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Continuous Gas Lift Optimization Using Genetic Algorithm

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Abstract: Gas lift is one of a number of processes used to artificially lift oil or water from wells where there is insufficient reservoir pressures to produce the well. The process involves injecting gas through the tubing-casing annulus. Injected gas aerates the fluid to reduce its density; the formation pressure is then able to lift the oil column and forces the fluid out of the wellbore. Gas may be injected continuously or intermittently, depending on the producing characteristics of the well and the arrangement of the gas-lift equipment. Being somehow an ancient tool with an age of over a century, gas lift is though still a challenging problem when overall optimization is the concern. When the injection gas is of a limited supply the problem is finding the best gas allocation scheme. However there are increasingly emerging cases in certain geographic localities where the gas supplies are usually unlimited. The optimization problem then totally travels to the wellbore and completion string and fully engages with multiphase flow concepts. In the present study an intelligent genetic algorithm has been developed to simultaneously optimize all effective factors namely, gas injection rate, injection depth and tubing diameter towards the maximum oil production rate with the water cut and injection pressure as the restrictions. The computations and real field data are mutually compared.

Key words: continuous gas lift; Genetic algorithm optimization; depth of injection; gas injection rate; tubing size

INTRODUCTION

When oil is first found in the reservoir, it is under pressure from the natural forces that surround and trap it. If a hole (well) is drilled into the reservoir, an opening is provided at a much lower pressure through which the reservoir fluids can escape. The driving force which causes these pressured fluids to move out of the reservoir and into the wellbore comes from the compression of the fluids that are stored in the reservoir. The actual energy that causes a well to produce oil results from a reduction in pressure between the reservoir and the producing facilities on the surface. In many wells the natural energy associated with oil will not produce a sufficient pressure differential between the reservoir and the wellbore to cause the well to flow into the production facilities at the surface. In some wells also, natural energy will not drive oil to the surface in sufficient volume. The reservoir's natural energy must then be supplemented by some form of artificial lift. There are four basic ways of producing an oil well by artificial lift. These are Gas Lift, Sucker Rod Pumping, Electric Submersible Pumping and Subsurface Hydraulic Pumping (Takacs, 2005). Gas lift is a widely used method among artificial lift methods, in which gas is injected into the producing well providing energy to the flow. Continuous gas lift being cost effective, easy to implement, very effective in a wide range of operating conditions and requiring less maintenance in comparison to the other alternatives, is one of the most typical forms of artificial lift in oil production (Ayatollaki *et al.,* 2004). It is a usual technique where there is enough natural gas resources (Taheri and Hooshmandkoochi, 2006). The basic principle is decreasing the pressure gradient in the liquid by means of the injected gas, Figure. 1. The resulting mixture becomes less heavy than the original oil so that it eventually starts flowing .See Figure.1&2 (http://www.answers.com/topic/gas-lift-1).

In gas lift operations, three problems are the most important ones. The first one is finding the optimal position for injection point and the other is estimating the optimal gas injection rate. These parameters are interrelated, the more the rate of gas injection the deeper could be the injection point. In other words, the deeper the injection point the more gas volumes would be needed. The third one is finding the optimal tubing (string) size. The major problem in gas lift design is the optimization. In the present study a new method is devised for optimization of continuous gas lift with an unlimited supply.

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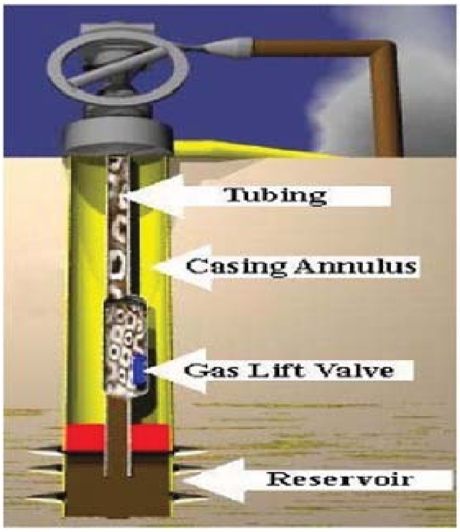


Fig. 1: Schematic of a valve position in gas lift well

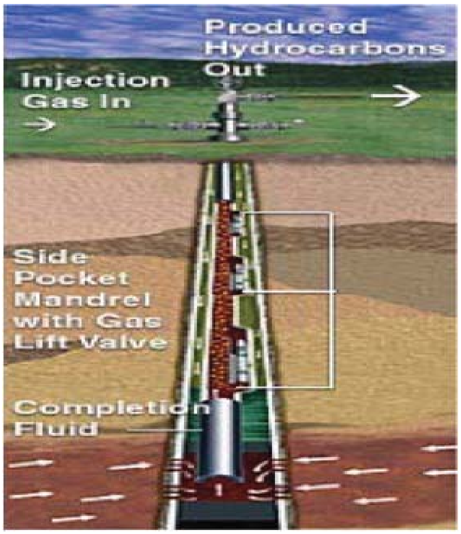


Fig. 2: Schematic of a gas lift well

What Is Gas Lift Optimization?

