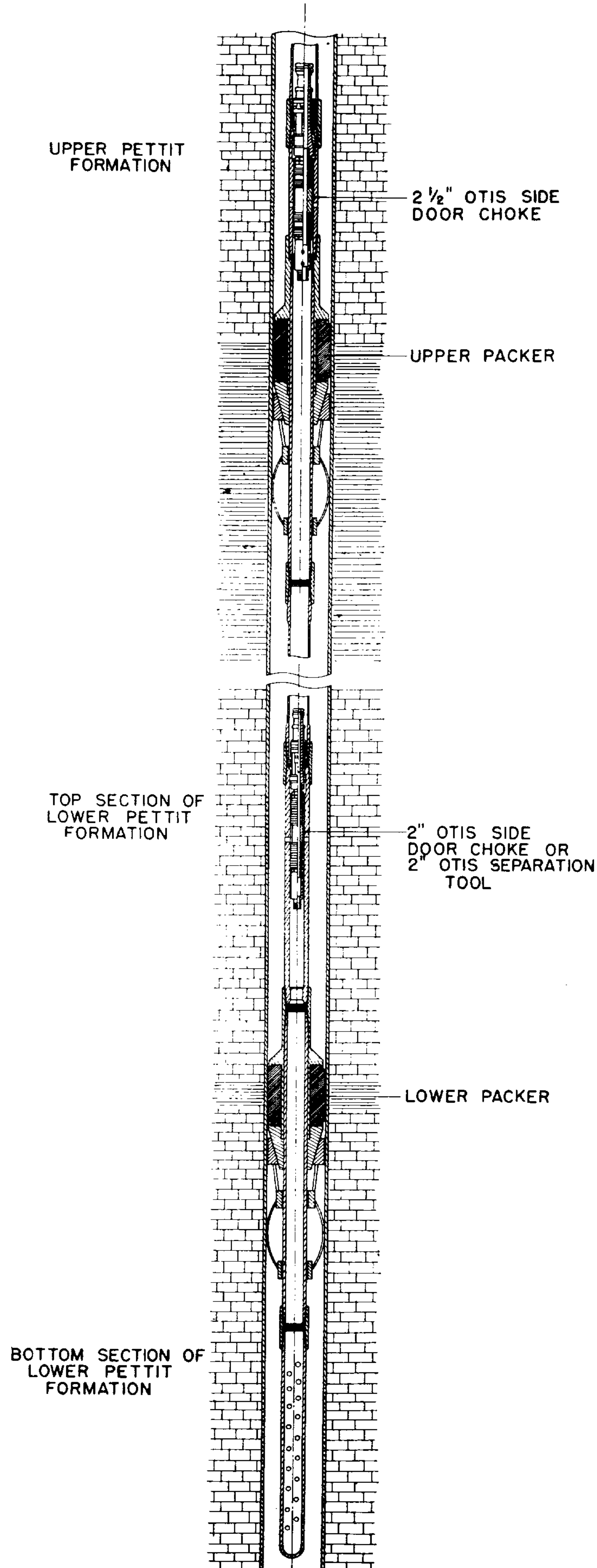


FIG. 3

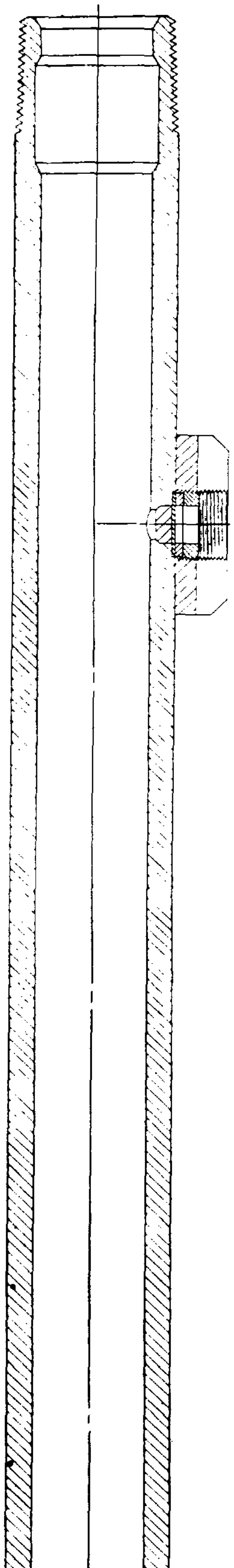


FIG. 4

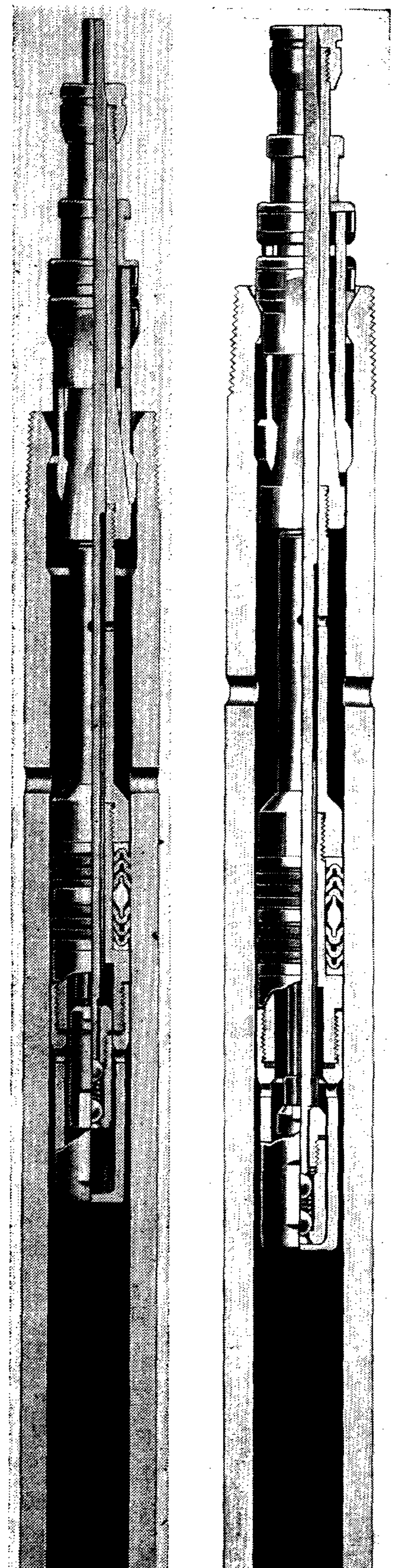


FIG. 5

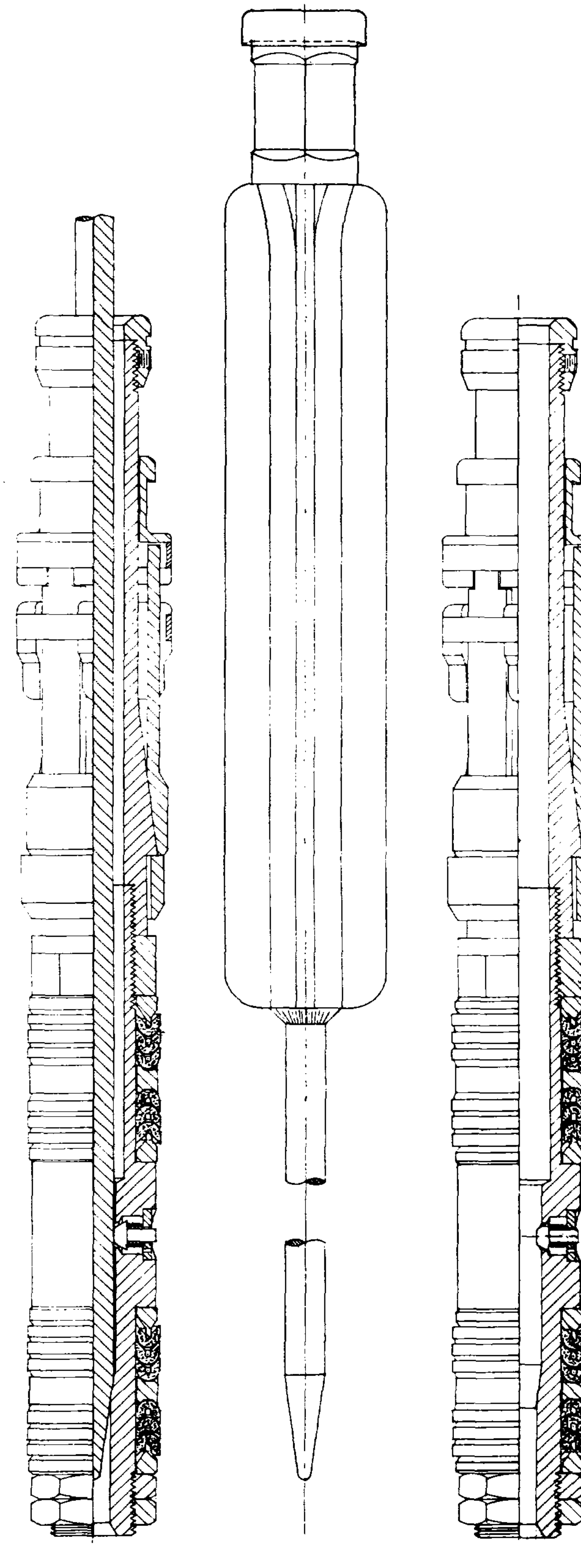


FIG. 6

one set shown in Fig. 2, the lower set of ports being enclosed by an enlarged section of tubing that connects these ports into the tubing rather than the annulus. The removable plug is locked into an extension of the landing nipple, which extends into the enlarged section of tubing beneath the lower set of side ports. The choke is run and pulled and landed in the nipple under pressure on a steel measuring line.

The side door choke is made up of a locking mechanism that will permit the choke to move within the nipple and a packoff section on which are mounted eight sets of vee-type packing. When the choke is in its uppermost position within the nipple opposed sets of packing completely block off the upper set of side ports and the lower set of side ports are left open. When the choke is moved to its lowest position in the nipple the lower set of side ports is blocked off by the vee packing leaving the upper pay connected into the tubing through the upper set of side ports.

By means of small tools run under pressure on a steel measuring line the choke may be driven to its lower position or raised to its upper position in the nipple in order to connect either the upper or lower pay into the tubing as is desired. This choke makes it possible to perform the following operations without removing the choke from the nipple and connecting the two pays.

(1) Take bottom-hole pressures or flow potentials of each zone independently of the other.

(2) Establish circulation to kill the well or wash out above a packer.

(3) Swab in either pay through the tubing.

The purpose of the removable plug, which is located in the nipple below the lower ports, is to provide a means for opening the lower end of the nipple in the event the annular space surrounding the lower ports should become blocked with sand or trash.

● **Separation tool used for testing upper pay.** Fig. 5 illustrates a tool that is frequently used in the type landing nipple shown in Fig. 2. This equipment is known as a separation tool and is used to test the upper pay of dual wells for pressure, potentials, kind of fluids, etc. The assembly consists essentially of two parts; namely, the landing nipple and the separation tool proper. The nipple has side ports and is run in the tubing string. The separation tool consists of a locking device, a mandrel on which is mounted opposite sets of vee-type packing, a prong, and a valve and shear washer component.

One view in Fig. 5 shows the tool in the "up" position with the lower pay closed off. The upper pay is opened into the tubing. When testing of the upper pay is completed, the prong and tool are driven with wire line tools to the position shown in the second view. In so doing a metallic washer is sheared, permitting the pressure of the two pays to equalize across the tool. The tool is then ready to be removed by means of small tools run and operated on an ordinary

