BEFORE THE
OIL CONSERVATION COMMISSION
SANTA FE, NEW MEXICO
El Paso EXHIBIT No. 1
CASE 1755

PACKER SETTING AFFIDAVIT

I, ______________________________, being of lawful age
Name of Party Making Affidavit
and having full knowledge of the facts hereinbelow set out do state:

That I am employed by ______________________________ in the capacity of ______________________________, that on ______________, 195__,
Date
I personally supervised the setting of a ______________________________
Make and Type of Packer
in ______________________________, ______________________________
Operator of Well — Lease Name
Well No. ______________ located in the ______________________________,
Field
______________________________ County, New Mexico, at a subsurface depth of __________ feet, said depth measurement having been furnished me by ______________________________ ______________________________; that the purpose of setting this packer was to effect a seal in the annular space between the two strings of pipe where the packer was set so as to prevent the commingling, in the bore of this well, of fluids produced from a stratum below the packer with fluids produced from a stratum above the packer; that this packer was properly set and that it did, when set, effectively and absolutely seal off the annular space between the two strings of pipe where it was set in such manner as that it prevented any movement of fluids across the packer.

____

STATE OF NEW MEXICO) (
COUNTY OF ______________) (

Before me, the undersigned authority, on this day personally appeared ______________________________, known to me to be the person whose name is subscribed to this instrument, who after being by me duly sworn on oath, states that he has knowledge of all the facts stated above and that the same is a true and correct statement of the facts therein recited.

Subscribed and sworn to before me on this the ______________ day of ______________, 195__.

____
Notary Public in and for
______________________________ County,
New Mexico

My Commission Expires ______________

W. S. Althouse graduated from the California Institute of Technology in 1938 with a BS degree in mechanical engineering. He joined Baker Oil Tools, Inc. shortly after graduation and served as design engineer and chief engineer prior to assuming his present position as manager of engineering and research.

H. H. Fisher received a BS degree from Louisiana Polytechnic Institute in 1950. Following graduation he joined Baker Oil Tools as a sales and serviceman. He subsequently joined Cardwell Manufacturing Co. as a design engineer, returning to Baker after two years as a design engineer. He now serves as division mechanical engineer for the Central Div.

The Selection of a Multiple Completion Hook-Up

W. S. ALTHOUSE, JR. | BAKER OIL TOOLS, INC.
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DUAL ZONE — SINGLE DRILLABLE PACKER

Tubing and Annulus Production | Parallel String Production | Pumping Parallel String Gas-Vent with Two Sets of Rods

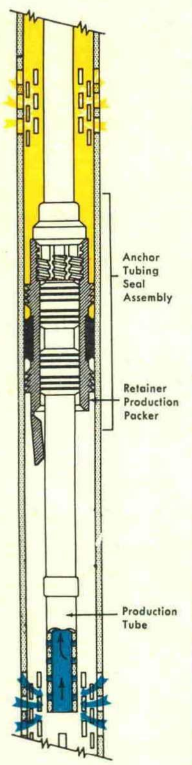

Fig. 1

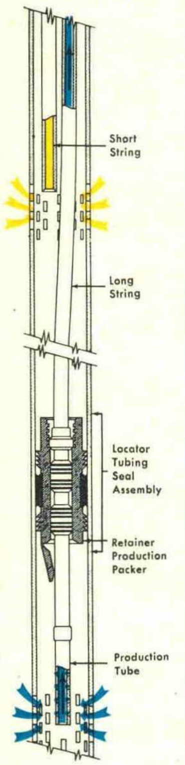

Fig. 2

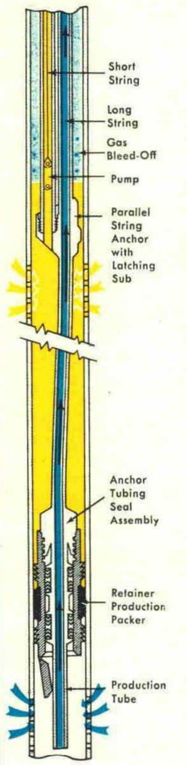

Fig. 3

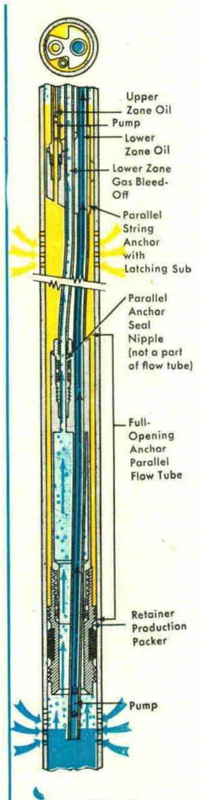

Fig. 4

DUAL ZONE

Single Drillable Packer | Two Packer—Upper Packer Retrievable—Lower Drillable

Pumping, Parallel String—Gas Vent with Single Set of Rods | *Pumping — Tubing and Annulus Production with Single Set of Rods* | *Selective Tubing and Annulus Production*

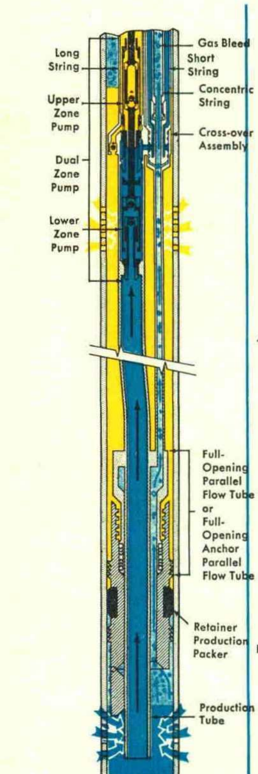

Fig. 5

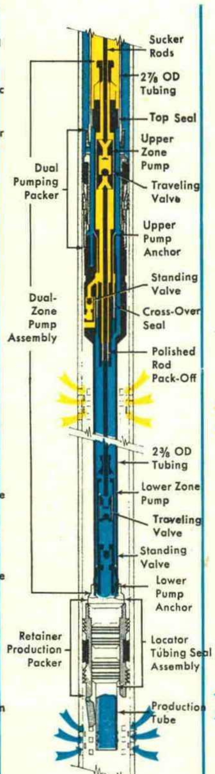

Fig. 6

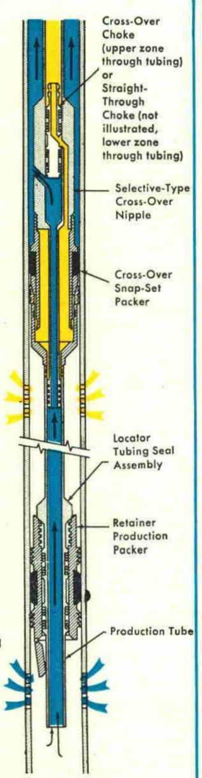

Fig. 7

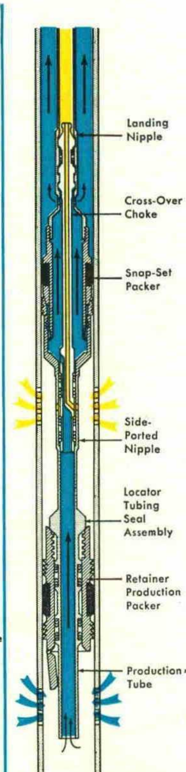

Fig. 8

cost is contained in tubing and flowline costs. Now here is an interesting fact: *all* these costs, which total nearly 90 per cent of the completion costs, are accrued in connection with operations that require no particularly special development for multiple completion application. Note that the costs of the downhole equipment (packers, circulation valves, seating nipples) that make the multiple completion practical, *cost but a fraction of the cost of the extra string of tubing required in each case.*

Hypothetically, each zone of a triple can be completed at a cost of only slightly more than one-third the cost of a single-zone well, with production potential that could be three times as great and a payout time one-third as long. When related to total well costs in view of increased production, and decreased payout time, the cost of equipment that makes a multiple completion practical becomes an exceed-

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Fig. 1—Shows packer set in casing with anchored production string for dual-zone production. Tubing can be released from packer by rotating to right.

