Computerized Gas Lift Design -A New Field Tool

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INTRODUCTION

Considerable emphasis has been placed on the diversification of petroleum engineers in oil companies. As a result, much of the detailed repetitive hand calculations must be done utilizing high speed computers. In line with this, two computer programs have been developed during the past two years which facilitate the rapid calculation of gas lift installation designs. One program performs the detailed calculations necessary for continuous flow gas lift installations while the second designs intermittent lift installations. These programs are capable of calculating installations for a single well or entire field studies for which the data received varies from well to well. The programs are used to investigate a number of the varying parameters for the same well which influence the resulting gas lift installation. These parameters include injection gas pressure, wellhead pressure, P.I., etc. The results obtained from the computer calculations are extremely accurate, and unlimited versatility is provided for changes in data. The final designs which have been run have performed according to calculation.

APPLICATIONS

The primary application of the computer programs is the design of a gas lift installation for a single well based on the data given. An installation can be obtained for either continuous flow or intermittent lift which locates the valve depths and lists the respective valve opening pressures in a tester opposite the valve depths. If the well contains previously installed retrievable valve mandrels, the resultant installation design will note which mandrels should be used, and the valve opening pressure in a tester at the respective mandrel depth.

The more complete the data is, the more sophisticated the resulting design becomes. When the well data is limited, the more generalized the final design becomes. In either case, the same detailed design procedures are employed, and the resultant installation is reliable barring a data error. When very little data is known for a particular gas lift candidate, the pertinent parameters to the design, such as flowing wellhead tubing pressure, productivity index, static bottom hole presure, water-oil ratio, bottom hole temperature, flowing wellhead temperature, etc., can be investigated in the same computer run. Then, the most appropriate design can be selected.

Another application of the computer programs is their use in field studies. Many gas lift installations may be designed for any number of wells. Installations may be designed using the high speed digital computer for 50 or 100 wells just as quickly as for one well. In the design of a closed rotative gas lift system, the appropriate injection gas pressure and flowing wellhead tubing pressure can be determined for the given well conditions. This is done by assuming various injection and wellhead tubing pressures, and determining which combination provides the greatest efficiency for the system. From these results, the suction and discharge pressures of the compressor can be determined.

The computer programs may be used in an optimization study for the improvement of a presently installed gas lift system. Gas volume and pressure, number of valves, maximum valve depth, etc., can be determined for the evaluation of changes in reservoir conditions, producing rates, conduit sizes, etc. These programs have been used as a research tool in the determination of valve spacing charts. As many as 500 different installation designs for a given set of field conditions may be obtained which allow a graphical representation of the appropriate valve depths and port sizes. An operator can have on file typical installation designs for an entire field. Therefore, whenever a well in that field is considered for gas lift, the operator selects the appropriate design from his files.

While these programs are readily adaptable for conventional gas lift designs, they may also be used for the calculation of installations for annular flow as well as gas lift up small tubing. For casing flow, an equivalent tubing diameter is selected whose area is approximately 60 to 70 per cent of the actual annular area. The appropriate gradient curves are calculated by the computer for this equivalent tubing diameter in the design of the installation. For continuous flow up small conduits, the average unloading flowing gradients are selected and used as data since a correlation for small tubes is not available at this time. Actual emperical flowing gradients are published which permit the design of continuous flow up small diameter tubing.[4] The same installation design procedures are applied for both cases. These programs may be used for the design of dual completion gas lift installations with a common injection source. In this case, it is desirable to obtain complete data for both zones, since the operation of one zone depends on that of the other.

A composite installation may be designed in order that continuous flow be used while lifting from the upper valves in the string and intermittent lift employed below. For this type of design, it is necessary to use both programs and combine the results.

CONTINUOUS FLOW INSTALLATION COMPUTER DESIGN

The continuous flow computer program designs an installation utilizing casing pressure operated valves. It contains two basic sections. The first section designs a complete installation including the determination of gas lift valve depths and valve opening pressures in a tester. The second section designs an installation for a well in which retrievable valve mandrels have previously been installed. The program follows the graphical procedure for the design of continuous flow gas lift installations presented in the Camco Gas Lift Manual.[1] with two exceptions. The minimum reopening casing pressure is based on a maximum tubing pressure at valve depth which is determined graphically by drawing a straight line from the flowing wellhead tubing pressure at zero depth to the flowing tubing pressure at the next lower valve depth when this valve is uncovered. In the manual, this value is determined using flowing gradient curves. The second exception concerns the determination of the injection gas pressure at depth. The program uses a decreasing gradient with lower surface pressures while the manual utilizes the same gradient for all surface pressures. The difference in the two designs results in the computer calculations being on the safe side.

There are basically two types of continuous flow installations: (1) The point of gas injection known and not changing, and (2) The point of gas injection unknown and/or changing. In terms of data required, these types can be divided as follows: (1) Productivity index and static bottom hole pressure given, and (2) Productivity index not given. Continuous flow installation designs can be further subdivided dependent upon: (1) Limited or unlimited injection gas volume available for unloading; (2) Kickoff and operating injection gas pressures the same or different, and any combination of the above. Although the static bottom hole pressure may be known, the point of gas injection cannot be determined if the P.I. is unknown. When the point of gas injection cannot be determined, the installation must be designed to permit obtaining the desired producing rate from any valve in the string. It either the static bottom hole pressure or P. I. is known, but either change, the point of gas injection will also change and the installation should be designed as though the P.I. were unknown. If the P.I. is given and the kickoff pressure exceeds the operating pressure, the kickoff pressure will be used to calculate the unloading valve depths and valve opening pressures for all valves above the depth at which the desired drawdown could occur for either unloading or operating conditions. Below this depth, the operating pressure is used. If the P.I. is unknown, the kickoff pressure is used to calculate the top valve depth only. The depths of the remaining valves and opening pressures for all valves are based on the given operating injection gas pressure.

