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Preventing Instability Phenomenon in Gas-lift Optimization

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Abstract

One of the problems that sometimes occur in gas allocation optimization is instability phenomenon. This phenomenon reduces the oil production and damages downhole and surface facilities. Different works have studied the stability and suggested some solutions to override it, but most of them (such as making the well intelligent) are very expensive and thus they are not applicable to many cases. In this paper, as a new approach, the stability has been studied in gas allocation optimization problems. To prevent the instability, instability has been assumed as a constraint for the optimizer and then the optimizer has been run. For the optimization, first a genetic algorithm and then a hybrid of genetic algorithm and Newton-Quasi have been used, and their results are compared to ensure the good performance of the optimizer; afterwards, the effect of adding the instability constraint to the problem on production reduction have been discussed. The results show that the production loss with adding this constraint to the system is very small and this method does not need any additional and expensive facilities for preventing the instability. Therefore, the new method is applicable to different problems.

Keywords: Stability Phenomenon, Genetic Algorithm, Newton-Quasi, Gas Allocation, Stable Flow

1. Introduction

Instability is a phenomenon that occasionally occurs in gas lift operation, periodically stops the oil flow, and causes vibrations that damage downhole and surface facilities.

For the first time in 1945, Gilbert (Gilbert, 1954) studied the instability. He suggested using some kind of packer to eliminate its vibration, which means that he summarized the problem of the instability just in vibration and clearly ignored the periodically flow cease. Afterwards, in 1953, Bertuzzi (Bertuzzi et al., 1953) showed that for preventing the instability, the amount of injected gas should be more than a minimum; his finding was very important and became a basis for further studies. In fact, all the following equations and maps are based on Bertuzzi's idea. In 1984 and 1985, Grupping (Grupping et al., 1984) used a dynamic model to simulate the instability; this model was a little more complicated. In 1988, Asheim (Asheim, 1988) and later Alhanati et al. in 1993 (Alhanati et al. 1993) introduced an equation to predict the occurrence of instability; these kinds of equations have been very useful. Asheim's equations were an analytical one and have an acceptable accuracy. After that, in most of the proceeding works, Asheim's surface tension in multicomponent systems is inapplicable (Poling et al., 2000). Furthermore, in this work, his equation is used to specify the stable and unstable flow. Additionally, at the same time, Blick (Blick et al., 1988) used the Laplace transform to simulate the instability phenomenon. He derived an equation that showed the stable and unstable regions. In 2004, Fairuzov (Fairuzov et al., 2004) drew some maps to predict the stable and

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unstable flow and thus bypassing instability; he used different previously introduced models to draw his maps and then compared them. In 2005, Aamo (Aamo et al., 2005) introduced a model for predicting the instability; his model depended on just well head measurements (not bottom hole ones). Meanwhile, Godhavn et al. (2005) used a choke to limit the oil production and escaped the instability; his model was good but as the production continued the parameters of the reservoir and well changed and thus the size of the choke required for preventing the instability changed. In addition, usually these chokes were installed in downhole and changing them was very expensive. It should be mentioned that if the well is intelligent, changing the size of the choke is easy but making the well intelligent is costly. In 2008 and 2009, Jahanshahi et al. (2008), using a linear quadratic Gaussian approach, considered the stability as a dynamic problem and controlled that; then, he (Jahanshahi et al., 2009) used a multiphase simulator to predict the instability. In 2012, Meglio et al. (2012) studied the flow stabilization using observer-based control design and compared that with maintaining sensors in deep location. It is obviously clear that installing sensor in deep location is not easy and is expensive. In this study, cost is an important factor and it is attempted to find an applicable and cheap method. In 2013, Guerrero-Sarabia et al. (2013) performed the linear and nonlinear analysis of flow instability in gas lift wells and determined the effect of different production parameters on flow rate oscillations. This work was very useful to find out which parameter should be changed to prevent the instability in most economical way, but, it is not definitely a method for preventing instability. Moreover, Salahshoor et al. (2013) introduced a nonlinear model to predict the flow instability. Furthermore, Willersurd et al. (2013) used a nonlinear predictive control to reject time varying pressure disturbance and ensure a stable flow. In addition to these models, there are some new methods which can model stability phenomenon (Mahdiani and Khamehchi, 2014).

As can be seen, different works have studied the instability phenomenon and suggested some solutions to eliminate that. But none of them has studied the instability in a gas allocation optimization problem. Herein, as a new approach, this phenomenon will be considered as a constraint in a gas allocation optimization problem and the effect of considering this constraint on the reduction of total oil production will be discussed. This study shows that using this method is an inexpensive and applicable way to escape the instability.

2. Problem modeling

First some wells of Iranian oil fields were selected. The problem is to allocate a specific amount of lift gas between these wells in a way that maximizes the total production oil rate. At the beginning of the reservoir development, the wells were operated in natural flow. As the production continues, the oil rate declines and gas lift is used to increases the production rate. The amount of available gas is limited, and thus, if the stability is ignored in finding the optimum point of lift gas allocation, it is probable that some wells fall in an unstable region. As mentioned above, if some wells produce in an unstable manner, it causes some great technical problems. None of the studied wells is intelligent and if they were, they would not fall in an unstable region and there would be no need for using the method of this paper.

Now, three choices are available: letting wells fall in an unstable region (not a reasonable choice), making wells intelligent (which is not applicable because it is very expensive), and considering the instability as a constraint for the optimizer from the beginning, which is applicable and inexpensive and will be discussed here.