Fig. 2—Hook-up with short string hanging free, permits removal of either string independently of the other regardless of sequence. Full-opening (tubing ID) long string to lower zone.

Fig. 3—Pumping, short string anchored, gas bleed-off through annulus. Permits removal of either string independently of the other; long string must be run first — short string pulled first. Full-opening (tubing ID) long string.

Fig. 4—Pumping lower zone with lower zone gas bleed-off through separate string. Upper zone flowing or pumping through separate (short) string, and gas bleed-off through annulus.

Fig. 5—Both zones pumped simultaneously with gas-bleed through concentric string for lower zone, and through annulus for upper zone. Short string and concentric bleed-off string run separately after long string is landed.

Fig. 6—Both zones pumped simultaneously; lower zone through annulus, upper zone through tubing. Does not provide for gas venting either zone.

Fig. 7—Upper zone produced through tubing, lower zone through annulus. Removal of cross-over choke and installation of straight-through choke with wire line produces lower zone through tubing, upper through annulus.

Fig. 8—Similar to Fig. 7 except choke contains integral flow tube that is retrievable. Removal of choke provides full-opening access to lower zone.

The Selection of a Multiple Completion Hook-Up

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Abstract

The reasoning behind the inception, rate of development and successful application of current dual, triple and quadruple completions is highly economic in character. Selection of a practical multiple completion hook-up therefore must necessarily involve strong economic considerations. Type and subsequent cost of any multiple completion hook-up is directly related to number of zones to be produced and workover and artificial-lift requirements of each zone. An analysis of available subsurface equipment that makes the modern multiple completion practical in the light of design, advantages and limitations provides a base for selection of components. A systematic presentation of multiple completion hook-ups from the simplest, most inexpensive two-zone completion to the most complex four-zone completion, in order of increasing cost and flexibility provides a graphic systematic base for selection of a practical multiple completion hook-up.

Introduction

Advancement in multiple zone techniques and equipment has been so rapid in recent years that it becomes difficult even for those who specialize in this field not only to keep up with it, but to maintain an over-all perspective. Hardly a month goes by that a trade publication does not present a new dual, triple or quadruple completion method. Many of these articles not only imply widespread acceptance of the particular method but strongly suggest that previous methods are shortly doomed for obsolescence. The facts are that there are many areas, perhaps an overwhelming majority, where the complex dual, triple or quadruple completion would not be economically feasible.

Operators in these areas are confronted with the problem of selecting not only a practical multiple completion hook-up but one that is economical as well. In order to make this selection they should have as broad a view of all multiple completion techniques and equipment as possible and some sort of systematic method of evaluating each method in light of any given set of conditions. The systematic basis for this selection in our opinion involves (1) number of zones to be produced; (2) flowing, artificial-lift and workover requirements of each zone; (3) general knowledge of various types of subsurface equipment and its limitations; and (4) general knowledge of possible remedial operations that can be performed with certain fundamental hook-ups.

It is the purpose of this paper to present this information in such a manner that the selection of a practical and economical multiple completion hook-up for any given set of conditions will be within the capabilities of any operator regardless of his previous experience with this type of completion.

Brief Historical and Economic Background

Multiple completion has an interesting history. It was born in the lanquid atmosphere of the purely speculative but exceptionally attractive economic theory: two wells for the price of one. It had hardly started to grow when it was drafted as a wartime expedient to save steel or get maximum production with minimum steel. Through forced feeding it was nurtured and grew widespread, but not in other directions, with the result that through one misapplication after another it collapsed and nearly died.

For the next few years after World War II it had a chance to mature and grow naturally, though slowly, through careful application and development of downhole equipment designed specifically for multiple zone, not merely adaptations of single zone equipment. By 1953 modern dual completion in many areas had grown rapidly to the point where it was commonplace.

About three years ago the multiple completion was called upon to meet a need that was only partially stated in the "two wells for the price of one" theory behind its initial conception. Staggering development and completion costs of offshore operations made multiple completion an economic necessity. Even two wells for the approximate price of one was not enough, three and four or more if possible were required to make use of every square foot of space, to reduce total dollars invested and to get this investment back sooner with a greatly decreased payout interval.

This great need served to underwrite the high cost required for development of downhole equipment, with the result that practical equipment has been designed and perfected to permit as many as four zones to be produced, each through its own individual tubing string, through one common wellbore.

Because of the high cost of offshore operations, current equipment comes close percentage-wise to providing two, three and four wells for the approximate price of one.

Table 1[5], which serves to illustrate this, also contains some interesting information pertinent to relative cost of completion components.

Referring to Table 1, note that the well costs for the single, dual and triple are the same. Under completion costs, note that by combining perforating operations, perforating cost per zone becomes less and that there is also a slight saving in rig time. Note that more than half of the completion

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[5]References given at end of paper.

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TABLE 1—BREAKDOWN OF COSTS FOR TYPICAL 10,000-FT OFFSHORE WELLS ON LOUISIANA GULF COAST

	Single Completion	Dual Completion	Triple Completion	Each Additional Alternate*
Well cost				
Drilling cost	$235,000	$235,000	$235,000	0
Mud cost	65,000	65,000	65,000	0
Casing	95,000	95,000	95,000	0
Cementing and cementing services	11,000	11,000	11,000	0
Logging services	20,000	20,000	20,000	0
Share of platform	50,000	50,000	50,000	0
Total well cost	$476,000	$476,000	$476,000	0
Completion cost				
Perforating	800	1,400	2,000	800
Drill-stem testing	1,000	2,000	3,000	1,000
Tubing	14,200	28,400	42,600	0
Packers	600	3,700	6,000	1,800
Circulation valves, seating nipples, etc.	900	2,000	3,900	900
Christmas tree	2,500	7,500	9,500	0
Flowing cost	20,000	40,000	60,000	0
Rig time	9,000	18,000	24,000	3,500
Total completion cost	$49,000	$103,000	$150,000	$8,000
	$525,000	$579,000	$626,000	$8,000

*Refers to zones produced as alternates through use of an additional packer and wire line sleeve valves or side-ported nipples.

ingly small factor. It would also follow that rather extensive and expensive workover operations could be absorbed should they be required without materially affecting the tremendous economic advantage of the multiple completion.

Economics of Subsurface Equipment

Packers, circulating valves, sealing nipples and wellhead equipment required for an offshore quadruple or triple must through necessity be approximately the same for any quadruple or triple completion regardless of its location or relative drilling and completion cost. This is true because problems of isolation, required surface communication and accessibility for workover are the same. Even so, in most instances the cost of all this equipment will nearly always be less than the cost of the extra string of tubing even in the average 5,000-ft well. It would seem therefore, that the triple and quadruple might become increasingly popular wherever two, three, four or more exploitable zones exist. Some companies have already planned to complete as many zones as possible, whenever possible.

There are, however, many areas where the complex dual, triple or quadruple will not be economically feasible. Multiple completion in these areas will more than likely be dual completions. Equipment required for these installations is considerably less complicated and consequently less expensive.

