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# GAS LIFT OPTIMIZATION: USING A NIGER DELTA FIELD AS CASE STUDY

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**Abstract**

Gas lift is a method used on maximizing oil production when there is a decline in production of a given oil field. It practically involves the injection of gas at a very high pressure into the tubing string so that the weight of the fluid column will be lightened and oil can flow freely to the surface. The method used in this work, to optimize oil production rate, is known as multi-objective gas-lift optimization, where different methods of gas-lift optimization are applied on 21 producing wells in the same field in Niger Delta. This project work developed gas lift injection (GLINC) optimization method which allocated less Lift-gas than the existing methods. However, it is more efficient and capable of generating for wells where flow interactions is through a common flow lines. Also, Lift-gas rate oscillation of individual well can be mitigated using developed method.

***Keywords:*** n-Heptane reforming; Impregnation; CVD, Pt-Re-Sn/$Al_2O_3$ catalyst; Dispersion.

## 1. Introduction

Gas lift optimization is a process by which incremental production is generated and operating expenses are reduced. The process basically involves: the injection of gas at a very high pressure into the gas lift valve in the well, lifting the well from a single point of injection and injecting the optional amount of gas for the given production based on individual well performance. It is imperative to note that in mature oil field operations, hydrocarbon production often assisted by continuous lift-gas injection are constrained by the gas –handling and/or liquid –handling capacities of surface facilities. Optimal allocation of production and lift-gas rates are subject to reservoir deliverability and surface facility capacities.

However, real-time production optimization and optimal rate allocation in long–term reservoir simulation have been a serious challenge to engineers. Determining rate-allocation optimizers which must be highly efficient and have a minimal impact on simulation convergence while generating quality results is a difficult task. Fang and Lo [1] proposed a linear programming technique to allocate lift-gas rates and production streams subject to multiple flow-rate constraints. This method was implemented in a reservoir simulator and was demonstrated to be efficient in several field studies. Unfortunately, the surface facilities consideration was completely ignored. Hepguler *et al.* [2] works coupled a separate commercial surface pipeline network (SPN) optimizer with a commercial reservoir simulator through iterative procedure. The surface network optimizer used a sequential quadratic programming (SQP) optimization algorithm to perform general operation and design optimization. Thus, the optimization approach is more efficient when applied in several field studies.

Wang *et al.* [3] developed a procedure to optimally allocate the production rate, lift-gas rate and well connections to surface pipeline systems simultaneously. In this case, all the essential variables are involved and thus, it proved to be the best approach but it is very complex. David and Becker [4] research study considered integrating surface facility and reservoir model such that the rate-allocation problem is solved in the facility model with sequential quadratic programming methods and presented detail procedure on how unfeasible conditions would be handled with the aim of minimizing complexity characterized Wang *et al.* [3] approach.

Similarly, Kosmis *et al.* [5] developed a mixed-integer non-linear optimization formulation basically to address gas-lift optimization problems due to flow interactions through common flow lines. The resulting model is solved by a variation of the sequential linear programming (SLP) method. Ray and Sarker [6] study applied multi-objective evolutionary approach purposely to eliminate the need of solving gas-lift optimization problems on a daily basis while maintaining the quality of solution.

Out of all gas optimization methods developed so far, Fang and Lo [1] method is most simple in application but the least efficient approach. The inefficiency of this method can be traced to the fact that, apart from surface facility that was not considered, it ignores the pressure interactions among wells through common flow lines, thus, in some cases cause unrealistic result. Also, some research studies, (Hepguer *et al.* [2]; Davidson and Beckner [4]; Kosmis *et al.* [5]) relied on powerful non-linear optimization tools which serve as a constraint to the efficient use of Fang and Lo [1] method.

In this research study, multi-objective optimization method is developed. In this case, all the short-comings of previous researchers are adequately catered for and however, the impact of lift-gas rate oscillations on simulation convergence which has never been considered previously is given adequate consideration using a Niger Delta oil field as a case study.

## 2. Methodology

### 2.1. Gas Lift optimization procedure

The gas lift optimization method developed in this study takes into account, apart from lift-gas rate oscillations, flow interaction among wells through common surface pipelines. The procedure adapted is described as follows:

(i) Start with existing lift-gas rates for all wells on automatic lift-gas allocation. Solve the multiphase flow problem in the surface pipeline network (SPN). Build a linear programming model to scale down production and lift-gas rates to satisfy flow rate and/or velocity constraints. The objective function value obtained in this step is denoted as $f^o$.