Gas being of a limited or unlimited supply completely changes the optimum gas lift system design and operation. The limited supply problem where the gas allocation is the focal point has been the subject of many researches, the most notable ones being summarized in Table1. In such a study the researcher is needles of the physics of the well and the reservoir, and the solution is obtained through several mathematical approaches.

What Are the Main Challenges in Gas Lift Optimization with Unlimited Gas Supply (Gopugs)?

In this problem at least three variables are of importance, gas injection rate, tubing internal diameter and injection location.The current methods have the two following weaknesses:

1- Fundamentally they do not perform optimization and rather, run a sensitivity analysis in fact. Sensitivity analysis is the next step to optimization and should not be used instead.
2- In the repeated literature sensitivity analysis is run in a single variable fashion and not multi- variable. This means that when one variable is changed the others are kept constant and in queue for being analyzed for sensitivity.

Gopugs Complexity:

An essential question may bear in mind about the reason why this optimization problem has not been yet attacked though there have been the two aforementioned weaknesses. And the answer lies in the complexity of multiphase flow problem. The core of nodal analysis is based on the IPR (Inflow Performance Relationship) that formulates the reservoir response and OPR (Outflow Performance Relationship) that defines the nature of well performance, the intersection being the operation point as shown in Figureure 3.

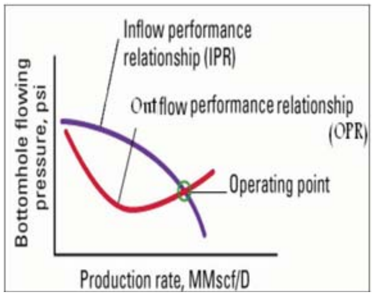


Fig. 3: Relation between IPR and OPR (Nodal Analysis)

The relationships usually used for IPR are well defined and relatively simple expressions such as Darcy and Vogel. The difficulty is in solution for OPR and simultaneous optimization of some several variables with the maximum operating rate as the problem objective. In the multiphase flow problem we are not faced with an explicit and exact function for which a classical approach suits. The variables are of integer and discrete nature and relationships and restrictions also are nonlinear. Metaheuristic methods are perhaps the best suitable way outs currently available and this superiority comes from their independence up on explicit and derivability of the function. The possible methods are for example, Simulated Annealing, Genetic Algorithm, Tabu Search and etc. We used the genetic algorithm.

Solution Approach to Gopugs:

Methodology and Modeling:

Interactive user-friendly software was developed in the VB.NET2008 environment called GOPUGS. The program is capable of predicting the performance of a single well under natural and gas lifted flows. The software is composed of different divisions and the solution bone is nodal analysis.

Gopugs Software 3.2.1. Reservoir Control:

In this section some physical properties of the reservoir and the data needed for obtaining IPR are entered. For the undersaturated reservoirs the solution is based on the Darcy’s equation and for the saturated reservoir the Vogel’s equation is used.

Well Data:

The parameters entered in this section are pertinent to OPR. The entered data are then manipulated through a Mechanistic model presented by Ansari. The reason for application of Ansari’s model is its high accuracy and its intrinsic capability for pressure and flow regime prediction (Ansari *et al.,* 1994; Abdul-Mashat, 2000).

Fluid Data:

In this section fluid data such as API, GOR, Pb and others are entered.

Gas Lift Parameters:

As discussed earlier the variables are gas injection rate, injection depth and tubing size. The first two are of discrete and integer nature and the third of discrete nature but not integer. An upper limit is also entered in this section that does not imply limited supply restriction but is taken as a boundary for solution purposes. The user will also define the number of segmentations. The bigger number of segments used the more accuracy is obtained in expense of increased solution times. The user can choose a batch of segments for the optimum segment to be found among them. For choosing the tubing size the user can choose between the default option that refers to standard IDs in the market or can enter some tubing sizes by hand.

There is another option in the software and that is capability for selection between different gases with different specific gravities. In this case the problem will have four variables, two of which are integer and the other two discrete. Two constraints are also considered, gas injection pressure and produced water rate. The user can arbitrarily switch these options on or off.