The calculations are discontinued by the computer when the distance between valves is less than 100 ft or a valve depth equals the total tubing length. When the P.I. is given, the calculations will terminate before these two stops, if the maximum depth of lift required to unload and produce the desired producing rate is reached first. If retrievable valve mandrels have previously been installed, the calculations will terminate at the bottom mandrel depth or when the flowing tubing pressure at mandrel depth is greater than the available casing pressure at that depth.

Well Data

Fig. 1 is a sample of the data sheet for continuous flow computer design calculations. Although the data sheet contains 37 items, only items numbered 5, 6, 7, 15, 22, 23, 24, 26, 28, 29, 31, 33 and 34 are actually well data. The remaining items on the data sheet are used for identification and control purposes. Instructions for correctly completing these data sheets are detailed in previously published literature.[2]

FIGURE 1

WELL DATA SHEET FOR CAMCO'S CONTINUOUS FLOW GAS LIFT COMPUTER PROGRAM CALCULATIONS

(Please read instructions carefully prior to completing data sheet)

1. Company ______
2. Lease and Well No. ______
3. District ______
4. Date ______
5. Tubing I. D. (i.e. 2"=1.995;2-1/2"=2.441;3"=2.992;etc) ______ in.
6. Total tubing length (HTD) = ______ ft.
7. Formation gas-oil ratio = ______ cu. ft./bbl.
8. Static fluid level = ______ ft.
9. Will well be unloaded to pit? (Use 0 if yes; 1 if no) ______
10. Average flowing temperature above point of gas injection (140°F. or 190°F.) = ______ °F.
11. Average flowing temperature below point of gas injection (140°F. or 190°F.) = ______ °F.
12. Setting temperature of valves in tester (usually 60°F.) = ______ °F.
13. Additional drop in casing pressure (safety factor) between valves = ______ psi
14. Difference between casing and tubing pressures at valve depth during unloading (usually 50 psi) = ______ psi
15. Bottom hole temperature at HTD = ______ °F.
16. Type of Camco gas lift valves to be run ______
17. Minimum valve port size desired = ______ /16 in.
18. Maximum valve port size desired = ______ /16 in.
19. Number of mandrels in well ______
20. Mandrel depths in feet (leave blank if Item 19 is zero) ______
21. Desired daily producing rate (total liquid) = ______ BLPD
22. Water-oil ratio = ______
23. Static bottom hole pressure at HTD = ______ psig
24. Kickoff injection gas pressure at surface = ______ psig
25. Kickoff injection gas pressure at HTD = ______ psig
26. Operating injection gas pressure at surface = ______ psig
27. Operating injection gas pressure at HTD = ______ psig
28. Flowing wellhead tubing pressure = ______ psig
29. Gross productivity index (if not given, put 0) ______ BLPD/psi
30. Maximum gas volume available for gas lift = ______ cu. ft./day
31. Formation gas-liquid ratio = ______ cu. ft./bbl.
32. Temperature of injection gas at surface = ______ °F.
33. Flowing wellhead tubing temperature = ______ °F.
34. Static gradient of load fluid = ______ psi/ft.
35. Will additional investigations for this well be made? (Use 1 if yes; 0 if no.) ______
36. Average unloading gradient for traverse below point of gas injection (for computer to calculate this gradient, leave blank) ______ psi/ft.
37. Average unloading gradient for traverse above point of gas injection (for computer to calculate this traverse, leave blank) ______ psi/ft.

COMMENTS:

For equipment considerations, please note casing I. D. = ______ in.

It is apparent from the well data sheet that numerous items can be varied and their effect investigated; such as, wellhead pressure, injection pressure, P.I., tubing size, etc. There are installations for which much of the data must be assumed, and it is desirable to design the installation conservatively to assure unloading. Some of the control data which can be varied to incorporate significant safety factors in the design are "Additional Drop in Casing Pressure Between Valves", Difference Between Casing and Tubing Pressures at Valve Depth During Unloading", "Operating Injection Gas Pressure at Surface and at HTD", and "Flowing Wellhead Tubing Temperature".

If measured unloading gradients for a particular field vary considerably from gradients based on the Poettmann and Carpenter Correlation,[3] the actual average unloading gradient above the point of gas injection can be included as data (Item No. 37), and the installation will be designed accordingly. This feature is particularly applicable in the design of the continuous flow installations with small tubing.

Any static load fluid gradient can be used in the calculation of an installation. The top valve depth is calculated by the computer based on this gradient. This calculated top valve depth is compared to the static fluid level and the top valve is located at the greater depth. The static gradient is used also to calculate all additional valve depths which are located above the point at which drawdown in bottom hole pressure first occurs. For some installations, the separator and flowing wellhead tubing pressures are significantly different. Since the well is U-tubed into the separator during initial unloading, the top valve depth can be calculated based on separator pressure. This depth can be used as the static fluid level on the data sheet, and the computer program will locate the top valve at this depth. With the exception of the top valve depth, calculated valve depths below the point at which drawdown first occurs are based on the average unloading gradient for the traverse below the point of gas injection. If this value is unknown and not given, it is calculated by the computer based on the static load fluid gradient, tubing size, desired producing rate and zero gas liquid ratio.

