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Solving the Continuous Gas Lift Allocation Problem Using Simulated Annealing

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Abstract

Continuous gas lift is one of the most used artificial lift methods. This method supposes the injection of the same gas rate into fluids current produced by the well. The major problem which appears in the case of a continuous gas-lift wells system is the gas rate determination which will be injected per well to produce the optimum flow rate per reservoir in accordance with the capacity of the gas source. To solve this problem we apply the nodal analysis and build the gas-lift performance curve also for each well. This curve provides the maximum, respectively the optimum flow rate which can be produced by the well in some condition and the gas injection rates corresponded. The maximum flow rate is obvious, but the optimum flow rate and its corresponded gas injection rate must be determined by applying an optimization method.

Consequently, in this paper we present a new optimization method called "simulating annealing" and the application of this to determine the optimum gas injection rate and flow rate corresponding for each well. We make several tests for six wells and it has resulted that these wells do not necessary produce the maximum flow rate because in this case the gas capacity must be huge and the costs would be important. The tests were carried out with various values of the gas source capacity and we have obtained the optimum total flow rate for the reservoir very close to the maximum total flow rate produced by this.

Key words: *gas-lift, performance curve, simulating annealing, optimization, nodal analysis, gas injection.*

Introduction

The continuous gas lift is one of the most used artificial lift methods. This method assumes the gas injection into produced fluid current to reduce the oil-water mixture density and therefore for to diminish the bottom hole pressure to obtain certain liquid flow rate. The gas injection rate can reduce the bottom hole pressure down to a limit in order to increase the well flow rate. If the gas injection rate is too large the reduction effect of the bottom hole pressure is null because of the acceleration and friction gradients augmentation. On the other side, the gas injection rate considered must correspond to a flow rate and a bottom hole pressure in correlation with the production capacity of the formation. This is the reason for which we use the nodal analysis which supposes the determination of the equation flow solution (flow through the formation and flow through the tubing). The results obtained from the nodal analysis are used to determine the performance gas lift well curve which provides the maximum gas-lift well flow rate.

If a reservoir is exploited by several gas-lift wells with different characteristics, we must obtain for each well the performance gas-lift curve. For unlimited gas source we can obtain the maximum flow rate for each well. Therefore, the maximum flow rate for reservoir is the sum of the maximum flow rate of the wells. On the other hand, if the gas source is limited in most cases it is insufficient to obtain the maximum flow rate for each well. Therefore, it is necessary to allocate a different injection gas rate to each well in an optimum way to obtain the maximum oil production from the reservoir. An optimal allocation of injection gas for each well is very important for gas - lift design improvement.

To that purpose several studies have been conducted to determine the optimum gas injection rate for each well. Therefore, Mayhill [6] has defined the most efficient gas injection rate as the rate at which an incremental expense for gas injection is equal to some percentage of the incremental oil produced at the gas injection rate.

Kanu et al.[4], based on an economic optimization, have established the method of equal slope allocation under both unlimited and limited gas source. They have defined the economic slope and its use to allocate a total amount of gas at the optimal economic point for a group of wells in a step-by-step procedure.

Gomez [3] has approximated the gas lift performance curve with a second degree polynomial used to determine which well produces the largest oil rate when equal amounts of incremental gas are injected into each well. For this well, this incremental amount of gas would be allocated, and the procedure would be continued until the entire amount of gas is used.

Nishikieri [7] takes the equal slope technique and makes an extension of this based on the application of non-linear optimization methods of quasi-Newton type, to find the optimum gas injection rates for a group of the wells.

Buitrago et al. [1] presents a novel nonlinear methodology to determine the optimal distribution of a given amount of the gas, without restriction in the well response and the number of the wells in the system.

This paper proposes an optimisation method of gas lift allocation using the annealing method for a group of wells in order to maximize the total oil production rate for a given total amount of gas.

Nodal Analysis and Performance Gas- Lift Well Curve

Any production system is composed of the following elements: the reservoir formation, the bore hole and the surface installations. We have to make an analysis of all these elements to establish the operating regime of the well. Also we must determine a correlation between them to obtain the maximum production with minimum expenses. To evaluate each production system element we use the nodal analysis. That supposes the isolation of an unique system point called “node”, the determination of the flow rate and bottom hole pressure of the upstream and downstream of the node, and consequently the determination of a correlation between the bottom hole pressure and flow rate. In many cases, the node is chosen at the middle of perforations, hence the production system is divided in two components: the upstream component, which includes all the elements between node and the formation border; the downstream component, which includes all the elements between node and surface separation installations.

