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Optimizing and Stabilizing the Gas Lift Operation by Controlling the Lift Gas Specific Gravity

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ABSTRACT

One of the factors which affects the gas lift performance is specific gravity of a lift gas (or the Molecular weight), which can influence the gas solubility in oil and has a direct effect on the gas lift performance. There are some previous researches which have included the lift gas specific gravity in their modeling, but in none of them, a comprehensive research about the effect of lift gas specific gravity in gas allocation optimization, gas lift stability, economic factors, and some other aspects of gas lift is done. This research, concentrating on lift gas specific gravity, introduces an easy and inexpensive method for increasing the oil production in gas lifted wells. In addition, the effect of injection gas specific gravity in some phenomena such as the stability of the flow in a single well and in a gas allocation optimization has been studied, and an easy way to escape the unstable flow introduced. Moreover, the result shows that changing the gas composition causes three different behaviors based on the range of changes. In a group of wells, changing the specific gravity of gas causes a different injection pattern, but its effect on total production is not huge. Finally, similar to the case of single wells, changing the specific gravity of a group of wells has changed the production in three regions and has its specific sensitivity to the change of the injection gas specific gravity in each region.

Keywords: Gas Lift, Molecular Weight, Gas Allocation, Optimization.

INTRODUCTION

As oil production continues, the production oil rate decreases. This reduction continues until it falls behind the economic rate. In this situation, the reservoir has enough power to send the oil to the bottom well but it is not strong enough to send it to the well-head. In this situation, the artificial lift methods should be used and one of the most common ones is the gas lift. In this method, gas is injected through the annulus to the tubing, it is solved in the oil, it decreases the oil column weight, and it facilitates the oil production [1, 2]. The amount of gas solubility in the oil depends on the pressure, temperature, and the lift gas specific gravity. A lighter gas can expand more and increase the gas fraction (in a specific point of the well). Increasing the gas fraction causes a decrease in total density of the fluid (in that section) and exposes

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the bottom hole to a lower hydrostatic pressure. Thus, the lower parts of the well are exposed to a lower pressure, and the gas section may expand, Furthermore ,this two phenomena together lead a lower fluid column weight in the well, lower inserted hydrostatic pressure, and thus an easier flow of the fluid.

Since as the injected gas molecular weight can change the other properties of the fluid [1,3,8] and flow regime [9, 10], it is needed to develop a completed model and check the effect of a specific lift gas. Specific gravity of a lift gas can be set by mixing different gases (maybe different hydrocarbon gas from different gas layers or hydrocarbon and non-hydrocarbon gas such as natural gas with nitrogen and carbon dioxide).

In this study, the specific gravity of a lift gas on different cases will be discussed and a comprehensive review of the results will be presented. First, previous studies on the gas lift are reviewed. Of course, there are different studies that have focused on the gas lift process, but, none of them has studied the effect of specific gravity of a lift gas in various aspect of gas lift. Here, previous works in the gas lift operation will be briefly discussed.

Some studies about the gas lift valves were carried out by Anon in 1944 [11]. Also, their studies could be carried out differently based on the pressure and situation of the casing and tubing. His work was continued by different researchers, and different valves were registered as invention in US patents [12-16]. In 1981, the economic aspects of the gas lift operation was studied by Kanu [17] moreover this study was continued by Clegg [18], Nishikiori [19], Martinez [20], Buitrago [21], Ghassemzadeh [22], and Abdalsadig [23].

In 1988, the instability in the gas lift operation was studied by Asheim. Instability ceases the production and causes downhole and surface damages [24]. After Asheim, his work was continued, and different aspects of it were studied by Guerrero-Sarabia and Fairuzov [25] and Larsen and Asheim [26]. In 2007, different parameters in gas lift performance was studied by Saepudin et al [28]. In addition, a numerical model for gas lift performance was developed, and this development showed the effect of different parameters including the lift gas molecular weight on it. His study about lift gas molecular weight was very brief, and different aspects of the effect of lift gas specific gravity on other operations was not considered. In 2011, the effect of lift gas composition and molecular weight on gas lift stability was studied by Maijoni and Hamouda [29]. Also, it was shown by them that the gas gravity can change the region of instability. In 2013, the gas allocation optimization among some wells has been studied by Sharma and Glemmestad [30]. In their study and several other similar studies, it was assumed that a predefined gas is available, and it is allocated between wells. Thus, its composition cannot be changed. There are other studies similar to that which have focused on the optimization process, not injection gas itself [5,31,34]. In 2015, in two different studies, the gas lift allocation among some wells was optimized by Mahdiani and Khamehchi using the genetic algorithm and Newton Raphson [6,35]. They also considered the stability criteria but did not discuss lift gas molecular weight. They assumed a fixed lift gas molecular weight and worked with that in their entire studies. In 2015, some sensitivity analyses in gas lift operation were done by Tahsin and Jaf [36]. Based on their studies, it was found out that lift gas molecular weight is one of the effective parameters in the gas lift, but it was assumed that it was fixed in entire of his study. In 2016, different types of modeling were studied by Shao et al [37,38] and their control parameters were considered. Moreover, some mathematical theories were used for his modeling, and finally reported that his model was accurate and very good in control problems. Also, the mass flow among phases was considered by them, but the effect of gas weight on this transfer and the gas lift process was not considered. In 2017, the gas lift process under different uncertainties was studied by Krishnamoorthy et al [39] studied, but unfortunately, the lift gas molecular weight was not discussed clearly and completely. In 2018, dynamic optimization in a gas lift problem was used by Santos et al [40]. Moreover, different parameters in his studies were studied, and a multi-objective optimization was done Santos et al [40], but lift gas molecular weight was not among his optimization parameters.

As can be seen, there are different papers that have studied different aspects of gas lift operation, but none of them has a complete discussion in the gas lift specific gravity. Here, as a new approach, the effect of lift gas specific gravity on the gas lift is discussed. For this purpose, the effect of lift gas specific gravity on about 100 wells is studied, and the results are categorized. In addition, the stability of the flow is discussed. Then in a network of wells, the effect of gas specific gravity on different aspects of gas allocation optimization is discussed, and the results are reported.

EXPERIMENTAL PROCEDURE

Methodology

The purpose of this paper is to study the effect of specific gravity of a lift gas on the performance of the gas lift operation. Thus, there is a need to initially create some models for the wells. In this study, a static model for predicting the gas lift performance is developed. It means that the simulation is considered in a time point, and in that for dynamic parameters, in which their value varies with time, such as the reservoir pressure, water cut, gas oil ratio, a constant value is considered. For developing these models, the data of an Iranian oil field has been used. The range of the fluid, rock, and other parameters of the reservoir are listed in Table 1. This table shows comprehensive information about the wells, but it should be considered that in the next part of this paper, in some sensitivity analyses, the range of parameters has gone beyond the defined range in Table 1. This is just to show the effect of this parameter in a wider range.

