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Genetic Algorithms Applied to Solving the Gas - lift Allocation Problem

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Abstract

Continuous gas lift is an artificial lift method mostly used after the naturally flow period ceases. This method assumes the continuous gas injection directly into produced fluid current for reduction the oil-water mixture density and therefore for diminution of the bottom hole pressure to obtain certain liquid flow rate. 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 for producing the optimum flow rate per reservoir in accord with the capacity of gas source. For solve this problem it is necessary to build the gas-lift performance curve for each well in order to provide the maximum, respectively the optimum flow rate produced by the well in some condition and the gas injection rates corresponded. The maximum flow rate is evidently, but the optimum flow rate and its corresponded gas injection rate must be determined by applying of an optimization method.

Consequently in this paper we analyze three approximation methods of the gas-lift performance curve and also we present the genetic algorithm and its application for determining the optimum gas injection rate and flow rate per well and per reservoir. Further we studied the influence of the genetic algorithm configuration and approximation methods of the gas-lift curve on the optimization results. The tests were effectuated with a small value of the gas source capacity and we have obtained the optimum total flow rate for the reservoir close by the maximum total flow rate produced by this.

Key words*: gas-lift, performance curve, genetic algorithm optimization, nodal analysis, gas injection.*

Introduction

Continuous gas lift is an artificial lift method mostly used after the ceasing of naturally flow period. This method assumes the continuous gas injection directly into produced fluid current for reduction the oil-water mixture density and therefore for diminution of the bottom hole pressure to obtain certain liquid flow rate. The gas injection rate required for a well is determined in accord with the gas source capacity and also with the production capacity of the formation.

Consequently we use the nodal analysis which supposes 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 gas lift performance curve for a well which can provides the possible pairs of production rate and gas injection values for analyzed well.

If a reservoir is exploited by several gas-lift wells with different characteristics we must obtained for each well the gas-lift performance curve which provide the input data in gas allocation process. Gas allocation supposes that each well will receive some gas injection rate proportional with its production capacity. If the gas source is unlimited we can allocate the gas injection rate for each well in order to produce the maximum flow rate. Therefore the maximum flow rate for reservoir is the sum of the maximum flow rate of the wells.

By another side, if the gas source is limited in the most cases it is insufficient to obtain the maximum flow rate for each well. Therefore it is necessary to allocate a different gas injection rate to each well in an optimum way to obtain the maximum oil production from the reservoir in these conditions. Consequently an optimal allocation of gas injection rate for each well is very important for gas - lift design improvement.

For that the several studies have been conducted to optimize gas injection rate for each well. Therefore, Mayhill [10] 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.[9], based on an economic optimization, have defined the economic slope and it utilisation to allocate a total amount of gas at the optimal economic point for a group of the wells in a step by step procedure.

Gomez [5] has approximated the gas lift performance curve with a second degree polynomial used to determine which well produce the largest oil rate when equal amounts of incremental gas were injected into each well. For this well this incremental amount of the gas would be allocated, and the procedure would be continued until all amount of gas is used.

Nishikiori [11] take the equal slope technique and make an extension of this based on the application of nonlinear optimization methods of quasi-Newton type, to find the optimum gas injection rates for a group of the wells.

Buitrago et al. [2] presents a novel nonlinear methodology for determining the optimal distribution of a given gas source capacity, without restriction in the well response and the number of the wells in the system.

Alarcon et al. [1] propose a new model to approximate the gas-lift performance curve and also a global optimization method of gas allocation to a group of wells using nonlinear constrained programming.

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

Gas- lift Performance Curve

Gas-lift performance curve represents the relationship between the gas injection rate and the oil production rate of a continuous gas-lift well. This curve can be obtained from the field data, or can be determined numerically using nodal analysis. Nodal analysis suppose the isolation an unique system “node”, determination of the flow rate and bottom hole pressure of the upstream and downstream of this node, and consequently determination of a correlation between the bottom hole pressure and flow rate.

The node, obviously is chosen at the middle of perforations, hence the production system is divided in two components as: the upstream component, which means the fluid flow through porous media from the reservoir to the wellbore characterised by the IPR curve; downstream component which means the fluid flow through the tubing characterised by the tubing performance curves. The intersection between these two curves plotted simultaneously on the same diagram provide the flow rate and the bottom hole pressure of the node (fig.1).