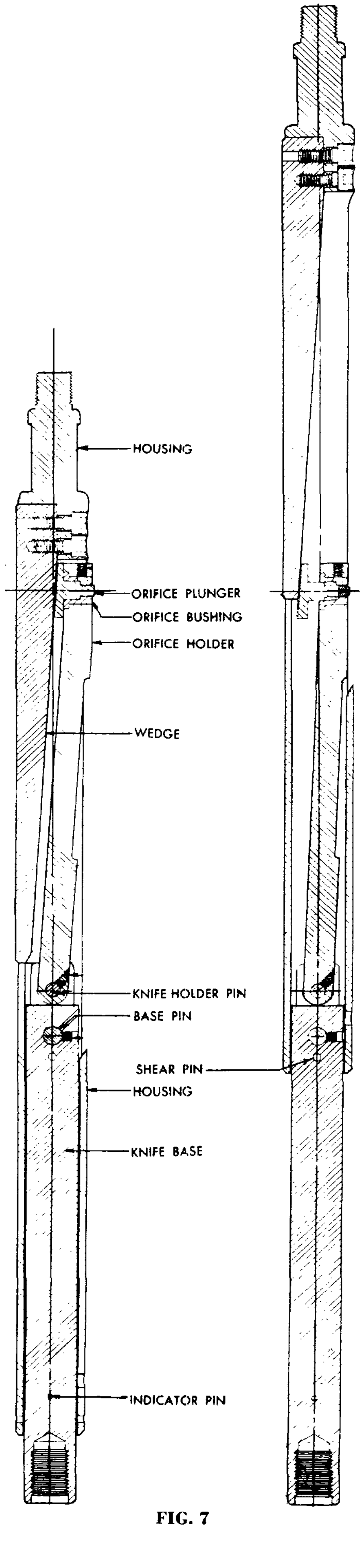


FIG. 7

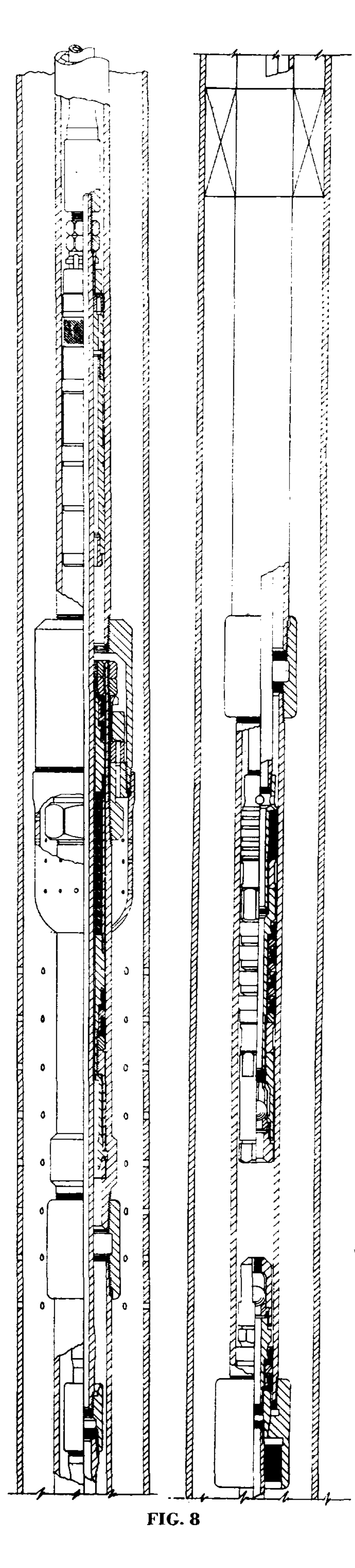


FIG. 8

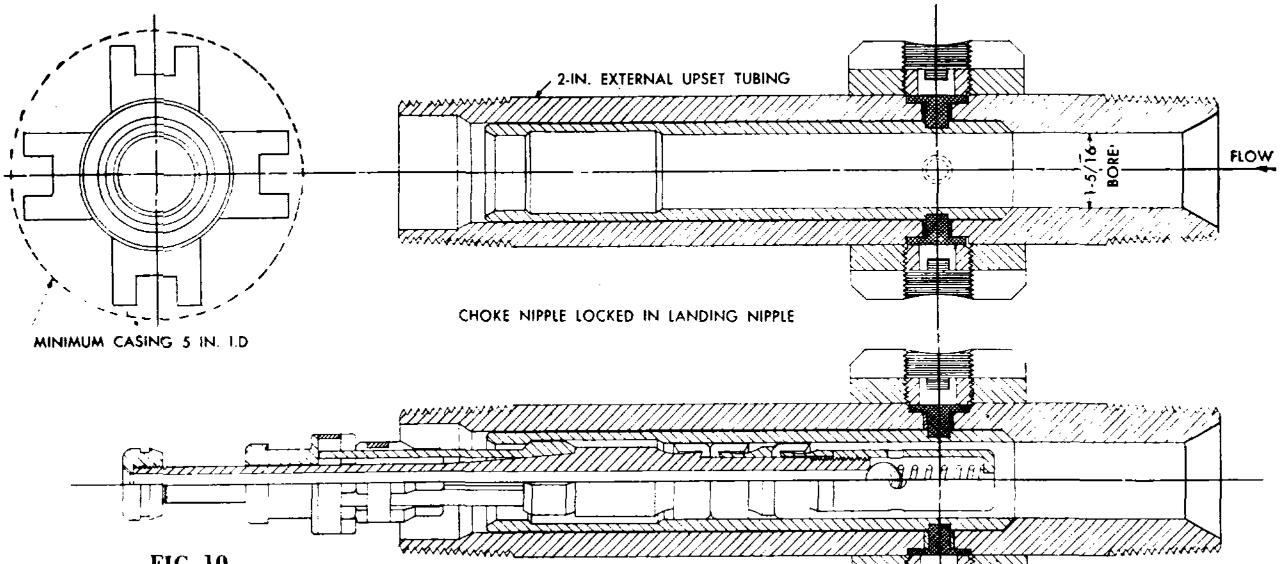
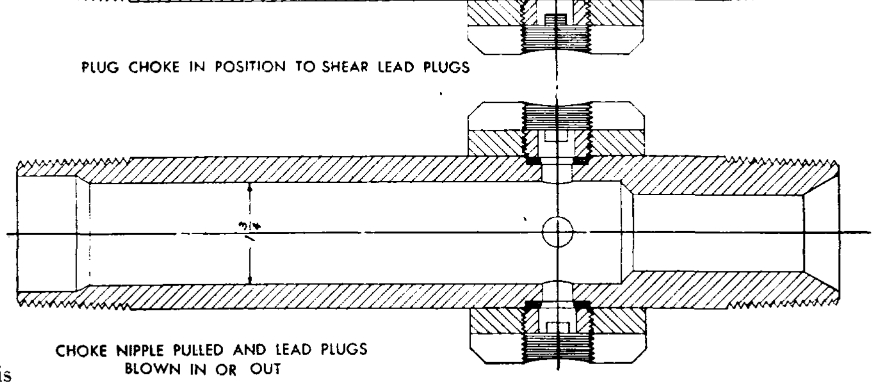


FIG. 10



tated by the failure of some mechanical part of the dual well installation properly to maintain separation. In other cases the remedial work was required due to causes common to singly completed wells. Examples of this are found in operations to correct bad cement jobs, to open more of the pay sections, to shut off water, to repair leaky tubing, etc.

● **Disadvantages of dual wells.** It is true that, because of the necessity of taking care of two formations, workover time on dual wells is usually longer than on singly completed wells.

Sometimes, however, operators may charge expenses and troubles to the fact that the well is a dual producer, when the troubles are actually the same that would be encountered in a single producer.

● **New equipment being developed.** News tools and equipment are being designed and developed to enable operators to cope with the problems involved in producing dual wells. A new type packer that departs from the use of conventional hook wall slips and large unsupported packing elements has been designed especially for use in dual wells. This packer lands in a nipple that is a part of the casing string. The inside diameter of the landing nipple is machined to a definite diameter within close limits and has a fine machined finish. This nipple provides a definitely located precision seat for the packer. The packer itself carries heavy locking lugs, which are expanded beneath the lower end of the landing nipple by a special joint of tubing through the packer to lock positively the packer in place. The packer is provided with vee-type asbestos base packing, which is a close slide fit in the bore of the nipple and is capable of withstanding high bottom-hole temperatures and pressure differentials.

The side door choke arrangement shown in Fig. 2 is so constructed that flow from the upper into the lower pay is prevented when the choke is removed from the nipple. The check valve will not prevent the flow from the lower into the upper pay with the choke removed, however. To prevent flow of lower pays into upper zones, a side door choke landing nipple with external check valves on the side ports has been designed (Fig. 9).