Equipment for Multiple Completions

The equipment that makes the multiple completion practical are those tools that provide: (1) required isolation of zones, (2) surface communication, (3) access for workover, (4) means of accomplishing workover through tubing, and (5) means of lifting production artificially. This group consists of the following items.

1. Packers
2. Wire line actuated sleeve valves, non-ported nipples, side-ported nipples, cross-over nipples
3. Permanent completion tools such as tubing perforating guns, retrievable tubing extensions, expendable plugs, plug cutters, etc.
4. Wire line and permanent gas-lift mandrels and valves
5. Wire line plugs and cross-over or straight-through chokes
6. Dual-zone pumping equipment
7. Wellhead equipment

Each of these components will be discussed briefly as to types, operation, advantages and limitations under applications to which they may be put in various multiple completion hook-ups.

Packers

Regardless of their individual design differences all packers used for multiple completions fall into two basic classes: permanent (drillable) and retrievable. Generally, either type can be used interchangeably or in combination throughout all multiple completion hook-ups regardless of complexity. Each has inherent advantages and disadvantages for each application. Selection of the proper packer usually involves a compromise, in that to date it has been impossible to combine desirable features of each type into one packer.

The design of multiple completion packers has become increasingly difficult in direct proportion to the number of strings of tubing required in any given completion. The basic problem is one of how to seal-off and provide passage for the required number of strings and still retain sufficient cross-sectional area in the packer wall to provide space for components such as the packing element, slips, releasing or setting mechanism, which are required to bring about a dependable pack-off. It becomes increasingly difficult to build a high performance pack-off into a continually decreasing cross section of the packer wall area. Nevertheless, packer design has apparently been adequate to date for conditions thus far encountered. Within current casing programs and available tubing, the point of diminishing returns is rapidly being reached within the concepts of current packer design.

Permanent (Drillable) Packers

Used for any multiple zone completion—as single packer; upper, intermediate and lower packers.

These packers, sometimes referred to as retainer-type packers, are run into the well and set on electric conductor cable or on tubing. When these packers are set they become for all practical purposes a permanent, though drillable part of the casing. The smooth packer bore, which contains a flapper-type back-pressure valve at its lower end, provides a sealing surface for seal units that are made up as an integral part of the tubing string. This arrangement permits the tubing to be removed from the packer bore and reinstalled whenever required.

Through use of various accessories the tubing can be anchored to the packer and subsequently released if required. The permanent packer is characterized by two complete sets of opposed slips and a packing element that is confined by expanding retaining rings that back up the expanded packing element and improve its high pressure, high temperature performance.

These packers are available with a choice of different bore sizes for a given casing ID. By utilizing the smallest bore size for the lowest packer, the next larger bore size for the intermediate packer and the largest bore size for the upper packer and the proper sealing accessories, as many as three zones or even four, can be produced each through its own individual tubing string. In many installations a permanent packer is used as the lower packer and retrievable packers for the upper packers.

The permanent packer offers two prime advantages from the standpoint of multiple completion applications: (1) the permanence and reliability of its pack-off particularly under high pressure, high temperature conditions, and (2) the flexibility provided by a removable tubing string. A third advantage, its prime disadvantage in some installations, is that it is designed to be removed by drilling out. Under many conditions where an operator might be concerned over the amount of steel in the hole, known drillability might outweigh questionable retrievability. Recent progress in the development of special packer milling tools has greatly improved the drilling-out operation.

Retrievable Packers

Tremendous progress has been made in development of special retrievable packers for multiple completions, particularly those installations requiring two or more strings of tubing. These packers are available in a variety of designs that differ principally in method of setting and releasing, packing element design, number of bores through the packer and design of the parallel heads or receptacles in which the various retrievable strings of tubing seat and seal-off. The basic types are as follows.

CONVENTIONAL SET-DOWN WITH OR WITHOUT HOLD-DOWN

Packer is set and pack-off maintained by tubing set-down weight. Hydraulic button-type hold-down actuated by pressure differentials from below packer keeps packer from being pumped up hole by pressure differential from below packer. Can be used in some single-packer, single-string dual-zone installations.

SNAP-SET PACKERS WITH OR WITHOUT HOLD-DOWN

For use in two packer single-string

Fig. 9—Shows two-packer selective dual-zone production hook-up with crossover choke installed. Flow pattern can be switched with substitution of different choke.

Fig. 10—Shows two-packer parallel string installation with each zone confined to its individual tubing string. Full opening to lower zone permits use of permanent-type completion tools.

Fig. 11—Production from each zone confined to its individual tubing string. Short string separately retrievable. Full-opening long string, retrievable packer and seals from lower packer run and retrieved together.

Fig. 12—First, second and third alternate zones to lower completion produced through sleeve valves following installation of blank-off tool or plug in non-ported nipple below. Alternate to upper completion produced through side-ported nipple.

Fig. 13—Three-packer installation (permanent packers). Production from three zones using triple string flow tube; each zone confined to an individual and isolated tubing string.

Fig. 14—Four-packer installation. Production from four zones; each zone confined to an individual and isolated tubing string.

DUAL ZONE

Upper and and Lower Packers Drillable | Upper Packer Retrievable, Lower Packer Drillable

Selective Tubing and Annulus Production | Parallel String Production

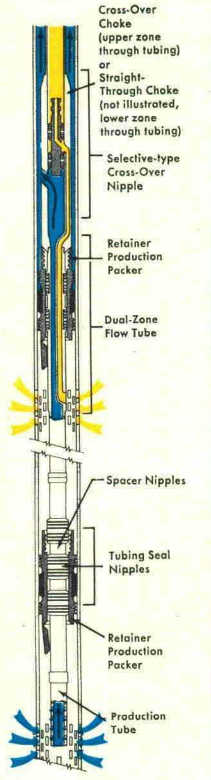

Fig. 9

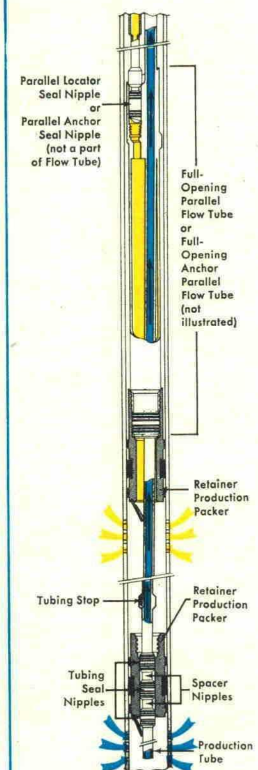

Fig. 10

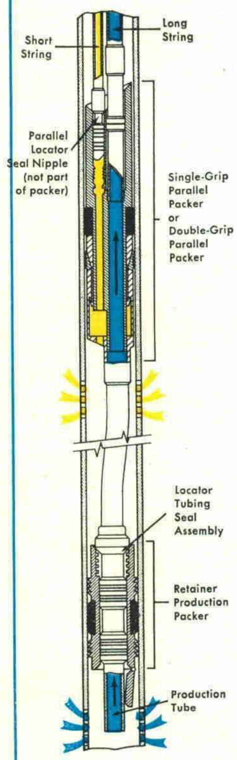

Fig. 11

PARALLEL STRING PRODUCTION

MULTIPLE (produced two at a time) Five Production Packers | *TRIPLE Three Drillable Packers* | *QUAD Four Retrievable Packers*