One of the most important parts of optimization problems is to define a fitness function. In this study, the fitness function should takes all of the injection rates of the wells as inputs and returns the total production oil rate as the output. The other properties of reservoir and well are assumed to be fixed and their ranges are shown in Table 1. In fitness function, first the oil rate production of a well should be calculated. There are some methods to calculate this as reported elsewhere (Khishvand and Khamehchi, 2012; Rasouli Sadabad, Rashidi, Karimi, and Khamehchi, 2014) Herein, the nodal analysis has been used. In nodal analysis, a specific production rate is assumed and the well head is considered as the top node. Additionally, the whole length of the well is divided to about 200 ft sections in a way that the injection point and the end of tubing lies in the boundary between two adjacent sections. Then, an average temperature and pressure for the uppermost section are assumed and, by using Ansari's equation (Ansari et al., 1994) which models the two phase flow, the pressure at the end of the uppermost section is calculated. Ansari models need PVT properties and thus the PVT properties are estimated using the black oil correlations, which are listed in Table 2. These correlations are the most accurate ones based on different literature surveys (Brill et al., 1991; Takacs, 1989; Takacs, 1989; Bendakhlia et al., 1989; Renanto et al., 1998; Patton et al., 1980). For estimating the PVT properties, the temperature of the fluid should be known; thus using the temperature of the top node and the Hasan-Kabir's (Hasan-Kabir, et al., 1994) model, the temperature of the bottom of the section can be estimated. Then, using the calculated pressure and temperature of the bottom of the section, the average temperature and pressure of the section are calculated. The PVT properties of the fluid in the new average conditions are calculated; afterwards, using the work of Ansari and Hasan-Kabir, the pressure and temperature at the end of the section are calculated. If the new values agreed with the previously calculated ones, it was acceptable; otherwise, the procedure was repeated until the pressure and temperature at the end of the section converged to specific values. The parameters of the bottom of the uppermost section are the same as the parameters of the top of the proceeding section. Thus the above procedure can be repeated for other sections until the pressure and temperature at the bottom hole is calculated. Then, a new rate should be assumed and using the previous procedure, the bottom hole pressure will be calculated. Next, the value of bottom hole pressure is cross plotted against the oil rate, and its common point with IPR curve (drawn using Vogel's (Vogel, 1968) correlation) is found. This point shows the bottom hole pressure and the production oil rate of the well. The effect of gas lift was imported to the problem by having a higher gas to oil ratio in the sections above the injection point. Using the above procedure, the oil rate of all well is calculated and summed up to become the total production oil rate and the output of the fitness function.

To consider the instability, as a constraint for the optimizer, the Asheim's equations have been used. These equations are shown in Equations 1 to 3:

$$F_1 = \frac{\rho_{gsc} B_g q_{gsc}^2}{q_{Lsc}} \times \frac{J}{(EA_i)} \tag{1}$$

$$F_2 = \frac{C\ V_t}{V_C} \times \frac{1}{gD} \times \frac{p_{ti}}{(\rho_{fi} - \rho_{gi})} \times \frac{(q_{fi} + q_{gi})}{qfi(1 - F_1)} \tag{2}$$

$$C \sim= 1 \tag{3}$$

Asheim introduced two factors, namely F_1 and F_2, to predict the stability of the flow. To ensure the stable flow, one of these factors should be more than 1. It is clear that in our problem all of the Asheim's equation input parameters, i.e. the reservoir, well, and PVT properties, are constant and the only variable is the injection rate.

Table 1
Range of the parameters of each well.

Parameter	Maximum	Minimum
API gravity (API)	34.14	23.61
Productivity index (STB/day/psi)	2.75	1.64
Reservoir pressure (psi)	4300	2900
Water cut (%)	15	1.5
Tubing internal diameter (in)	4.87	2.75
Well depth (ft)	10500	8300
Well head pressure (psi)	540	207
Injection depth (ft)	8500	3900
Injection gas gravity	0.92	0.68
Casing inner diameter, (in)	9.85	4.37
Tubing outer diameter (in)	5.33	3
Interfacial tension (dyne/cm)	64	50
Water gravity	1.12	1.00
Well head pressure (psi)	180	110
Gas gravity	0.95	0.67
Gas liquid ratio (SCF/STB)	640	410
Oil viscosity (cP)	3.54	1.97
Reservoir temperature (°F)	315	200
Bubble point pressure (°F)	650	430
Tubing depth (ft)	9,320	6,340
Bottom hole orifice size (1/64 in)	58	20

Table 2
Black oil correlations used in production modeling.

Properties	Correlations
Critical temperature and pressure	Standing
Dead oil viscosity	Beal
Gas compressibility factor	Papay
Gas viscosity	Lee
Inflow performance	Vogel
Live oil viscosity	Chew- Connaly
Solution gas oil ratio	Laster
Stability criteria	Asheim
Surface tension	Swerdloff
Temperature profile	Hasan Kabir

It should be mentioned that all the variables of this study are in field units; but to save the original form of the Asheim's equations, their units have not been changed. Therefore, before the parameters are inserted into Asheim's equation, their units are changed to be consistent with Asheim's units and then are inserted into the equation.

3. Model optimization

In this section, the effect of considering the instability as a constraint for the optimizer in different gas allocation optimization problems will be discussed. To this end, in four different cases, an assumed amount of available lift gas will be allocated between some assumed wells in a way that the total oil rate production becomes maximum. A summary of the number of wells and amount of available lift gas in each case are shown in Table 3. In this study, genetic algorithm is supposed to be used as the optimizer and its parameters are shown in Table 4. Genetic algorithm is a heuristic method and performs well in complex problems, in which different variables are changing simultaneously. Thus it has been selected for this study. However, it suffers from some deficiencies. It does not lead to an absolute optimum point and different runs of the algorithm lead to different solutions. Of course, the positive point of the genetic algorithm is that it can search the whole space rapidly. There are some other optimization algorithms such as Quasi-Newton (QN) method that can be used as a hybrid with genetic algorithm to override the GA deficiencies. In this paper, a hybrid of GA and QN is used as the optimizer. This hybrid overcomes the GA deficiencies, but it is not as slow as QN. In fact, in the hybrid form, GA makes different generations and QN processes the life of individuals in the end of each generation. Afterwards, this algorithm will be explained with more details. Finally, its results will be compared with the GA algorithm. Another point that should be mentioned is that the genetic algorithm is a random-base procedure, and thus different GA runs lead to different solutions and all of them are not certainly the best optimum point. To solve this, the genetic algorithm has been run for five times in each case and the best one is selected for further studies and investigations. "Five" is selected for having various runs but not so many, which requires a long runtime.

Table 3
The four cases of production.