Table 1: The range of different parameters of the wells of this study.

Parameter	Maximum	Minimum
Oil gravity (°API)	34.14	23.61
Productivity Index (STB/day/psi)	2.75	1.64
Reservoir pressure (psi)	4,296.00	2,923.89
Water cut (%)	14.95	1.39
Tubing Internal diameter (in)	4.87	2.75
Well depth (ft)	10,884.70	8,365.92
Wellhead pressure (psi)	543.81	207.16
Injection depth (ft)	8,491.72	3,913.12
Lift gas gravity (-)	0.92	0.68
Casing inner diameter (in)	9.85	4.37
Tubing outer diameter (in)	5.33	2.99
Interfacial tension (dyne/cm)	64.22	50.28
Produced water specific gravity	1.12	1.00
Well head temperature (°F)	179.68	113.84
Gas gravity (-)	0.95	0.67
Gas liquid ratio (SCF/STB)	640.34	411.97
Oil viscosity (cP)	3.54	1.97
Reservoir temperature (°F)	314.75	202.89
Bubble point pressure (psi)	648.18	432.65
Tubing depth (ft)	9,319.89	6,342.96
Orifice size (1/64 in)	58	20

In addition to the data of Table 1, for developing the model, there is a need for some other parameters at different pressures and temperatures. For example, the pressure of the tubing changes from the downhole to the surface, the pressure changes as the gas is injected in the well. Thus, there is a need to calculate fluid properties with some methods. There are various methods to predict the fluid properties. The best one is to measure them experimentally, which is not applicable at all. Another method is to use the equation of states and compositional methods; compositional model is more accurate, but the problem involves lift gas composition change. Many scenarios must be included in order to take into account the effect of composition in gas lift performance, Thus it seems that using black oil model and just concentrate on molecular weight is a good method to have a good estimation.

In addition, the black oil models are fairly accurate. To show the accuracy of the black oil models in gas solubility estimation, the prediction of black oil and compositional models are compared. For that 4 gases with four compositions are assumed. These compositions are shown in Table 2.

Table 2: Oil and four assumed gas composition.

Component	Molecular Weight	Oil Composition	Gas Composition			
			Gas 1	Gas 2	Gas 3	Gas 4
N_2	28.01	0.01	0.76	0.71	0.65	0.70
CO_2	44.01	0.02	2.28	2.12	1.94	2.11
H_2S	34.08	0.00	0.08	0.07	0.06	0.07
C_1	16.04	0.93	91.36	84.62	77.44	84.47
C_2	30.07	0.12	2.04	9.26	16.95	7.40
C_3	44.10	0.27	0.81	0.75	0.68	2.77
C_4	58.12	0.87	0.42	0.39	0.36	0.39
C_5	72.05	0.78	0.25	0.23	0.21	0.23
C_6	84.00	1.48	0.25	0.23	0.21	0.23
C_7	94.11	1.65	0.21	0.20	0.18	0.20
C_8	105.06	1.82	0.18	0.17	0.15	0.17
C_9	116.50	1.97	0.16	0.15	0.14	0.15
C_{10}	128.24	2.12	0.14	0.13	0.12	0.13
C_{11}-C_{13}	151.93	6.71	0.33	0.31	0.28	0.31
C_{14}-C_{25}	233.10	22.81	0.50	0.46	0.43	0.46
C_{25}-C_{50}	435.05	33.77	0.20	0.18	0.17	0.18
C_{+50}	906.02	24.67	0.02	0.02	0.02	0.02
Specific Gravity		32.84	0.72	0.74	0.77	0.75

Then, by assuming different pressures and temperatures, the solution gas oil ratio using both compositional and black oil models and their differences are calculated. The results are shown in Table 3. In this table, the compositional model is assumed as exact, and the errors are calculated with respect to that.

Table 3: Comparison between the estimation of black oil and compositional models in solution gas oil ratio prediction.

	Gas 1	Gas 2	Gas 3	Gas 4
Max Temperature(°F)	200	200	200	200
Min Temperature (°F)	50	50	50	50
Max Pressure (°F)	4500	4500	4500	4500
Min Pressure (°F)	500	500	500	500
Number of Test Point	100	100	100	100
Max error	1.952	1.514	1.285	1.553
Min Error	-1.863	-1.122	-1.942	-1.924
Average Error	0.081	0.103	-0.038	-0.141
Average Absolute Error	1.392	0.863	1.035	0.853
Median Error	1.686	0.995	1.243	0.668

As can be seen, the average absolute error is about 1 percent which is acceptable (in comparison with other errors in a simulation), and the simulation can run with the black oil model.

In this paper, the most accurate correlations have been selected and are used to create the models, these correlations are selected based on the work of Khamehchi [1]. Table 4 lists these correlations.

In addition to PVT correlations, there is a need for a two-phase flow correlation, and all are listed in Table 4.

Table 4: The correlation that has been used in the modeling of this study.

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- Connally
Multiphase flow	Beggs and Brill
Solution gas oil ratio	Laster
Stability Criteria	Asheim
Surface Tension	Swerdloff

After selecting the correlations, the model is used to predict the flow rate. In this paper, PROSPER is used for developing the model. For, technical descriptions and how PROSPER is calculating the oil rate, its technical document [41] can be read. Gas lift is done in the well, its effect should be applied in the well (pink part). It is usually being applied by considering its effect in the gas oil ratio of the sections above the injection point.

As mentioned earlier, the models of this study are static, thus, the effect of the reservoir (SS or USS) is not included in the research. When the development of the model is completed, it is the time to see the effect of injection gas specific gravity. Thus, in the two approaches, one time the effect of injection gas specific gravity in a single well and another in a network of wells are discussed. In each approach, different cases are discussed to give generality to the work.

RESULTS AND DISCUSSION

In this part, the effect of specific gravity of a lift gas on the performance of the process is studied. First, its effect on the production oil rate in a single well is discussed. Then the study is extended by considering a network of wells.