Genetic Algorithm:

A genetic algorithm (GA) is a search technique used in computing to find exact or approximate solutions to optimization and search problems. Genetic algorithms are categorized as global search heuristics. Genetic algorithms are a particular class of evolutionary algorithms (also known as evolutionary computation) that use techniques inspired by evolutionary biology such as inheritance, mutation, selection, and crossover (also called recombination) (Goldberg, 1989). The genetic algorithm method was first introduced by Holland in (1975), this technique has earned many interests among petroleum production specialists (Mohaghegh, 2000).

GA allows precise modeling of the optimization problem, although not usually providing mathematically optimal solutions. Another advantage of using GA techniques is that there is no need to having an explicit objective function. Moreover, when the objective function is available, it does not have to be differentiable (Lee and El- Sharkawi, 2008).

In the present study we have developed a GA that is novel with respect to selection method. A thorough flexibility feature is provided in the software the way that GA design parameters like Ps, Pm and Pc and cross over types are not limited to a definite value or interval and the user is given the chance to select and vary them according to his/her specific problem. The employed genetic algorithm has the following sections:

Representation:

After the first generation is randomly selected the following operations may be performed on them in order for the next generation to be produced.

Chromosome Design:

Each chromosome is composed of four genomes. These genomes are tubing diameter, gas injection rate, the specific gravity of injected gas and injection depth. The four genomes are discrete variables and all operator and applied methods are also specific to discrete variables.

Initial Population:

A definite number of chromosomes are generated randomly that comprise the first generation. For the next generations the following operators and methods are used.

Evaluation:

A rank is attributed to each of the chromosomes based on the oil production predicted by the Ansari's model for that chromosome. If the Ansari's model does not converge or if the chromosome is formed in an out of borders format then (-1) and (-2) ranks would be attributed to that respectively.

Constraints:

There are two conditions to constrain the chromosomes. These constraints are maximum water production and the maximum gas injection pressure. If any of these conditions are given a zero value that constraint won't be applied.

Generation Pool

At any step for the next generation to be produced a pool of chromosomes would participate for reproduction based on the following rules and with their attributed rankings.

Crossover:

This determines the percentage and the way the offspring chromosomes take after each of their parents.

Parent Mutation:

This is a special case of the crossover operation that exactly duplicates the parents in the next generation. The more the probability of crossover the longer will be the simulation run but the less will be the probability of converging to a local optimum.

Rw Select from Parents:

This operator transfers the parents to the next generation based on the ‘Roulette Wheel’ and with a probability proportional to its rank.

Include Parents:

If this option is activated all parents would be directly copied to the generation pool and will have the chance to compete with the offspring.

Selection:

In this section the user may be able to select between the roulette wheel, and tournament options for selection. There is also the option for removing one chromosome from options once it is selected. This way each chromosome would have the chance to be selected utmost once.

The members of the next generation are selected based on the ‘Roulette Wheel’ technique the probability of selection for each member is proportional to its rank. Or the tournament method in which a definite number of pool members are selected randomly and the best ranked members are then raised to the next generation. If ‘Use Each Generation Once’ is switched on, the chromosome transferred to the next generation is removed from pool not to be probably selected again.

Mutation:

In this section the mutation option can be checked on and the mutation probability be entered to the software. If the ‘Reduce’ option is checked on the mutation probability would approach zero as the run goes forth and at the last generations the mutation phenomena almost vanishes. This way we won't roust about the target.

***Elitism*:**

In case this option is activated one position is always reserved for the best member of the previous generation.

Run Section:

After all the input variables are entered the run button can be clicked and meanwhile the solution user is able to monitor fitness and error versus generation number.

Result Section:

In this section the IPR and OPR curves and their intersection point can be viewed. The above mentioned features were implemented in the software but there is the possibility for developing the software for taking into account the compositional effects besides the 'Black Oil' formulations. Or for the well performance calculations, we may add models other than Ansari to activate calculations for horizontal well configurations.

RESULTS AND DISCUSSIONS

For the purpose of evaluating the accuracy of the generated model for gas lift optimization, some data were obtained from three Iranian oil wells that are under gas lift operation. To show that the conventional optimization method is not an accurate method, the problem is analyzed here using an example. Assume a well that produces 1000 bbl of an oil with GOR of 420 scf/stb per day with natural flow conditions. If we graph the injected gas rate or GOR vs. produced oil rate for gas lifted conditions an illustration like Figure 4 would appear. This Figure shows that at GOR=2000 the oil production would be maximum. As previously mentioned this Figure is generated by sensitivity analysis on GOR. There are two shortcomings for this point. First it is calculated based on sensitivity analysis which means that this point is not essentially the optimum point but is the best among the tested guesses. The second is that this point is obtained based on sensitivity analysis on only GOR and the rest of variables are kept constant. Let's consider that the optimum point is for example GOR=1565 that is corresponding to 2420 oil rate. In table 2 the optimum GOR that is 1565 may never be inspected due to the employed algorithm. If the performance of GOR vs. Qo is graphed we may obtain a Figure like Figure 4. It is apparent that GOR=2000 is addressed as the optimum point. This means a greater injected gas volume and at the same time lesser oil production rate. The wells in this study are adopted from three Iranian oil fields with their specific reservoir and well characteristics as summarized in table 3.After the needed data were imported to the GOPUGS, the simulations were run for the three wells separately. The results are shown in Figure 6 to 11. The fitness function versus generation number and IPR against the best OPR are graphed. The results are also presented in tabulated format in table 4.