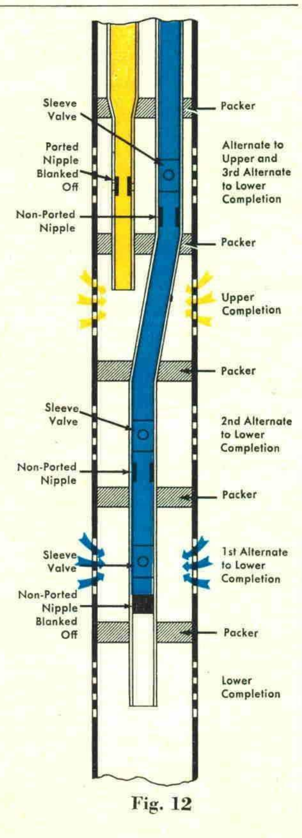

Fig. 12

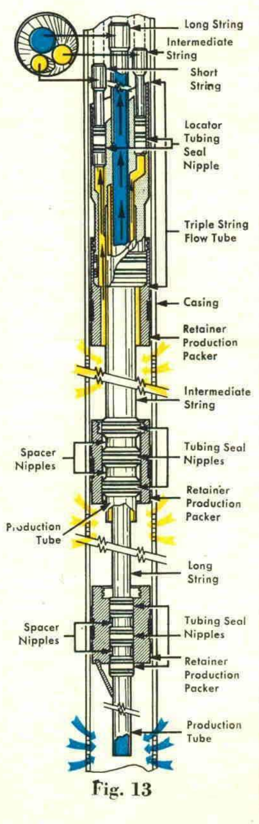

Fig. 13

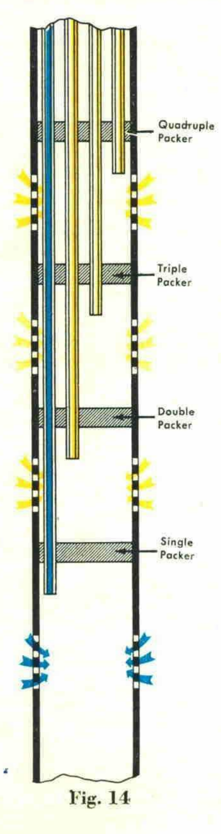

Fig. 14

installations (involving selective cross-over) as the upper packer. Run in on tubing string until seals on tubing string seat and seal-off in bore of lower permanent packer. Set-down weight against resistance provided by lower packer sets the packer. Uses shear pin or spring-type snap-latch setting and release mechanism.

ROTATION SET PACKERS

For use in two-packer, single-string installations (involving selective cross-over) as the upper packer. Packer contains a single set of dual-direction slips and two packing elements that are expanded by cone action, set by left-hand rotation of the tubing and released by right-hand rotation.

DUAL CUP-TYPE PACKERS

Many varieties of dual cup-type packers are available, including parallel-string types. Most of these packers employ opposed cups. Some types have mechanically set slips, whereas other types contain slips that are molded into the rubber cups and are set by differential pressure. Most of these packers can be used either with a retrievable or a permanent-type lower packer.

Mechanically Set Parallel Retrievable Packers Hook-Wall Type

These packers are run in on a long string which seats and seals off in sealing bore of a lower permanent or retrievable packer. Set-down weight against resistance provided by lower packer sets packer. In one design shear pins provide control for release. The snap-latch release in another design permits the packer to be set and released as many times as required for measuring, circulating, etc. This type also available with integral button-type hydraulic hold-down. Parallel head of packers contains sealing bore for separately retrievable short string.

Hydraulic Retrievable Packers

Available with heads for one, two, three or four strings, packer is set by hydraulic pressure that is trapped in packer by closing a valve. As many as four of these packers can be run together, wellhead flanged up, fluid displaced and all packers set hydraulically through their own individual tubing strings. Packer(s) released by opening valves to release trapped pressure. Can be used for any multiple-zone application.

Advantages and Disadvantages of Retrievable Packers

The prime advantage of the retrievable packer is its retrievability. This is a desirable feature in any completion, particularly so in many multiple completions where access for truly extensive workover can only be provided by complete removal of the packer. Loss of retrievability, of course, can be a decided disadvantage.

Although it is subject to controversy, field preferences seem to indicate that the permanent packer is capable of providing a better, longer lasting pack-off particularly under exceptionally rigorous conditions of pressure and temperature than retrievable packers. One of the possible reasons for this could be that the permanent packer does not have to make any design concessions to provide for retrievability.

Wire Line Actuated Sleeve Valves and Side-ported Nipples

This equipment provides means of selectively establishing communication between the tubing string and the tubing-to-casing annulus. It can be used to circulate out mud or when it is positioned opposite any isolated zone, it can be opened to allow production of that zone through the tubing. The two different designs accomplish a similar result in a different manner. In one design the control is provided by a sleeve valve that can be opened or closed by means of a special tool run in on piano wire. The other design provides control by blanking off the ports in a special nipple by means of a small plug or choke that is run in and retrieved on piano wire.

Permanent Completion Tools

These tools include small-diameter perforating guns that can be run through the tubing, and a number of retrievable plugs, chokes and tubing extensions that are run and retrieved on wire line that permit extensive workover of zones through the tubing from perforating, cementing-off perforations, to well stimulation operations.[3]

Wire Line and Permanent Gas-Lift Mandrels and Valves

This equipment makes it possible to anticipate future gas-lift requirements by installing certain gas-lift components in the tubing string or strings at the time the well is completed. When gas lift is required, fluid is removed from the annulus and the gas-lift valves installed or actuated by wire line and the well is placed on gas lift using the annulus as a reservoir. The valves are either of the side-pocket retrievable type or of flush type of coupling OD. Both types are used interchangeably; however, in some parallel-string installations the side-pocket type is run on the long string and the flush type on the short string to facilitate installation or where rotational release of the short string is desired.

Dual-Zone Pumping Equipment

A number of pump manufacturers now provide pumping equipment that makes it possible to pump two zones simultaneously with a single set of rods. Standard pumping equipment can be adapted for pumping two zones with two sets of rods through two strings of tubing. Hydraulic pumping has also been used successfully.

Wellhead Equipment

The design of wellhead equipment has kept pace with the increased number of tubing strings being run in one wellbore. Equipment that will handle up to four strings of tubing has been developed and used successfully. Equipment is now available that will allow each string of a multiple completion to be handled selectively after all strings are landed.

Summary

From the preceding brief description of the equipment that makes a multiple completion practical, it is obvious that there is not only a variety of different basic types of equipment, but a choice of differently designed components within each category that accomplish similar results in a different manner. It is safe to say that no one manufacturer completely dominates any category. In actuality, a given hook-up may involve both drillable and retrievable packers of different manufacture, both sleeve valves and side-ported nipples of different manufacture, and possibly side-pocket and flush-type gas-lift valves also of different manufacture. Each specific component has its definite design advantages and disadvantages, the choice depends upon the particular conditions encountered in each individual well, future requirements and over-all cost extrapolated through workover, artificial lift to abandonment.