The Effect of Lift Gas Injection Rate in a Single Well

About using PROSPER software, about 100 wells with the parameters in the range of Table 1 and the correlation of Table 2 are built. Then a sensitivity analysis is done on them for lift gas specific gravity. As the effect of the gas injection rate and the wellhead pressure is significant, in the sensitivity analysis, the effect of gas injection rate is considered, and in all of them, the wellhead pressure is assumed to be 250 psi. Afterward, the graphs of the production oil rate vs. the specific gravity of the lift gas (and considering different injection rates) are plotted. After investigating them, all 100 wells are categorized into 6 groups based on their response to the lift gas specific gravity. Figure 1 shows these categories.In Figure 1, all curves are assigned a number from 0 to 9. Each number is a representative for the amount of lift gas injection rate, 0:0, 1:1.11, 2:2.22, 3:3.33, 4:4.44, 5:5.55, 6:6.66, 7:7.77, 8:8.88, and 9 is representative for 10 MMSCF/day.

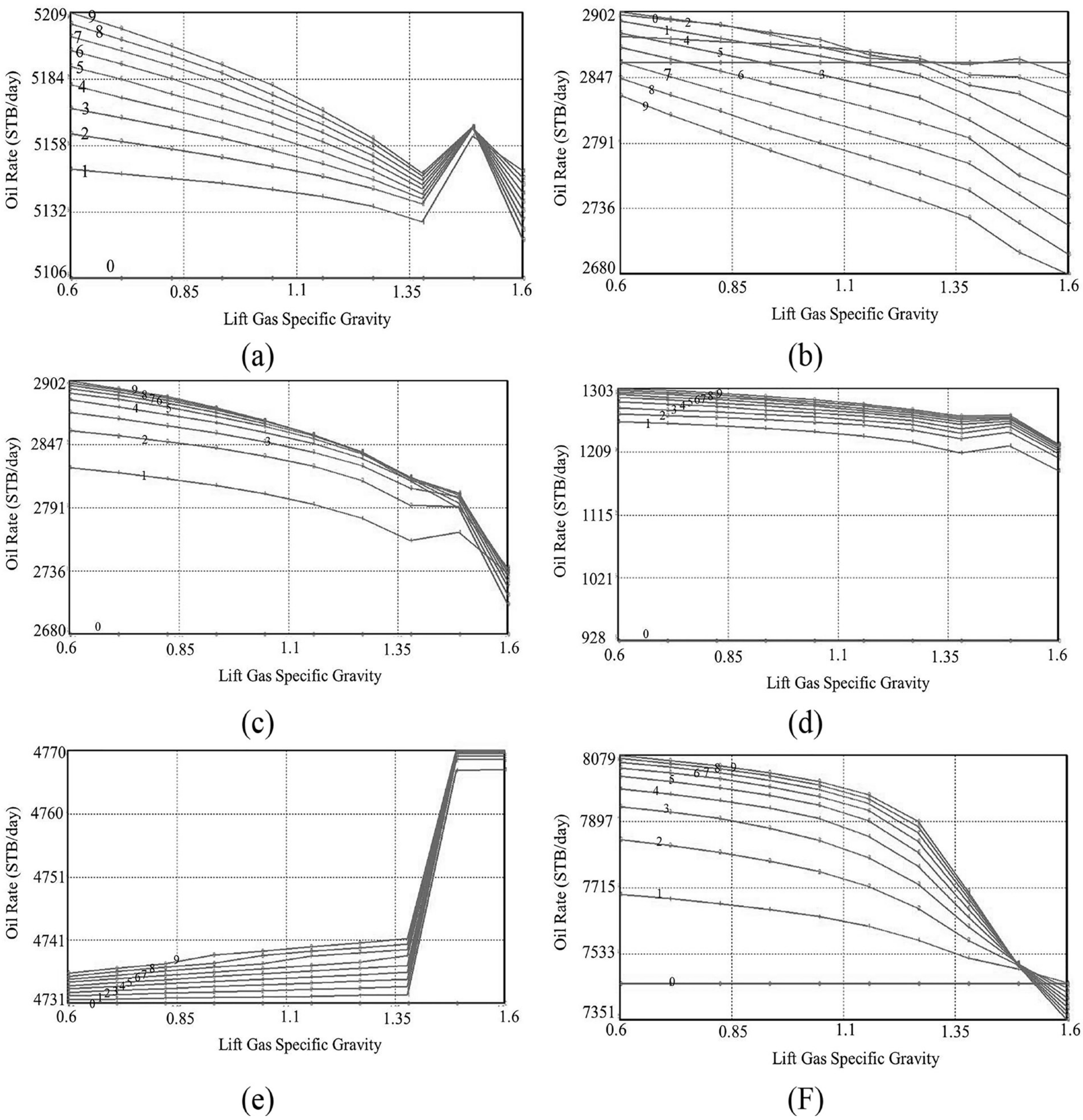

Figure 1: The effect of lift gas injection rate on the production rate of the wells, the horizontal axis shows the lift gas gravity, the vertical axis shows the production oil rate (STBD).

In testing the different wells, some wells have shown the behavior of Figure 1 (a). Gas molecular weight can have some main effects. First, as it increases, it becomes more similar to the liquid and thus can solve better and can carry more oil to the surface. Here this effect is called the solubility effect by us. Second, it affects the flow regime of the fluid flow in the pipe. The third effect is that by increasing lift gas specific weight, the total weight of the oil column increases, and thus the pressure difference decreases, and the oil production decreases; in addition, as the fourth factor, as lift gas specific gravity increases, its expandability decreases and the gas fraction in well decreases, which causes an increase in total fluid column weight.

These four factors have a positive and negative effects on the fluid flow rate. In each situation, some of these factors may have the dominant effect and thus based on that the fluid flow can increase or decrease. In the first part of Figure 1 (a), the effect of solubility is not dominant because all the covering range belongs to light gas and the solubility behavior is similar. In addition, the effect of oil column weight is dominant. Afterward, in some ranges, as the molecular weight increases, the oil rate production increases, and after that oil production decreases once more.

At first glance, Figure 1(b) seems similar to the first part of Figure 1(a). But in fact, it has a great difference with that. In Figure 1(a), as the effect of solubility decreases, the effect of weight increases and vice versa, but in Figure 1(b), something is different, generally, increase of specific gravity of the lift gas decreases the production oil rate, but the amount of this reduction depends on specific gravity of the lift gas itself. For some specific gravity, this reduction is higher and for some other it is lower, some intersections may be observed in curves because of that. This phenomenon depends on the well, fluid, and reservoir properties. Maybe if in Figure 1(a) more injection rates and more injection gas weight were tested, some equilibrium would be observed, but it was not in their applicable range. The third group of wells is shown in Figure 1(c). These groups have two main properties. First, as can be observed, the space between two adjacent curves decreases as the injection rate increases. This means that for a specific weight of the injection gas, as the injection rate increases, the amount of oil rate production increment decreases. In Figure 1(a), the main effect is the solubility in this range, but in Figure 1(c), despite the increase in the effect of solubility, the effect of gas weight is dominant, and thus only the slope of the curve decreases. And in the third part, all things go back to the previous.