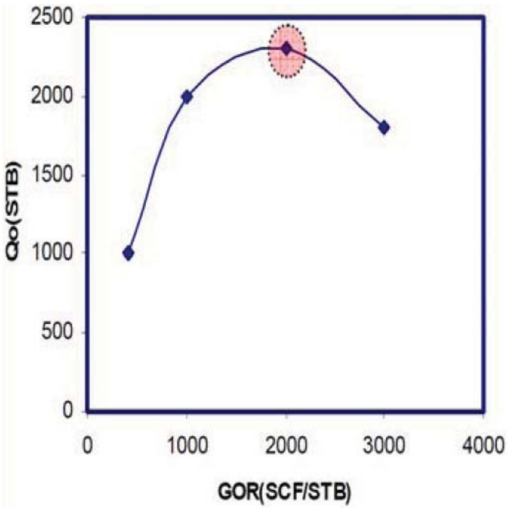


Fig. 4: Gas lift Performance with Sensitivity Analysis

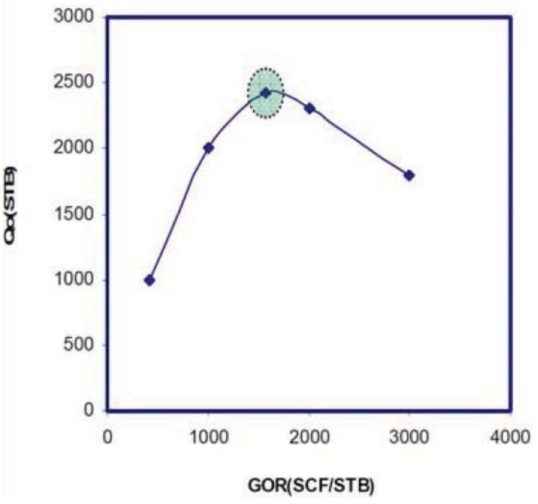


Fig. 5: Gas lift Performance with Optimization

Table 2: Sensitivity analysis to GOR

N	GOR(scf/stb	Qo(stb)
1	420	1000
2	1000	2000
3	*1565*	*2420*
4	2000	2300
5	3000	1800

Table 3: Some of the data for this study

Section	Some Parameters	Well 1	Well 2	Well 3
Reservoir	Pr(psi)	4000	5000	6500
	Pwf(psi)	3200	4650	3800
	Qo	3500	4150	3780
	K(md)	10	2	7
well	Well Depth (ft)	10000	12290	14500
	Tubing Size	5	5	4.5
	Pwh(psi)	526	700	1000
Fluid	γo	0.75	0.8	0.68
	γg	0.63	0.65	0.57
	GOR(SCF/STB)	700	450	850
	Water Salinity(ppm)	15000	2000	8500
	WOR (%)	3	1	0.5
Gas lift	Qinj (MMSCF/D)	4.5	5	6
	Pinj (psi)	1800	2200	2000
	Tubing Size (in)	5	5	4.5
	Depth of Injection (ft)	7300	9800	12200

Table 4: Result summery of using GA for 3 wells

Gas Lift Parameters	W1-SA	W2-SA	W3-SA	W1-GA	W2-GA	W3-GA
Tubing size (in)	3.5	5	4.5	4.5	4	6
Depth of Injection (ft)	7300	9800	12200	9523	7100	12250
Qginj (MMSCF/D)	4.5	5	6	4.25	3.81	6.21
Qo (STB)	3500	4150	3780	3900	4729	4127