In order to solve this problem, we must determine the IPR (Inflow Performance Relationships) curve that characterises the upstream component, and the equipment performance curves that characterise the downstream component. These curves are plotted on the same diagram pressure = f (flow rate), and their intersection provides the flow rate and the bottom hole pressure of the node (fig. 1).

In this system, the reservoir pressure and the surface separation pressure are the limit points, these being the only fixed values which are not variable with the flow rate.

The IPR curve is determined from the well testing data or using analytical methods. The performance tubing curves are determined on the basis of the multiphase flow trough tubing theories and the gas flow through the annular space and these correspond for some injection gas flow rate value.

Once established the flow rate and the bottom hole pressure of the node for each injection gas rate, we can plot the flow rate function of the gas injection rate, and finally we obtain the performance gas lift well curve. We can read on this curve the pairs of the values (flow rate, gas injection rate) at the maximum and the optimum points (fig. 2).

For a reservoir exploited by the gas lift wells, the scheme of a gas lift system is presented in figure 3.

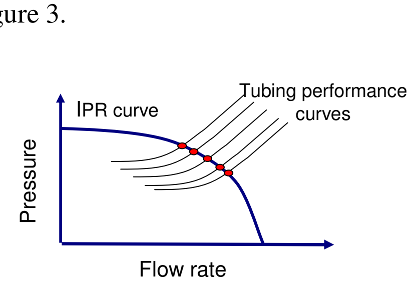

Fig. 1. Nodal analysis

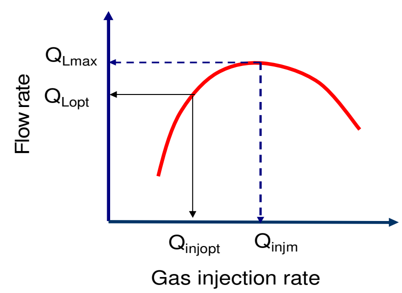

Fig. 2. Gas lift well performance curve

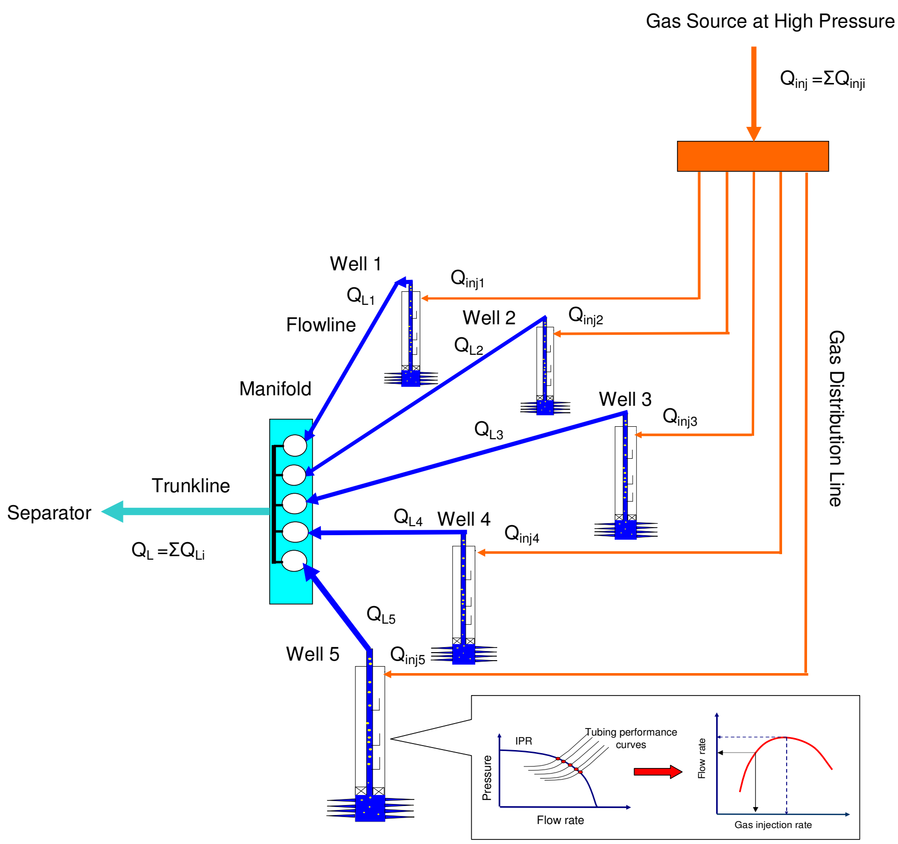

Fig. 3. Scheme of a gas-lift system

In this case each well has different characteristics. For that, it is necessary to build a gas-lift performance curve for each well. Also it is necessary to analyse these curves in order to allocate an appropriate gas injection rate to obtain the maximum or optimum flow rate.

The optimal flow rate is chosen by applying the optimization theories. In many cases it is preferred because it is too expensive to produce at the maximum flow rate or the gas capacity source gas is limited. When the reservoir produces using the gas lift wells, only few wells with large production capacity can produce at the maximum rate, the others produce to optimal flow rate since the gas source capacity does not cover the existent gas injection rates to obtain the maximum flow rate for each well.

Simulating Annealing Optimization Method

Classical optimization method can be divided into two great categories: gradient and direct methods [2] (Deb, 1995; Reklaitis, Ravindran, and Ragsdel, 1993). The gradient-based methods use the first and/or second derivative of the objective function and constraints and therefore they show a fast rate of convergence. On the other hand, the direct methods use only the evaluation of objective function and/or constraints in order to determine the optimum values and therefore these methods have a slow rate of convergence but they can be used for problems which have discrete variables or for which we can not calculate the derivative.