Figure 1(d) is similar to Figure 1(a), but it is different from two aspects. First, the curves for different injection rates are almost parallel for each specific weight of the injected gas. This means that no matter how much the injection rate is, the behavior of the well is similar. However, in a specific weight for a higher injection rate, there is a higher oil production. The second point is that the effect of the specific weight of the injected gas is not very important because the curves in all points have a small slope.

The next graph is shown in Figure 1(e). In this figure, despite other figures in the small specific weight, the well behavior is not controlled by the specific weight of the injected gas. It is controlled by the solubility of the gas, flow regime, and maybe the liquid hold up, thus as the specific weight increases the amount of oil production increases. In fact, in this cases, changing increasing the specific gravity of the lift gas leads flow regimes, with higher holdup and lower friction, or at least the result of these forces is to increase the flow rate. Of course in this area, the effect of gas weight as the oil column weight exists, but it is not dominant. However, after a specific weight, the effect of gas weight decreases much more and a huge increase in slope is observed. Finally, the effect of gas weight affects the process and the slope of the graph decreases once more, in addition, the change of flow regime is probable too. It should be mentioned that in Figure 1, just the results of some case studies are summarized. Also, in Figure 1, the effect of lift gas specific gravity on different wells is categorized. It does not have the duty of explaining the tiny technical detail of the reasons.

The final part of Figure 1 is Figure 1(f). As can be seen in this graph, it is some kind of combination or despite the behavior of Figure 1 (b) and Figure 1(c). In the first part, it is similar to most of the previous cases, and the main effect belongs to the gas weight effect in oil column weight. By increasing the specific weight of the gas injection rate, the effect of the oil column weight increases exponentially and causes the oil rate reduction

Now, all the above cases can be put in a general case. The effect of the specific weight of the injected gas is divided into three parts based on its range. In each part, decreasing the molecular weight can increase or decrease the production oil rate. More details are shown in Figure 2.

As can be seen in this figure, the production oil rate is completely different from the condition of lighter gas when the gas specific gravity changes from 1.35 to 1.6. Of course, rarely, such as heavy gas is available for gas lift, and in this study, it was investigated to have a complete study of the effect of gas lift specific gravity. As the gas becomes heavier, its physical properties change substantially the behavior of a usual gas, and it is somehow similar to liquids, and because of that its behavior can be seen as above. Another point worth mentioning is that the specific gravity of 1.35 was just an example and based on the case it may have some changes.

It should be mentioned that the production rate has an inverse relation with pressure drop. Thus as the pressure drop increases, the oil rate decreases and vice versa. Based on the pressure drop curve, for each case, the upside down of the oil rate is plotted. In addition to the above explanation, it has been tested for different cases, and the results have been confirming that.

In Figure 2 (a), the sensitivity of a typical well oil rate to the gas lift specific gravity is shown. Also, in Figure 2 (b), the sensitivity of pressure drop in well to the gas lift specific gravity is shown.

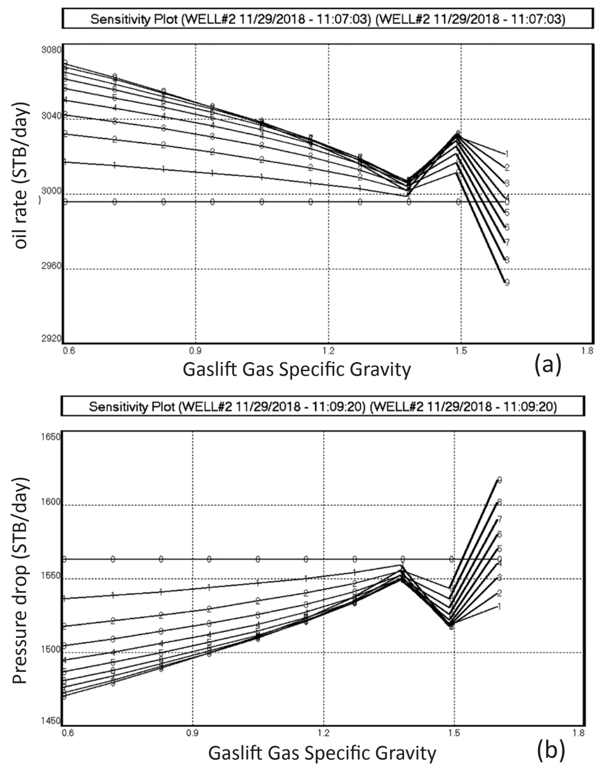

Figure 2: The sensitivity of (a) oil rate and (b) pressure drop in well to the gas lift specific gravity.

Another factor is the amount of gas solution in the oil based on different gas lift specific gravity. It is clear that as the gas lift sets heavier, its physical properties are more similar to the oil, and thus higher amount of that will be solved in the oil. The amount of gas solution in oil in each section of the reservoir is different, and because of that, the fluid mixture density in each section is different from other points.

Here, for a better understanding, the effect of increasing the gas injection rate in a typical gas lift well is studied. Figure 3 shows this behavior.

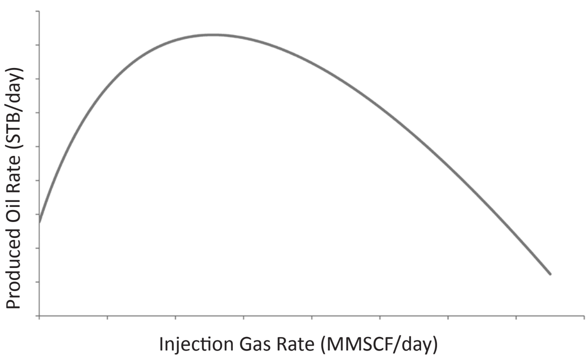

Figure 3: The effect of gas injection rate on the oil production of a typical well.

As Figure 3 shows, in the low gas injection rate, the main affecting parameter is the lift gas weight reduction. As the injection rate increases, the flow regime changes, and thus gas slips, and the liquid remains, and causes the oil rate reduction. Flow regime and gas slippage are not just dependent on the gas flow rate, but depends on gas specific gravity toot.

Now, each of the plots of Figure 1 is investigated again by considering its situation with respect to Figure 3. Figure 4 categorize different parts of Figure 3 based on the slope of the curve.