FIGURE 2

THE FOLLOWING RESULTS WERE OBTAINED USING THE CAMCO CONTINUOUS FLOW GAS LIFT PROGRAM
FOR THE CIGITAL COMPUTER

PROB. EX. NO. 1 SAME KICKOFF AND OPR. PRESS. PI GIVEN AND NOT GIVEN
WELL DATA
TUBING 2.441 INCHES ID., LENGTH 6000. FEET
SPECIFIC GRAVITY GAS C.65, OIL 0.85, WATER 1.00
FORMATION GAS-OIL RATIO 400. CU.FT./BBL.
STATIC FLUID LEVEL 0. FEET
WELL WILL NOT BE UNLOADED INTO PIT
AVERAGE FLOWING TEMPERATURE 14C. DEG.F. ABOVE AND 140. DEG.F. BELOW PT OF INJ
ADDITIONAL DROP IN CASING PRESSURE 0. PSI.
DELTA P ACROSS VALVE DURING UNLOACING 50. PSI.
BOTTOM HOLE TEMPERATURE 170. CEG. F.
VALVE TYPE J20 TO BE SET AT 6C DEG. F
PORT SIZES ARE LIMITED BETWEEN 4 AND 4/16 INCHES.

DESIRED PRODUCING RATE 800. BLPD. WATER-OIL RATIO 24.00
FORMATION GAS-LIQUID RATIO 24. CU.FT./BBL.
STATIC BOTTOM HOLE PRESSURE 260C. PSIG.
KICKOFF INJECTION PRESSURE AT SURFACE 650. AND AT BOTTOM HOLE 739. PSIG.
OPERATING INJECTION PRESSURE AT SURFACE 650. AND AT BOTTOM HOLE 739. PSIG.
FLOWING WELLHEAD TUBING PRESSURE 100. PSIG.
PRODUCTIVITY INDEX 2.0C BLPC/PSI.
MAXIMUM GAS VOLUME AVAILABLE FOR GAS LIFT 2360000. CU.FT./DAY
TEMPERATURE OF INJECTION GAS AT SURFACE 80. DEG.F.
FLOWING WELL HEAD TUBING TEMPERATURE 80. DEG.F.
STATIC GRADIENT OF LOAD FLUID C.4440 PSI/FT.

VALVE NUMBER	DEPTH (FEET)	PORTSIZE (INCHES)	OPENING PRESSURE (PSIG)
1	1175	4/16	432
2	2033	4/16	421
3	2693	4/16	411

POINT OF GAS INJECTION IS AT VALVE NO. 2 AT A DEPTH OF 2033. FEET.
INJECTION GLR IS 207 CU.FT./BBL., INJECTION GAS REQUIREMENT IS 166 MCFD.

NEW DATA FOR THIS PROBLEM

PROB. EX. NO. 1 SAME KICKOFF AND OPR. PRESS. PI GIVEN AND NOT GIVEN
PRODUCTIVITY INDEX 0. BLPD/PSI.

VALVE NUMBER	DEPTH (FEET)	PORTSIZE (INCHES)	OPENING PRESSURE (PSIG)
1	1175	4/16	432
2	2033	4/16	421
3	2693	4/16	411
4	3192	4/16	402
5	3568	4/16	395
6	385C	4/16	389
7	4061	4/16	385
8	4218	4/16	382
9	4335	4/16	38C

VALVE DEPTH CALCULATION TERMINATED. NEXT VALVE AT 4422. FEET.
LESS THAN 1C0 FEET BELOW 9TH VALVE.
MAXIMUM UNLOADING PRODUCING RATE = 800. BLPD AT 4335 FEET.

Printed Results

The printout for the continuous flow computer program calculations contains two pages for each design investigated. The first page includes all of the well data used as input for the computations and a tabulation of the proposed installation (See Fig. 2). The second page includes a tabulation of all intermediate calculated results pertinent to the design which allows a complete check of these calculations by hand. The nomenclature for the symbols used in the second page of the printout (See Fig. 3) is included in the Appendix.

While the final tabulation of the recommended installation is necessary, other valuable information may appear on the first page of the printout. When the P.I. is given, the program will make such checks as whether the well will produce at the desired producing rate by natural flow after unloading and whether the desired producing rate can be obtained based on the data given. These checks are made prior to calculating valve depths. If the well is capable of flowing the desired rate, a printout, "WELL WILL FLOW AFTER UNLOADING" will appear above the tabulation. A printout of "DESIRED PRODUCING RATE CANNOT BE OBTAINED BASED ON DATA GIVEN" will appear when the second check reveals this condition. When the latter appears, a producing rate which is possible is calculated and a design will follow for that rate. The printout reads: "CHANGE PRODUCTION RATE TO ____ BLPD AND RECOM-

FIGURE 3

THE FOLLOWING RESULTS WERE CBTAINED USING THE CAMCO CONTINUCUS FLOW GAS LIFT PROGRAM
FOR THE CIGITAL COMPUTER

PROB. EX. NO. 1 SAME KICKOFF AND CFR. PRESS. PI GIVEN AND NOT GIVEN

HOVM = 2569.56 POVM = 638.1 HNPI = 2013.24 GRACP = 0.4736 PROCI = 2.0C DCOMP = 849.08

NO.	MINPT	PBHF	BLPC	IGLR	MAXPT	PCAS	TV	IDPORT	PBT	RECPL	REOPS	TVALVE	PVC	L	L NEXT
1	224.	25C9.	183.	386.	4C6.	667.	98.	4/16	638.	654.	637.	98.	632.	1175.	2C33.
2	314.	2193.	815.	528.	457.	667.	111.	4/16	643.	654.	625.	111.	622.	2C33.	2693.
3	383.	1950.	13C1.	667.	539.	663.	120.	4/16	644.	652.	614.	12C.	611.	2693.	3193.