A side door type choke has been designed to establish communication between the tubing and tubing annulus without the necessity of removing the choke from the nipple with a wire line. The ports in the nipple are opened by applying pressure to the tubing. This pumps the choke to its down position in the landing nipple, placing all the packing below the side ports, thus opening them into the tubing and annulus. This tool should be very useful in cases of emergency when it is necessary to kill the annulus pay safely and rapidly. The necessary pressure could be applied by connecting a pump to the flow line of the tubing pay.

In Fig. 10 is shown an assembly designed to provide a means for establishing communication between the pays. It consists essentially of three parts; namely, a landing nipple, a sleeve fit within the nipple, and a special plug choke. The special nipple and sleeve, as seen in the upper view, will be made up in the tubing string just above the packer. The well will be produced normally through the nipple and sleeve as shown in this view. The inside diameter of the sleeve is large enough to pass greater flow volumes than some other chokes. When it becomes necessary to connect the annulus with the tubing, the plug choke is run on an ordinary steel measuring line or dropped into the tubing and seated in the sleeve as shown in the center view. The running tools are removed from the well and the tubing opened to flow. When a pressure differential of approximately 200 lb. per sq. in. is established across the plug choke, pressure will blow the sleeve and choke from the nipple by shearing the ends of lead plugs. Then pressure differential across the lead plugs will shear and displace them, connecting the tubing and annulus. The plugs may be easily sheared by applying pump pressure if necessary. The side ports can be quickly opened without use of wire line equipment or moving the tubing, and should prove useful for circulating above a packer in single completions as well as duals.

Many wells in many fields have been dually completed with satisfactory results, both economically and mechanically. It is true that many problems remain unsolved, but it must be recalled that dual completions are relatively new, and that many of the problems became apparent at a time, during the war, when neither the operators or equipment manufacturers were in a position to meet the problems. Both the operators and the manufacturers have made considerable progress, however, in developing technique and equipment to meet the requirements of this type well. The economic advantages of dual completion practice in many instances is expected to foster continued development of improved equipment and production practices.

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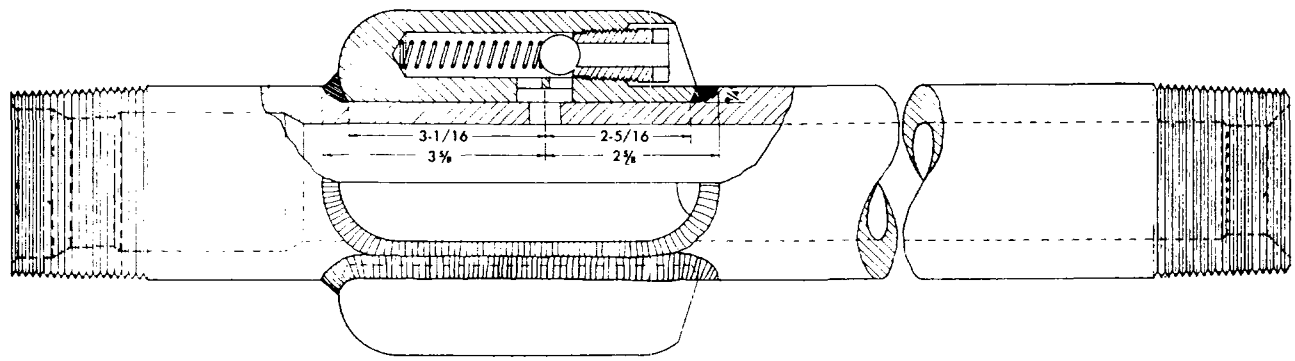

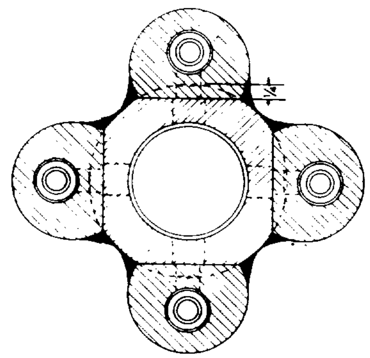

FIG. 9

steel measuring line. After removal of the tool, a side door choke of the type shown in Fig. 2 is placed in the well and separate production of the two pays resumed.

Shown in Fig. 6 is another type side door choke that is used to take pressure of the upper pay, without pulling the choke, when its pressure is greater than that of the lower pay. The right view shows the choke as it would normally be used in a dually completed well. In the picture can be seen a valve installed in the mandrel of the choke, and near the bottom of the mandrel can be seen a valve seat. To take the pressure of the upper pay, the prong tool is run on a wire line into the choke as shown in the left view. The guided prong functions to open the mandrel valve into the tubing and also close off the lower pay by seating in the bottom of the mandrel. This equipment is effective in some wells that produce sand with the oil.

● **Wire line tubing perforator used.** Some wells were not equipped at the time the tubing was run so that communication between the tubing and tubing-casing annulus could be established by removing or shifting equipment in the well. In removing the tubing and packer from the hole for work-over purposes it is very often necessary that the well be killed before unseating the packer. Fig. 7 shows equipment that has helped operators solve this problem.

This wire line tubing perforator is a mechanically-operated tool that is run on an ordinary steel measuring line into the tubing of a well, under pressure, to drive ¼-in. diam. holes through the wall of the tubing. The perforator consists essentially of a housing, a tapered wedge, a base, and a perforator punch assembly. The perforator with auxiliary tools is run in the tubing to the position in the tubing string that circulating holes are desired using a wire line stuffingbox and lubrication. Then, by manipulating the wire line on the surface, as many holes as desired may be punched through the tubing. With a removable check valve placed beneath the perforations, the operator can circulate the desired fluid to control hydrostatically the upper and lower pays before disturbing the tubing or packer.

● **Macaroni tubing reduces ratios in dual wells.** Many operators of dual wells have experienced high gas-oil ratios when flowing the upper pay through the annulus. In many of these cases the excessive ratios are due to the inefficient flow string represented by the tubing-casing annulus, because the large flow area permits much gas slippage. Excessive ratios have been reduced effectively by the use of a macaroni string of tubing run inside the regular tubing and having a packoff assembly that lands in a side door choke landing nipple. The packoff assembly, which is run on the lower end of a macaroni string, is provided with a valve that closes the lower end of the string to allow its being run under pressure. When the packoff lands in the nipple the weight of the macaroni string opens the valve and the packing is so placed in the nipple that flow from the lower zone is through the macaroni string and flow from the upper zone is admitted through the side ports in the nipple into the annular space between the macaroni string and the regular tubing. The upper pay is afforded a much more efficient flow string. Also, in some wells, the macaroni string connected to the lower pay might yield more desirable ratios.

