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A novel multi-objective estimation of distribution algorithm for solving gas lift allocation problem

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ABSTRACT

Gas lifting is a common practice in the oil industry. Using an appropriate gas lift injection rate can ensure that the desired oil production rate would be achieved. In the case of an oil field, the problem of distributing a certain amount of the available gas among a number of wells is formally known as a gas lift allocation problem. In this paper, a multi-objective optimization algorithm, based on the Gaussian Bayesian Networks and the Gaussian kernels, is proposed in order to determine the best injection points, considering multiple objective functions. Firstly, the problem is solved in a similar approach to the previous literature with similar gas lift data and similar function approximation method, to compare the performance of the proposed algorithm with the older ones. Thereafter, an extended problem is discussed, with minimizing the water production as a new optimization criterion. The developed multi-objective scheme is capable of handling and optimizing a gas-lift problem with several constraints and conflicting objectives such as controlling the gas usage and increasing the oil production, whereas in the conventional single-objective optimizations, any alteration in the constraints demands a new optimization process and often there is no place for considering an additional objective in the gas-lift allocation problem. The results obtained by the proposed optimization algorithm significantly overcame those reported in the previous similar literature. For a single-objective fifty-six well problem, the results exhibited 16.24% improvement in the total oil production.

1. Introduction

The demands for high oil production rate leads to a gas lift operation, which consists of injecting a certain amount of high-pressure gas through the tubing, and consequently, lowering the hydrostatic pressure difference along the tube. However eventually, at some points, the increase in the friction pressure loss offsets the hydrostatic pressure reduction which, in turn, limits the increase in the production rate and yields in the convexity of the gas lift performance (GLP) curve. Determining the optimum injection rates in a multiple well production network is known as the gas lift allocation problem. Many researchers have tackled this problem from different points of view by using a wide range of optimization techniques, from the quasi-Newton (Nishikiori et al., 1989) to the genetic algorithm (Martinez et al., 1994). Alarcon et al. (2002) improved the quasi-Newton optimization algorithm and offered a new mathematical model to fit the field data. Ray and Sarker (2007) challenged the problem as a bi-objective problem through maximizing the oil production level and minimizing the gas usage rate as the optimization criteria. They suggested a variant of multi-objective genetic algorithm called, the non-dominated sorting genetic algorithm II (NSGA-II) as the optimization tool. Other approaches, such as mixed-integer programming (Kosmidis et al., 2005) and dynamic programming (Camponogara and Nakashima, 2006), explored the additional aspects of the problem, including the activation of wells and their interactions. Wang and Litvak (2008) provided a heuristic method and considered the long-term reservoir developments by incorporating a reservoir simulator.

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They also used a multi-objective scheme to reduce the rate oscillations besides maximizing the oil production. However, the nature of the local search does not even guarantee to find local solutions. Furthermore, Sukarno et al. (2009) extended the operational condition to the case of a dual gas lift system. Zerafat et al. (2009) presented a comparison of different methods to the Genetic Algorithm and examined the capabilities of the algorithms in solving the uni-objective gas-lift optimization problem with the constraints on the lift-gas injection rates. They also proposed a variant of Ant Colony Optimization to deal with the problem. It can be witnessed that with the exception of two cases (Ray and Sarker, 2007; Wang and Litvak, 2008), the literature has chiefly focused on the single objective optimization of the gas lift problem.

In this study, it is aimed to confront the problem as a multi-objective problem and expand the idea of multiple criteria optimization, since the presence of constraints in the real gas-lift problems is an inevitable fact. In the conventional single objective approach, for every update in the constraints, the process of gas lift allocation problem should be re-solved. For example, if the amount of the available gas or the capacity of compressors changes, a new solution is needed by the single objective approach. On the other hand, the multi-objective approach provides a set of solutions for different criteria, which makes it easier to compare several production strategies altogether. In a multi-objective approach, it is possible to simultaneously handle several conflicting objectives in the optimization process.

For instance, by a multi-objective method, it is likely to optimize the total oil production rate and minimize the number of required wells at the same time, but through a single objective method, the number of wells should be assumed as a constraint for the problem.