HOVM = 4854.11 POVM = 610.9 HNMI = 4854.11 GRACP = 0.4736 PROCI = C. CCCMP = 849.08

NO.	MINPT	PBHF	BLPO	IGLR	MAXPT	PCAS	TV	IDPORT	PBT	REOPL	REOPS	TVALVE	PVC	L	L NEXT
1	224.	25C9.	8C0.	386.	4C6.	667.	98.	4/16	638.	654.	637.	98.	632.	1175.	2033.
2	314.	2193.	8C0.	528.	457.	667.	111.	4/16	643.	654.	625.	111.	622.	2C33.	2693.
3	383.	1950.	8CC.	667.	539.	663.	120.	4/16	644.	652.	614.	12C.	611.	2693.	3193.
4	436.	1766.	8C0.	772.	560.	659.	128.	4/16	644.	650.	606.	128.	602.	3193.	3569.
5	476.	1627.	8C0.	851.	572.	655.	134.	4/16	643.	648.	599.	134.	595.	3569.	3851.
6	505.	1523.	8CC.	919.	579.	652.	138.	4/16	642.	647.	595.	138.	59C.	3851.	4061.
7	527.	1446.	800.	996.	583.	650.	141.	4/16	642.	646.	591.	141.	586.	4061.	4218.
8	544.	1388.	8C0.	1C54.	586.	648.	143.	4/16	641.	645.	588.	143.	583.	421E.	4335.
9	556.	1345.	8C0.	1097.	588.	646.	145.	4/16	640.	644.	586.	145.	58C.	4335.	4422.

VALVE DEPTH CALCULATION TERMINATED. NEXT VALVE AT 4422. FEET.
LESS THAN 100 FEET BELOW 9TH VALVE.
MAXIMUM UNLOACING PRODUCING RATE = 80C. BLPD AT 4335 FEET.

PUTE". However, no installation is calculated when a theoretical maximum producing rate of less than 200 BLPD is possible. Then the computer prints: "MAXIMUM OBTAINABLE PRODUCING RATE IS LESS THAN 200 BLPD, CALCULATIONS TERMINATED".

When the valve depth calculations are terminated because the next valve is less than 100 ft below the previous valve depth, printout reads: "VALVE DEPTH CALCULATIONS TERMINATED. NEXT VALVE AT _____ FEET, LESS THAN 100 FEET BELOW _____ VALVE".

When the productivity index is given, the depth to the point of gas injection and the injection gas requirement are printed in the following manner: "POINT OF GAS INJECTION IS AT VALVE NO. ____ AT A DEPTH OF _____ FEET. INJECTION GLR IS ____ CU.FT./BBL., INJECTION GAS REQUIREMENT IS ____ MCFD" (See Fig. 2).

When an item of data is changed for the same installation design (Items No. 21 through 37), the resulting printout contains the following heading: "NEW DATA FOR THIS PROBLEM". This is followed by a print of the item or items of data which has or have been changed and the tabulated results as in Fig. 2.

The maximum unloading producing rate from the bottom valve may be shown as follows: "MAXIMUM UNLOADING PRODUCING RATE = ____ BLPD AT ____ FEET". If the unloading producing rate is negative, the computer will print: "NO DRAWDOWN IN BHP IS POSSIBLE FOR UNLOADING CONDITIONS WITH THIS INSTALLATION". When the P.I. is unknown and the static bottom hole pressure is given, the latter printout may appear if no drawdown is possible based on this static bottom hole pressure.

The computer calculates a producing rate from the bottom valve based on the formation gas liquid ratio when the P.I. is given and the installation design is terminated due to a distance between valves of less than 100 ft. If the desired rate cannot be obtained, the computer prints: "FOR THE OPERATING CONDITIONS THE MAXIMUM PRODUCING RATE FROM THE BOTTOM VALVE IS ______ BLPD". If the desired rate may be obtained from the bottom valve depth, the following printout appears: "FOR THE OPERATING CONDITIONS THE PRODUCING RATE _____ BLPD CAN BE OBTAINED".

Limits On Continuous Flow Program

No continuous flow installation will be designed for a producing rate less than 200 BLPD except for wells where Item No. 37 of the data sheet is greater than zero. When the P.I. is given, the computer calculates a minimum flowing bottom hole pressure based on the given flowing wellhead tubing pressure, total tubing length and an arbitrarily selected flowing gradient based on the tubing I.D. These gradients are 0.13 psi/ft for 1.995 in., 0.10 psi/ft for 2.441 in., 0.08 psi/ft for 2.441 in., and 0.04 psi/ft for an I.D. of 4.0 in. or greater. If 200 BLPD or greater can be obtained, a second check is made based on operating conditions. The operating conditions are based on the obtainable producing rate from the first check, if this value is less than the desired producing rate. Otherwise, the operating conditions are based on the calculated flowing bottom hole pressure for the desired producing rate, traverse below the point of gas injection for the produced formation fluid, the traverse above the point of gas injection (including formation and maximum injection gas liquid ratio) and the operating injection gas pressure. If this check reveals that less than 200 BLPD can be obtained, the calculations will terminate. The reason for this termination is due to the limitations of the flowing gradient correlation used in the program.[3]

No gas liquid ratio greater than 3000 cu ft/bbl can be used in this program. The maximum available injection gas volume which can be used as input is 9999999 cu ft /day. No tubing inside diameter less than 1.610 in. should be used in this program unless the value of Item No. 37 on the data sheet is given greater than zero. Again, this is due to the limitations of the flowing gradient correlation used in the program.

Only one valve type can be used for an installation design. If two types of valves are to be run in the same tubing string, two different designs should be calculated and the final design selected by combining the two.

INTERMITTENT GAS LIFT INSTALLATION COMPUTER DESIGN

The intermittent lift computer program utilizes a design procedure whereby the calculated distance between valves is based on the closing pressure of the valve above at depth, intermittent spacing factor, static load fluid gradient, minimum wellhead tubing pressure between injections and the depth to the valve above. This procedure is outlined in detail in Camco's Gas Lift Manual.[1] The valve opening pressures in a tester are calculated based on the input Av/Ab ratio of the valve selected, valve closing pressure at depth and the valve temperature.

Similar to the continuous flow computer design, an intermittent installation can be calculated for a well with or without previously installed retrievable valve mandrels. An installation may be calculated using the detail design technique whether the productivity index and static bottom hole pressure of the well are known or not.