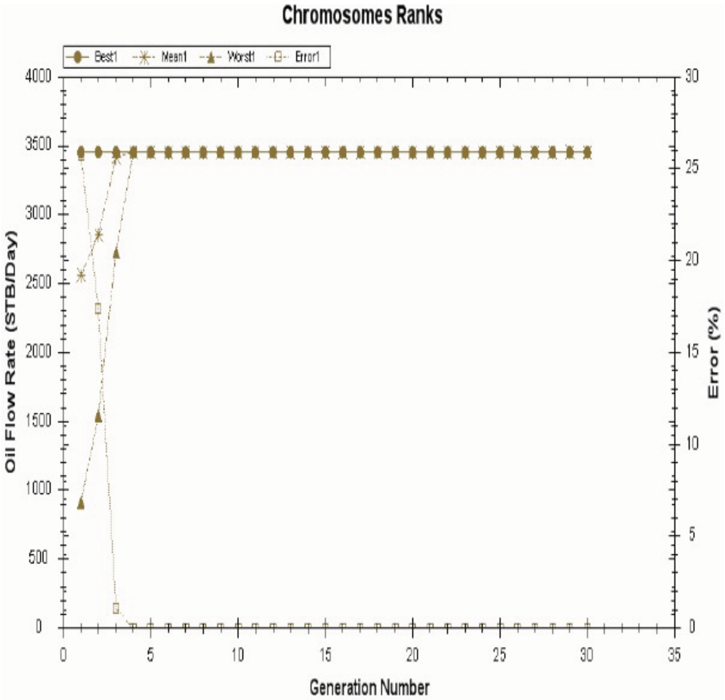


Fig. 6: Error and Fitness Function versus Generation for well#1

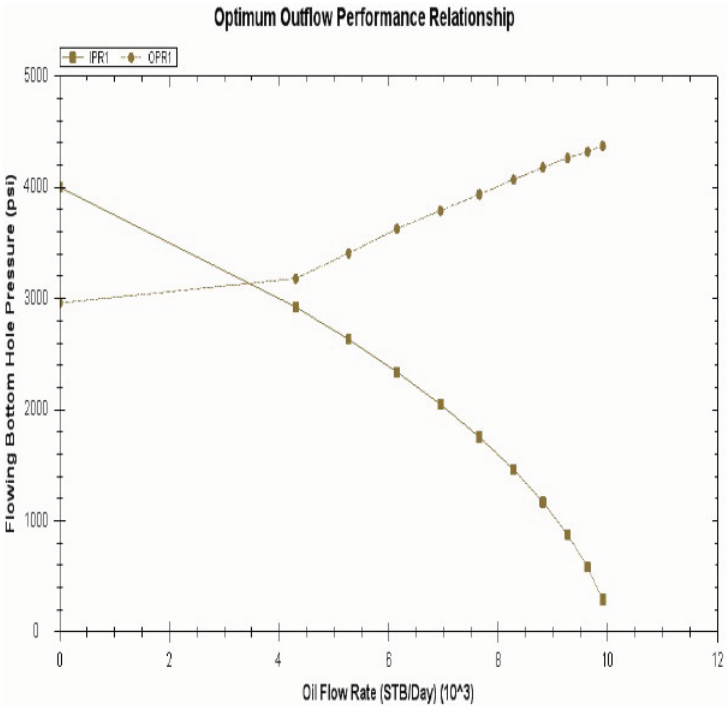


Fig. 7: IPR versus Max OPR for well#1