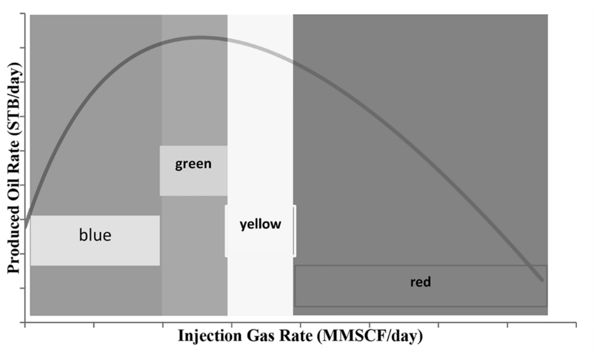

Figure 4: Different parts of the curve of production oil rate vs. the injection gas rate.

The blue part shows the region in which as the gas injection rate increases the production oil rate increases. This is because of the oil column weight reduction. In the green part, the gas injection rate still results in increase of the production oil rate. But its slope is slight. This is because of the effect of the flow regime and friction. In the yellow part, the effect of friction increases a little and decreases the production oil rate as the gas injection rate increases. And the red part is the continuation of the yellow part, the friction factor is much higher and thus the production reduction has a higher slope. Some of the behavior of Figure 1 will can be explained with respect to Figure 4. The specific weight of the injection gas can change the shape of Figure 4. Thus, maybe it will be in the yellow part of Figure 4. However, as the specific gravity and the shape of the curve changes, the current location will be on the green or even the blue part of the new curve. Thus, until now, by increasing the injection rate, the oil rate increases but after a point injecting more gas reduces the production oil rate. Thus, the behavior of Figure 1(f) and other behaviors of the figures after the intersection point can be explained.

Considering the Effect of the Specific Gravity of Injected Gas on Stability

Instability is a phenomenon that sometimes occurs in the gas lift process. It reduces the oil rate and shuts off the well. In addition, it causes high vibration that damages the downhole and surface facilities [35]. One of the most common methods to predict the instability is the Asheim [42] method. Also, two factors (F1, F2) have been introduced by Asheim, it has been proved that instability occurs if both F1 and F2 are lower than 1. PROSPER can calculate F1 and F2. Here, for two wells, the value of F1 and F2 which are calculated in which different gases with different specific gravity have been injected. In Table 5, the values of F1 and F2 when different gases are injected into these wells are shown.

Table 5: The stability parameters for different gas molecular weight for two typical wells.

Injected gas specific gravity	Well 1		Well 2	
	F1	F2	F1	F2
0.7	0.23	0.6	0.014	1
0.8	0.24	0.55	0.013	1.04
0.9	0.24	0.58	0.013	1.08
1	0.25	0.62	0.01	1.21

As this table shows, just in the case of well 2, the value of F2 is near to 1 and determines the stability of the well by changing the specific gravity of the injected gas. In other cases, despite the changes of F1 and F2, there is not an important effect on the stability of the well. Altogether,it is necessary to investigate the effect of the specific gravity of the injected gas on F1 and F2. Figure 5 shows the changes of F1 and F2 values as the specific gravity of the injected gas changes for two wells.

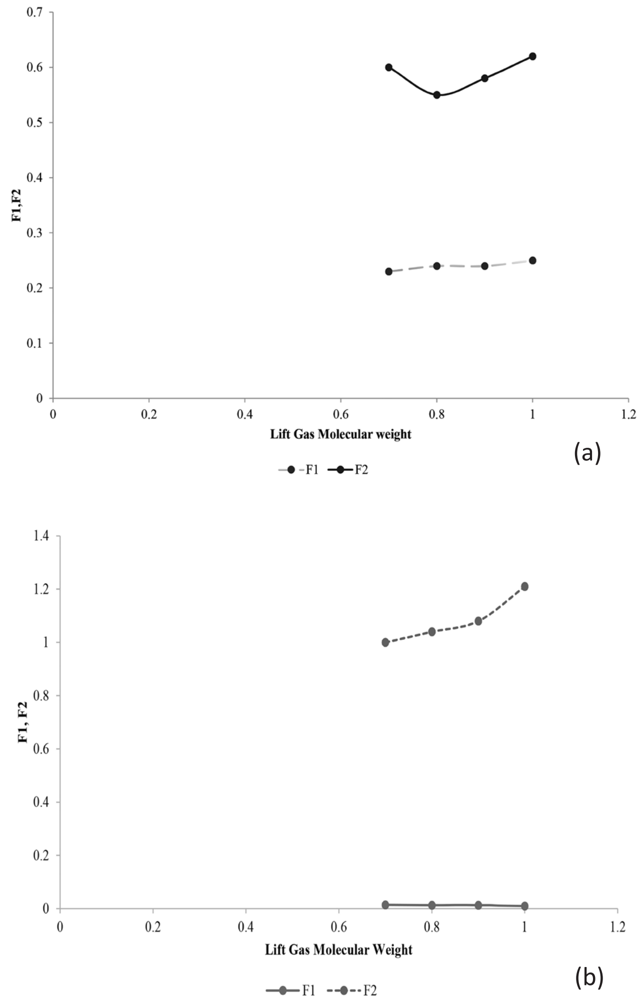

Figure 5: The variation of F1, F2 with the lift gas injection rate for two different wells.

Based on Table 3, it is shown again in a figure because the change of the parameter in the figure is much clearer but because they were in some cases very near 1, The table was needed to show the stability of the flow.

As Figure 5(a) shows, the value of F1 in some parts is ascending and descending in other parts, but in Figure 5(b), F1 is ascending in its entire range. Thus, predicting its behavior is not as easy as it may seem. Moreover, F2 in both wells is descending, and its slope is different. The behavior of these two wells cannot be easily extended to all cases.

The Effect of the Specific Weight of Injected Gas on Optimum Gas Allocation

In the gas lift process, usually, there are some wells in which some amount of gas is available that should be allocated between them. The allocation should be such that it causes the maximum profit. The profit is defined as below using the following equation (Equation 1) [43,46].

$$NPV=(N_p.\,P_o + G_p.\,P_g - W_p.\,P_w).t - C_p \qquad (1)$$

NPV: Net present value, $

N_p: Production oil rate, STBD

P_o: Oil price, $/STB

G_p: Produced gas rate, MSCFD

P_g: Gas price, $/MSCF

W_p: Water production rate, STBD

P_W: Water disposal cost, $/STB

t: Time, Day

Cp: Capital cost, $

There are two types of gas allocation optimization, first with an unlimited amount of available lift gas and second with a limited amount.

Unlimited Amount of Lift Gas

When the amount of lift gas is unlimited, Equation 1 is considered separately for each well. In these cases, usually, the capital cost (the compressor) is designed based on the well performance. For a well, maybe, by increasing the amount of lift gas, oil rate increases but the amount of increase may not cause an increase in NPV (the value of cost increases more).