A Graphic Outline of Multiple Completion Hook-Ups

Having become generally familiar with the basic types of multiple completion tools and equipment, their advantages and limitations, the systematic selection of a practical hook-up requires general knowledge of application of this equipment. This knowledge can best be acquired by a systematic study of actual hook-ups that use this equipment. For this purpose we have arbitrarily selected 11 basic hook-ups for study. These hook-ups are arranged in sequence in accordance with the number of zones to be produced, in order of increasing completion cost, as follows:

TWO-ZONE PRODUCTION

1. One string of tubing and one packer
2. One string of tubing and two packers
3. One string of tubing and two or more packers
4. Two parallel strings of tubing and one packer
5. Two parallel strings of tubing and two packers
6. Two parallel strings; two packers; no permanent string between packers
7. Two parallel strings; two or more packers

THREE-ZONE PRODUCTION

8. Two parallel strings; two packers
9. Three parallel strings; three packers

FOUR-ZONE PRODUCTION

10. Three parallel strings; three packers
11. Four parallel strings; four packers

Each of these 11 basic hook-ups will be analyzed from the standpoint of (1) the general completion practice, which may include several variations; (2) artificial-lift possibilities, which include both pumping and gas lift; (3) advantages of the hook-up; and (4) disadvantages of the hook-up.

In all, nearly 50 hook-up drawings would be required to illustrate fully each of the basic hook-ups and their many variations. Since this would be beyond the practical limits of this or any other paper, only 14 drawings (Figs. 1 through 14) will be used to illustrate this entire section. The printed outline, however, will cover most of the possible variations.

To appreciate more fully the limitations and advantages of these hook-ups, some preliminary comment should be made regarding the hook-ups that produce one zone through the tubing and one zone through the tubing-to-casing annulus (tubing and annulus production) and hook-ups that produce each zone through its individual tubing string (parallel-string production). Each method has certain constant requirements and limitations that can be discussed generally initially, and thus avoid endless repetition in the graphic outline.

Tubing and Annulus Production

The most inexpensive multiple-zone completions fall in this category. A great number of dual-zone completions are tubing and annulus completions. The production, however, of one zone in the annulus can have many disadvantages. It is nearly impossible to run instruments in the annulus. This can be overcome by running a side-ported nipple blanking off the zone produced through tubing and opening up the zone produced through the annulus. The large area makes flow more difficult, encourages gas separation and loss of natural gas lift. Artificial lift of the zone produced in the annulus is difficult and awkward. Full pressure of the zone is on the casing, making control somewhat hazardous. The casing is also exposed to corrosive attack. Where conditions are right, however, and zones of strong flowing characteristics are present without corrosion or other complications, this method is entirely satisfactory. Some states do not allow annulus completion in all fields. For example, Louisiana will not allow annulus completion of offshore wells.

Parallel-String Production

(1) Permits each zone to be produced through an individual tubing string so that each zone will flow throughout a longer portion of the well's producing life. (2) Keeps production from the two zones isolated from each other and casing. This is most desirable from a corrosion and bursting standpoint. (3) Makes it possible to gas lift or pump either or both zones.

Not every parallel-string hook-up incorporates all these advantages.

Most operators prefer to run and pull each tubing string independently. This does not necessarily mean that either string can be removed independently of the other, but may mean that one string can be either removed or run at a time provided a certain sequence is followed. Usually the short string (string producing the upper zone) must be removed before the long string (string producing the lower zone) can be removed and vice-versa when running in. Equipment is also being developed to permit removal of either string selectively.

Planning Parallel-String Hook-Ups

Most operators prefer to have both strings full-opening (tubing ID) through the packer; however, the size of the tubing strings that are to be run within any given casing ID determines whether or not full-opening in one or both strings can be obtained. Consequently, the starting point for planning any parallel-string hook-up is the determination of the combined diameter of the long- and short-string joints desired with respect to the ID of the casing through which these strings are to be run.

This information, when compared with the theoretical casing ID less the recommended diametral clearance of 3/16 to 5/16 in., will permit selection of a practical combination of tubing strings. (Refer to Tables 2 and 3.)

Two-Zone Production

One String of Tubing and One Packer

A. Completion Practice
  1. Lower zone through tubing and upper zone through annulus (Fig. 1)

B. Artificial-Lift Possibilities
  1. Pumping
    a. Rod pump lower zone (no venting possible)
    b. Both zones pumped alternately through tubing by use of a valve positioned in tubing above packer that is opened or closed by rotating the tubing.
  2. Gas Lift
    a. Run concentric or parallel macaroni string (small diameter pipe) for hydraulic lift or single point gas injection to lift lower zone.

C. Advantages
  1. Economical
    a. By far the most widely used multiple-zone hook-up.
    b. Requires minimum investment in equipment.
    c. Simple for remedial work. Retainer-type packer, which permits removal of the tubing string and contains a flapper-type back-pressure valve, which closes to isolate lower zone when tubing is moved, permits packer to be used in place as a squeeze tool for lower zone workover. Packer can be converted to temporary bridge plug for pressuring operations required for upper zone. Retrievable packers can be removed following mudding-off of both zones permitting full-scale workovers of both zones.

D. Disadvantages
  1. Difficult to take bottom-hole pressure of upper zone. Can be done with side-ported nipple or sleeve valve.
  2. Impossible to swab or produce upper zone oil when bottom-hole pressure declines.
  3. Alternate production of zones awkward and inefficient.

One String of Tubing and Two Packers

A. Completion Practice
  1. Fixed cross-over
    a. Permits a strong lower zone to flow up annulus and weaker upper zone to flow or be pumped through tubing.
  2. Retrievable selective cross-over non-full opening. (Figs. 7 and 9).
    a. Either zone can be produced up annulus or tubing, switch

in flow accomplished by running cross-over or straight through choke on wire line. Does not provide full-opening for workover below packers.

3. Retrievable selective cross-over full opening. (Fig. 8)

a. Permits either zone to be produced up annulus or tubing; switch in flow accomplished by running cross-