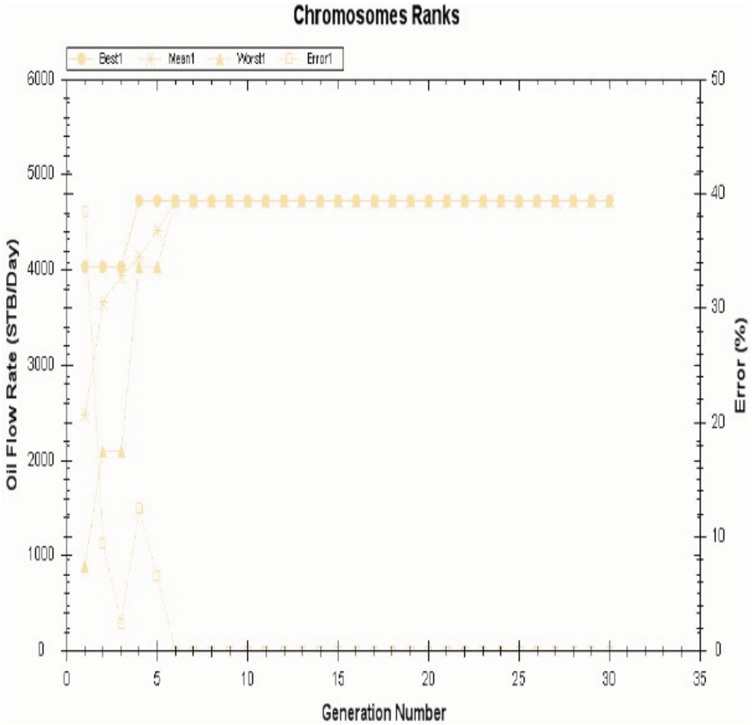


Fig. 8: Error and Fitness Function versus Generation for well#2

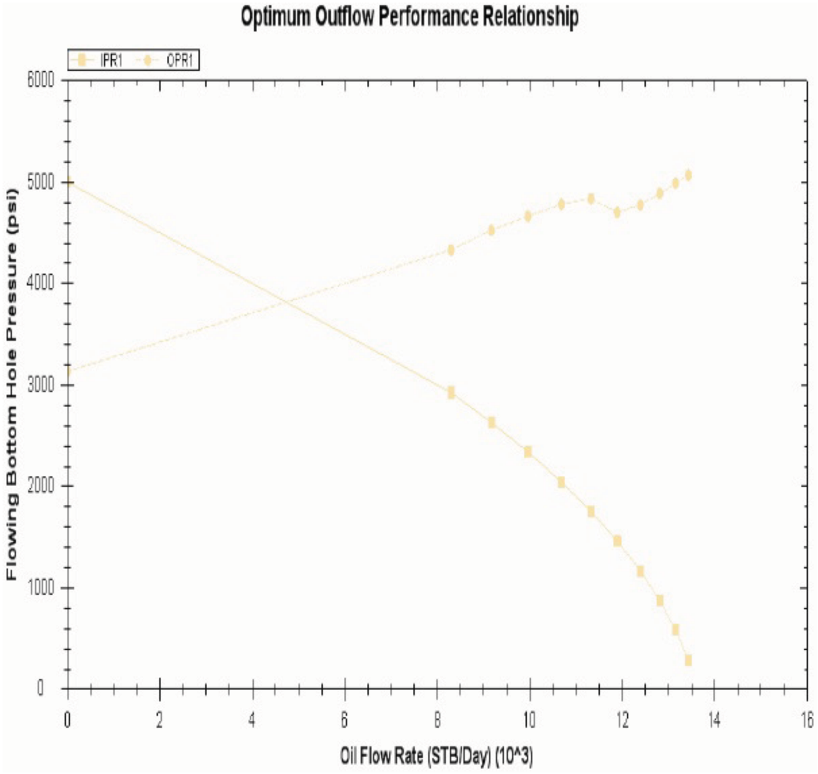


Fig. 9: IPR versus Max OPR and for well#2

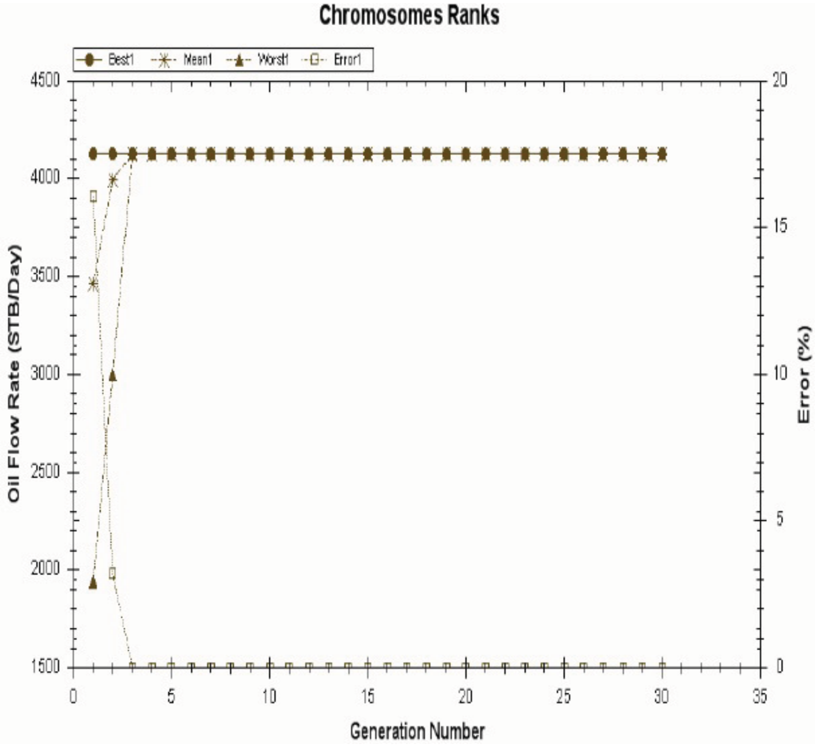