For studying the effect of injection gas specific gravity on NPV, the model of the wells network is needed. Thus, using GAP software, a model was developed. Figure 6 shows this model.

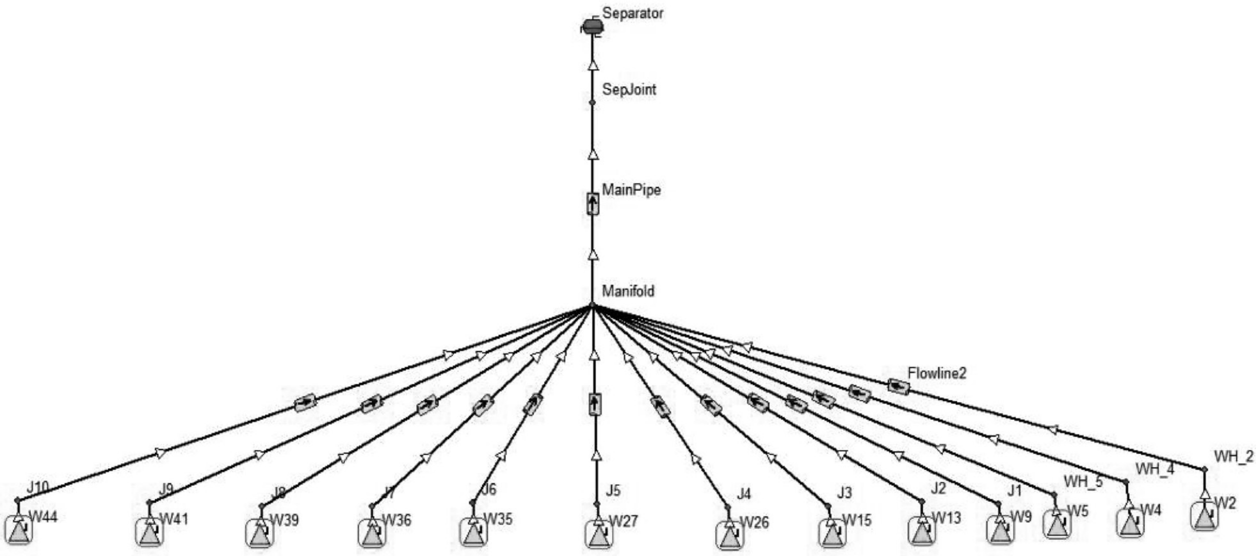

Figure 6: the network model of wells.

As Figure 6 in all the wells, similar gas is injected. Here, using the GAP software and by considering the unlimited amount of lift gas, an optimum gas lift rate for each of them is found. This optimization is done by considering the different specific gravity for injected gas. Figure 7 shows the results. In all cases of Figure 7, a wellhead pressure of 250 psi is considered, and four injection gases with specific gravities of 0.7, 0.8, 0.9, and 1 are assumed.

Figure 7 shows the production oil rate of the wells. As this figure shows, the value of the oil production of different wells when using different injection gas is similar. It should be mentioned that it is similar, not the same, of course, there is a small difference among them. Another point is that the production rate of Well 3 is zero in all cases. This means that using gas lift for this well causes more cost than the profit of the oil and gas production, thus the optimizer has decided to close it. Now, it is better to see the injection rate of the wells of the above cases. Figure 8 shows the injection rate corresponding to the production rate of Figure 7.

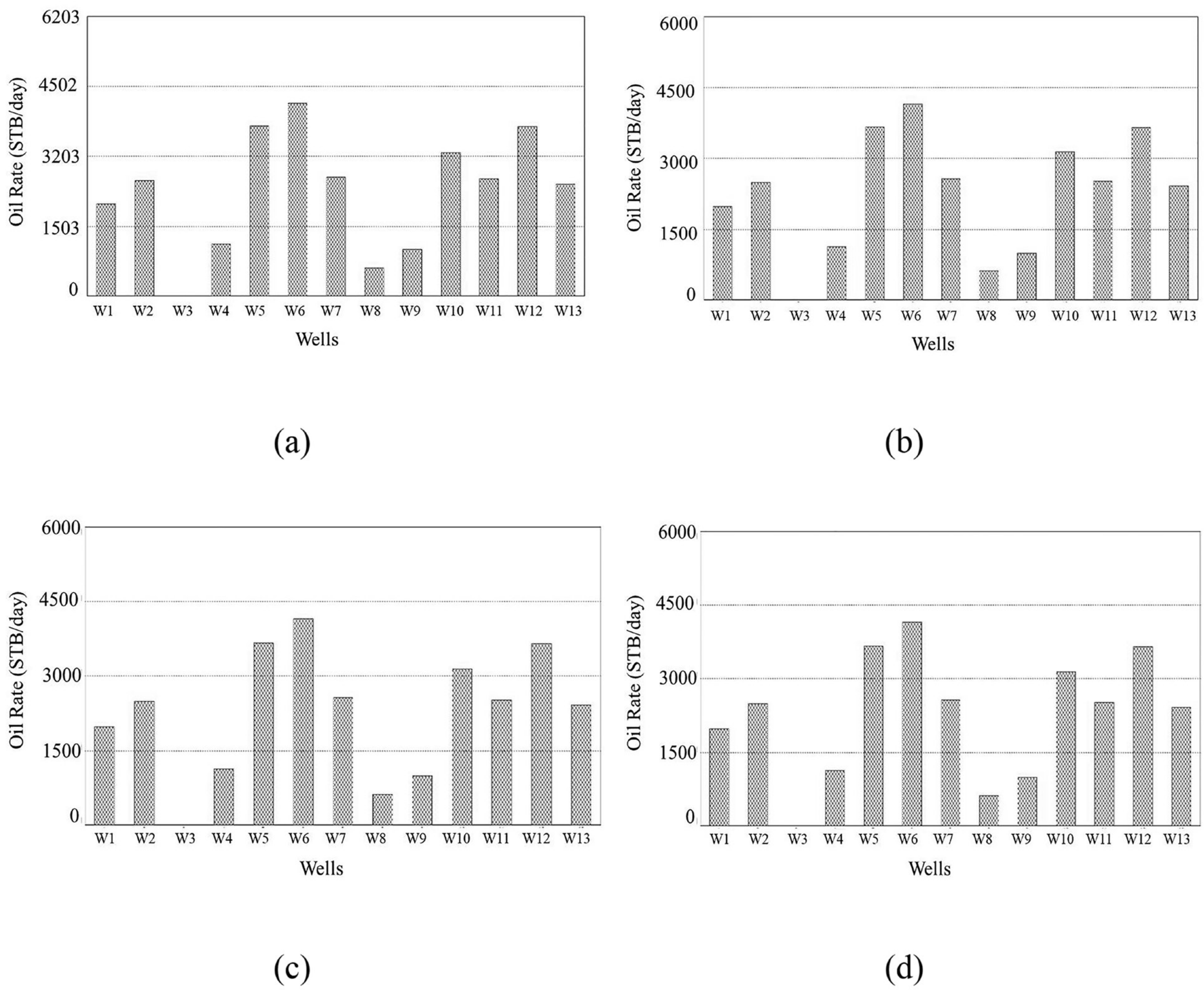

Figure 7: The oil rate of the wells when unlimited amount of lift gas is available to be allocated optimally between wells, Wellhead pressure of 250 psi (a) lift gas specific gravity of 0.7, (b) lift gas specific gravity of 0.8, (c) lift gas specific gravity of 0.9, and (d) lift gas specific gravity of 1.