Hence, since it is necessary to compare different scenarios for the gas lift design, a multi-criteria optimization approach is an efficient tool for solving such a multi-dimensional problem with different constraints. The proposed optimization algorithm is an estimation of the distribution algorithm (EDA) based on the Gaussian Bayesian networks (P. Larrañaga et al., 2000) and the Gaussian kernels (Socha and Dorigo, 2008). The general idea of an EDA is to construct probabilistic models based on a set of promising solutions, and guide the search process by sampling the probabilistic models. Furthermore, in order to adjust the algorithm for solving the multi-objective problems, the concept of non-dominating sorting (Deb et al., 2002) has been employed. The obtained results from the EDA are compared with those reported by using the multi-objective genetic algorithm (Ray and Sarker, 2007) due to the evolutionary nature of both algorithms and lack of any other similar multi-objective optimization algorithm in the literature on the topic of gas lift optimization. It should be pointed out that in the field of petroleum engineering, very few works have ever employed any variant of the estimation of distribution algorithms. For instance, Abdollahzadeh et al. (2013) utilized an EDA-BOA (Bayesian Optimization Algorithm) for history matching. To the best of the authors' knowledge, there exists no study on applying any multi-objective EDA in the literature of petroleum engineering.

2. Problem statement

In order to solve the conventional gas lift allocation problem, the GLP curve for each well should be determined by using a proper fitting tool, in order to demonstrate the response of wells to various gas injection rates. As mentioned earlier, the GLP is a convex function. Hence, a quadratic function or a piece-wise polynomial function approximation – i.e., cubic spline interpolation, should be selected to maintain the convexity of the objective function.

Another technique is to use a piece-wise linear interpolation, which is easier to be used, but cannot keep the smoothness of the convex GLP curve. Generally, in such model selection problems, an adequate care should be taken in order to avoid an over-fitting of the function approximation. For example, using a high-order polynomial may seem to describe the given GLP data in a precise manner, but it amplifies the possibility of over-fitting. Besides producing a smooth convex curve, the use of a detailed and complicated model for approximation of the GLP function can be computationally expensive. Thus, it should be expected to sacrifice the accuracy of approximation of the shape of the GLP curve at the expense of computational costs.

Nevertheless, it is worth to indicate that for a fair comparison between the optimization methods, the objective functions and all the constraints and conditions should be similar; otherwise, comparing the results of an algorithm, using a quadratic objective function with an algorithm by using a piece-wise linear objective function, would be in vain. This is because of this fact that the quadratic function may overestimate the function and yield better solutions, and this does not properly demonstrate the advantage and efficiency of the optimization method.

To this end, the same GLP data (Buitrago et al., 1996) and the same function approximation method (i.e., piece-wise linear function) are applied in order to effectively compare the proposed multi-objective optimization algorithm with the other applications of the multi-objective optimization (Ray and Sarker, 2007). The optimization problem in this case is a bi-objective optimization, which maximizes the oil production rate as one criterion and minimizes the gas usage as the other one:

$$\max\ Z_1 = \sum_{i=1}^{\#of\ \ Wells} (Q_o)_i \tag{1}$$

$$\min Z_2 = \sum_{i=1}^{\#of\ \ Wells} (Q_g)_i \tag{2}$$

Therefore, instead of using a fixed constraint on the available lift-gas, a criterion function for the total gas usage is considered which, in turn, presents a bi-objective optimization problem. In this manner, rather than searching for a single optimum solution, a number of solutions will be acquired, which are all optimal. The resulting set of solutions can be used according to the availability of the injection gas. Any further criteria can be introduced in this way to create a vector of objective functions to be optimized. At the end of this study, in order to extend the idea of multi-criteria optimization and one-step advance using its advantages, a case is explored in which another criterion is added to the problem, viz. minimizing the daily water production. This extra criterion is to serve toward expanding the case of bi-objective algorithm to the three-objective optimization.

3. Optimization algorithm

An EDA in essence is a stochastic algorithm based on probabilistic models. Contrary to the other evolutionary algorithms such as Genetic Algorithm, in an EDA, the search operators such as crossover and mutation are substituted by probabilistic models. In the conventional genetic algorithm, the solutions are produced by mutating individual solutions and applying crossover to a pair of solutions (parents). In contrast, an EDA mutates