In addition to the recommended final design which includes valve number, valve depth and valve opening pressure in a tester, the printout includes the approximate cycle frequency and injection gas requirement necessary to make the desired producing rate from each valve in the string. The injection requirement at each valve is based on the volume of gas required to fill the tubing under the liquid slug each cycle and the approximate cycle frequency. The design calculations are normally terminated when the next valve depth exceeds the total tubing length.

Well Data

A sample of the well data sheet used for the intermittent lift computer program is illustrated in Fig. 4. The majority of the items included on this data sheet are identification and control data for the program. The actual well data required are items numbered 5, 6, 7, 9, 18, 19, 23, 25, 30, 31 and 33. The remaining items are used for identification and control of the computer calculations. These assumptions are normally used for hand calculations. The instructions for accurately completing this data sheet have been previously published.[2]

Data such as injection pressure, wellhead tubing pressure, desired top valve depth (static fluid level, Item No. 22), desired producing rate, etc., can be varied for the same well and resulting installations calculated with little effort. Variations in control data such as maximum and minimum intermittent spacing factors, depth at which the design spacing factor should begin, minimum distance between valves and desired decrease in surface closing pressure between valves, make possible the selection of the best intermittent lift installation for the well data submitted.

The value of the static fluid level, Item No. 22, will be the top valve depth if it is greater than the calculated top valve depth based on kickoff pressure, flowing wellhead tubing pressure and static load fluid gradient. To let the computer cal-

FIGURE 4

WELL DATA SHEET FOR CAMCO'S INTERMITTENT GAS LIFT COMPUTER PROGRAM CALCULATIONS

(Please read instructions carefully prior to completing data sheet)

1. Company ______
2. Lease and Well No. ______
3. District ______
4. Date ______
5. Casing I. D. ______ in.
6. Tubing I. D. (i. e. 1" = 1.049; 1-1/4" = 1.380; 1-1/2" = 1.610; 2-1/16" = 1.750; 2" = 1.995; 2-1/2" = 2.441; 3" = 2.992) ______ in.
7. Total tubing length (HTD) = ______ ft.
8. *Setting temperature of valves in tester (usually 60°F) =* ______ °F.
9. Bottom hole temperature at HTD = ______ °F.
10. Will well be loaded prior to running valves? (Use 0 if yes; 1 if no) ______
11. Will well be unloaded to pit? (Use 0 if yes; 1 if no) ______
12. Minimum intermittent spacing factor (usually .04) ______ psi/ft.
13. Number of mandrels in well ______
14. Mandrel depths in feet (leave blank if Item 13 is zero) ______
15. Type of Camco gas lift valves to be run ______
16. Valve port size desired = ______ /16 in.
17. A_v/A_b Ratio of valve selected = ______
18. Desired daily producing rate (total liquid) ______ BLPD
19. Water-oil ratio (WOR) = ______
20. Gross productivity index (if not given, put 0) ______ BLPD/psi
21. Static bottom hole pressure at HTD = ______ psig
22. Static fluid level = ______ ft.
23. Kickoff injection gas pressure at surface = ______ psig
24. Kickoff injection gas pressure at HTD = ______ psig
25. Operating injection gas pressure at surface = ______ psig
26. Operating injection gas pressure at HTD = ______ psig
27. Desired surface closing pressure of top valve = ______ psig
28. Closing pressure of top valve at HTD = ______ psig
29. Desired decrease in surface closing pressure between valves = ______ psi
30. Flowing wellhead tubing pressure = ______ psig
31. Static gradient of load fluid = ______ psi/ft.
32. Temperature of injection gas at surface = ______ °F.
33. Flowing wellhead tubing temperature = ______ °F.
34. Maximum intermittent spacing factor (if undecided, use .20) ______ psi/ft.
35. Depth at which spacing factor for desired producing rate should begin ______ ft.
36. Minimum distance between valves: ______ ft.
37. Will additional investigations for this well be made? (Use 1 if yes; 0 if no)

COMMENTS:

culate the top valve depth, the value of the static fluid level should be set equal to zero or less than the previously hand-calculated top valve depth.

The minimum intermittent spacing factor, Item No. 12, is used in the calculation of the distance between valves above the depth at which drawdown first occurs. The depth at which drawdown first occurs is the first changeover depth on the printout (see Fig. 5). The minimum intermittent spacing factor is always used to calculate the second valve depth. In a very low bottom hole pressure well, with low desired rate, it is not uncommon for the minimum spacing factor to be used for spacing all valves (see Fig. 5).

Previously published spacing factors are calculated by the computer program for the desired rates and tubing diameters. [1,2] The calculated spacing factor for a design is compared to the given maximum spacing factor (Item No. 34) and the lower value is used. If a lower spacing factor is preferred for the desired rate, it may be placed in Item No. 34 and used in the calculations. Item No. 35 of the data sheet, depth at which the spacing factor for desired operating conditions should begin, is the second spacing factor change-over depth on the printout if the P.I. is not given. When the P.I. and static bottom hole pressure are given, the computer will calculate the minimum depth at which the desired producing rate can be obtained. This depth is compared to the value of Item No. 35 and the shallower of the two is the second spacing factor changeover depth. One can therefore control the depth at which the spacing factor for the design conditions is used. By selecting the minimum distance between valves (Item No. 36), the number and spacing of valves in an installation can be controlled. When the calculated distance between valves becomes less than the desired minimum distance between valves, the program instructs the computer to space the remaining valves based on the minimum distance between valves. Since the valve specifications are used primarily for the calculation of the valve opening pressure in a tester, installation designs for the well data submitted for different valve types or port sizes will have exactly the same valve depths. Therefore, a design can be obtained for each valve type or port size to be used, and a composite installation can be selected from the different computer runs.