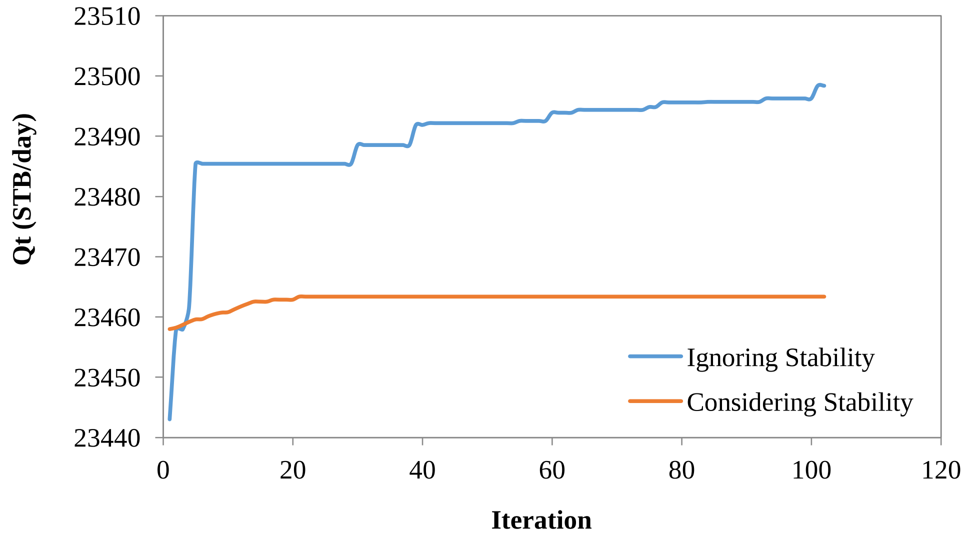
Case	No. of wells	Available gas (MMscf)
Case 1	5	3
Case 2	5	4
Case 3	20	12
Case 4	20	16

Chromosomes or individuals (in a GA or GQL problem) are a series of injection rates of different wells. In this study, initially some chromosomes were created randomly. Then, in each iteration, a chromosome life was defined and QN was applied to each solution and modified that to improve the quality of the optimum point. At the end of this process, the new created solutions were evaluated and the ones that did not meet the stable flow were penalized. Then, four individuals with the highest total production oil rate were selected and gone directly to the next generation (elite). Other individuals for the next generations were produced by cross over and mutation. Crossover and mutation starts by best individual and then if it is needed, it uses less suitable ones; hence in all the iteration it is more probable for a better individual to participate in creating the next generation. In each iteration, it was checked to see whether the tolerance of the total production of best individual was less than 10^{-6} or not' if it was less, the stopping criteria were met and the algorithm stopped; otherwise the algorithm continued searching for better individuals.

4. First case

In the first case, there are 3 MMscf available lift gas which should be allocated between 5 wells in a way which maximizes the total production oil rate. There are two options in the optimization, namely ignoring the stability as it has been done until now, or considering it. Both options have been carried out one time using genetic algorithm (GA) and then using a hybrid of genetic algorithm and Quasi-Newton and their results are showed. Using two optimizers ensures us that the results of this study have not been affected by the optimizer deficiencies. Figures 1(a) and 1(b) show the convergence to the optimum point by GA and GQL methods respectively.

a)



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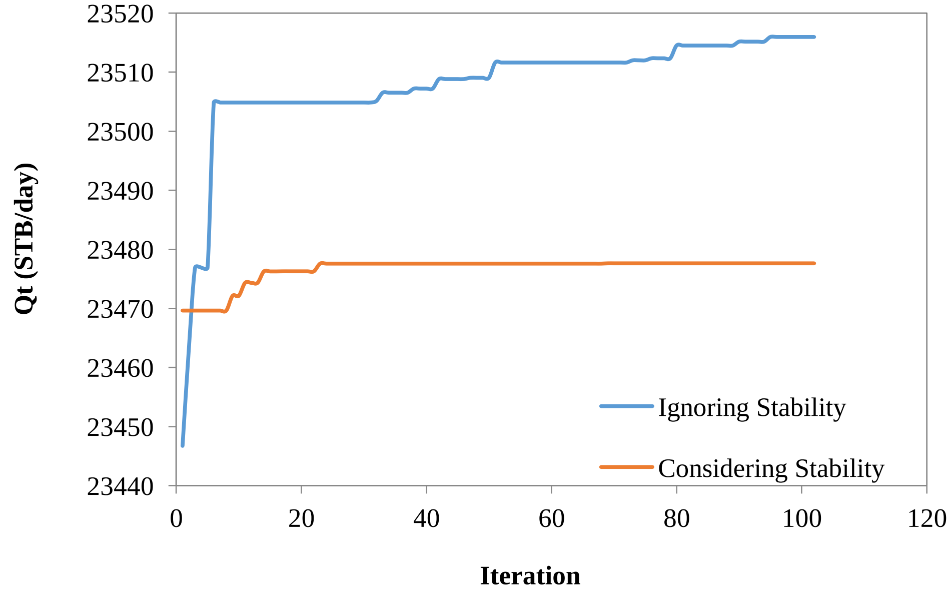