● **Pumping assembly for dual oil wells.** In some fields upper and lower oil pays have ceased to flow, thus creating the need for pumping equipment to separately and simultaneously produce the pays. In Fig. 8 is shown a dual pump that has effectively pumped dual wells less than 3000 ft. deep. The assembly consists of the following: a hollow pumping string (¾-in. upset tubing has been used), an upper pump, a lower pump, and a pack-off section separating the two pumps. The upper pay is produced through the tubing-pumping string annulus, and the lower pay is produced inside the hollow pumping string. The writer understands that this equipment is being used to pump simultaneously both zones of about 20 dual wells that have an average depth of about 2800 ft.

● **Advantages of dual completion.** Although there are some factors unfavorable to dual completion, there are other factors favorable to the practice. Dual completion permits a well to receive two allowables to pay out such major expenditures as cost of hole, casing, and producing equipment that formerly had to be paid out of one allowable. In shallow fields the pay out time for a dually completed well is much shorter than for wells singly completed to the same producing formations. In deeper fields the added depth necessary to reach a second productive pay is hardly appreciable when compared to the depth required to reach the first productive horizon. It is in the deeper fields that the initial investment savings are the greatest, and many operators are of the opinion that it would not be economically feasible to drill some wells to one pay alone.

Regardless of depth, the initial expense of drilling a dual well is usually much less than, for example, drilling twin wells to the producing formations, or waiting until the depletion of the upper pay, and then drilling the well deeper to produce the lower pay. Most operators acknowledge the initial savings to be had, but some state that money spent subsequent to completion in the form of work-overs and remedial operations more than offsets the savings effected, inasmuch as the expense of reworking dual wells has been very high in some cases.

These expenses are sometimes necessi-

ECONOMICS OF MULTIPLE COMPLETIONS

The aspects of multiple completion of wells in New Mexico as affects conservation are as follows:

1. Since it is a basic fact that as much oil can be produced from one well bore by dual or multiple zone completions as can be produced from two or more individual wells, most states have approved rules and regulations permitting such operation, under proper supervision.

2. It will be generally agreed that in certain instances the production from one pool only will be economically impractical whereas simultaneously producing from two pools through a common well bore will result in a pay-out on investment and a profit to the operator. The right to so complete a well is, therefore, definitely a conservation measure since lack of the right would undoubtedly result in the failure of the operator to drill a well to one or both pools, leaving many barrels of oil in place which would otherwise be recovered. The production obtained from zones which would not allow individual well completions due to economics would definitely benefit both the royalty owner and the State.

3. The arguments for dual completions are based almost entirely on an economic consideration which is undisputedly the principal consideration in conservation. The additional cost of dually completing a new well will increase the cost of the well by some 20 to 25 per cent. It is rather obvious therefore that less attractive pools can be exploited than would be possible if multiple development was required.

Following are detailed cost estimates showing the economic advantage of dual completion:

SUMMARY OF TOTAL SAVINGS BY DUAL COMPLETION

Combination Zone	Bbl Recovery	Example	At Average Cost of Drilling to Date	At Present Cost
Drinkard & Ellenberger	280,000	1-A	$65,287	$43,094
	560,000	1-B	44,287	22,094
	360,000	1-C	59,287	37,094
	480,000	1-D	50,287	28,094
Holt & Ellenberger	320,000	2-A	46,671	20,822
	600,000	2-B	25,671	-178
	520,000	2-C	31,671	5,822
	400,000	2-D	40,671	14,822
Holt & Drinkard	360,000	3-A	34,053	18,184
	200,000	3-B	46,053	30,184
	280,000	3-C	40,053	24,184

MULTIPLE COMPLETION PRACTICE

Most multiple zone completions involve only two producing horizons, although a comparatively small number of wells have been completed with three producing horizons being produced separately. In a majority of instances all the horizons flow although there are numerous cases where one zone flows and one zone is lifted artificially, and a few cases where two zones are pumped simultaneously. One or two instances have been reported where two horizons were produced simultaneously by gas lift.

The practice of pumping two zones alternately reached considerable proportions in Kansas but was recently discontinued. In this type of completion it was necessary to raise and lower tubing through a packer in order to pump each zone alternately. This practice caused an excessive amount of leakage, or failure of the packer seal between tubing and packer.

Texas has the greatest number of multiple completions of any mid-west state.

Most dual completions utilize the annulus between tubing and casing for producing the upper horizon and utilize the tubing for producing the lower zone. A standard packer, run on tubing and set between the two zones, and a side door choke, to facilitate completion and permit access to either formation, is all the special equipment required. This procedure lends itself readily to artificially lifting the lower zone. The principal drawback is the relative inefficiency and difficulty of sustaining flow through the annulus. As an aid in overcoming this difficulty, a double side door choke has been devised which permits both zones to be flowed alternately through the tubing. Vertical movement of four inches is required to change the ports in the tool. This movement is accomplished by a wire line attachment for raising and lowering the choke.

A device known as the Lewis valve has been used to unload condensate or fluid from the annulus. In this arrangement a packer and the Lewis valve are run on tubing, usually 4". A macaroni string of tubing is run inside the production string and attached to the Lewis valve. Time and pressure actuated surface equipment automatically raises and lowers the macaroni string periodically, permitting the annulus to unload through the macaroni string when the valve is in the raised position. The lower zone produces through the production string at all times and can unload through the macaroni string when the valve is lowered.

The usual procedure of producing the upper zone through the annulus and the lower zone through the tubing may be reversed, if desirable, by using two packers, one of which is a "cross-over" type. In one type of installation both packers are run on tubing and set simultaneously. In another type of installation, the bottom packer is non-removable and is run on drill pipe or tubing prior to running the upper or "cross-over" packer, which is run on the production tubing. The lower packer is set between the producing zones and the cross-over packer is set above the top zone. A section of flush joint tubing extends through the lower packer.