FIGURE 5

THE FOLLOWING RESULTS WERE OBTAINED USING THE CAMCO INTERMITTENT GAS LIFT PROGRAM FOR THE DIGITAL COMPUTER

INTERMITTENT MULTIPOINT DESIGN FOR HIGH AND LOW CAPACITY WELLS

WELL DATA
CASING I.D. 4.892 INCHES, TUBING I.D. 1.995 INCHES, LENGTH 5200. FEET
BOTTOM HOLE TEMPERATURE 155. DEG. F.
WELL WILL BE LOADED PRIOR TO RUNNING VALVES
WELL WILL NOT BE UNLOADED INTO PIT
CAMCO TYPE J20 VALVES WITH 7/16 IN. PORT TO BE SET AT 60. DEG. F. IN TESTER

DESIRED DAILY PRODUCING RATE 300. BLPD. WATER-OIL RATIO 9.00
PRODUCTIVITY INDEX 0.500 BLPD/PSI.
STATIC BOTTOM HOLE PRESSURE 1520. PSIG., STATIC FLUID LEVEL 0. FEET
KICKOFF INJECTION PRESSURE AT SURFACE 600. AND AT BOTTOM HOLE 670. PSIG.
OPERATING INJECTION PRESSURE AT SURFACE 600. AND AT BOTTOM HOLE 670. PSIG.
DESIRED CLOSING PRESS. OF TOP VALVE AT SURF. 500. AND AT BOTTOM HOLE 560. PSIG.
DESIRED DROP IN SURF. CLOSING PRESS. BETWEEN VALVES 0. PSI.
FLOWING WELLHEAD TUBING PRESSURE 60. PSIG.
SPECIFIED RATIO BETWEEN TUBING AND CASING PRESSURES AT INSTANT VALVE OPENS .600
SPECIFIED PERCENT FALLBACK PER THOUSAND FEET OF LIFT 4.0
STATIC GRADIENT OF LOAD FLUID 0.4900 PSI/FT.
TEMPERATURE OF INJECTION GAS AT SURFACE 100. DEG. F.
FLOWING WELLHEAD TUBING TEMPERATURE 100. DEG. F.
MINIMUM INTERMITTENT SPACING FACTOR 0.0400 PSI/FT. AND MAXIMUM 0.2000 PSI/FT.
DEPTH AT WHICH SPACING FACTOR FOR DESIRED OPR. CONDS. SHOULD BEGIN 5200. FT.
MINIMUM DISTANCE BETWEEN VALVES 250. FEET
CHANGEOVER DEPTHS FOR SPACING FACTORS ARE 2146. AND 5165. FEET.
CORRESPONDING TUBING PRESSURES AT THESE DEPTHS ARE 146. AND 504. PSIG.

BELOW THE TOP VALVE A BLANK IN THE SPACING FACTOR COLUMN INDICATES THAT THE GIVEN MINIMUM DISTANCE BETWEEN VALVES HAS BEEN USED.

VALVE NO.	DEPTH (FT.)	SPACING FACTOR (PSI/FT)	VALVE TEMP. (DEG.F)	VALVE CL. PRESSURE AT SURF. (PSIG)	VALVE CL. PRESSURE AT DEPTH (PSIG)	OP. PRESS. IN TESTER (PSIG)	APP. CYC. FREQ. (CYC/DAY)	INJ GAS REQMT. (MCFD)
1	1200		112	500	519	577	137	92
2	2101	0.040	122	500	524	578	142	133
3	2944	0.040	131	500	534	579	147	211
4	3594	0.042	138	500	541	580	152	274
5	4094	0.072	143	500	547	580	156	324
6	4472	0.070	147	500	551	581	159	362
7	4760	0.081	150	500	554	581	162	394
8	5010		153	500	557	581	164	420

NEW DATA FOR THIS PROBLEM

INTERMITTENT MULTIPOINT DESIGN FOR HIGH AND LOW CAPACITY WELLS

DESIRED DAILY PRODUCING RATE 60. BLPD. WATER-OIL RATIO 0.
PRODUCTIVITY INDEX 0.040 BLPD/PSI.
STATIC GRADIENT OF LOAD FLUID 0.3500 PSI/FT.
MINIMUM DISTANCE BETWEEN VALVES 500. FEET
CHANGEOVER DEPTHS FOR SPACING FACTORS ARE 1543. AND 4367. FEET.
CORRESPONDING TUBING PRESSURES AT THESE DEPTHS ARE 122. AND 235. PSIG.

BELOW THE TOP VALVE A BLANK IN THE SPACING FACTOR COLUMN INDICATES THAT THE GIVEN MINIMUM DISTANCE BETWEEN VALVES HAS BEEN USED.

VALVE NO.	DEPTH (FT.)	SPACING FACTOR (PSI/FT)	VALVE TEMP. (DEG.F)	VALVE CL. PRESSURE AT SURF. (PSIG)	VALVE CL. PRESSURE AT DEPTH (PSIG)	OP. PRESS. IN TESTER (PSIG)	APP. CYC. FREQ. (CYC/DAY)	INJ GAS REQMT. (MCFD)
1	1542		116	500	517	576	22	10
2	2674	0.040	128	500	530	579	23	26
3	3714	0.040	139	500	542	580	24	42
4	4649	0.040	149	500	553	581	25	56
5	5700	0.040	154	500	559	582	26	66

Printed Results

A sample printout for the intermittent lift computer program is illustrated in Fig. 5. The printout contains on one page the well data used as input for the calculations, and a tabulation which includes all intermediate calculations and the final design. Such input information as whether the well will be loaded prior to running valves and whether the well will be unloaded into the pit is printed with the well data and installation design.