(ii) Select a well $i$ on automatic lift-gas rate allocation, denote its lift-gas rate at this stage as $q_{\lg i}$ and Increase its lift-gas rate by $\partial q_{\lg i}$. Solve the multi-phase flow problem in the SPN with the updated scale production and lift-gas rates to satisfy the flow rate constraints. The value of the objective function obtained in this step is $f^1$.

(iii) Compute the lift-gas efficiency for well *i* using

$$e = \frac{f^1 - f^0}{\partial q_{\lg i}} \qquad (1)$$

If $e \geq e_{\min}$ where $e_{\min}$ is the user specified minimum lift-gas efficiency coefficient, update $f^o$ by setting

$$f^o = f^i \qquad (2)$$

Then, go to step (vi) with the increased lift-gas rate for well $i$.

if $0 \leq e \leq e_{\min}$, Re-set the lift-gas rate of well $i$ to $\partial q_{\lg i}$ i and go to step (iv).

(iv) Decrease the lift-gas rate of well $i$ by $\partial q_{\lg i}$ where $\partial q_{\lg i} \geq 0$. Solve the multi-phase flow problem in the SPN with the updated lift-gas rates. Optimally scale the production rates and lift-gas rates to satisfy flow-rate constraints. The value of objective function in this step is denoted $f^2$.

(v) Compute the gas-lift efficiency for well i with the equation given as

$$e = \frac{f^2 - f^0}{\partial q_{\lg i}} \qquad (3)$$

If $e \geq e_{\min}$, update $f^o$ by setting $f^0 - f^2$ and go to step (vi) with the decreased lift-gas rate well $i$ otherwise, reset the lift-gas rate of well $i$ to $q_{\lg i}$.

(vi) Repeat step (ii) through (v) for every well on automatic lift-gas allocation.

(vii) Repeat step (ii) through (vi) until no lift-gas rate change can be made or the maximum number of iterations allowed is reached

## 2.2. Constraints

For a set of lift-gas rate $\vec{q}_{1g,}$ the corresponding production rates $(\vec{q}_{0,} \vec{q}_{w,} \text{ and } \vec{q}_g)$ may exceed the flow rate and/or velocity constraints and not be feasible. The overall gas-lift optimization method used a linear programming model developed by Fang and Lo *et al.* [1] to scale the unfeasible lift-gas and pro-duction rates to the feasible region. This linear programming model takes a set of flow streams (either from production wells or from satellite reservoir) as the input and scale them to meet flow-rate and velo-city constraints in a way that maximizes the objective function. A flow stream is represented by the un-constrained oil, water, formation-gas and lift-gas rates of a well or a satellite reservoir. For example, to maximize the total oil rate of a field subject to a total-gas-rate constraint, the problem can be formulated as:

Maximize $\sum_{i=1}^{nw} \bar{x}i \mathrm{q}_{0,\mathrm{i}}$ (4)

Subject to $\sum_{i=1}^{nw} xi\,(\mathrm{q}_{\mathrm{g,i}} + \mathrm{q}_{1\mathrm{g,i}}) \leq Q_g{}'$ (5)

$0 \leq \bar{x}i \leq 1,\ \mathrm{i} = 1, \quad - \ - \ - \mathrm{n_w}$ (6)

where $n_w$ is the number of flow streams, $\vec{x}_i$ denotes the decision variables for this problem, $Q_g$ is the total gas-flow-rate capacity of the field and $q_{0,i}$, $q_{g,i}$ and $q_{1g,i}$ are the oil, formation-gas and lift-gas rates for well i respectively. In the optimal solution, $x_1$ = o indicates that well i should be shut in, $x_1$ = 1 indicate that well i should produce at rates $q_{o,i}$ and $q_{1gi}$ and xi E(0,1) indicates that well i should be choked back.

In this formulation, all the flow-rate constraints of the gas-lift optimization are satisfied. The optimal objective function value of equations 4-6 are regarded as the objective function value corresponding to a set of lift-gas rate specified in steps I, ii and/or iv of the overall gas-lift optimization method.