FORMATION CHARACTERISTICS - DRINKARD AREA

	Paddock (Holt)	Blinbry	Tubb	Drinkard Vivian	Drinkard Andrews	Ellenberger
Initial BHP	2120 lbs @ -1825'	2300 plus*		2660 @ -3050'	2812 @ 3525'	3150 @ -4650'
Original Sol. GOR, Diff.	771			1178	1117	1132
Flash	951			1402	1385	1349
Sat. Press.	2000			1959	2326	2918
Viscosity, Cp. Sat. Pr.	.76			.54	.63	.29
Residual	2.48			2.9	2.58	2.0
BHT	102° F			104°	106° F	130° F
Oil Gr.	36 - 38			41-42	43	41
Perm. Range	0-300 MD			0-700 MD	0-40 MD	0-220 MD**
Por. Range	4-22%			3-21%	1-13%	1-16%
H_2S	yes	no	no	no	no	no
Well	Paddock #1			Vivian #1	Watkins #1	Sticher #2
Flowing Test	5-3-45			3-4-46	3-10-46	9-30-46
Rate Bbl/Day	99			155	79	110
GOR	475			4222	1263	948
Csg Pr	975			1600	-	615
Tub Pr	580			1240	625	925
BHP	2024 (-1874)			2024	2370	3008
Rate Bbl Day	453			509	259	552
GOR	461			3258	1240	1037
Csg Pr	1010			975	1175	615
Tub Pr	330			700	600	925
BHP	1331			1169	1437	2920
P.I.	.537			.411	.24	5.16
Static Pr.	2137			2407	2495	3027
Static Pr.	1832 12-1-45		2561	2216	2312	2990
			5-13-46	5-14	5-14-46	11-13-46
Static Pr.	1765		2510	2180	2107	
	2-20-45		8-24-46	8-22	8-22-46	
S Static Pr.	1525		2094	2213	1903	
	5-20-46		9-22-46	11-14	11-30-46	
Static Pr.	1386					
	9-6-46					
Static Pr.	1344					
	11-13-46					

* 15 min. build up pressure in DST was 2300 lb.

** Permeability occurs mostly in fractures, which are not measured in laboratory tests.

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ECONOMICS OF MULTIPLE COMPLETIONS IN MARGINAL PAYS

Although multiple completions show an improved payout and overall profit in most instances, the practice appear particularly applicable to pays which are marginal in nature.

In the Drinkard area there are two pays, the Blinbry and Tubb, which on the basis of present information appear to be gas-distillate zones. Although data are inadequate for making accurate estimates of recovery, it appears that recovery will probably not exceed 25,000 Mcf gas and 500 bbl of distillate per acre. On this basis, net revenue, after taxes and royalty would amount to $1,050* per acre or $42,000 for a 40-acre well. Assuming $75.00 per month operating expense and a twenty-year life, total operating expense would be $18,000 leaving only $24,000 to pay drilling and equipment expense. Since drilling and equipping wells in these formations will cost approximately $65,000 for Blinbry and $70,000 for Tubb wells, it is obvious that these pays could not be exploited on 40 acre, or even 80-acre spacing. However, the exploitation of these formations would be profitable in a dually completed well and, in cases where the other pays are doubtful the possibility of making a dual completion might well be the deciding factor in determining whether or not to drill a well.

It also appears that the Paddock, Drinkard and Ellenberger pays will be marginal over certain portions of the area, and the use of dual completions in such cases may have a definite bearing upon the completeness of development and the overall efficiency of recovery. A case in point is Gulf's L. I. Baker, Section 5-22S-37E, currently being drilled to the Ellenberger pay. This well appears to be near the edge of the Ellenberger pay and will probably have a thin pay section and produce water early in its life. Overall recovery is expected to be approximately 100,000 bbl, and due to early water production, operating expense will undoubtedly be above average, possibly amounting to 20¢ per barrel. Estimated life of the wells is $8\frac{1}{2}$ years of which 6 years will be required to pay out the drilling cost and net profit will amount to only $17,000. Considering the risk involved, cost of tank batteries, etc., this is a rather poor investment. However, if the Drinkard pay, which in this area appears to be fairly productive, can be exploited through the same well, the Ellenberger oil can be recovered for total additional expense of $62,000 and total profit of $67,000. In the case of the Baker well the Ellenberger pay will be exploited regardless of dual completions but it is doubtful if very many wells of this type would be drilled and certainly wells which might recover only 50,000 or 75,000 barrels could not be drilled.

* Gross income $.02 per M for gas & $1.55 per bbl for distillate.

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PRORATION ASPECT OF MULTIPLE COMPLETIONS

The general rules and regulations now in effect in New Mexico concerning proration are adequate and will be applicable to multiple completion wells as outlined in the Gulf application.

A duly authorized representative of the Oil Conservation Commission may make such tests as he deems advisable to determine that segregation of the pools producing in a multiple completion well exists.

RESERVOIR ASPECTS OF MULTIPLE COMPLETIONS

In the Drinkard area there are five pay horizons below a depth of 5000'. These pays and their approximate depths are tabulated as follows:

Paddock (Holt)	- 5100'
Blinbry	- 5500'
Tubb	- 6150'
Drinkard	-6500-6900'
Ellenberger	- 7900'

The principal oil productive zones are the Paddock, Drinkard and Ellenberger pays. Characteristics of these pays are shown on the attached summary. The Blinbry and Tubb pays are primarily gas-distillate zones and very little reservoir information has been developed. However, from the standpoint of multiple completions these formations are considered quite important both because the economics of single completions in these pays are questionable and because they may occur principally in areas where the other pays are marginal.

Although it is anticipated that production from the various pays will be produced separately, the possibility of accidental or temporary commingling does exist, and the effect of such commingling has been considered. With the possible exception of the Ellenberger zone, which may prove to be a water-drive reservoir, the other reservoirs are similar in characteristics and there is little or no possibility of damage. At present the Ellenberger pay has a considerably higher pressure than the other pays, and should this condition continue after water encroachment becomes serious, the segregation of this pay might become more important. Even in this eventuality, however, there are compensating factors which reduce the possibility of damage resulting from commingling. There is already evidence of declining pressure in the Ellenberger and even though a water drive is present, it may occur only at reduced pressure. Also, the greater depth of the Ellenberger formation reduces the effect of the differential pressure. Further it is considered that even though water temporarily entered any of the other pays, no permanent damage would be done. Water is commonly used to kill wells without any resulting damage.

The matter of ascertaining whether or not segregation is actually accomplished will undoubtedly be important insofar as enforcement regulations are concerned. The Paddock oil contains sulphur and is the only pay so affected. Consequently the commingling of Paddock production with that of any other zone could be easily detected. Under present conditions the commingling of Ellenberger oil with that of any other formation would be indicated by pressure effects and if the formations produce water, analysis of the water would be indicative. The commingling of Blinbry or Tubbs production with any other pays would, in all probability, be reflected in gas-oil ratios.

Multiple completions would probably complicate, to some extent, the problem of obtaining reservoir data. It is considered inadvisable at this time to make definite or specific recommendations regarding taking bottom-hole pressures, etc. in such wells. In general, it is believed that multiple completions will be more applicable to marginal or small wells, which are frequently unsuitable for use in obtaining reservoir data, and that in any particular area there will ordinarily be enough single completions to permit obtaining essential data. As long as all zones flow, the taking of reservoir data can be accomplished either by the use of side door chokes or by using fluid level determinations, and it is considered that reservoir data, subsequent to the installation of artificial lift equipment is of secondary importance.

The probability of oil produced from one zone being credited to another zone has also been considered. It is believed that segregation under the proposed rules, with reasonable enforcement of regulations will eliminate any commingling other than a negligible amount which may occur accidentally or temporarily. Even though commingling should be permitted during the extreme later life, a large majority of the production will have been obtained and the total production of any particular reservoir can be determined accurately enough for any but strictly academic purposes. Such academic accuracy is seldom of any practical value and is considered to be of negligible importance as compared to obtaining the greatest possible economic recovery.