When the productivity index and static bottom hole pressure are given, the program interrogates whether the desired producing rate can be obtained. If the desired producing rate cannot be obtained, the computer calculates an obtainable rate and the following printout appears above the tabulated results: "DESIRED PRODUCING RATE CANNOT BE OBTAINED BASED ON THE DATA GIVEN, CHANGE PRODUCTION RATE TO ____ BLPD AND RECOMPUTE". Should the static bottom hole pressure be so low that it cannot be reduced based on the calculated spacing factor for the desired producing rate, the following is printed and no installation is calculated: "NO DRAWDOWN IN BOTTOM HOLE PRESSURE IS POSSIBLE BASED ON THE DATA GIVEN".

If the well is to be loaded prior to running valves and the top valve is spaced based on the value given for the static fluid level, the following printout will follow the tabulation: "SINCE WELL WILL BE LOADED PRIOR TO RUNNING VALVES, IT MAY BE NECESSARY TO SWAB TO NEARLY TOP VALVE DEPTH". The same printout will occur when retrievable valve mandrels have previously been installed, the well is to be loaded and the top mandrel is deeper than the computer-calculated top valve depth.

Only the tubing inside diameters given opposite Item No. 6 on the data sheet can be used in this program. Any variation will result in no installation being calculated and the printout will read: "TUBING I. D. OF ______ CANNOT BE USED IN PROGRAM".

The spacing factor used to calculate a valve depth is printed in the spacing factor column opposite that depth. The spacing factor is increased proportionately with depth between the given minimum spacing factor and that for the desired rate. When the calculated distance between valves is less than the minimum distance between valves, the minimum distance between valves is used to space the remaining valves and the spacing column factor is left blank for each. Accordingly, the following is printed above the tabulated results: "A BLANK IN THE SPACING FACTOR COLUMN INDICATES THAT NO SPACING FACTOR HAS BEEN USED TO COMPUTE THIS VALVE DEPTH".

With mandrels in place, an attempt is made to place the necessary valve at the mandrel depth following the same procedure used in the design of complete installation with no mandrels previously installed. The resultant printout could show mandrels skipped with the valves placed only where necessary. If this occurs, the computer will print: "NOT USED", opposite the mandrel(s) skipped. When the mandrels are too far apart for the desired producing rate and the calculated distance between valves is less than the distance between mandrels, the following printout will occur below the tabulated results: "VALVE CALCULATIONS TERMINATED, SINCE CALCULATED DISTANCE BETWEEN VALVES NUMBER ______ AND ____ IS LESS THAN THAT BETWEEN MANDRELS NUMBER ______ AND ______". Both of the above printouts can be eliminated by special instructions. It may be desirable to have no mandrels skipped and/or not have the calculations terminated based on too wide a mandrel spacing. If the former is requested, the printout will be: "IN THIS PROBLEM NO MANDRELS ARE SKIPPED BELOW THE TOP VALVE DEPTH". When the latter is preferred, the printout will contain: "PROVISION HAS BEEN MADE TO CONTINUE CALCULATIONS EVEN THOUGH THE DISTANCE BETWEEN MANDRELS EXCEEDS CALCULATED DISTANCE BETWEEN VALVES".

When data is changed for the same well, (Items 18 - 36), the next page will have the following heading: "NEW DATA FOR THIS PROBLEM". This is followed by the data which has changed and the tabulated results.

RESULTS OF COMPUTER DESIGNS FOR FIELD STUDIES

In the design of closed rotative gas lift systems, the desired injection gas pressure and volume must be determined before the compressor can be selected. The requirements for any system will vary depending on differences in well conditions, and all data available must be taken into account. The complexity of such a problem depends upon the availability of accurate well data and the number of wells involved. When little data is available, it is necessary to over-design the system based on assumptions while the installations can be custom designed for each well when accurate data is available. When the productivity indices, static bottom hole pressures and decline are known. it is possible to accurately predict the gas lift requirements for both present and ultimate conditions. Should this information be unavailable, it must be assumed and an accurate engineering evaluation is not possible resulting in an over or under-designed system. Regardless of the amount of data obtainable, these calculations must be made. For a large system, all calculations can be made in one day with the aid of high speed computed design and the results will be reliable, eliminating human error in the actual calculations.

Fig. 6 is a tabulation of computer results used in a closed rotative system design for 12 wells. Since P.I.'s were not available, the problem was

FIGURE 6

TABULATION OF COMPUTER RESULTS

SAMPLE RUN NO. 1

INVESTIGATION OF INJECTION PRESSURE

Inst No	Tubing O. D. (IN.)	Desired Prod. Rate (BLPD)	Injection Gas Press. (PSIG)	Last Valve Depth (FEET)	No. of Valves	Loss in Opr. Press. (PSI)
1-001	2-3/8	600	600	3275	7	42
1-002	2-3/8	800	600	3159	7	38
1-003	2-3/8	1000	600	2948	6	34
1-004	2-3/8	600	800	4554	6	58
1-005	2-3/8	800	800	4550	7	56
1-006	2-3/8	1000	800	4334	7	50
1-007	2-3/8	600	850	4600	5	59
1-008	2-3/8	800	850	4517	5	55
1-009	2-3/8	1000	850	4536	6	52
1-010	2-3/8	600	900	4558	4	57
1-011	2-3/8	800	900	4600	5	60
1-012	2-3/8	1000	900	4600	5	53
1-013	2-7/8	600	600	4265	9	68
1-014	2-7/8	800	600	4163	9	65
1-015	2-7/8	1000	600	3932	8	59
1-016	2-7/8	600	800	4600	5	79
1-017	2-7/8	800	800	4600	5	76
1-018	2-7/8	1000	800	4600	5	71
1-019	2-7/8	600	850	4600	4	73
1-020	2-7/8	800	850	4600	4	70
1-021	2-7/8	1000	850	4600	4	67
1-022	2-7/8	600	900	4600	4	79
1-023	2-7/8	800	900	4600	4	77
1-024	2-7/8	1000	900	4600	4	73

to select an injection pressure which would permit lifting 600 to 1000 BLPD from total depth (4600 ft) with 2-3/8 or 2-7/8 in. tubing. Only continuous flow was considered due to the high desired producing rates. The majority of the wells (10) under consideration contained 2-3/8 in. tubing and an injection pressure of 850 psig was selected. Had productivity indices been available, the injection pressure selected may have been much less and other valuable results could have been obtained. This includes whether the desired producing rate could be obtained, injection gas requirements, etc. The same type of calculation is possible when intermittent lift is necessary.