The results generated by the new gas-lift optimization procedure will be sub-optimal because of the following two facts:

- The function evaluation procedure employed in the overall optimization algorithm. As a result, the function value obtained from this procedure is only an approximation.
- The new method is a local search method and may get stuck at a local sub-optimal point. In several case studies, it was demonstrated that the new method produces quality results for long-term reservoir development studies.

Minimum gas lift efficiency threshold, ($e_{\min}$) is a parameter used to control how easily a lift-gas rate can escape from its current value. if $e_{\min}$ is large, the lift-gas rate is not sensitive to small changes in reservoir and operation conditions. Consequently, the result will be less near the true optimum, but there will be a lesser simulation convergence problem from lift-gas rate oscillations.

Conversely, if $e_{\min}$ is small, the allocated lift-gas rates will be more noisy, but the solution will be close to true optimum.

## 3. Lift Gas rate damping

For constrained gas-lift optimization problems, there may exist case in which multiple vastly different lift-gas distributions result in similar total oil rate increases. For such cases, although moving from the current gas-lift injection scenario to another gas-lift injection scenario may increase the total oil production by only a small amount, the resulting production rates for individual wells can be significantly different, making simulation convergence difficult to achieve. When gas-lift injection scenarios oscillate frequently in different Newton iterations, the computational efficiency of the simulation run deteriorates significantly. Using the GLINC method, this problem can be mitigated by use of a large value of $e_{min.}$

For the separable programming (SP) method, a different strategy was used. This strategy procedure is described below:

To minimize the impact of lift-gas oscillation on simulation convergence, the gas-lift optimization problem was re-formulated as a multi-objective optimization problem (Miettinen [7]) with two competing objectives.

- Maximize the total oil production rate subject to the flow rate and velocity constraints. This objective expressed mathematically as:

$$f^1 = \sum_{i=1}^{nw} q_{o,i} \tag{7}$$

- Minimize the absolute change of lift-gas rates between two consecutive Newton iteration subject to the flow rate and velocity constraints. This objective expressed mathematically as:

$$f = \sum_{i=1}^{nw} /q_{1g,i} - q^{o}_{1g,i1}, \tag{8}$$

where $q^{o}_{1g,i}$ is the lift-gas rate of well I allocated in the previous iteration and $q_{1g,i}$ is the lift-gas of well i to be allocated in the current Newton iteration.

The multi-objective optimization problem was solved by hierarchical optimization method (Azarm [8] and Wang [3]). This method allows the decision maker to rank and optimize the objectives in descending order of importance. For this particular gas-lift optimization problem, the first objective $f^1$ is the most importance and the second objective $f^2$ is the least important. The decision variable of the optimization problem is $\vec{x}$. The flow rate and velocity constraints are:

$$C_t(\vec{x}) \le 0, i = 1, \quad - \ - \ - \ -, m \tag{9}$$

## 3. Method of solution

The solution procedure for the multi-objective optimization problem is described as follow:

- Find the optimum point $\vec{x}^{1^*}$ x for the first objective, $f^1$ subject to the original set of constraints:

Maximize $f^1(\vec{x}),$ (10)

Subject to $C_t(\vec{x}) \le 0, i = 1$ - -,m (11)

As in Fang and Lo [1] and Wang [3], this problem was re-formulated and solved as a linear programming problem.

Let $f^1(\vec{x}^{1,*})$ denote the optimal value of the objective function of equation 10.

(ii) Find the optimum point $\vec{x}^{2,*}$ for the second objective function $f^2$ subject to the original and an additional constraint.

Minimize $f^2(\vec{x})$, (12)

Subject to $(i(\vec{x}) \le 0, i = 1$ - -,m (13)

$$f^1(\bar{x}) \geq (1-\alpha)\, f^{1,*}(\vec{x}^{1,*}) \tag{14}$$

where $\propto \mathrm{E}(0,1)$ is the damping factor, if $\propto$ equal 0, the solution is $\bar{x}^{1,*}$, and there is no lift-gas rate damping. If $\propto$ = 1, the solution will be the lift-gas rates of the previous Newton iteration, $q^{o}_{g,i}$ by adjusting the damping factor between o and 1 the competition between maximizing the total oil production, $f^1$ and minimizing the discrepancy of lift-gas rates between two consecutive Newton iterations, $f^2$ can be balanced, with appropriate reformations [9].