The simulating annealing method is different from the classical optimization methods. It does not use the gradient information and it is a stochastic search and optimization procedure. The simulating annealing method has an increasing popularity because of its wide spread applicability and because it is a method of global optimization, it does not trap into a locally optimal solution. The method was first presented by Kirkpatrick, Gelatt and Vecchi [5] which is a probabilistic hill-climbing algorithm simulating the crystallization of material when they are first heated to a high temperature and then cooled down slowly.

The gas allocation problem for wells in gas-lift exploitation system is a complex problem where the variables involved in objective function are discrete values obtained after a lot of calculations are performed on a simulation software. The algorithm for this method is presented in figure 4:

```
Assume the temperature T and the rate of temperature reduction RT
Generate randomly the initial solution S
Repeat
    Generate randomly a neighbour solution S1 of S
    Compute the difference D=Fobj(S1)-Fobj(S)
    If d<=0
       Then S=S1
        Else S=S1 with probability exp(-D/T)
    End if
    T=RT*T
Until stop criteria is satisfied.
```

Fig. 4. Simulating annealing algorithm

The simulating annealing method allows approximate solutions when the value of the objective function is not in the right direction toward the optimum point. Consequently, this method has the ability to avoid the possibilities of being attracted by locally optimum.

Test Case

We have applied the simulating annealing optimization method to gas allocation of a system of six wells selected from one oil reservoir. For each well we have built the performances gas-lift curve presented in figure 5. Also from each curve we have taken the coordinates of maximum value ($Q_{\text{injm}}, Q_{\text{Lmax}}$). If all the wells would be produced at these values the total gas injection rate required, Q_g is:

$$Q_g = \sum_{i=1}^{6} Q_{injmi} = 0{,}49 \cdot 10^6 \text{ Sm}^3\text{/D},$$

and the expected total production liquid rate, Q_T would be:

$$Q_T = \sum_{i=1}^{6} Q_{L\max i} = 454{,}642 \text{ m}^3\text{/D}.$$

The main goal is to determine the optimum values of produced oil and gas injected when the available total gas injection rate is sensibly less than these values taken from the maximum conditions.