TABLE 2—COMBINED PARALLEL-STRING DIAMETERS, PARALLEL STRINGS RUN SEPARATELY

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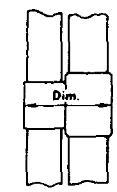
Tubing O.D. and Type Thread	1.050 E.U.	1.315 E.U.	1.315 "CS" HYDRIL	1.315 "SS" HARDY-GRIFFIN	1.660 "CS" HYDRIL	1.660 "SS" HARDY-GRIFFIN	1.660 E.U.	1.900 "CS" HYDRIL	1.900 "SS" HARDY-GRIFFIN	1.900 N.U.	1.900 E.U.	2.062 "CS" HYDRIL	2.062 "SS" HARDY-GRIFFIN	2.375 "CS" HYDRIL	2.375 "SS" HARDY-GRIFFIN	2.375 "XL" SPANG	2.375 N.U.	2.375 E.U. (2.910 Cplg. O.D.)	2.375 E.U.	2.875 "CS" HYDRIL	2.875 "SS" HARDY-GRIFFIN	2.875 "XL" SPANG	2.875 N.U.	2.875 E.U. (3.460 Cplg. O.D.)	2.875 E.U.	3.500 "CS" HYDRIL	3.500 "XL" SPANG	3.500 N.U.	3.500 E.U.
1.050 E.U.	3.320																												
1.315 E.U.	3.560	3.800																											
1.315 "CS" HYDRIL	3.212	3.452	3.104																										
1.315 "SS" HARDY-GRIFFIN	3.212	3.452	3.104	3.104																									
1.660 "CS" HYDRIL	3.543	3.783	3.435	3.435	3.766																								
1.660 "SS" HARDY-GRIFFIN	3.560	3.800	3.452	3.452	3.783	3.800																							
1.660 E.U.	3.860	4.100	3.752	3.752	4.083	4.100	4.400																						
1.900 "CS" HYDRIL	3.773	4.013	3.665	3.665	3.996	4.013	4.313	4.226																					
1.900 "SS" HARDY-GRIFFIN	3.856	4.096	3.748	3.748	4.079	4.096	4.396	4.309	4.392																				
1.900 N.U.	3.860	4.100	3.752	3.752	4.083	4.100	4.400	4.313	4.396	4.400																			
1.900 E.U.	4.160	4.400	4.052	4.052	4.383	4.400	4.700	4.613	4.696	4.700	5.000																		
2.062 "CS" HYDRIL	3.990	4.230	3.882	3.882	4.213	4.230	4.530	4.443	4.526	4.530	4.830	4.660																	
2.062 "SS" HARDY-GRIFFIN	3.990	4.230	3.882	3.882	4.213	4.230	4.530	4.443	4.526	4.530	4.830	4.660	4.660																
2.375 "CS" HYDRIL	4.360	4.600	4.252	4.252	4.583	4.600	4.900	4.813	4.896	4.900	5.200	5.030	5.030	5.400															
2.375 "SS" HARDY-GRIFFIN	4.410	4.650	4.302	4.302	4.633	4.650	4.950	4.863	4.946	4.950	5.250	5.080	5.080	5.450	5.500														
2.375 "XL" SPANG	4.660	4.900	4.552	4.552	4.883	4.900	5.200	5.113	5.196	5.200	5.500	5.330	5.330	5.702	5.750	6.000													
2.375 N.U.	4.535	4.775	4.427	4.427	4.758	4.775	5.075	4.988	5.071	5.075	5.375	5.205	5.205	5.577	5.625	5.875	5.750												
2.375 E.U. (2.910 Cplg. O.D.)	4.570	4.810	4.462	4.462	4.793	4.810	5.110	5.023	5.106	5.110	5.410	5.240	5.240	5.612	5.660	5.910	5.785	5.820											
2.375 E.U.	4.723	4.963	4.615	4.615	4.946	4.963	5.263	5.176	5.259	5.263	5.563	5.393	5.393	5.765	5.813	6.063	5.938	5.973	6.126										
2.875 "CS" HYDRIL	4.880	5.120	4.772	4.772	5.103	5.120	5.420	5.333	5.416	5.420	5.720	5.550	5.550	5.922	5.970	6.220	6.095	6.130	6.283	6.440									
2.875 "SS" HARDY-GRIFFIN	4.880	5.120	4.772	4.772	5.103	5.120	5.420	5.333	5.416	5.420	5.720	5.550	5.550	5.922	5.970	6.220	6.095	6.130	6.283	6.440	6.440								
2.875 "XL" SPANG	5.160	5.400	5.052	5.052	5.383	5.400	5.700	5.613	5.696	5.700	6.000	5.830	5.830	6.202	6.250	6.500	6.375	6.410	6.563	6.720	6.720	7.000							
2.875 N.U.	5.160	5.400	5.052	5.052	5.383	5.400	5.700	5.613	5.696	5.700	6.000	5.830	5.830	6.202	6.250	6.500	6.375	6.410	6.563	6.720	6.720	7.000	7.000						
2.875 E.U (3.460 Cplg. O.D.)	5.120	5.360	5.012	5.012	5.343	5.360	5.660	5.573	5.656	5.660	5.960	5.790	5.790	6.162	6.210	6.460	6.335	6.370	6.523	6.680	6.680	6.960	6.960	6.920					
2.875 E.U.	5.328	5.568	5.220	5.220	5.551	5.568	5.868	5.781	5.864	5.868	6.168	5.998	5.998	6.370	6.418	6.668	6.543	6.578	6.731	6.888	6.888	7.168	7.168	7.128	7.336				
3.500 "CS" HYDRIL	5.525	5.765	5.417	5.417	5.748	5.765	6.065	5.978	6.061	6.065	6.365	6.195	6.195	6.567	6.615	6.865	6.740	6.774	6.928	7.085	7.085	7.365	7.365	7.324	7.533	7.730			
3.500 "XL" SPANG	5.910	6.150	5.802	5.802	6.133	6.150	6.450	6.363	6.446	6.450	6.750	6.580	6.580	6.952	7.000	7.250	7.125	7.160	7.313	7.470	7.470	7.750	7.750	7.710	7.918	8.114	8.500		
3.500 N.U.	5.910	6.150	5.802	5.802	6.133	6.150	6.450	6.363	6.446	6.450	6.750	6.580	6.580	6.952	7.000	7.250	7.125	7.160	7.313	7.470	7.470	7.750	7.750	7.710	7.918	8.114	8.500	8.500	
3.500 E.U.	6.160	6.400	6.052	6.052	6.383	6.400	6.700	6.613	6.696	6.700	7.000	6.830	6.830	7.202	7.250	7.500	7.375	7.410	7.563	7.720	7.720	8.000	8.000	7.960	8.168	8.364	8.750	8.750	9.000

The Dimensions listed in this Chart are the exact minimum combined O.D. as shown in the illustration. It is recommended that a diametrical clearance of 3/16" to 5/16" be subtracted from the theoretical I.D. of the casing.



It is recommended that the long string of tubing above the Flow Tube have tapered joints or beveled couplings. It is possible that the standard couplings would cause damage to the seals on the Parallel Seal Nipple or threads of Latching Sub when the short string is being run into the well.

TABLE 3—TUBING DIMENSIONAL DATA

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Tubing O.D.	Type Thread	Nominal	Wt. per Ft.	I.D.	Drift Dia.	Inside Dia. Sq. in. Area	Joint I.D.	Cplg. O.D. or Joint O.D.	Special Joint O.D.
1.050	E.U.	3/4	1.20	.824	.730	.533		1.660	
1.315	E.U.	1	1.80	1.049	.955	.864		1.900	
1.315	Hydril "CS"	1	1.80	1.049	.955	.864	.970	1.552	
1.315	Hardy-Griffin "SS"	1	1.80	1.049	.955	.864	.970	1.552	
1.660	Hydril "CS"	1-1/4	2.40	1.380	1.286	1.496	1.301	1.883	
1.660	Hardy-Griffin "SS"	1-1/4	2.40	1.380	1.286	1.496	1.301	1.900	
1.660	E.U.	1-1/4	2.40	1.380	1.286	1.496		2.200	
1.900	Hydril "CS"	1-1/2	2.90	1.610	1.516	2.036	1.530	2.113	
1.900	Hardy-Griffin "SS"	1-1/2	2.90	1.610	1.516	2.036	1.531	2.196	
1.900	N.U.	1-1/2	2.75	1.610	1.516	2.036		2.200	
1.900	E.U.	1-1/2	2.90	1.610	1.516	2.036		2.500	
2.062*	Hydril "CS"	—	3.4	1.750	1.657	2.405	1.700	2.330	
2.062*	Hardy-Griffin "SS"	—	3.4	1.750	1.657	2.405	1.700	2.330	
2.375	Hydril "CS"	2	4.70	1.995	1.901	3.126	1.945	2.702	2.630
2.375	Hardy-Griffin "SS"	2	4.70	1.995	1.901	3.126	1.945	2.750	
2.375	Spang "XL"	2	4.70	1.995	1.901	3.126	1.935	3.000	
2.375	N.U.	2	4.60	1.995	1.901	3.126		2.875	
2.375	E.U.	2	4.70	1.995	1.901	3.126		3.063**	
2.375	E.U.	2	5.95	1.867	1.773	2.737		3.063**	

* Non A.P.I. Tubing.
** N-80 Couplings are sometimes turned to 2.910 by the operators. This dia. is listed for reference and does not constitute a recommendation by Baker Oil Tools, Inc.