If we consider the different values for the injection gas rate we can obtain in the same way the bottom hole pressure and the flow rate for each injection gas rate considered and finally to obtain the performance gas lift curve which provide the pairs of the values (flow rate, gas injection rate) at the maximum and the optimum points (fig.2).

Gas-lift performance curve may have different shapes depending of the well response to gas injection (fig.3). After the shape of the gas-lift performance curve we can split the gas-lift wells behavior in two categories as: gas-lift well without lower limits on injection gas rates which respond immediately to gas-lift injection, and gas-lift well with lower limits on injection gas rates which require an amount of gas injection to start up.

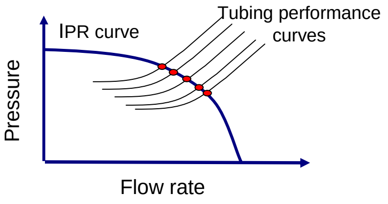

Fig. 1. Nodal analysis.

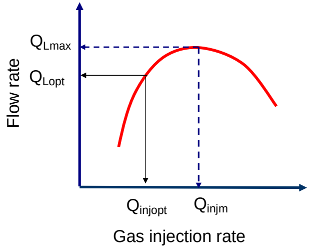

Fig. 2. Gas lift well performance curve**.**

In the figure 3 the curves for the wells 1 and 2 are included in the first category. The curve for well 1 indicate that this well can produce naturally a lower flow rate, but to improve this flow rate the well 1 is exploited by gas-lift. By other side the well 2 can not produce naturally, but its response to gas-lift injection is instantaneously. In the case of the wells 3 and 4 the gas-lift performance curves indicate a minimum gas injection rate to start up.

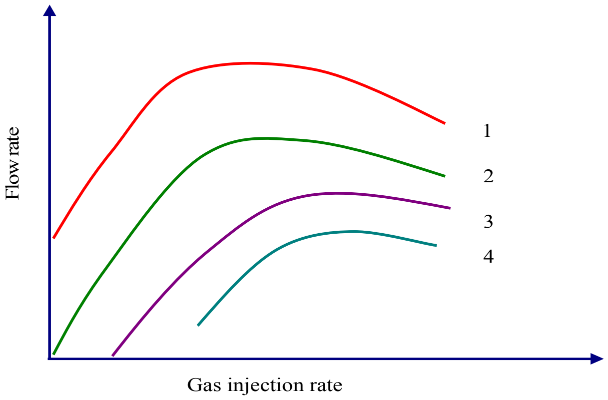

Fig.3. Type of the gas-lift performance curve [1].

For a group of the gas-lift well, each well having different characteristics, is necessary to build gas-lift performance curve for each well. It is necessary also 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 is too expensive to produce at the maximum flow rate or the gas capacity source gas is limited.

To implement the data points of the gas-lift performance curves in an optimization algorithm it is necessary to find an equation which fit these data points. Practically for that it was used linear interpolation or in many cases the second or the third degree polynomial method. To improve the approximation of the gas-lift performance curve Alarcon et al. [1] propose a new model.

To compare the results of the three approximation methods of gas lift performance curve (linear interpolation, second degree polynomial and model of Alarcon) we use the data points of Buitrago et al.[2] for four wells. In the figures 4 and 5 we present the results of the three approximation methods and the data of Buitrago et al. [2] for four gas-lift performance curves with different density of points.