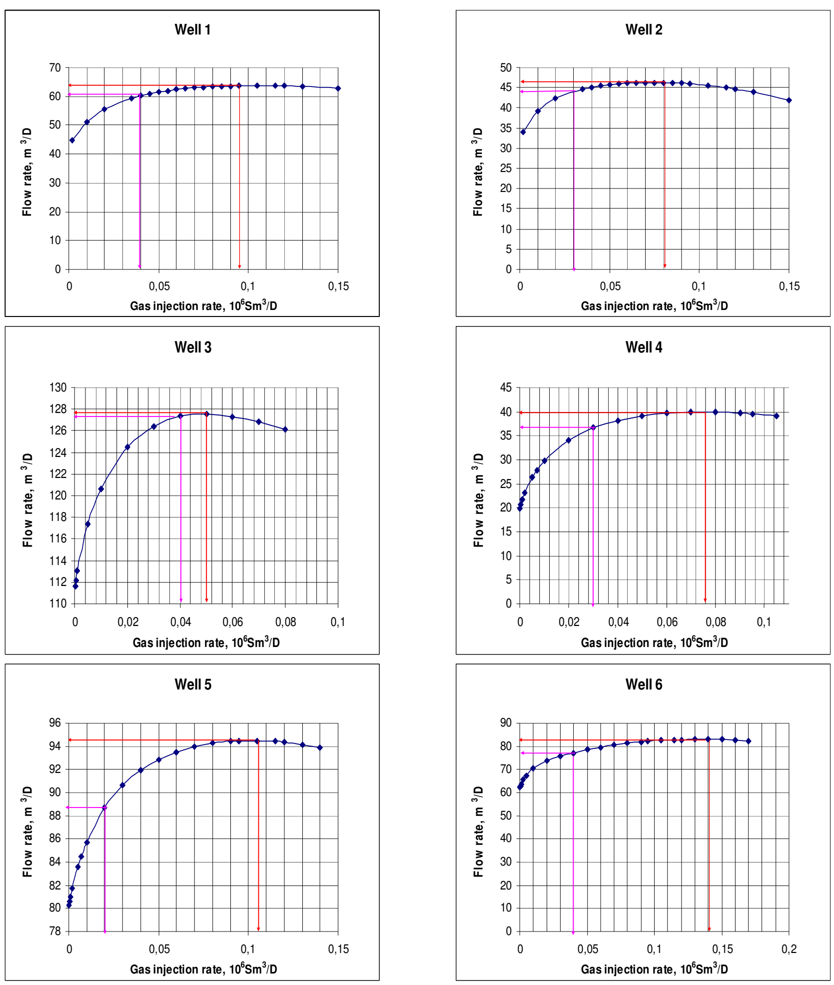

Fig.5. Gas-lift wells performance curves with maximum and optimum coordinates

We have assumed various capacities of the gas sources available as: $0{,}05 \cdot 10^6$ Sm^3/D; $0{,}1 \cdot 10^6$ Sm^3/D; $0{,}15 \cdot 10^6$ Sm^3/D; $0{,}20 \cdot 10^6$ Sm^3/D; $0{,}25 \cdot 10^6$ Sm^3/D; $0{,}3 \cdot 10^6$ Sm^3/D; $0{,}35 \cdot 10^6$ Sm^3/D; $0{,}4 \cdot 10^6$ Sm^3/D. For these values and the performance gas-lift curve of each well we applied the simulating annealing to determine the gas allocation for each well and the total flow rate for these six wells. The results are presented in table 1 and figure 6. In figure 5 it is show the results of optimization for $Q_g = 0{,}2 \cdot 10^6$ Sm^3/D.

Table 1. The results of optimization with simulating annealing for six wells.

	Gas allocation per well			
Gas source capacity, 10^6 Sm^3/D	0,05	0,1	0,15	0,2
No. of well	10^6 Sm^3/D	10^6 Sm^3/D	10^6 Sm^3/D	10^6 Sm^3/D
Well 1	0,005000	0,020000	0,024999	0,040000
Well 2	0,005000	0,010000	0,020001	0,030000
Well 3	0,010000	0,020000	0,030000	0,039996
Well 4	0,010000	0,020000	0,020000	0,030000
Well 5	0,010000	0,010000	0,020000	0,020004
Well 6	0,010000	0,020000	0,035000	0,040000
Total flow rate, Sm^3/D	391, 737	412,730	426,109	435,021

Gas allocation per well			
0,25	0,3	0,35	0,4
10^6 Sm^3/D	10^6 Sm^3/D	10^6 Sm^3/D	10^6 Sm^3/D
0,055000	0,069999	0,090000	0,100006
0,040000	0,050000	0,060000	0,070000
0,040000	0,050000	0,050000	0,060000
0,030000	0,040000	0,040000	0,040000
0,035000	0,040000	0,045000	0,054995
0,050000	0,050002	0,065000	0,07500
441,605	446,424	449,993	452,525