The production of two zones, both of which flow, or the production of one flowing horizon and one requiring artificial lift, has been accomplished in numerous instances, and appears entirely practicable from a mechanical standpoint. Some difficulty has been encountered due to packers leaking, sanding up and sand cutting, but these do not appear to be serious. Also, it may be anticipated that special conditions such as extremely high differential pressures, high temperatures or extreme paraffin conditions might require special consideration and might, in some instances, make dual completions impractical.

The production of two zones both of which require artificial lift has had a rather limited application. Some 80 completions, designed to permit alternate pumping of two zones, were made in Kansas during the war period when material shortages and spacing regulations restricted drilling. These installations were not successful in preventing co-mingling due to packer failures, and have been discontinued by order of the Corporation Commission. In almost every case failure occurred at the seal between tubing and packer. It is considered that improvement could be made in the method of sealing off the tubing which would largely overcome the difficulties that were encountered.

An installation designed to permit pumping two zones simultaneously has been used to a very limited extent in Texas. This method utilizes tubular sucker rods as the production tubing for the lower horizon and regular tubing for the upper horizon. A packer run on the tubing separates the two horizons and a "packer" pump is utilized to separate the production.

Only one instance of gas-lifting two zones simultaneously has been ascertained. In this case, two concentric strings of tubing are utilized, the outer string being equipped with casing flow valves and the inner string being equipped with tubing flow valves. Further details of this installation are not known but it appears that a non-removable packer and a section of flush joint tubing would be required and that a side door choke on the inner tubing string would be helpful.

Other possible methods of artificially lifting two zones include (1) the use of parallel strings of tubing, or the use of concentric strings of tubing, the inner string of which could be utilized for gas lift and the other for pumping and the outer string could be utilized for gas injection for lifting the upper zone.

Undoubtedly the matter of artificially lifting two producing zones will encounter some difficulties and numerous problems will have to be solved. However, it is considered that the problems are by no means insurmountable, and that the necessity for reducing the cost of producing oil and of obtaining all possible oil at an economic cost will be incentive for such mechanical improvement as may be necessary.

COMPARATIVE DRILLING COSTS, SINGLE COMPLETION VS. DUAL COMPLETION

A. COST OF SINGLE COMPLETIONS

Paddock Pool Wells	Estimated	Actual
Paddock #1	$95,463	$91,642
Paddock #2	79,694	81,162
Paddock #4	72,427	66,304
Eaves #3	57,813	
Eaves #4	56,013	

Average estimated cost per well	$72,282	based on drilling 5 wells
Present estimated cost per well	56,413	based on present drilling costs

Drinkard Pool Wells	Estimated	Actual
Andrews #1	$109,351	$111,353
Vivan #1	138,120	129,958
Boyd #2	120,523	115,476
Boyd #3	75,233	60,201
Drinkard "B" #1	117,795	114,746
Drinkard "B" #2	91,976	
Gutman #1	154,328	138,047
Higgins #1	126,054	125,583
Hugh #1	97,795	99,670
Lineberry #1	118,421	103,312
M. Owen #3	91,303	81,454
M. Owen #4	64,795	
Scarborough #1	125,871	127,690
Watkins #1	92,900	89,491
Ella #1	91,593	
Vivian #2	93,220	
M. Owen #5	71,027	
McCormack #9	71,640	
E. King #4	56,013	
Carson "C"	63,524	
Mark #2	70,682	

Average estimated cost per well	$97,193	based on 21 drilling wells
Present estimated cost per well	75,000	based on present drilling costs

Brunson Pool Wells		
Sticher #2	113,109	
Baker #3	87,210	

Average cost per well	$100,156	based on 2 drilling wells
Estimated drilling cost per well	87,210	based on present drilling costs

B. ESTIMATED DRILLING COSTS FOR COMBINATION ZONES

Drinkard & Ellenberger Zones	Average	Present
Estimated drilling cost for Drinkard well	$97,193	$ 75,000
Estimated drilling cost for Ellenberger well	100,156	87,210
Total Cost	$197,349	$162,210

Holt & Ellenberger Zones	Average	Present
Estimated drilling cost for Holt well	$ 72,282	$ 56,413
Estimated drilling cost for Ellenberger well	100,156	87,210
Total Cost	$172,438	$143,623

Holt & Drinkard Zones	Average	Present
Estimated drilling cost for Holt well	$ 72,282	$ 56,413
Estimated drilling cost for Drinkard well	97,193	75,000
Total Cost	$169,475	$131,413

Estimated Additional Cost Due to Dual Completions

10 Days Additional Rig Time @ $450/Day	$ 4,500
Perf. Casing w/6 shots per ft for 100 ft	1,800
Equipment & material (packer, chokes, & etc.)	2,000
Other expense	3,700
Total	$ 12,000

COMPARISON OF DRILLING COST

Example No. 1 - Drinkard & Ellenberger Completion

Single Completions

	Drinkard		Ellenberger	
	Average	Present	Average	Present
Drill & Completion Cost	$ 97,193	$ 75,000	$100,156	$ 87,210
Equip to Flow Cost	3,915	3,915	4,500	4,500
Total	$101,108	$ 78,915	$104,656	$ 91,710

Total Cost - 2 Wells

Average Cost - $101,108 plus $104,656 o4 $205,764
Present Cost - $78,915 plus $91,710 or $170,625

Dual Completions

		DRinkerd & Ellengerger	
		Average	Present
Drill & Completion Cost		$100,156	$ 87,210
Additional Expense		12,000	12,000
Equip to Flow Cost			
Present avg. ETF Cost	$4,500		
Incr. due to 3" tbg	2,221		
Dual flow line	600		
Sub-Total	$7,321	7,321	7,321
Total Cost		$119,477	$106,531

Initial Drilling & Completion Savings Due to Dual Completion Practice

Average $205,764 - $119,477 or $86,287

Present $170,625 - $106,531 or $64,094

COMPARISON OF DRILLING COST

Example No. 2 - Holt & Ellenberger Completion

Single Completions

	Holt		Ellenberger	
	Average	Present	Average	Present
Drill & Completion Cost	$ 72,282	$ 56,413	$100,156	$ 87,210
Equip to Flow Cost	3,210	3,210	4,500	4,500
Total	$ 75,492	$ 59,623	$104,656	$ 91,710

Total Cost - 2 Wells

Average Cost - $75,492 plus $104,656 or $180,148
Present Cost - $59,623 plus $91,710 or $151,333