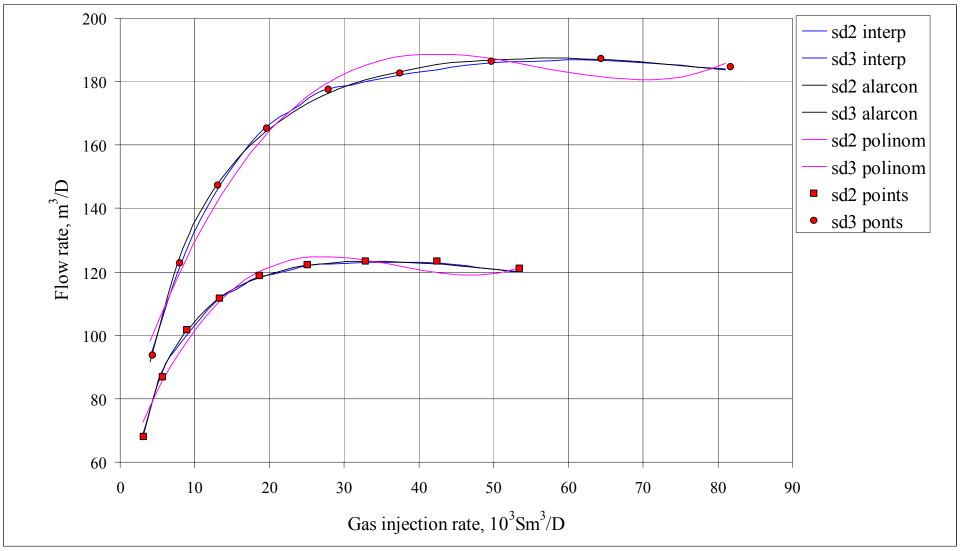

Fig. 4. Results of the gas-lift performance curve approximation methods and the gas-lift performance curves data points for wells 2 and 3.

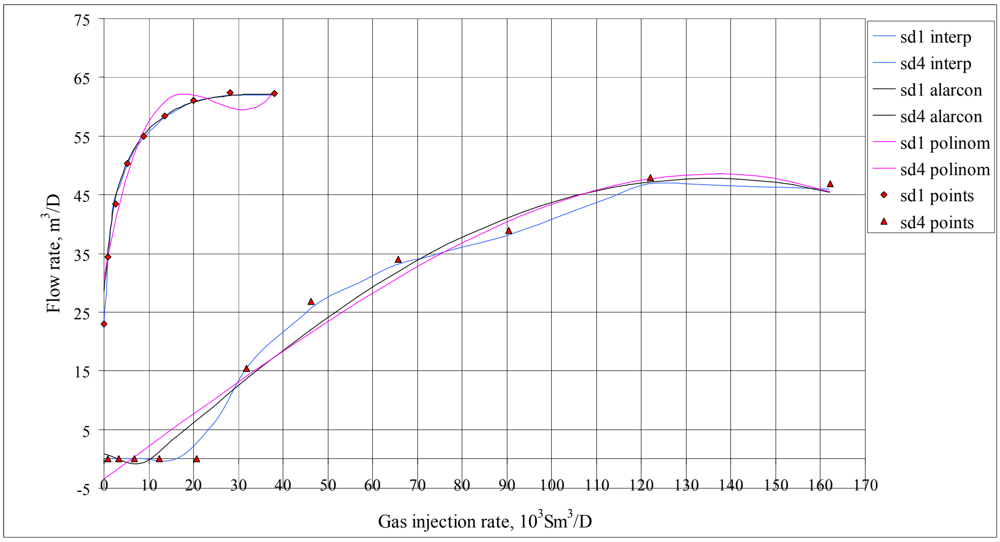

Fig. 5. Results of the gas-lift performance curve approximation methods and the gas-lift performance curves data points for wells 1 and 4.

From the figures 4 and 5 we observe that the Alarcon et al[1] model provide the best approximation of the gas-lift performance curves in the cases of the high and moderate density of the data points(well 1, 2, 3).

Linear interpolation use a straight line as approximation between two successive points and this is the reason that it can not follow the shape of the curve (especially convexity) and therefore can not determine with accuracy the maximum of function. Also it is recommended for large density of data points.

The polynomial method is less accurate, having high deviation from the data points of the gas-lift performance curves and predicting in many cases high gas injection rates necessary to start up the wells.

Genetic Algorithms Optimization Method

Optimization algorithms are divided, according to the method of operation, in deterministic and probabilistic optimization algorithms. Deterministic algorithms are used usually when exist a clear relation between of the parameters or characteristics of possible solutions and this relation is relatively simple and involve relatively small number of parameters. The probabilistic methods are used in all other cases. The probabilistic methods not guarantee the correctness of solutions; they always negotiate between accuracy of solution and runtime.