Tubing O.D.	Type Thread	Nominal	Wt. per Ft.	I.D.	Drift Dia.	Inside Dia. Sq. in. Area	Joint I.D.	Cplg. O.D. or Joint O.D.	Special Joint O.D.
2.875	Hydril "CS"	2-1/2	6.50	2.441	2.347	4.676	2.370	3.220	3.155
2.875	Hardy-Griffin "SS"	2-1/2	6.50	2.441	2.347	4.676	2.375	3.220	
2.875	Spang "XL"	2-1/2	6.50	2.441	2.347	4.676	2.381	3.500	
2.875	N.U.	2-1/2	6.40	2.441	2.347	4.676		3.500	
2.875	N.U.	2-1/2	8.60	2.259	2.165	4.008		3.500	
2.875	E.U.	2-1/2	6.50	2.441	2.347	4.676		3.668***	
2.875	E.U.	2-1/2	8.70	2.259	2.165	4.008		3.668***	
3.500	Hydril "CS"	3	9.30	2.992	2.867	7.031	2.920	3.865	3.805
3.500	Spang "XL"	3	9.30	2.992	2.867	7.031	2.907	4.250	
3.500	N.U.	3	9.20	2.992	2.867	7.031		4.250	
3.500	N.U.	3	12.70	2.750	2.625	5.940		4.250	
3.500	E.U.	3	9.30	2.992	2.867	7.031		4.500	
3.500	E.U.	3	12.95	2.750	2.625	5.940		4.500	
4.000	Hydril "CS"	3-1/2	11.00	3.476	3.351		3.395	4.343	4.315
4.000	N.U.	3-1/2	9.50	3.548	3.423			4.750	
4.000	E.U.	3-1/2	11.00	3.476	3.351			5.000	
4.500	Hydril "CS"	4	12.75	3.958	3.833		3.865	4.855	4.825
4.500	N.U.	4	12.60	3.958	3.833			5.200	
4.500	E.U.	4	12.75	3.958	3.833			5.563	

*** N-80 Couplings are sometimes turned to 3.460 by the operators. This dia. is listed for reference and does not constitute a recommendation by Baker Oil Tools, Inc.

over choke on wire line. Provides full opening through lower packer for permanent completion of lower zone.

B. Artificial-Lift Possibilities
   1. Pumping
      a. Pump either zone with remaining zone flowing up annulus.
      b. Pump one zone through tubing and one zone through annulus (Fig. 6) using dual-zone pump with single set of rods.
      c. Pump either zone hydraulically using concentric or parallel macaroni string for power oil.
   2. Gas Lift
      a. Both zones below packers can be gas lifted alternately using retrievable cross-over to open either zone to the tubing. Casing annulus above upper packer used as gas reservoir.

C. Advantages
   1. Increased flexibility, particularly in the area of artificial lift when compared to single-packer, single-string installations.

D. Disadvantages
   1. All disadvantages associated with producing one zone through the annulus.

One String of Tubing and Two or More Packers (to Permit Multiple-Zone Production Two Zones at a Time)

A. Completion Practice
   1. Packers separating two, three, four or more zones, tubing string runs through all packers and is bull plugged on bottom. Sleeve valves or side-ported nipples opposite each zone are opened and closed by wire line to produce selectively each of several zones. (Fig. 12 illustrates a parallel string hook-up; however, by considering the long string as the only tubing string—the hook-up illustrates the method referred to.)

B. Artificial Lift
   1. Same techniques used with one string and two packers apply to artificial lifting upper zone and any one of several lower zones.

C. Advantages
   1. Economical method of completing one or more marginal zones that would not normally be economically feasible to complete an individual well to these zones.

D. Disadvantages
   1. The same as those which apply to one string two packer completions (see section entitled "Tubing and Annulus Production").

Two Parallel Strings of Tubing and One Packer

A. Completion Practice
   1. Lower zone up long string; upper zone up short string.
   2. Separately retrievable short string hanging free; separately retrievable full-opening long string located, latched or tied to packer with threaded connection. Located or latched long string may be retrieved with short string in place (Fig. 2).
   3. Separately retrievable short string anchored to long string; long string located, latched or tied to packer with threaded connections (Fig. 3).

B. Artificial-Lift Possibilities
   1. Pumping (Fig. 4)
      a. Both zones pumped with two strings of rods, lower zone up long string and upper zone up short string. Upper zone gas bleed-off at casing head, lower zone gas bleed-off through macaroni string, where necessary.
      b. Both zones pumped with one string of rods using dual-zone pump (Fig. 5). Lower zone up short string; upper zone up long string. Upper zone gas bleed-off at casing head; where necessary, lower zone gas bleed-off through macaroni string concentric with short string. Gas bleed-off string separately retrievable.
      c. Pumping upper zone, gas bleed at casing head, lower zone flowing.
      d. Hydraulic pumping using concentric or parallel macaroni strings for power oil.
   2. Gas Lift
      a. Gas lift impractical.

C. Advantages
   1. Flexibility at lowest cost. Workover of either zone simple and economical. Lower zone can be permanently completed.
   2. Low cost method of converting single to successful parallel dual.

D. Disadvantages
   1. Cannot load annulus.
   2. Upper zone pressure on casing.
   3. Corrosive elements from upper zone in contact with casing.
   4. Gas lift impractical.

Two Parallel Strings of Tubing and Two Packers

A. Completion Practice
   1. Upper zone confined to separately retrievable short string that seats and seals off in head top packer (if retrievable); see Fig. 11. Lower zone confined to full-opening long string that passes through upper packer and seats and seals off in bore of lower drillable packer. Also furnished with long and short strings selectively retrievable.
   2. Upper zone confined to separately retrievable short string that seats and seals off in head of parallel-flow tube (Fig. 10). Parallel-flow tube seats and seals off in bore of upper drillable packer. Lower zone confined to full-opening long string that is connected to and extends through flow tube to seat and seal off in bore of lower drillable packer. Also furnished with long and short strings selectively retrievable.
   3. Upper zone confined to separately retrievable short string that seats and seals off in head of upper retrievable packer. Lower zone confined to full-opening long string that is connected and passes through upper packer to tie onto lower retrievable packer via threaded connections.

B. Artificial-Lift Possibilities
   1. Pumping
      a. Pump either or both zones through anchored string. Gas venting of lower zone possible if triple string flow tube or triple string packer is used.
   2. Gas Lift
      a. Gas lift both zones using casing as gas reservoir. Preplanned gas-lift installations run housings for wire line gas-lift mandrels at time tubing is run. When gas lift is required, annular fluid is removed, mandrels installed.

C. Advantages
   1. Complete isolation of each zone at all times.
   2. Can load annulus.

D. Disadvantages
   1. Difficult to vent either zone for pumping. See B-1a above.

Two Parallel Strings; Two Packers; No Permanent String Between Packers[4]

A. Completion Practice
   1. Both long and short strings terminate in upper packer. A retrievable production tube is run through the long string to the lower packer to isolate zones for production.

B. Artificial Lift (same as for two strings—two packers)

C. Advantages

1. Either or both zones may be permanently completed.

D. Disadvantages

1. Neither zone can be vented for pumping.
2. Hook-up more complex.

Two Parallel Strings and Two or More Packers

A. Completion Practice

1. Lower packers isolate two, three, four, or more zones (Fig. 12). Long string extends through all lower packers. Sleeve valve or side-ported nipples opposite each zone isolate or open each zone to the long string.
2. A variation of this hook-up has the short string extend down through to the zone below the second packer. By this method one or more zones can be selectively opened to the long string and two zones selectively opened to the short string.