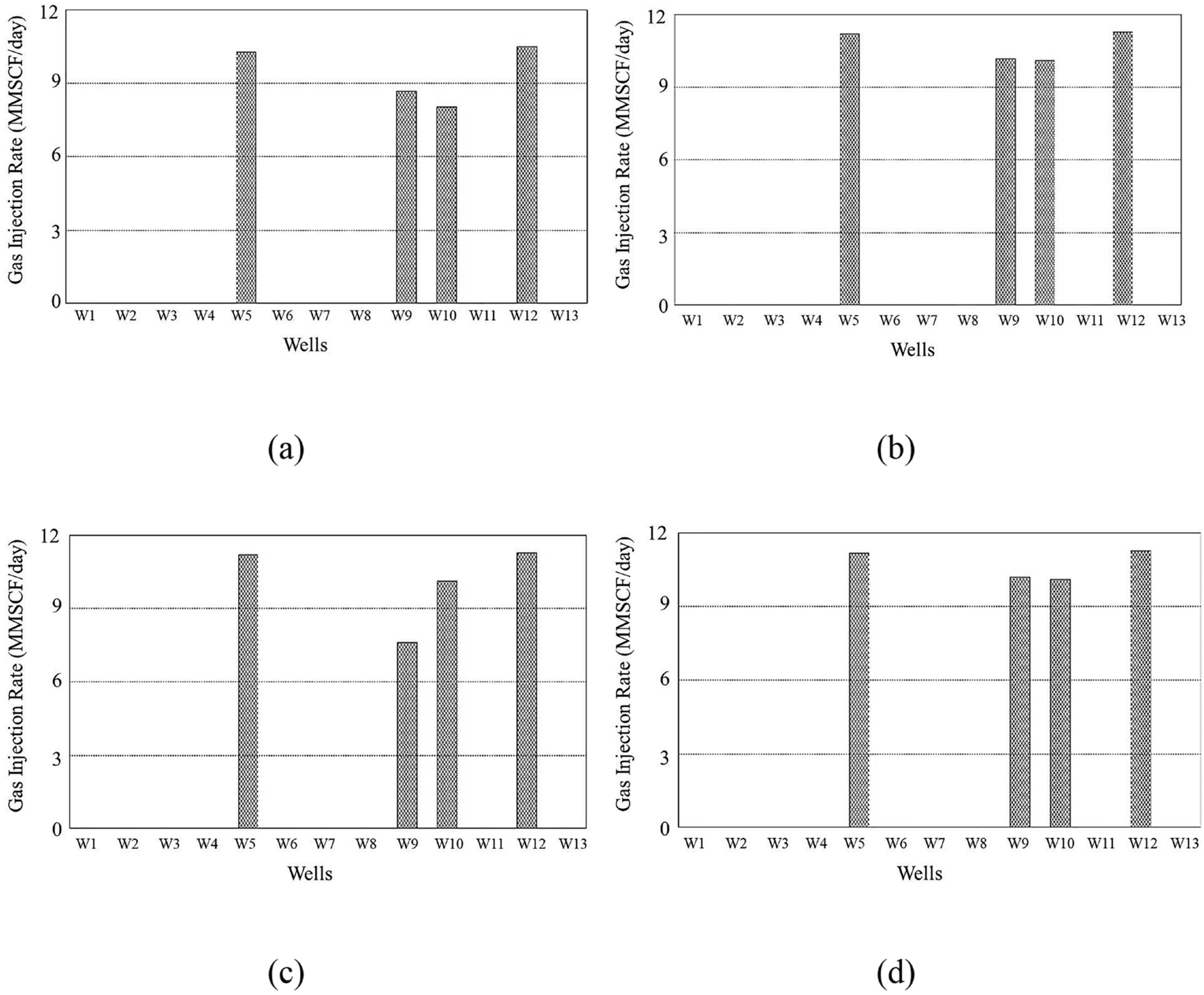

Figure 8: The optimum injection rates of the gas lift wells with the no limited total available lift gas, wellhead pressure 250 psi (a) lift gas specific gravity of 0.7, (b) lift gas specific gravity of 0.8, (c) lift gas specific gravity of 0.9, and (d) lift gas specific gravity of 1.

Figure 8 shows a very important point. It shows that even the production rate of the different wells are similar to each other, but their injection rates are different with each other. In this figure, it is clear that just for 4 wells, it was economic to use the gas lift. For others, the amount of oil and gas production has not been covering the capital cost of buying a compressor with a higher capacity.

A Limited Amount of Lift Gas

Usually, in real problems, there is not an unlimited amount of lift gas. But, there is a specific amount of lift gas that should be allocated among wells in a way that the profit is maximized [47]. Again the procedure of the previous part will be repeated for the case of the limited amount of available lift gas. For that, the available lift gas should be allocated among wells in a method that the total produced oil be maximized. Various wells respond differently to the gas lift. Thus an optimizer should be used [2,48,49]. Here the SQP (Sequential quadratic programming) is used for optimum gas allocation. This method is a numerical one, and as it is available in GAP software, it is selected for optimization of this problem.

It is assumed that the total amount of lift gas is 10 MMSCFD, and this gas is allocated among the wells of the network of Figure 6.

Figure 9 shows the oil rate production of the wells after the optimum allocation of the 10 MMSCF of gas.

As it can be seen in Figure 9 and compared with Figure 7, it can be seen that again well 3 has no production. It was possible to decrease the wellhead pressure to make it possible for well 3 to produce. But to show that in some cases there is a need to close some wells to maximize the profit, this is not done. The production rate of most wells is similar because, in the optimum gas allocation, some wells are assumed not to have the gas lift operation. To see which wells are gas lifted, Figure 9 shows the gas injected rate of optimum allocation. As can be seen, just 3 wells are gas lifted. When the amount of gas was unlimited, there were 4 wells, but as the amount of available lift gas decreased to 10 MMSCF, one well was not economic to produce any more.