Both probabilistic and deterministic can use heuristics to help the optimization algorithms to find the next possible solutions. A heuristic is a part of an optimization algorithm that use the information currently gathered by the algorithm to help to decide which candidate solution should be tested next.

A meta-heuristic is a heuristic method for solving a very general class of problems. Examples of deterministic optimization we can enumerate branch and bound, Newton, Levenberg-Marquardt. Among probabilistic methods we can enumerate Stochastic Hill Climbing, Tabu Search, Simulating Annealing, Genetic Algorithms.

Evolutionary Algorithms are population based meta-heuristic optimization algorithms that use biology inspired mechanisms. Genetic Algorithms are kind of Evolutionary Algorithms and are general purpose search algorithms which use principle inspired by natural genetic population to evolve solution to problems [6, 7].

Genetic algorithms are developed by Holland in 1975 like search algorithms. These algorithms process a population of chromosomes which represent search space solutions with three operations which underlay genetic process in biological organisms: selection, crossover and mutation. The first formulations use binary coded chromosomes, but when the optimization problem require continuous variables in search spaces the real coded chromosomes are used on wide scale.

Because the gas- lift allocation problem is a maximization problem which requires that gas injection rates in each well to be continuous, we will use the real coded chromosomes. The genetic algorithm starts with creating an initial population of chromosomes.

The value of objective function is computed for each chromosome and taking into account different characteristics of solution candidate to each chromosome is assigned a fitness value. Using a suitable method of selection which allows the chromosomes with good fitness to survive with a higher probability the chromosomes are chosen for reproduction.

A new population is created applying the reproduction operations like crossover and mutation. Hence, new chromosomes (offsprings) are created by varying or combining their genotypes. This new population will be evaluated and fitness will be assigned to the each chromosomes. During successive iterations called generations, chromosomes in the population improve their fitness until the termination criteria is achieved. The procedure for this method is presented in figure 6.

In figure 6 the significance of different parameters used are:

- *size* is the population size or number of chromosomes in population;
- *g* is the generation counter;
- *pop* is the population;
- *vf* is the fitness value assigned to each chromosome;
- *terminate* is a flag for iterations ending;
- *mate* is the mating pool, a place where are placed the selected chromosomes for reproduction.

Even if there are many variants of genetic algorithms, the fundamental operations that act over a generation of chromosomes or over an individual chromosome which represent possible solutions for optimization problems are:

- evaluation of objective function and assignation of fitness value to individual chromosome;
- creating of a mating pool that is an intermediate population using selection operator;
- reproduction of population using the mating pool using the crossover and mutation operator.

```
Genetic algorithm
  g=0
  pop=CreateInitialPopulation(size)
  repeat
    g=g+1
    evaluateObjectiveFunction(pop)
    vf=assignFitness(pop)
    terminate=testTerminationCriteria(pop,vf)
    if not terminate then
      mate=select(pop, vf)
      pop=ReproducePopulation(mate)
    endif
  until terminate
```

Fig. 6. Description of the genetic algorithm.

The selection operator determines how population chromosomes adapt to environment in order to survive and thereby reproduce. The selection operator provides an intermediate population (mating pool) containing copies of chromosomes from population. The number of copies for a specific chromosome depends on its fitness higher fitness determines greater probability to have copies in mating pool. The selection consists usually of two steps, the calculation of selection probability and the sampling algorithm. There are many selection methods and we use roulette wheel, rank, tournament, stochastic reminder, uniform.

The crossover operator is a method for sharing information between chromosomes; it combines the features of two parent chromosomes to form two offspring, with the possibility that good chromosomes may generate better ones. A random choice is made, where the chance of crossover being applied depends on probability defined by a crossover probability. As crossover methods we can enumerate one point cut, two point cut, uniform, arithmetic, blend (BLX), simulated binary crossover (SBX).

The mutation operator arbitrarily alters one or more components, genes, of a selected chromosome so as to increase the structural variability of the population. The role of mutation in Genetic Algorithms is that of restoring lost or unexplored genetic material into the population to prevent the premature convergence of GA to suboptimal solutions; it insures that the probability of reaching any point in the search space is never zero. Each position of every chromosome in the population undergoes a random change according to a probability defined by a mutation probability. Methods for mutation are Gaussian, uniform, boundary, swap, non uniform.