### 3.1. Field application of developed gas lift optimization techniques

The GLINC gas-lift optimization method and the lift-gas damping methods were applied successfully to the full-field long-term development studies of a Niger Delta Oil Field used as a case study. These applications demonstrate the advantages and shortcomings of the developed methods.

Data Used:

| | | | |
|---|---|---|---|
| Perforation depth (ft) | 4000 | Separator pressure (PSI) | 350 |
| Injection valve (ft) | 3000 | Oil gravity (deg API) | 30 |
| Tubing OD (in) | 4.0 | Gas gravity | 0.75 |
| Reservoir pressure (PST) | 2000 | Initial $e_{min}$ | 50STB/MSCF |
| Water cut (%) | 0 | Lift-gas rates | 500MSCF/D |
| Flow line length (ft) | 4 | No. of wells | 21 |

### 3.2. Application procedures

A full field model was developed to study the long-term development plan of a North Sea Oil Field. The model contains 21 production wells, with all but one production well on automatic lift-gas allocation. These wells are tied to processing center through a surface pipeline network (SPN) system. The production system is organized in such a way that the production wells are divided into two groups.

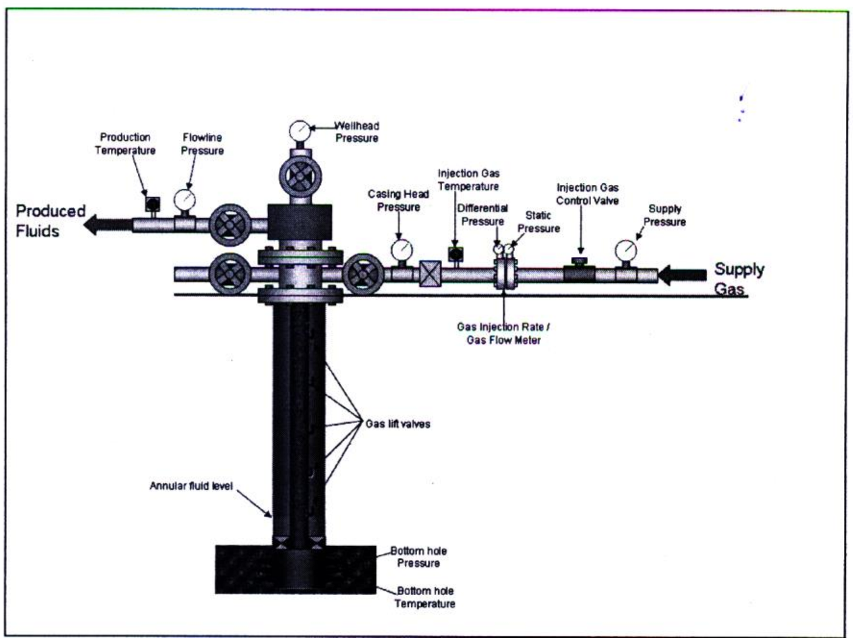


Fig. 4.1. Gas lift system data elements

Wells within each group share at least one common flow line. As a consequence of the SPN, the production rates of some wells interfere with each other through the common flow lines.

The goal of this field study is to investigate the appropriate surface facility capacities of the field and their input on long-term production profiles. Total lift-gas injection rates, as well as total oil, gas, water and liquid flow rates constraints, is specified on the model. The optimal allocation of lift-gas rates and production rates from simulation is crucial to identify the optimal facility capacities and corresponding rates profiles. The full-field model was first run with the SP rate allocation method. The minimum gas-lift efficiency was specified as 50STB/MSCF. The separable programming (SP) method builds the inflow and gas-lift performance curves by isolating a well from the SPN and assumes that the resulting performance curves represent the performance of the well on the entire production system. However, this assumption does not hold for this model because some wells have noticeable interference through common flow lines. This is shown in fig. 4.2, where the oil rate of well A1 from the gas-lift optimization on the first Newton iteration was far from the gas-lift performance curve built for that optimization. This leads to a subsequent iteration that corresponds to the gas-lift performance curve built for the SP gas optimization.