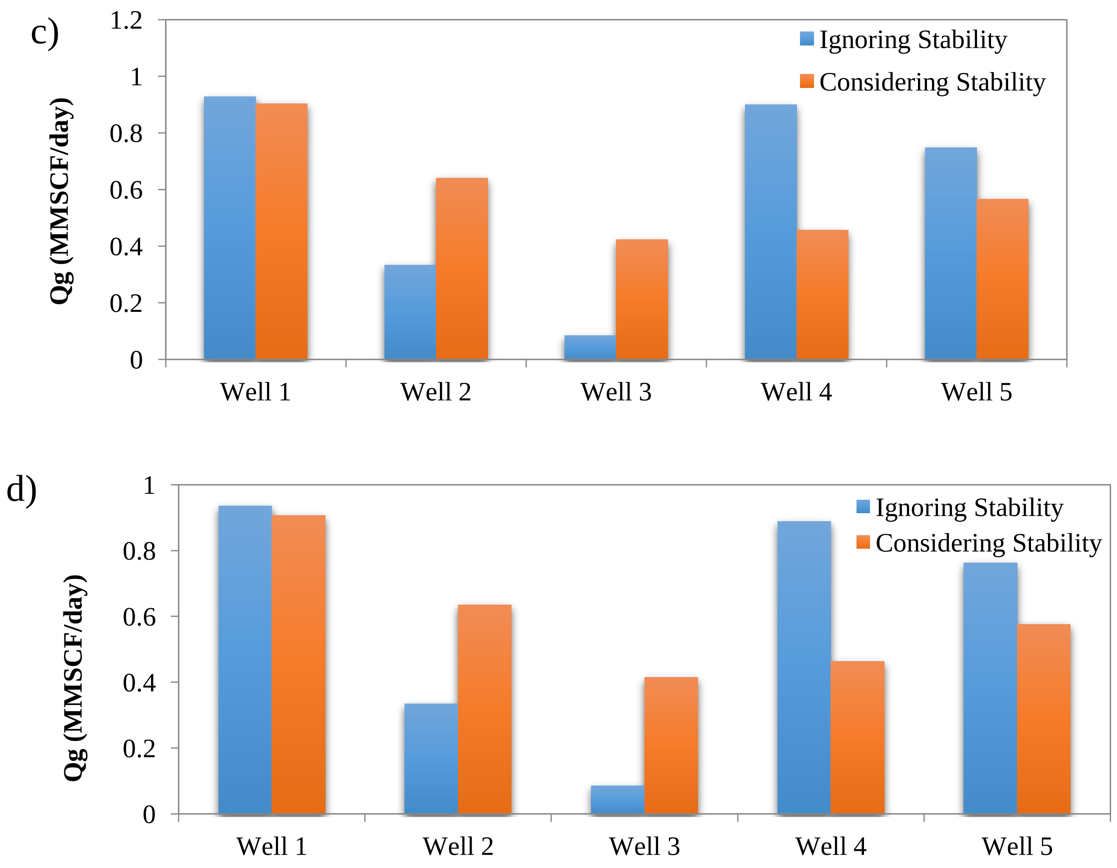


Figure1

Figure 1 Case 1: (a) convergence of the GA, (b) convergence of the GQL (c) the optimum points of GA, and (d) the optimum points of GQL.

Table 4

Genetic algorithm parameters.

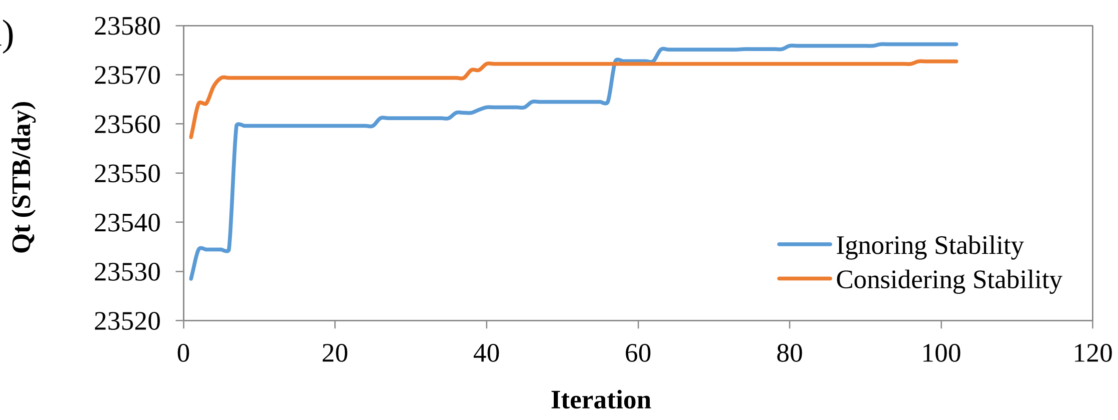
Property	Value
Population type	Double vector
Population size	20
Fitness scaling	Rank
Selection function	Stochastic uniform
Elite count	4
Crossover function	Scattered
Crossover fraction	0.8
Mutation function	Uniform
Mutation probability	0.05
Migration	Forward
Hybrid function	None
Max generation	500
Max Stall generation	100
Function tolerance	1.00×10^{-06}

It can be seen in these figures that, no matter which optimizer is used, including the stability has caused a small reduction in the total oil production of the optimum point. The total production oil rates in the cases of ignoring and considering stability using GA are 23498 STB/day and 23477 STB/day respectively and they are 23517 STB/day and 23477 STB/day respectively when GQL is used. Therefore, the production loss which considering stability imposes on the system is not large regardless of which optimizer is used. Another point in these figures is that, in both states of considering and ignoring the stability, GQL has found a better optimum point than GA with a similar number of iterations. Figures 1(c) and 1(d) show the value of injection gas in different wells in the case of considering stability and ignoring it using different optimizers. They show that although the values of total production oil rates are close, the gas allocations have a great difference. In wells 2 and 3, the value of the injected gas in the case of considering stability is more than the case of ignoring it, while, in wells 1, 4, and 5, the value of optimum injection gas when stability is ignored is more than its corresponding value in the case of considering stability. This means that these wells respond better to gas lift, but considering stability needs to give more gas to the other wells to create a stable flow and thus they have received less gas. In comparing Figure 1(c) and Figure 1(d), it can be seen that in both optimizers the allocations are similar but GQL finds a slightly better point. It means that despite the poorer performance of the GA, it has not fallen in a local optimum point trap. In fact, GA has searched for the global optimum point (if we assume the GQL optimum point is global), but it is not as near the optimum point as GQL point is.

5. Second case

The second case is similar to the first one but the available gas in this case is 3 MMscf instead of 4 MMscf. Figures 2(a) and 2(b) show the convergence of considering and ignoring stability optimizations using GA and GQL optimizer respectively. Similar to case 1, ignoring stability has led to an unstable point; however, comparing these figures with Figures 1(a) and 1(b)shows that in this case both curves of ignoring and considering stability have become closer. Comparing Figures 2(a) and 2(b) reveals that, similar to the first case, GQL has found better optimum points either by considering or ignoring stability. The difference between GA and GQL is not generally large but in considering stability it is a little larger than the state of ignoring that. Figures 2(c) and 2(d) show the value of optimum point of the allocated gas to different wells. Comparing these figures with Figures 1(c) and 1(d) show that the values of the allocated gas of different wells in the cases of considering and ignoring stability are become closer. Moreover, similar to the first case, the optimum of both GA and GQL is similar, meaning that both of them have tried to approach to a unique optimum point.

a)