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

Test Case and Comparison with Other Optimization Method

For a six gas-lift wells system we have applied the genetic algorithm method to optimize the gas allocation in the case of a limited gas source. Also we use the three approximation method (linear interpolation, second degree polynomial method and model of Alarcon et al. [1]) for gas-lift performance curve. We use the data points of Buitrago et al [2] for gas-lift performance curves in the case of these six wells which are presented in a figure 7.

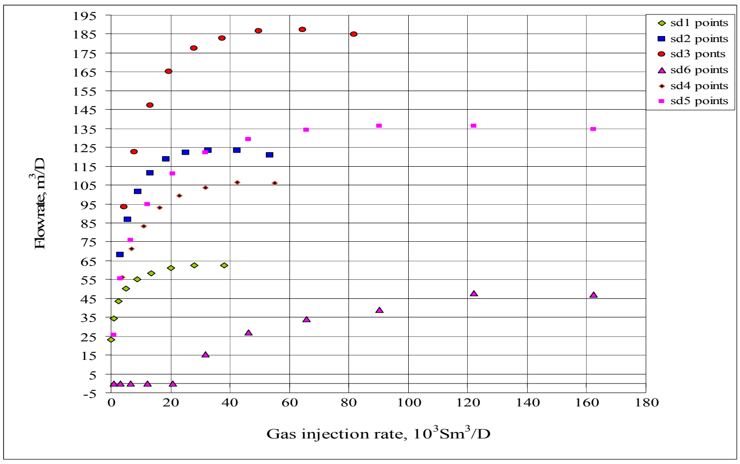

Fig. 7. Data points of the gas-lift performance curves for six wells[2].

Taking into account the gas-lift performance curves of these six wells, the expected total production flow rate Q_T would be:

$$Q_T = \sum_{i=1}^{6} Q_{L\max i} = 663{,}12 \text{ m}^3\text{/D}.$$

and the total gas-injection rate required Q_g is:

$$Q_g = \sum_{i=1}^{6} Q_{injmi} = 4216100 \text{ Sm}^3\text{/D}.$$

The gas injection rate available for all six wells is 130000 Sm^3/D. In this condition we applied genetic algorithm for optimization the gas allocation for each wells. The results of the optimization process are presented in the table 1.

Table 1. Flow rate and injection rate allocated for six wells assuming different approximation method for gas-lift performance curve.

Approximation method	Linear interpolation		Second degree polynomial method		Alarcon model	
	Q_g	Q_l	Q_g	Q_l	Q_g	Q_l
No. of well	10^3 Sm^3/D	m^3/D	10^3 Sm^3/D	m^3/D	10^3 Sm^3/D	m^3/D
Well 1	10,727	56,181	5,565	49,202	15,524	59,339
Well 2	22,210	120,406	15,641	115,489	27,583	122,721
Well 3	25,866	175,299	36,337	187,471	33,103	180,691
Well 4	24,094	99,547	23,656	101,383	15,976	92,675
Well 5	42,956	127,579	35,123	125,665	37,412	122,961
Well 6	4,1443	48,003	13,675	60,928	0,398	32,889
Total	129,997	579,0149	129,997	583,384	129,997	578,237

The results from the table 1 show that total flow rate obtained for gas injection rate available is relative close by the maximum total flow rate.

Also, the approximation methods of the gas-lift performance curve can influence the gas allocation per well. Consequently the approximation method which leads to accurate prediction of the gas-lift performance curve will determine the more correct results of the optimization process.

The results of the genetic algorithm optimization are compared with the results of the optimization method proposed by Buitrago et al. [2]. In the table 2 we present the result of Buitrago et al.[2].

Table 2. Flow rate and injection rate allocated for six wells using Buitrago et al optimization method[2].