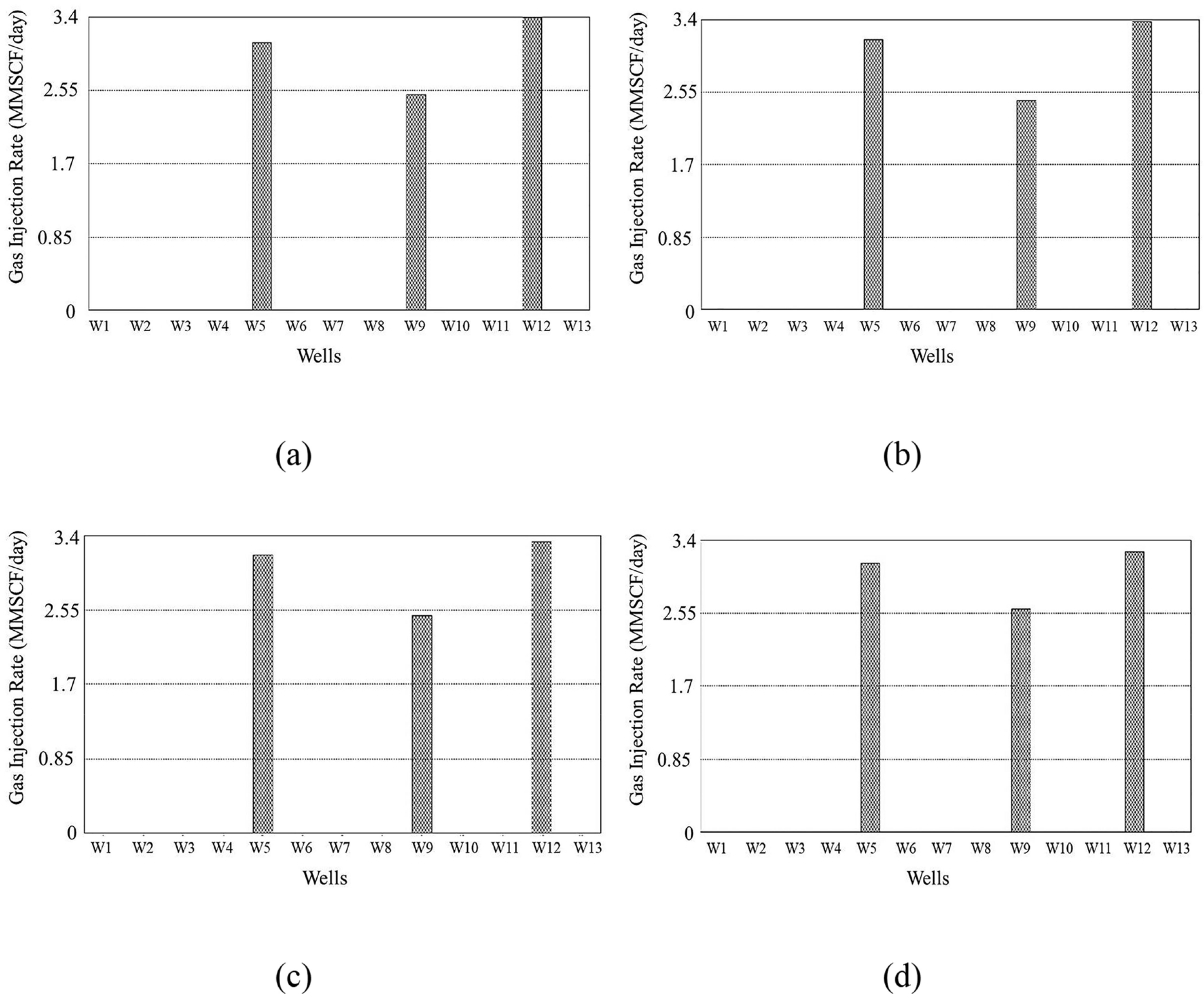

Figure 9: The optimum injection rates of the gas lift wells with the constraint of total available lift gas of 10 MMSCF (a) lift gas specific gravity of 0.7, (b) lift gas specific gravity of 0.8, (c) lift gas specific gravity of 0.9, and (d) lift gas specific gravity of 1.

In Figure 9, the first gas lifted well has a similar injection rate in all cases. Figure 9 shows a similar production rate for that well in all cases. This well was not very sensitive to the gas injection rate. This is probably similar to Figure 1 (d). The second gas lifted well has a small change in gas injection rate and also a small change in production oil rate. This is similar in the third well. As can be seen, as the amount of available lift gas has decreased, the sensitivity of the wells to the specific gravity of the injected gas decreases. This is because the range of the possible change of the gas injection rate decreases. Therefore, the sensitivity to the specific gravity is dependent on the injection rate. The final question is what the change of the total production is as the lift gas specific gravity changes. Figure 10 answers this question.

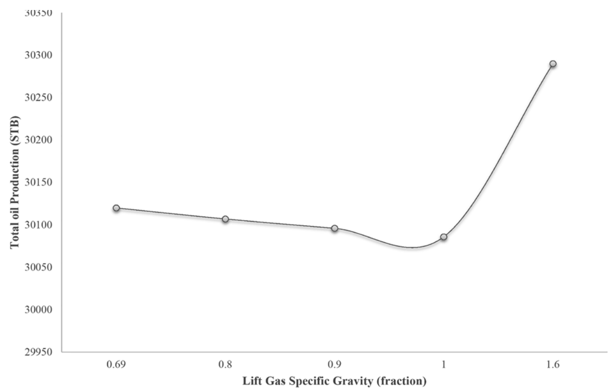

Figure 10: Total oil production based on the lift gas molecular weight.

This figure (Figure 10) is similar to Figure 4. It consists of three parts in which each has its specific slope. The reason for changing this slope backs to the competition between the friction force and the oil column weight. In each period, the effect of one is dominant, and thus the slope is different.

CONCLUSIONS

- The optimum allocation is very sensitive to lift gas gravity, thus if the specific gravity of the lift gas changes, it can cause the optimum gas allocation changes, and if ignored, a huge loss in profit occurs.
- Changing the specific gravity of the lift gas causes an inconsistent behavior of the stability factors (F1, F2) in different cases and does not follow a specific trend. Therefore, changing the specific gravity of the lift gas can easily cause instability in the flow, and this should be checked before changing that.
- In low lift gas injection rate, the specific gravity of the lift gas has a dominant effect on oil production, but as the injection rate increases, its effect reduces.

NOMENCLATURES

NPV	: Net present value
SQP	: Sequential quadratic programming

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