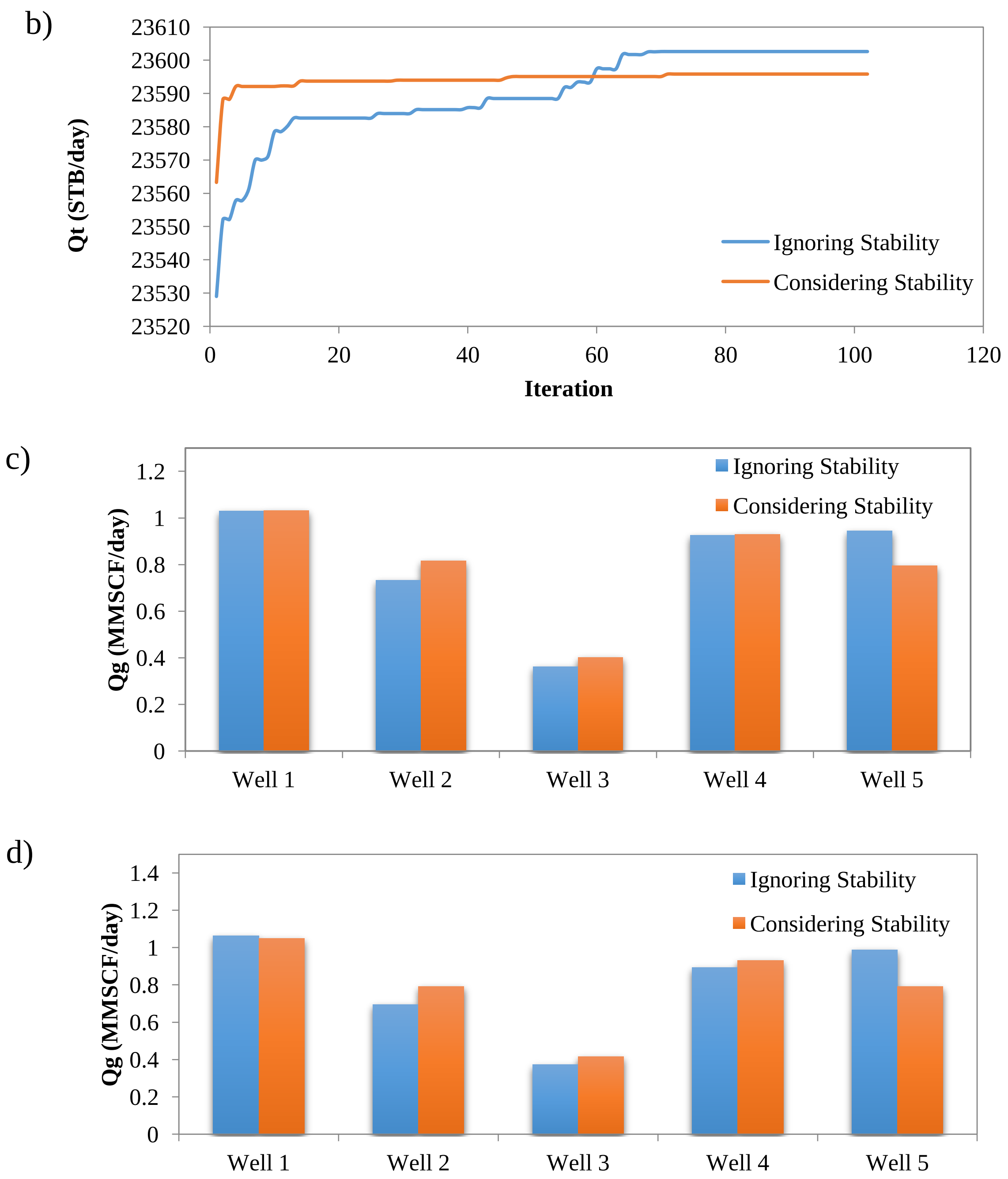
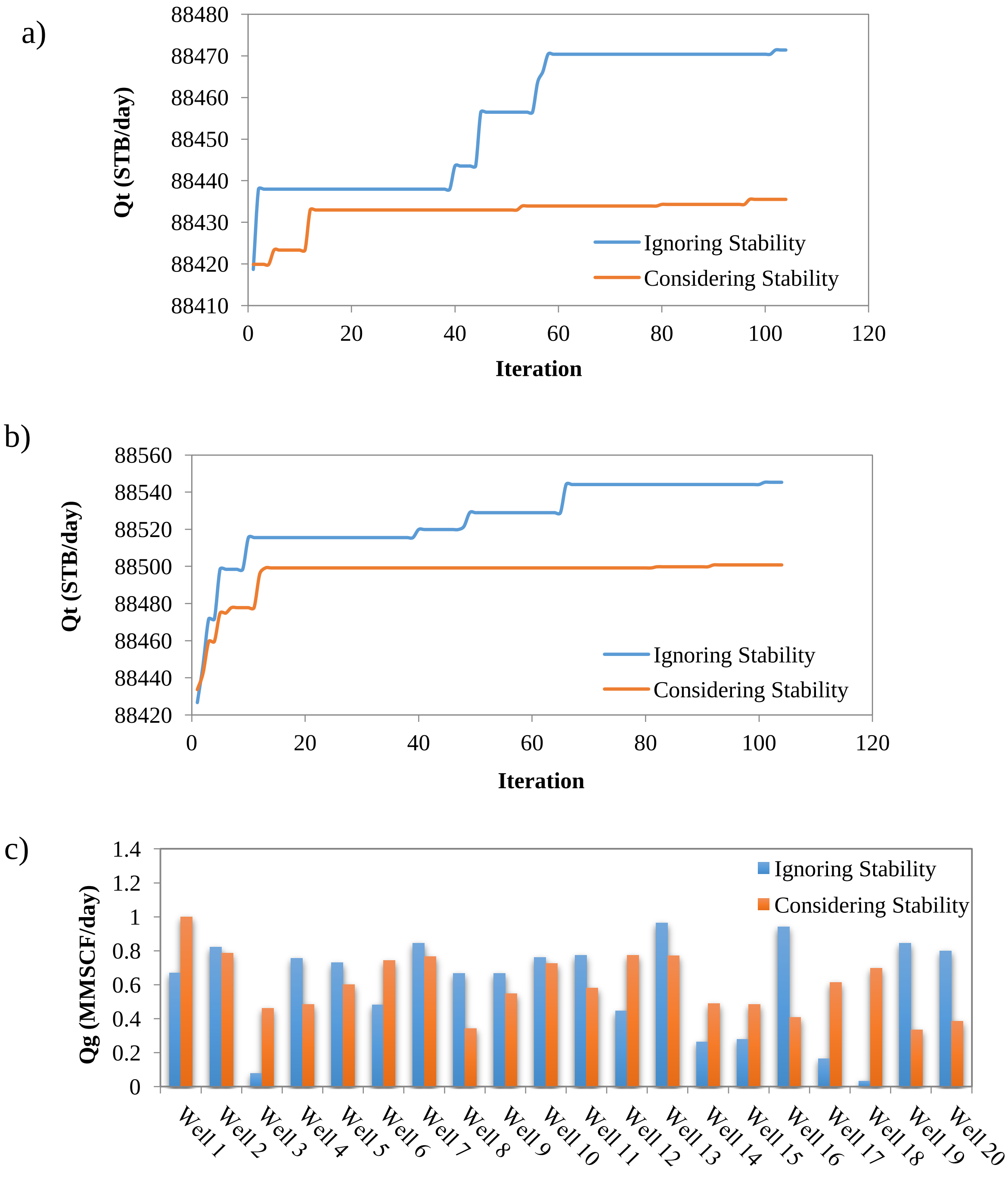