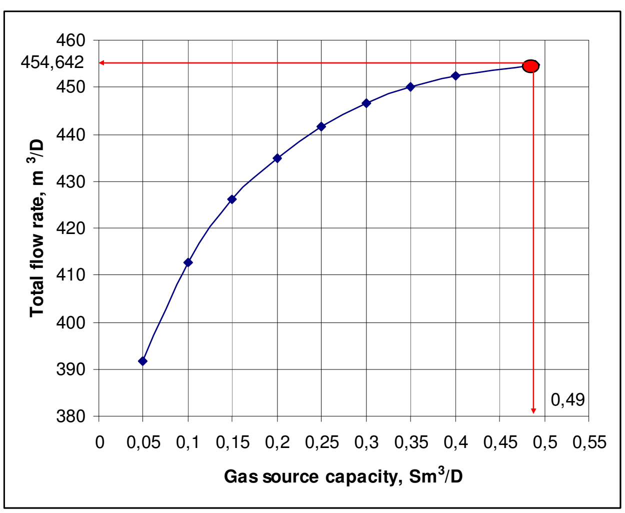

Fig.6. Total flow rate versus gas source capacity

Consequently, if we analyse the results presented in table 1, we can observe that the wells do not necessary produce at the maximum flow rate. We have made the tests with various values of the gas capacity and we have obtained the optimum total flow rate for the reservoir closely to the maximum total flow rate. This fact is reflected also in figure 6 where we can observe that the total flow rate per reservoir increases non-linearly.

Conclusions

The major problem for a continuous gas-lift wells system is the gas allocation per well to produce the optimum flow rate per reservoir according with the capacity of gas source. An inefficient gas allocation with limited gas source reduces production. Therefore, it is necessary to apply an optimization method.

The nodal analysis and the performance gas-lift curve for each well represented the base of the gas allocation optimizing.

The gas allocation problem for wells in continuous gas-lift system is a complex problem where the variables involved in the objective function are discrete values obtained after a lot of calculations performed with simulation software.

A new optimization method, simulating annealing, was used in gas allocation for a continuous gas-lift system. Simulating annealing method is different from the classical optimization methods because it is a stochastic search and optimization procedure. This method has an increasing popularity because of its wide spread applicability and because it is a method of global optimization, it does not trap into a locally optimal solution.

The results obtained with simulating annealing optimization method show that the wells do not necessary produce at the maximum flow rate. For a smaller capacity of the gas source we obtained the total flow rate per reservoir closely to the maximum value of this.

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Rezolvarea problemei alocării gazelor de injecţie la sondele exploatate prin gaz-lift continuu utilizând metoda “simulated annealing”

Rezumat

Gaz-liftul continuu reprezintă una dintre cele mai utilizate metode de liftare artificială. Aceasta presupune injecţia unui anumit debit de gaze în curentul de fluide produse de sondă. Principala problemă care apare în cazul unui sistem de sonde în gaz-lift continuu este determinarea debitului de gaze care va trebui injectat în fiecare sondă pentru a produce debitul de lichid optim pe zăcământ, ţinând seama de capacitatea sursei de gaze. Pentru a rezolva această problemă se aplică analiza nodală şi se construieşte curba de comportare în gaz-lift a fiecărei sonde. Această curbă furnizează debitul maxim, respectiv optim, care pot fi produse de o sondă în anumite condiţii, precum şi debitele de injecţie corespunzătoare. Debitul maxim de lichid este evident, însă debitul optim de lichid, precum şi debitul de injecţie corespunzător acestuia trebuie să fie determinate prin aplicarea unei metode de optimizare.

Prin urmare, în acestă lucrare se prezintă o noua metodă de optimizare numită “simulated annealing” şi aplicarea acesteia pentru determinarea debitului optim de injecţie şi a debitului de lichid corespunzător pentru fiecare sondă. De asemenea, cu această metodă s-a efectuat o serie de teste pentru şase sonde de unde a rezultat că acestea nu este necesar să producă debitul maxim de lichid deoarece în acest caz capacitatea sursei de gaze ar trebui să fie foarte mare, iar cheltuielile de asemenea ar fi importante. Testele efectuate au luat în considerare diferite valori ale capacităţii sursei de gaze obţinându-se valori ale debitului optim total produs de zăcământ apropiate de debitul maxim de lichid produs de acesta.