Fig. 10: Error and Fitness Function versus Generation for well#3

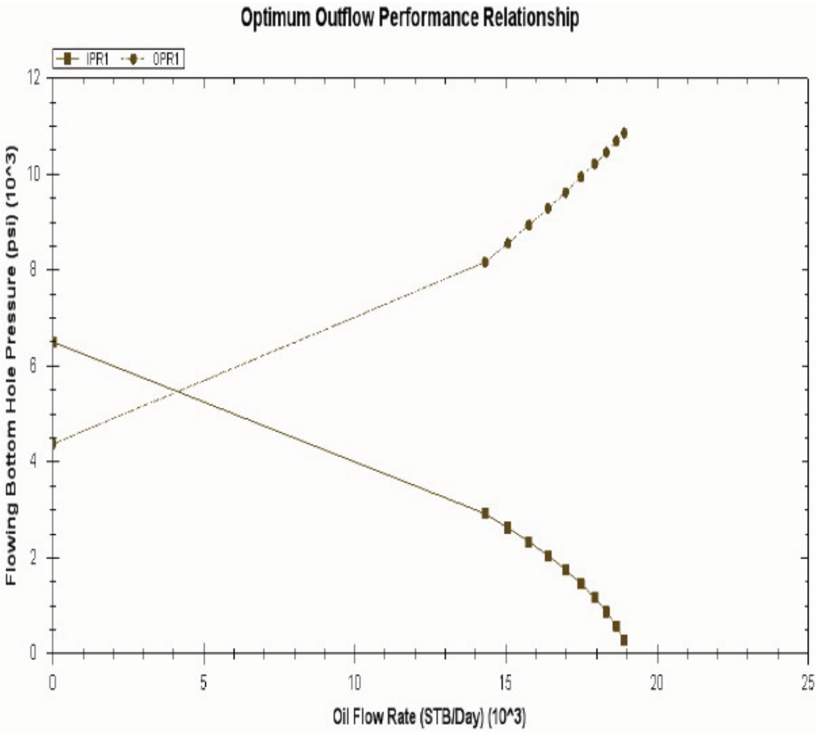
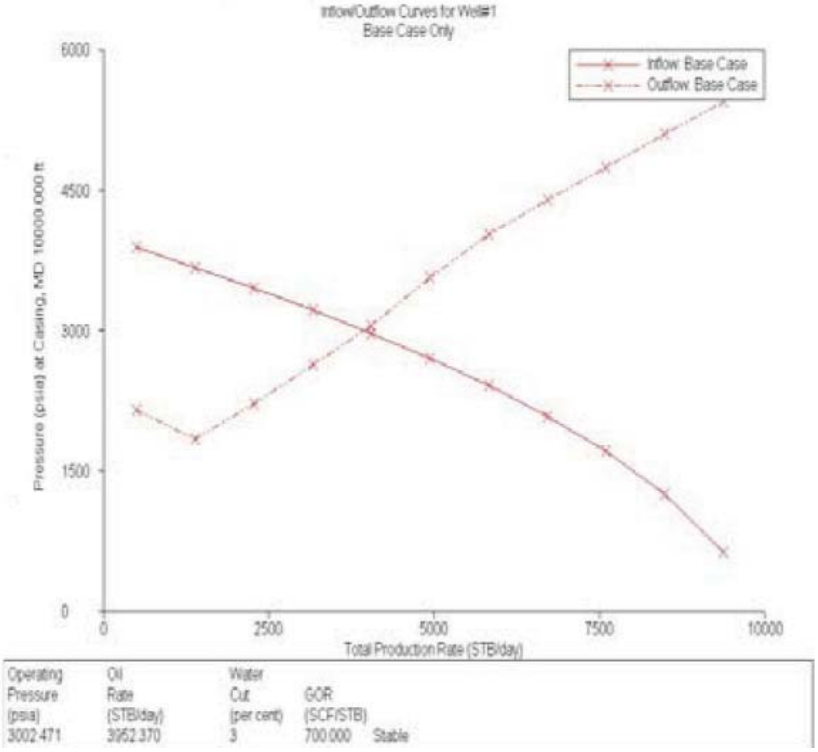
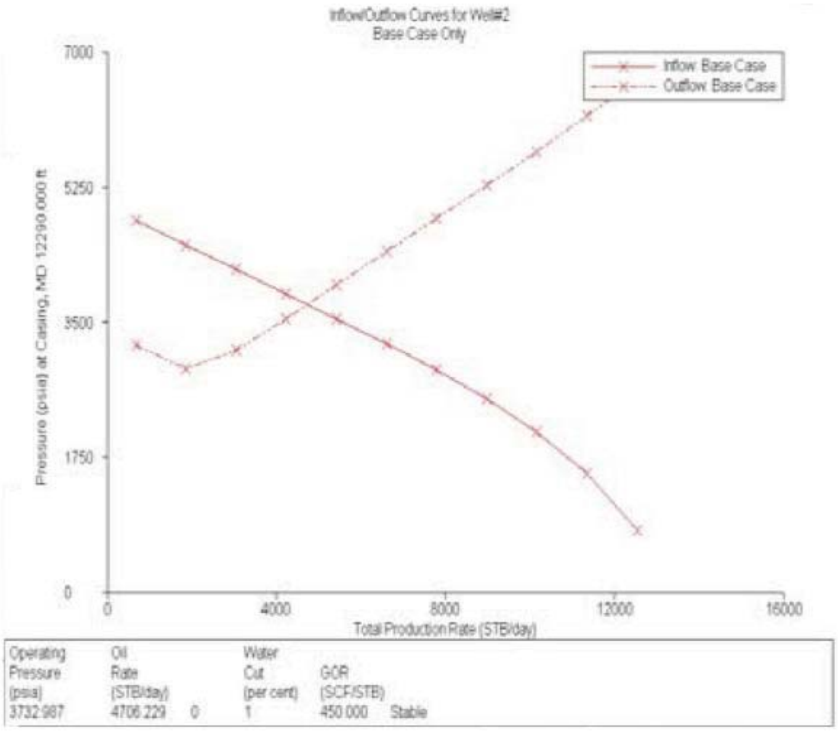