Dual Completions

		Holt & Ellenberger	
		Average	Present
Drill & Completion Cost		$100,156	$ 87,210
Additional Expense		12,000	12,000
Equip to Flow Cost			
Present avg ETF Cost	$4,500		
Incr. due to 3" tbg	2,221		
Incr. due to dual flow line	600		
Sub-Total	$7,321	7,321	7,321
Total Cost		$119,477	$106,511

Initial Drilling & Completion Savings Due to Dual Completion Practice

Average	$180,148 - $119,477 or $70,671
Present	$151,333 - $106,511 or $44,822

COMPARISON OF DRILLING COST

Example No. 3 - Holt & Drinkard Completion

Single Completions

	Holt		Drinkard	
	Average	Present	Average	Present
Drill & Completion Cost	$ 72,282	$ 56,413	$ 97,193	$ 75,000
Equip to Flow Cost	3,210	3,210	3,915	3,915
Total	$ 75,492	$ 59,623	$101,108	$ 78,915

Total Cost - 2 Wells

Average Cost - $75,492 plus $101,108 or $176,600
Present Cost - $59,623 plus $78,915 or $138,538

Dual Completions

		Holt & Drinkard	
		Average	Present
Drill & Completion Cost		$ 97,193	$ 75,000
Additional Expense		12,000	12,000
Equip to Flow Cost			
Present avg Etf Cost	$ 3,915		
Incr. due to 3" tbg	1,839		
Incr. due to dual flow line	600		
Sub-Total	$ 6,354	6,354	6,354
Total Cost		$115,547	$ 93,354

Initial Drilling & Completion Savings Due to Dual Completion Practice

Average	$176,600 - $115,547 or $61,053
Present	$138,538 - $93,354 or $45,184

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PROPOSED REPORTS TO NEW MEXICO OIL CONSERVATION COMMISSION

COVERING MULTIZONE COMPLETIONS

Under the present Rules and Regulations four reports are submitted to the New Mexico Conservation Commission when a well is drilled and later reconditioned:

Form 101 - Notice of Intention to Drill.
Form 102 - Miscellaneous Notices.
Form 103 - Miscellaneous Reports on Well.
Form 105 - Well Record.

INITIAL MULTIPLE ZONE COMPLETION

Dual or multiple completion of a well initially would necessitate only a slight change in these reports. Form 101, Notice of Intention to Drill, would be submitted as usual. At the same time, Form 102, Miscellaneous Notices, would be submitted. Under "Additional Information" on Form 101, it would be specified that the well is to be a dual or multiple zone completion. Form 102 would include a description of the work to be performed, such as zones to be exposed, procedure to be followed in completion, proposed packer setting depth, etc.

Reconditioning of a multiple zone producer would be submitted as usual on Form 103.

In lieu of the regular Well Record, Form 105, a special completion report would be submitted showing information on production from the various zones, gas-oil ratios, depth perforated, etc. A proposed well record form for dual or multiple zone wells is attached and could be designated as 105-A.

RECOMPLETION TO MAKE MULTIZONE COMPLETION

If the well is originally completed as a single well, but it is desired to recomplete it as a multizone well, it would be necessary to submit Form 102, Miscellaneous Notices, and Form 103, Miscellaneous Reports on Well. Form 102 would include information on pays to be produced, proposed packer setting and the production test as well as other pertinent data on the pay producing at the time the report is filed. Form 103 would show the work performed together with production data on each zone, packer setting, etc., similar to that reported on the special completion report for initial multiple zone completion.

In summary, the practice of multizone production will require only one additional report over and above those used for single well completion.

C-105 A

(Proposed Form)

NEW MEXICO OIL CONSERVATION COMMISSION
Santa Fe, New Mexico

WELL RECORD
For Multizone Producer

(PLAT)

Area 640 Acres
Locate Well Correctly

Mail to Oil Conservation Commission, Santa Fe, New Mexico, or its proper agent not more than twenty days after completion of well. Follow instructions in the Rules and Regulations of the Commission. Indicate questionable data by following it with (?). Submit in triplicate, Form C-110 will not be approved until Form C-105-A is properly filled out.

____
Company or Operator Address

____________________ Well No.____ in ____ of Sec.__________________, T________,
Lease

R________________, N.M.P.M.,____________________ Field,________________ County.

Well is _____ feet south of the North line and _____ feet west of the East line of___.
If State land the oil and gas lease is No.___________ Assignment No.___________
If patented land the owner is__________________________,Address_______________
If Government land the permittee is____________________,Address_______________
The Lessee is____,Address_______________
Drilling commenced________________19__. Drilling was completed____________,19__
Name of drilling contractor____________________________,Address_______________
Elevation above sea level at top of casing_____feet. Derrick Floor_______________
The information given is to be kept confidential until____________________,19__

Formation Tops: Anhydráte_________; Base Salt______;_______________ ______;______
_______________ __________;____________________ __________;_________________ _______.

Pays Producing Name & Depth	Initial Prod. Oil & Water	Date	G.O.R.	Oil Gr.	How Produced

Types of Well Logs Taken:____
Tubing Record: Size_________________________. Depth____________________.
Packer Record: Type_________________________________. Depth Set_______________
Type_________________________________. Depth Set_______________
Special Equipment:____

Other Information:____

IMPORTANT WATER SANDS

Include data on rate of water inflow and elevation to which water rose in hole.

No. 1, from__________________to__________________feet.________________________
No. 2, from__________________to__________________feet.________________________
Nos. 3, from__________________to__________________feet.________________________

CASING RECORD

Size	Weight Per Foot	Threads Per Inch	Make	Amount	Kind of Shoe	Cut & Filled From	Perforated From	Perforated To	Purpose

MUDDING AND CEMENTING RECORD

Size of Hole	Size of Casing	Where Set	No. Sacks of Cement	Methods Used	Mud Gravity	Amount of Mud Used

RECORD OF SHOOTING OR CHEMICAL TREATMENT

Date	Quantity of Acid or Explosive	Pay Section Treated	Results of Each Treatment

PLUGS AND ADAPTERS

Heaving plug - Material________Length____________________Depth Set____________
Adapters - Material____________________________Size____________________________

RECORD OF DRILL STEM AND SPECIAL TESTS

If drill-stem or other special tests or deviation surveys were made, submit report on separate sheet and attach hereto.

TOOLS USED

Rotary tools were used from______feet to________feet, and from_____feet to____feet
Cable tools were used from_______feet to________feet, and from_____feet to____feet

EMPLOYEES

_______________________________,Driller______________________________,Driller
_______________________________,Driller______________________________,Driller

FORMATION RECORD ON OTHER SIDE

I hereby swear or affirm that the information given herewith is a complete and correct record of the well and all work done on it so far as can be determined from available records.

Subscribed and sworn to before me this__________
day of___________________________________,19_____
______________________________Notary Public
My Commission expires____________________________

____
Place Date
Name__________________________
Position_______________________
Represanting___________________
Address________________________