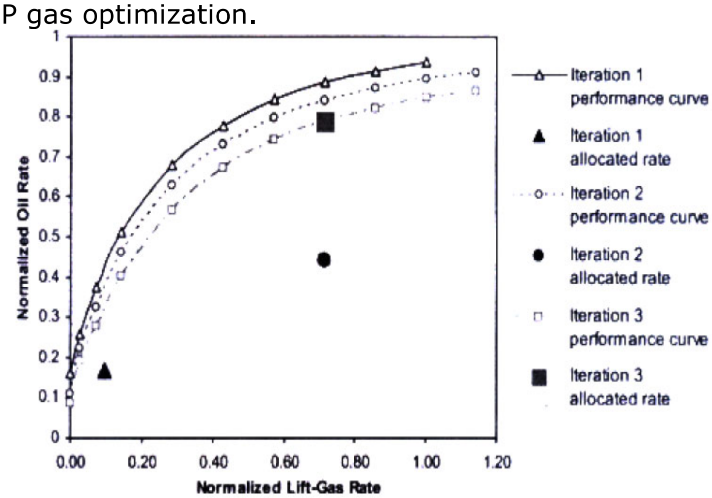


Figure 4.2.Gas Lift Performance curves and the allocated lift-gas and oil rates for well A1 at first three Newton iterations of the first time step. The oil rate and lift-gas rates are normalized

To assess the performance of the SP method, the GLINC method was used to allocate lift-gas and production rates for the same production objectives. In this case, $e_{min}$ was set to 10STB/MSCF at the beginning of the run. This was done to ensure that the optimization did not get stuck at a point far from the optimal lift-gas rates. After the first time step, $e_{min}$ was set to bigger value of 50STB/MSCF so that the lift-gas rates change less frequently and the simulator runs faster. $\delta q_{1g,i}$, was fixed at 500MSCF/D, the maximum number of iteration allowed in the GLINC method was set to 12.

## 4. Results and discussion

The results from four different rate-allocation methods are shown in Fig.4.3. Although the cumulative oil productions from the four optimization methods almost the same as shown in Fig.4.2, the daily field lift-gas injection volumes from the four methods are significantly different as shown in Fig.4.4. The SP and GLINC methods allocated significantly less lift-gas than GA and COBYLA methods. Fig. 4.5, 4.6 and 4.7 compared the lift-gas rate, oil rate and gas/oil ratio (GOR) allocated by the four optimization methods. The lift-gas rates allocated by the four methods follow roughly the same trend. Although the absolute lift-gas rate differences between them are significant, oil rates and GOR are similar for a gas lifted well, gas lift efficiency decreases to a small value. In actual Field operations, the Well will be operated with Lift-gas rates similar to those obtained from the GLNIC method which are considered to be the optimal in this study. Similarly, the efficiencies of the four optimization methods were also compared and the result is shown in Table 1. It is shown that runs with the SP and GLNIC methods required significantly less CPU time on both well management and overall simulation than the runs with the GA and COBYLA methods required.

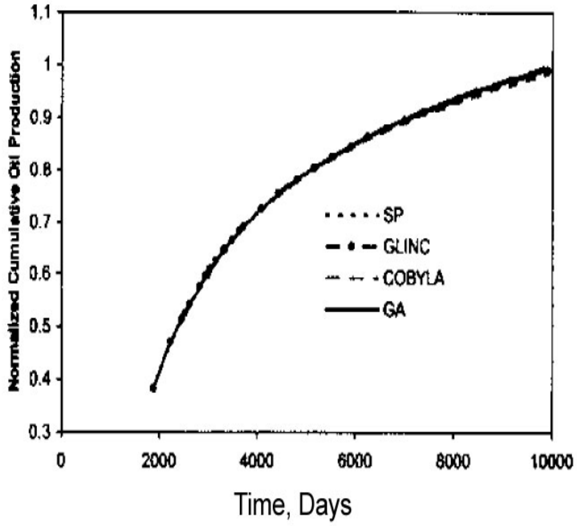


Figure 4.3. Field Example1- Normalized field Cumulative Oil Production allocated by the Four rate-allocation method