Figure 2
Case 2: (a) convergence of the GA, (b) convergence of the GQL, (c) the optimum points of GA, and (d) the optimum points of GQL.

6. Third case

In the third case, there is 12 MMscf available lift gas that should be allocated between 20 wells. This case is similar to the first case but both the number of wells and the available lift gas have been multiplied by 4. Like case 1, the optimum point of ignoring stability is in an unstable region. Figures 3(a) and 3(b) show the convergence of considering and ignoring stability optimization and Figures 3(c) and 3(d) show the optimum points. Comparing GA and GQL in this case shows that in both states of considering and ignoring stability the GQL showed better performance than GA and in the case of ignoring stability this is much noticeable.



d)

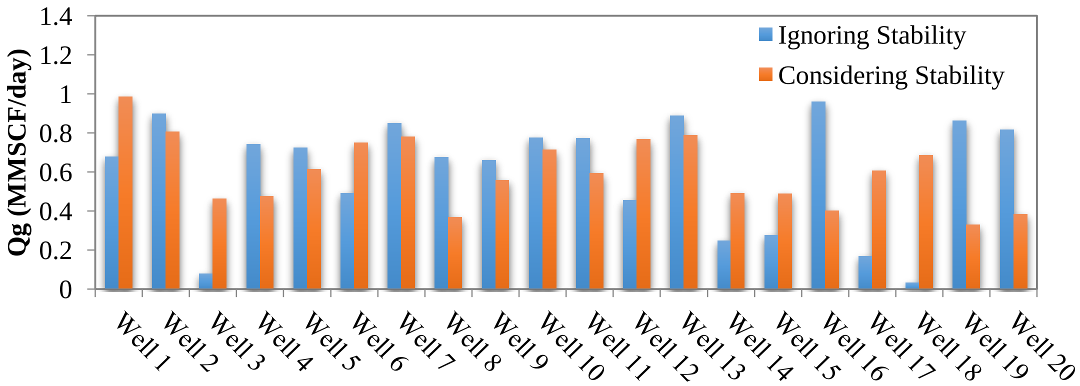
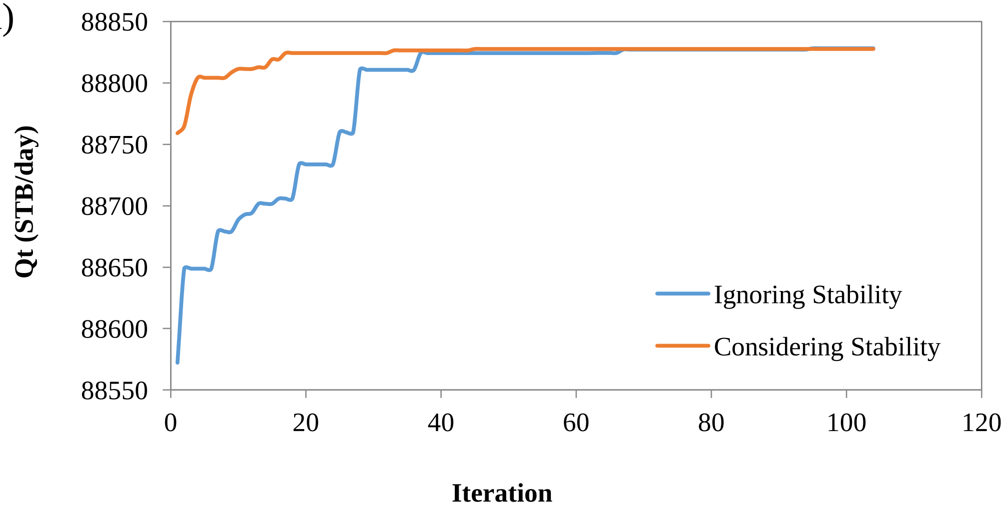


Figure 3
Case 3: (a) convergence of the GA, (b) convergence of the GQL, (c) the optimum points of GA, and (d) the optimum points of GQL.

7. Fourth case

This case is like the second case but both the number of wells and the available gas have been multiplied by 4. Figures 4(a) and 4(b) show the convergence of considering and ignoring gas allocation optimization. This case has the closest value of optimum point values of considering and ignoring stability. However, like other cases, ignoring stability has led to a point in an unstable region. Figures 4(c) and 4(d) show the values of the gas injections of both optimum points, which are also almost identical. Both optimizers have similar results in this case. Of course, GQL has found a better optimum point but, in both states of using GQL and GA, the difference between the optimum points of ignoring and considering stability is slight.

a)