	Q_g	Q_l
No. of well	10^3 Sm^3/D	m^3/D
Well 1	10,330	55,90
Well 2	23,695	121,10
Well 3	35,030	180,90
Well 4	17,301	93,60
Well 5	39,020	125,40
Well 6	0,000	0,000
Total	125,376	576,90

From tables 1 and 2 we observe that the genetic algorithm method leads to comparable results with those of Buitrago et al. The major difference consist in the fact that Buitrago method has not allocate the gas injection for the well 6 which has not an instantaneously response to gas injection.

Further we use the Alarcon et al.[1] model to approximate the gas-lift performance curves of the wells and we study how the mutation, cross over and selection influence the optimization results. For selection we consider the roulette wheel, rank, tournament and stochastic reminder. Also for the population size we consider 20 and 50.
The conclusions of this study are:

- The population size of 50 give the more stable results and lead to high value of the total flow rate than the population size of 20.
- The range of the total flow rate values for the studied combinations was [558,261 m^3/D ; 579,650 m^3/D].
- Various selection, cross over and mutation lead to the slightly different results for the same number of optimization program runs.

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, that being the reason of the optimization method using.

The performance gas-lift curve for each well represented the input data of a gas allocation optimizing method. Consequently it is necessary to find a mathematical expression to approximate this curve in order to implement this in an optimizing method. Practically for that we used linear interpolation, the second degree polynomial and Alarcon et al model and we compared the results obtained with the three methods and the data points of the real gas-lift performance curves. The best approximation of the gas-lift performance curves in the cases of the high and moderate density of the data points was obtained with Alarcon et al. model.

A new optimization method, genetic algorithm, was used in gas allocation for a continuous gas-lift system. Genetic algorithms have the advantage of a parallel searching using more individuals and consequently they may avoid the sticking in a local extreme like the other methods. Also they are easy to implement in some cases.

The results obtained with genetic algorithm show that the wells don't necessary producing at the maximum flow rate. For smaller capacity of the gas source we obtained the total flow rate per reservoir closely by the maximum value of it.

The results obtained with genetic algorithm are comparable with those of Buitrago et al.[2] and depend by the approximation method of the gas-lift performance curve used.

The study of genetic algorithms configuration which refer to the population size, selection, crossover and mutation lead to the conclusion that a population size of 50 give the more stable results and high value of the total flow rate, also various selection, cross over and mutation types lead to the slightly different results for the same number of optimization program runs.

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Algoritmii genetici aplicaţi la rezolvarea problemei alocării gazelor la sondele în gaz-lift

Rezumat

Gaz-liftul continuu este o metodă de liftare artificială utilizată de cele mai multe ori după ce perioada de erupţie naturală încetează. Această metodă presupune injectarea continuă a gazelor direct în curentul de fluide produse de sondăpentru reducerea densităţii amestecului apă-ţiţeişi deci pentru diminuarea presiunii dinamice de fund pentru a obţine un anumit debit de lichid. Problema principală care apare in cazul sondelor exploatate prin gaz-lift continuu este determinarea debitului de gaze care trebuie injectat în fiecare sondă pentru a produce un debit optim pe zăcământ în concordanţă cu capacitatea sursei de gaze. Pentru a rezolva această problemă este necesar să se determine curba de comprtare în gaz-lift pentru fiecare sondă în scopul furnizării debitului maxim, respectiv optim, care pot fi produse de o sondă în anumite condţii, precum şi debitele de injecţie coresunzatoare. Debitul maxim de lichid este evident, insă debitul optim de lichid, precum şi debitul de injectie corespunzator acestuia trebuie să fie determinate prin aplicarea unei metode de optimizare.

Prin urmare, în această lucrare se analizează trei metode de aproximare a curbei de comportare a sondei în gaz-lift şi de asemenea se prezintă metoda algoritmilor genetici şi aplicarea ei pentru determinarea debitului de injecţie optim şi a debitului de lichid pe sondă şi pe zăcămant. Mai departe se studiază influenţa configuraţiei algoritmilor genetici şi a metodelor de aproximare a curbei de comportare a sondei în gaz-lift asupra rezultatelor optimizării. Testele au fost efectuate pentru o valoare mică a capacităţii sursei de gaze obţinându-se debitul total de lichid pe zăcământ apropiat de debitul maxim total de lichid produs de acesta.