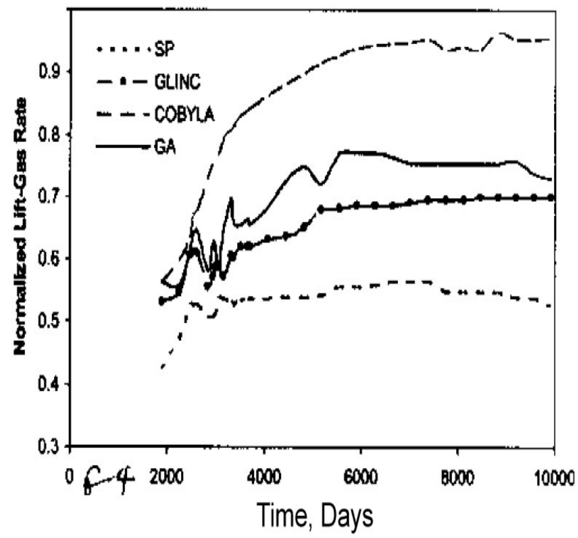


Figure 4.4. Field Example 1- Normalized field daily lift- gas rates allocated by the four rate-allocation method

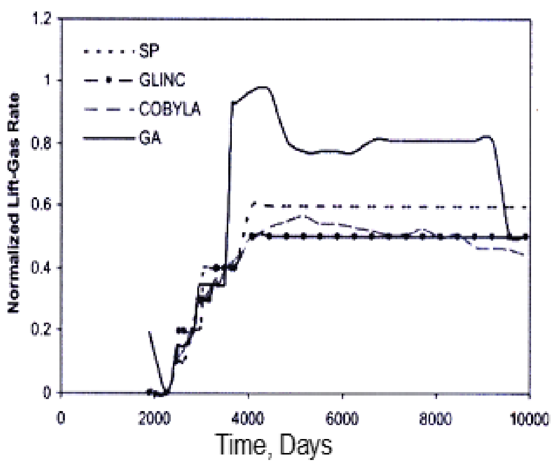


Fig. 4.5. Field example1. Normalized lift gas rate for well A2 allocated by four rate-allocation methods

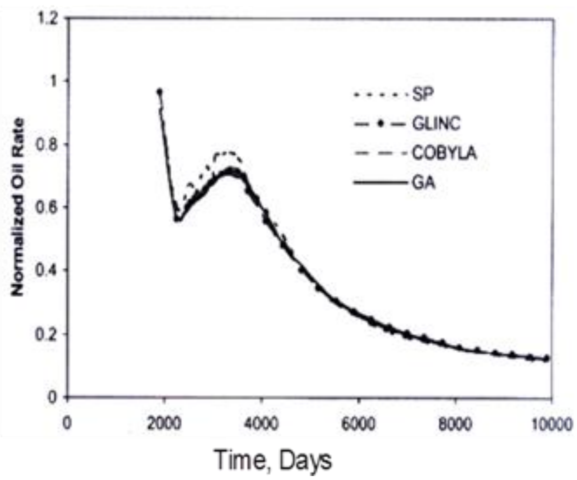


Fig. 4.6. Field example1. Normalized oil rate for well A2 allocated by four rate-allocation methods

Table 1. Performance statistic for simulation runs with different rate allocation method

| | SP | GLINC | GA | COBYLA |
|---|---|---|---|---|
| Number of time steps | 1,361 | 1,369 | 960 | 904 |
| Number of iterations | 4,703 | 4,522 | 5,136 | 4,562 |
| Time on well management (inmates) | 196 | 266 | 6,793 | 712 |
| Total CPU time (minutes) | 2,401 | 2,466 | 9,750 | 3,710 |

## 5. Conclusions

The field study was successful in demonstrating the benefits that can be derived from using multi-objective gas lift optimization method to enable production engineers to manage and optimize many more gas lifted wells than has been possible in the past. A variety of insights were gained from this project, these include:

1. The developed GLINC method is simple and easy to implement. Although the method is a local search method and handles the flow-rate constraints with approximations. It generates reasonable results for long-term simulation studies as verified by the SP, GA and COBYLA.
2. The SP method does not handle flow interactions through common flow lines, however, its execution in consecutive Newton iterations can mitigate this shortcoming.
3. The GLINC and SP methods have distinctive characteristics. The GLINC method is more rigorous in function evaluation. However, it does not guarantee local optimums, the SP method uses significant simplifications in its function evaluations, but if guaranteed local optimum of the reformed linear programming optimization problem.
4. It was verified by the GA and COBYLA methods that both the SP and GLINC methods are efficient and capable of generating quality results for some models with flow interactions among wells through common flow lines.
5. The new lift-gas damping method can mitigate lift-gas rate oscillations of individual wells. Significantly, reducing the excessive number of iterations caused by the lift-gas-rate oscillations thereby reducing total CPU time while yielding a reasonable results.