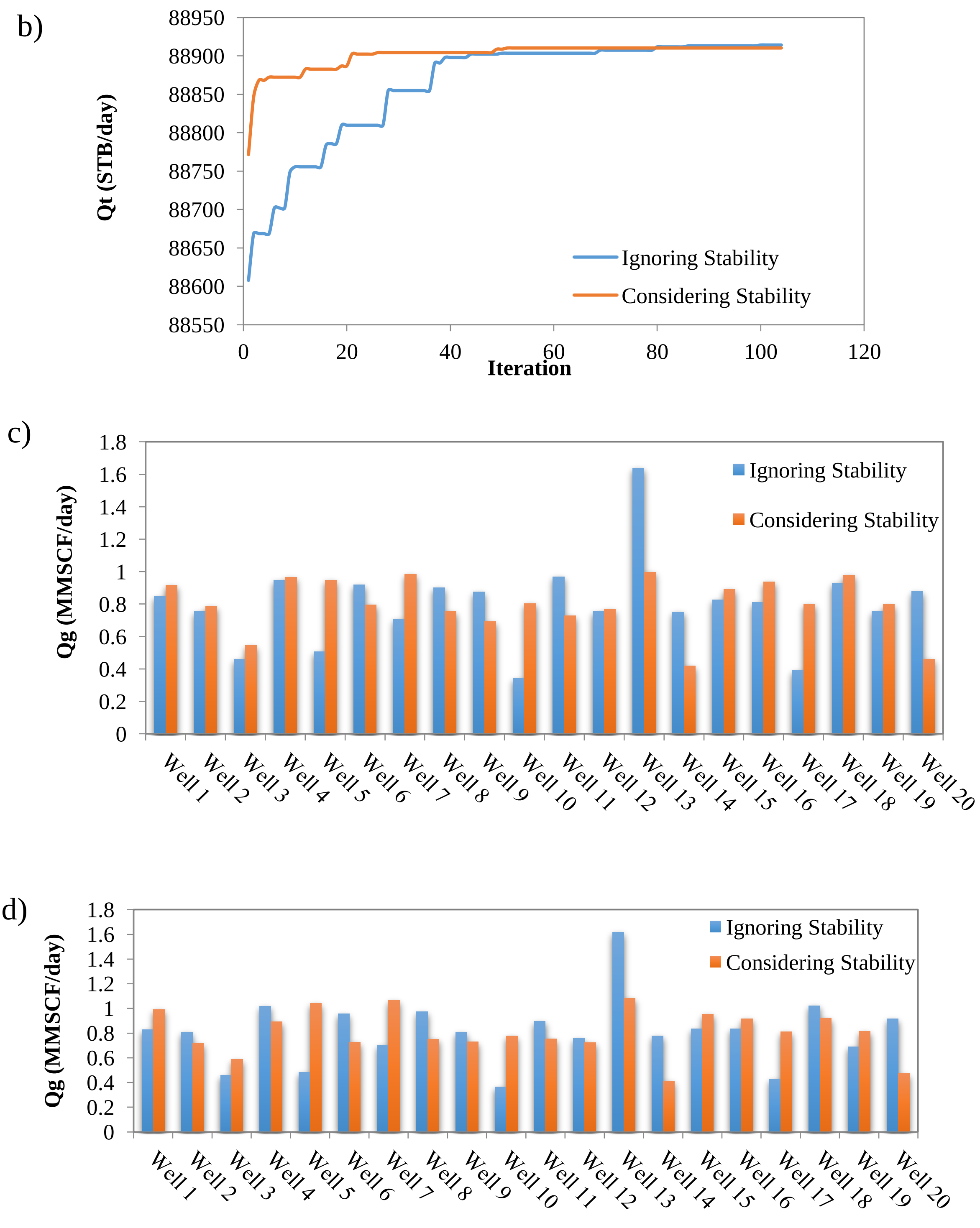


Figure 4
Case 4: (a) convergence of the GA, (b) convergence of the GQL, (c) the optimum points of GA, and (d) the optimum points of GQL.

8. Results and discussions

In all the four discussed cases, the optimization with considering stability has started by a point with higher value and has a smoother convergence (Figures 1-4). This is because of the fact that the amount of injected gas in each well should be more than a minimum for having a stable flow; so, the amount of the injected gas rate is higher than random values of the case of ignoring stability and thus their corresponding oil rates become higher. The convergence curve is smoother because adding a constraint to a problem makes its search space narrower. However, it should be noted that if the gas injection rate of the wells increases too much, the oil production decreases; thus increasing the available gas more than a specific value has no effect on the optimum points of considering and ignoring the stability and the difference between them. The number of wells and the amount of available lift gas affect the difference between the optimum points of considering and ignoring stability. Figures 5(a) and 5(b) show that as the amount of the available lift gas increases, the optimum points of considering and ignoring stability become more similar (comparing cases 1 and 2 and cases 3 and 4). Furthermore, as the number of wells increases, the difference becomes more remarkable. As these figures display, the results of using GA and GQL optimizers are in good agreement. In fact, the differences between the optimum points of these two optimizers are so slight that these figures are not affected. Figure 6 shows the production loss of different cases caused by considering stability. It shows that as the amount of the available lift gas or the number of wells increases, the production loss decreases, which is confirmed by both GA and GQL; in this figure, GQL shows a little higher reduction than GA.

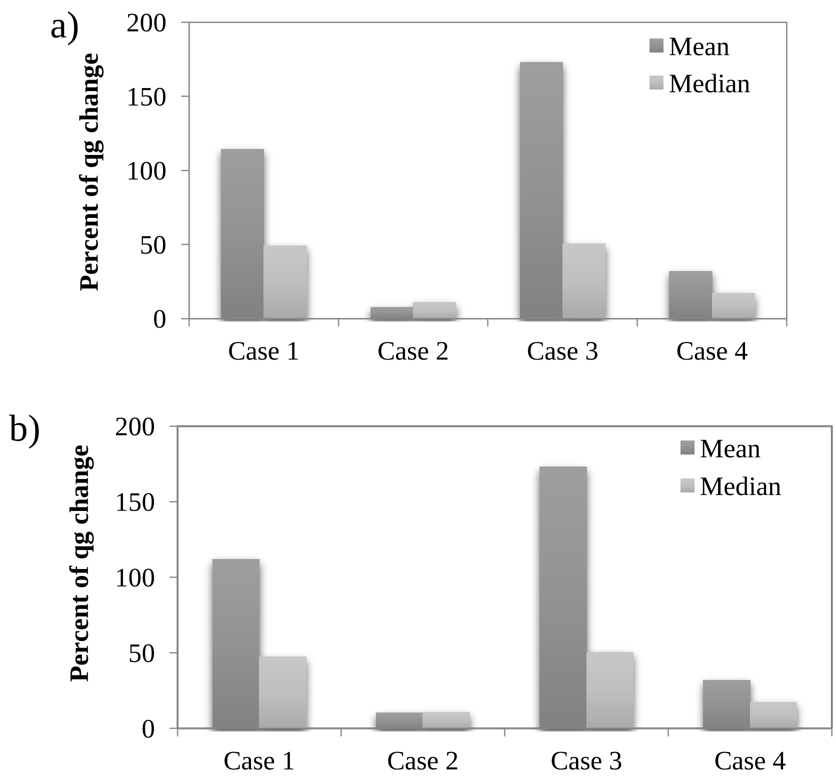


Figure 5
Absolute mean and median percentage of the allocated gas changes caused by considering stability (a) using GA and (b) using GQL.