Fig. 11: IPR versus Max OPR for well#3



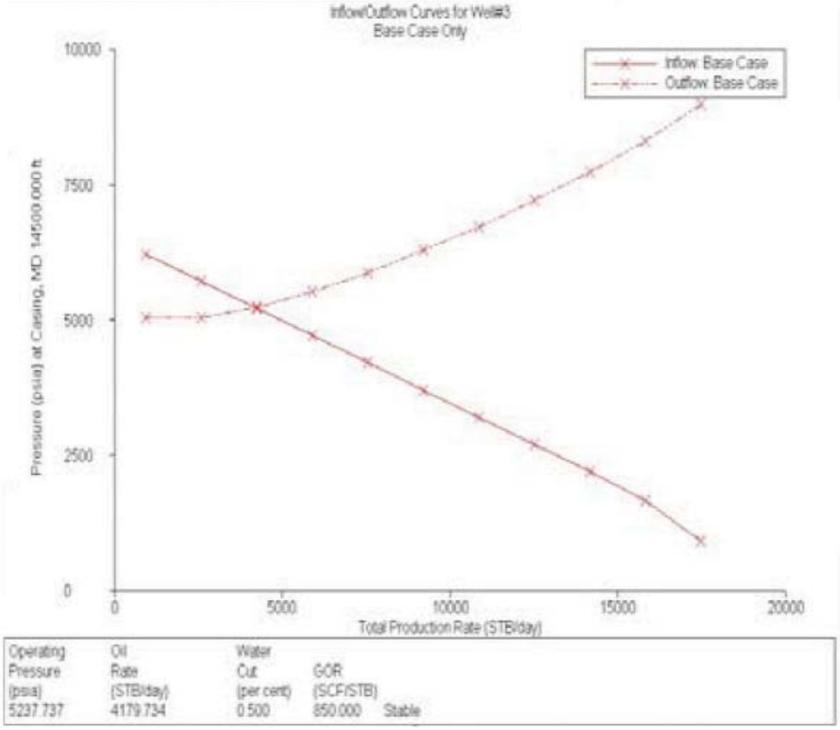
Operating Pressure (psia)	Oil Rate (STB/day)	Water Cut (per cent)	GOR (SCF/STB)	
3002.471	3952.370	3	700.000	Stable

Fig. 12: IPR versus Max OPR from commercial software output with using of optimized variables with GOPUGS for well#1



Operating Pressure (psia)	Oil Rate (STB/day)		Water Cut (per cent)	GOR (SCF/STB)	
3732.987	4706.229	0	1	450.000	Stable

Fig. 13: IPR versus Max OPR from commercial software output with using of optimized variables with GOPUGS for well#2



Operating Pressure (psia)	Oil Rate (STB/day)	Water Cut (per cent)	GOR (SCF/STB)	
5237.737	4179.734	0.500	850.000	Stable

Fig. 14: IPR versus Max OPR from commercial software output with using of optimized variables with GOPUGS for well#3

To verify the simulation results there are two possibilities. First, modification of field experiences for the suggested parameters and rerunning the commercial softwares with the given parameters as is suggested here and comparison with other designs. This is not plausible for the available producing company authorities. The second way was adopted and the suggested Qinj, Tubing size and Dinj were imported to the Wellflo software. The resulting Qo values were very close to the GA outputs. The small differences in results maybe attributed to the use of Ansari's model which is not implemented in Wellflo v.3.6.

Conclusions:

In this research a Metaheuristic method is developed for exact optimization of continuous gas lift in unlimited gas supply conditions. For this purpose general flexible software is developed and a novel innovative approach is presented that covers the shortcomings of currently used method. The proposed genetic algorithm in itself is a novel format in the operators category. Extensions to this study can be compositional thermodynamic 9 models, incorporating the horizontal well formulations and coupling with a reservoir simulator for long term prediction purposes.

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