B. Artificial Lift

1. See two parallel strings and two packer installation.

C. Advantages

1. Permits the depletion of one or more marginal zones that could not be produced economically by any other method.

D. Disadvantages

1. See two parallel strings and two packer installation.

Three Zone Production

Two Parallel Strings and Two Packers

A. Completion Practice

1. Identical with two zone and two parallel string; two packer hook-up except third zone is produced in annulus above upper packer.

B. Artificial Lift

1. See two zone, two parallel string, two packer installation.

C. Comment: Could be satisfactory completion if upper zone were gas. Upper zone producing sand or excessive paraffin could complicate retrievability of lower tubing string and retrievable packers.

Three Parallel Strings and Three Packers

1. Installation using three permanent packers (Fig. 13). Lower zone produced through full-opening long string that extends through all three packers. Intermediate zone produced through annulus between long string and intermediate string and on up intermediate string. Upper zone produced through annulus between intermediate string and outer flow tube housing and up through short string. Triple string flow tube and sealing accessories for lower packers are run on long string. Two short strings for upper and intermediate zones are then run in and are stabbed into sealing bores in flow tube head.
2. Installation using three retrievable packers. Lower zone produced through full-opening long string that extends through all three packers. Intermediate zone produced through second bore of intermediate retrievable packer through intermediate string that seats in receptacle of intermediate packer. Upper zone produced through third bore of upper retrievable packer. Upper zone short string is run and seated in receptacle of upper packer.

B. Artificial Lift

Because the modern triple string hook-up is of very recent origin, little information is available regarding the application of artificial lift to this method. It would seem, however, that two zones could be pumped with two strings of rods or that any or all zones could be gas-lifted using the casing as a reservoir.

Four Zone Production

Three Parallel Strings and Three Packers

A. Completion Practice

1. Identical with three parallel string; three packer hook-up described previously except that fourth zone (upper zone) is produced in the annulus above the upper packer.

B. Comment

1. As with the two string-two packer triple completion this hook-up is feasible if the upper zone is clean gas. Production of oil into this annular space might affect the retrievability of the strings and retrievable packers used for lower zones.

Four Parallel Strings and Four Packers

Completion requires use of four hydraulic retrievable packers containing heads to accommodate one, two, three and four strings of tubing, respectively (Fig. 14). Packers for all four zones are made up successively on long string with connecting strings stabbed into proper packer bores in sequence. Christmas tree installed, packers set in sequence from top down circulating around unset packers to unload successive zones. Because this is a relatively recent completion, other than its initial success, little is known of its future requirements from the standpoint of workover and artificial lift.[6]

Conclusion

It is obvious that there are innumerable ways to make multiple-zone completions, only a few of which can be discussed at any great length in a paper. Even though the systematic approach for the selection of a practical multiple completion hook-up, as presented in this paper, is followed, conditions may be such that none of the basic arrangements appear to be completely satisfactory. In such instances it is well to remember that manufacturers of multiple completion equipment more than likely have a number of solutions to completion problems of which even their own field men are not aware. It is suggested therefore, that whenever a seemingly unsolvable completion problem exists, that the individual manufacturers be contacted directly for their suggestions before attempting to design equipment for a specific "problem" installation.

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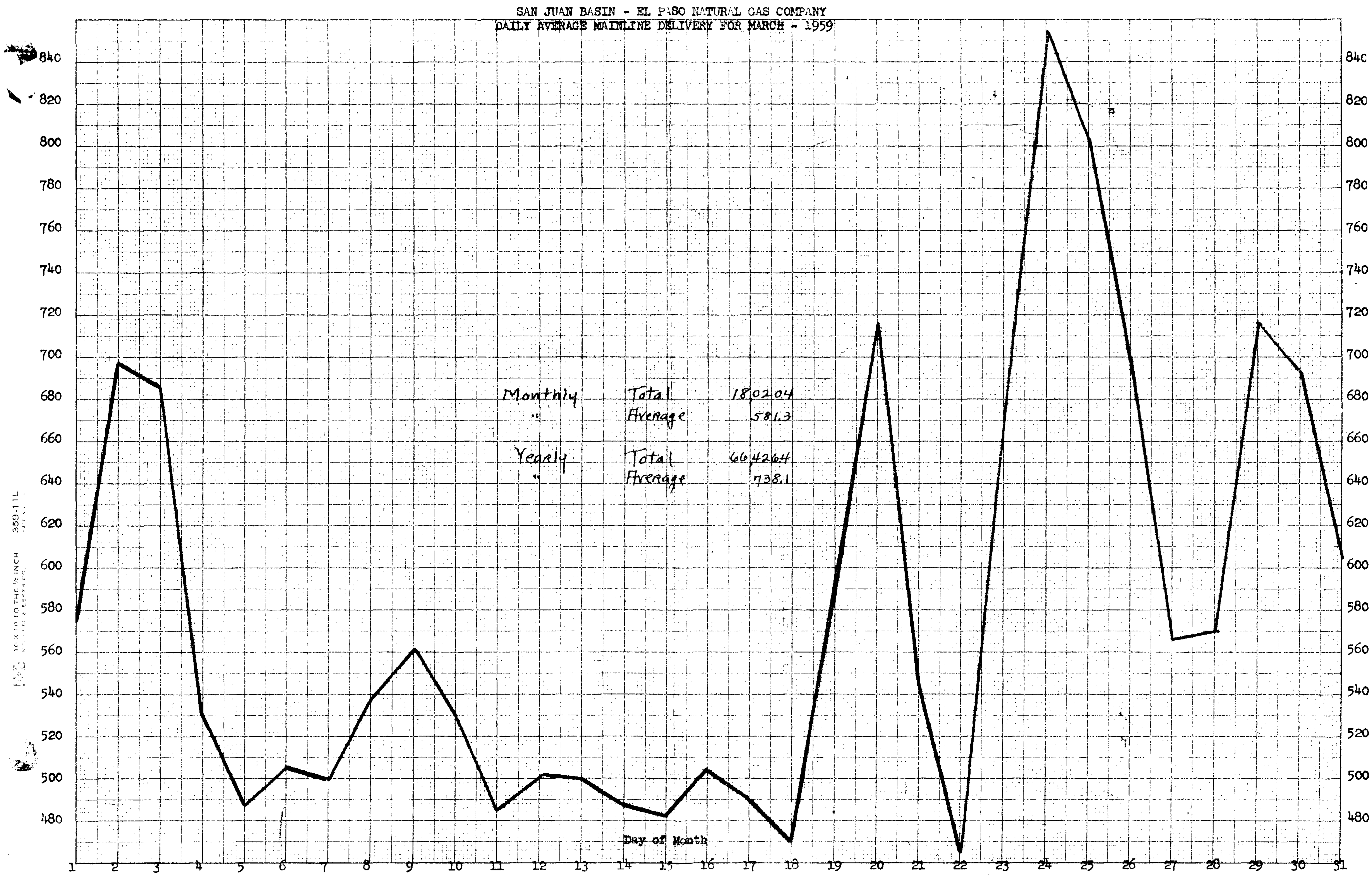
SAN JUAN BASIN - EL PASO NATURAL GAS COMPANY
DAILY AVERAGE MAINLINE DELIVERY FOR MARCH - 1959
Monthly Total 180204
" Average 581.3
Yearly Total 664264
" Average 738.1
Day of Month

SAN JUAN BASIN - EL PASO NATURAL GAS COMPANY
DAILY AVERAGE MAINLINE DELIVERY FOR APRIL
1959