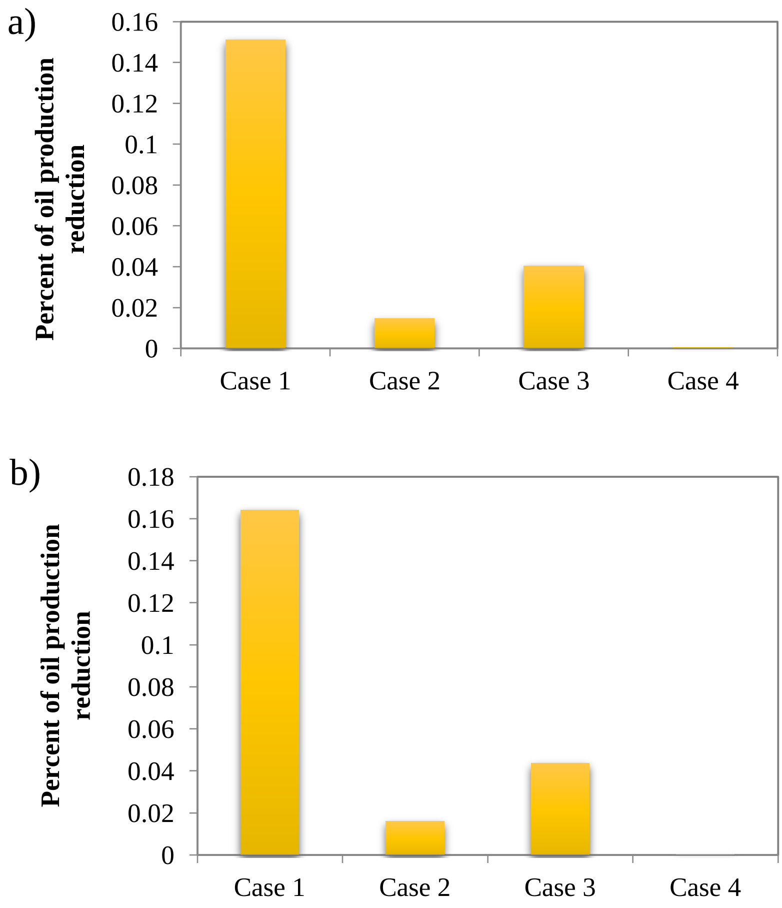


Figure 6
The percentage of oil production reduction caused by considering stability (a) using GA and (b) using GQL.

9. Conclusions

According to the results obtained the following conclusions can be drawn:

1. Instability is a phenomenon that is sometimes observed in gas allocation optimization and causes production loss and major damages to downhole and surface facilities. In this work, a novel approach to escaping this problem has been represented and discussed in different problems to test its applicability. Testing the new method in different case studies confirmed the good performance of the method;
2. Also, instability has been prevented in gas allocation optimization problem by considering it as a constraint in the optimizer. This method is very easy and inexpensive, does not need any special facilities, and is applicable to different wells and problems;
3. Although considering the instability in optimization problems leads to an optimum point with a smaller amount of total production oil rate, regardless of how many wells are considered and how much available lift gas is available, the production reduction is small; considering the overcome of the problems that the instability causes, this method is completely useful and advantageous;
4. Studying the different problems with different numbers of wells and the maximum available lift gas shows that as the amount of the available lift gas increases, the probability of wells to fall in an unstable region decreases. In addition, increasing the number of wells and

proportionally the amount of the lift gas makes the optimum points of considering and ignoring stability more similar, and thereby causing its production loss smaller;

5. Using both GA and GQL in gas allocation optimization leads to proper results, but GQL finds a better optimum point.

Nomenclature

A_i	: Injection port size (ft^2)
B_g	: FVF of gas at injection point
D_i	: Injection depth (ft)
D_t	: Tubing depth (ft)
D_{well}	: Well depth (ft)
E	: Orifice efficiency factor (0.9)
F_1, F_2	: Asheim stability factors
g	: Acceleration of gravity (ft/s^2)
GLR	: Gas liquid ratio (SCF/STB)
ID_c	: Casing inner diameter (in)
ID_t	: Tubing inner diameter (in)
IFT	: Surface tension (dyne/cm)
J	: Productivity index (scf/s.psi)
OD_t	: Tubing outer diameter (in)
Orifice size	: Orifice size (1/64 in)
P_b	: Bubble point pressure (psi)
PI	: Productivity index (STB/day/psi)
P_R	: Reservoir pressure (psi)
p_{ti}	: Tubing flow pressure at gas injection point (psi)
P_{wh}	: Well head pressure (psi)
q_{fi}	: Flow rate of reservoir fluids at injection point (ft^3/s)
Q_g	: Injected gas (MMSCF/day)
q_{gi}	: Flow rate of lift gas at injection point (ft^3/s)
q_{lsc}	: Flow rate of liquids at standard conditions (scf/s)
Q_o	: Produced oil of each well (STB/day)
Q_t	: Total produced oil (STB/day)
T_R	: Reservoir temperature (°F)
T_{wh}	: Well head temperature
V_C	: Gas conduit volume
V_t	: Tubing volume downstream of gas injection point (ft^3)
WC	: Water cut (%)
γ_g	: Gas gravity

γ_{ginj}	: Injection gas gravity
γ_w	: Water gravity
μ_o	: Oil viscosity (cP)
ρ	: Oil gravity (API)
ρ_{fi}	: Reservoir fluid density at injection point (lbm,ft^3)
ρ_{gi}	: Lift-gas density at the injection point (lbm/ft^3)
ρ_{gsc}	: Lift-gas density at standard surface conditions (lbm/scf)

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