FUTURE WORK

Development of a computer program is now being studied which will allow the calculation of an entire closed rotative system including the economics involved. The results will include individual installation designs, compressor sizing, line sizing and costs.

In the near future, computer programs will be available for the design of tubing pressure-operated valve and chamber installations. Work is now progressing on a program which will design a composite installation where continuous flow is used for lifting from the upper valves in a string and intermittent lift employed below the depth at which continuous flow cannot be used. This is possible at present only by making several designs for both continuous flow and intermittent lift and combining them.

REFERENCES

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2. Camco Computer Study, 1964.
3. Poetmann and Carpenter, "The Multiphase Flow of Gas, Oil and Water Through Vertical Flow Strings with Application to the Design of Gas Lift Installations, "API Drilling and Production Practices," 1952.
4. Winkler, Herald W., "Application of Gas Lift for Small Diameter Tubing Installations", Southwestern Petroleum Short Course, April 18-19, 1964.

APPENDIX

NOMENCLATURE USED IN CONTINUOUS FLOW DESIGN COMPUTER PROGRAM PRINTOUT

The second page of the printout (Fig. 3) is a tabulation of depths, pressures, temperatures, etc., which are used by the computer in the calculation of a continuous flow installation. Some symbols noted in the following list will not appear on the second page of all printouts. For example, PRODR and GLR are only shown if the desired producing rate cannot be obtained based on the given data.

HNM1 - Depth of lift in feet based on the unloading traverse above the point of gas injection, flowing bottom hole pressure and unloading traverse below the point of gas injection for zero gas-liquid ratio. If the P.I. is not given, HNM1 is based on the unloading traverse above the point of gas injection, full operating injection gas pressure at depth and a pressure difference at HNM1 of 100 psi or is set equal to the total tubing length when HNM1 exceeds this depth.

HOVM- Maximum depth of lift in feet based on the flowing bottom hole pressure, traverse below the point of gas injection for operating conditions, full operating injection gas pressure at depth and the given pressure drop across the valve. If the P.I. is not given, HOVM is set equal to HNM1.

POVM - Flowing tubing pressure at HOVM in psig and is based on the conditions noted for HOVM.

P AT HOVM - Flowing tubing pressure in psig at HOVM based on the traverse above the point of gas injection for operating conditions. It is printed only when the given producing rate cannot be obtained based on the data given.

PRODR - Given desired daily producing rate in barrels of liquid per day.

GLR - Total producing gas-liquid ratio in cubic feet per barrel for the traverse above the point of gas injection for operating conditions which includes the maximum injection and formation gas volumes.

GRADP - Pressure gradient in psi per foot for traverse below point of gas injection for unloading conditions based on static load fluid gradient and a zero gas-liquid ratio, or GRADP may be given.

PRODI - Gross productivity index in total barrels of liquid produced per day per psi drawdown in bottom hole pressure. If it is not given, PRODI is printed as zero.

DCOMP - Depth at which drawdown first occurs during unloading based on the static bottom hole pressure, static gradient of the load fluid and the traverse above the point of gas injection for unloading conditions. The static load fluid gradient is used for valve spacing above this depth and the calculated or given GRADP below.

NO - Valve number with number one being the top valve.

MINPT - Minimum flowing tubing pressure at valve depth in psig based on the flowing wellhead tubing pressure and the unloading traverse above the point of gas injection.

PBHF - Flowing bottom hole pressure in psig based on GRADP or static load fluid gradient and MINPT at valve depth. GRADP is used if valve depth exceeds DCOMP.

BLPD - Calculated daily producing rate in barrels of liquid per day based on the PBHF and static bottom hole pressure if the P.I. is given. When the calculated PBHF during unloading exceeds the static bottom hole pressure, the drawdown is numerically negative and a minus BLPD is indicated on the printout. BLPD is equal to the given desired daily producing rate if the P.I. is not given.

IGLR - Injection gas-liquid ratio in cubic feet per barrel required to attain MINPT during unloading.

MAXPT - Maximum flowing tubing pressure at valve depth in psig which could occur while lifting from the next lower valve.

PCAS - Operating injection gas pressure at valve depth in psig based on the reopening pressure of the valve above except for the top valve. PCAS for the top valve is based on the kickoff injection gas pressure if the top valve cannot be an operating valve and is based on the operating injection gas pressure if the top valve could be an operating valve.

TV - Temperature of injection gas at valve depth in °F based on the given temperature of the injection gas at the surface and the bottom hole temperature. This temperature is used to calculate the valve port size.

IDPORT - Port size of the valve in 16ths of an inch.

PBT - Bellows charge pressure in psig at operating temperature in the well. PBT is calculated using the valve specifications for the calculated IDPORT, PCAS and MINPT.

REOPL - Minimum reopening pressure of valve at valve depth in psig based on MAXPT, PBT and the valve specifications.

REOPS - Minimum reopening pressure of valve at the surface in psig.

TVALVE - Temperature of valve in the well in °F under operating conditions based on the given flowing wellhead tubing temperature and bottom hole temperature. TVALVE is used to calculate the valve opening pressure in a tester.

PVO - Valve opening pressure in a tester in psig. This set opening pressure is calculated for a valve temperature of 60°F unless specified otherwise.

L - Calculated valve depth in feet.

L NEXT - Calculated depth of next lower valve in feet.