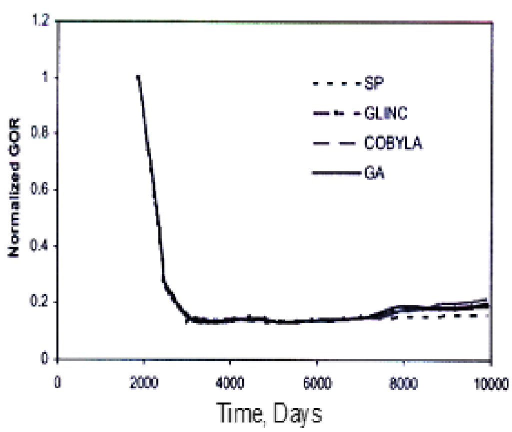


Fig. 4.7. Field example 1. Normalized GOR for well A2 allocated by four rate-allocation methods

***Nomenclature***

| | |
|---|---|
| $C_f(\vec{x}) = \pi h$ | *constraint function of decision variable $\vec{x}$* |
| $e$ | *gas lift efficiency* |
| $e_{min} =$ | *minimum gas efficiency threshold used in GLINIC methods* |
| $f =$ | *objective function* |
| $Q_g =$ | *number of constraints* |
| $n_w =$ | *number of wells* |
| $\vec{q}_{lg} =$ | *total gas-flow-rate capacity* |
| $q_{g,i} =$ | *formation-gas rate of Well $i$, Mscf/D* |
| $\vec{q}_{lg} =$ | *well lift-gas rate, Mscf/D* |
| $\vec{q}_o =$ | *well oil rate, STB/D* |
| $\vec{q}_w =$ | *well water rate, STB/D* |
| $\vec{x} =$ | *decision variable of an optimization problem* |
| $\alpha =$ | *damping factor for the lift-gas-rate-damping method* |
| $\delta\, q_{lg,i} =$ | *lift-as-rate change for Well $i$ in the GLINC gas lift optimization method* |

**References**

[1] Fang WY and Lo KK. A Generalized Well-Management Scheme for Reservoir Simulation. SPERE 1996; 11 (2): 116-120. SPE-29124-PA.
[2] Hepguler G, Barua S and Bard W. Integration of a Field Surface and Production Network With a Reservoir Simulator. SPECA, 1997; 12 (4): 88-92. SPE-38937-PA.
[3] Wang P. Development and Application of Production Optimization Techniques for Petroleum Fields. PhD Dissertation, Stanford University, 2003.
[4] Davidson JE and Beckner BL. Integrated Optimization for Rate Allocation in Reservoir Simulation. SPEREE 2003; 6 (6): 426-432 SPE-87309-PA.
[5] Kosmidis VD, Perkins JD, and Pistikopoulos EN. Optimization of Well Oil Rate Allocations in Petroleum Fields. Industrial & Engineering Chemistry Research, 2004; 43 (14): 3513-3527.
[6] Ray T and Sarker R. Multi-objective Evolutionary Approach to the Solution of Gas Lift Optimization Problems. IEEE Congress on Evolutionary Computation, 2006; 16-21 July: 3182-3188.

[7] Miettinen K. Nonlinear Multi-objective Optimization. Boston, Massachusetts, 1999, Kluwer Academic Publishers.
[8] Azarm S. Class Notes for Multi-objective Optimization, http// www.glue.umd.edu/-azarn/oplimum_notes/multi/html. Downloaded October 2002
[9] Bertsimas D and Tsitsiklis J. Introduction to Linear Optimization. Athena Scientific. 1997 Belmont, Massachusetts.
[10] Holland JH. Adaptation in Natural and Artificial Systems. Ann Arbor, Michigan1975: The University of Michigan Press.
[11] Landmark. 2003. VIP-EXECUTIVE Technical Reference. Houston: Landmark Graphics Corporation.
[12] Lo KK, Starley GP and Holden CW. Application of Linear Programming to Reservoir Development Evaluation. SPERE 1995; 10 (1): 52-58. SPE-26637-PA.
[13] Powell JMD. A direct search optimization method that models the objective and constraint functions by linear interpolation. DAMTP/NA5, Cambridge, 1992. England.

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