Optimization of gas injection allocation to increase oil production using Gbest-guided artificial bee colony algorithm

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Abstract. Oil comes from fossils thousands of years ago and it is natural resource that can’t be renewed. If it used continuously, the oil supplies will eventually run out. One way to optimize an oil production is by using gas lift. When the supply of the gas injection is limited, the total available gas should optimally distributed among the oil wells of the field such that the total production of oil is maximized. In this paper, Gbest-guided artificial bee colony (GABC) will became the optimization techniques while Least square is used to make the mathematical model from the correlation between gas injection and oil production. Contribution of this research is to find the fittest mathematical model and implement GABC to find the maximum value of mathematical model. The selected model is 10\textsuperscript{th} order polynomial with R-square value of 1 and Sum of squares error (SSE) is 34.091. GABC will optimize the model and it will be compared to another optimization method such as Artificial bee colony (ABC). The results are GABC is better than ABC for each case with 4812.877 barrel oil per day (Bopd), 5107.873 Bopd, and 5142.156 Bopd respectively, while the best C values in GABC is 2.

1. Introduction

Oil is a natural resource that can not be renewed and it can help human to do their work. With the increasing population on earth, the need for oil for daily needs is also increasing. If it used continuously, oil supplies will decrease and eventually run out. This is what causes researchers to always look for new ways to increase oil production, and one of them known as gas lift.

Gas lift is a method for lifting the oil by injecting gas into the well, which will cause the oil to rise to the surface so more oil production can be obtained [1]. It’s not always the more injected gas will produce more oil. The characteristics of each well differ from one another despite being in the same field [2]. Each well has their own optimum point, where the injected gas will produce more oil than the other points. The comparison curve between gas injection and oil production is called Gas Lift Performance Curve (GLPC) [3].

This paper will discuss about how to optimize oil production using Least square to find mathematical model on GLPC in each well and Gbest-guided artificial bee colony (GABC) to optimize it. The purpose of this research is to maximize oil production and minimize the gas injection. The dataset comes from previous research and synthetic data [4]. The rest of this paper are literature review (section 2), proposed method (section 3), result and analysis (section 4).
2. Literature review

The development of optimization methods in recent years is very fast. Some methods commonly used in optimization are Genetic algorithm (GA) [5], Particle swarm optimization (PSO) [6], Ant colony optimization (ACO) [7], Artificial bee colony (ABC) [8], Gbest-guided artificial bee colony (GABC) [9], Artificial neural network (ANN) [10], etc. ACO is usually used in combinatorial problem such as travelling salesman problem, while the others are used to maximize or minimize a function [7].

There have been many studies about optimization of gas injection in the case of gas lift. In 2008, Deni Saepudin et al. conducted a research about optimization of gas injection using Genetic algorithm (GA). The result of study tells that optimization with GA differs slightly from the calculation with exact. GA parameters used in that paper are total population of 100, probability crossover is 0.9, probability mutation is 0.1, and up to 500 generation formed [4]. In the same year, De La Cruz et al. conducted an optimization of gas lift using Neural network [10]. De La Cruz used sigmoid activation function in hidden layer, and linear activation function in output layer. The results are divided into 2 cases, single well and two wells case. The optimal solution in single well obtained when the iteration is 93. While the other case obtained when the iteration is 349. In this paper, De La Cruz only used 2 wells for his experiment. It means ANN can still be improved for gas lift problem.

Next in 2011, Robert N. Hatton and Ken Potter conducted the same study. This study stated that the optimal gas injection was at 40%-60% of GLPC [2]. This paper stated that high order polynomial was not good for gas lift problem [2]. Another study conducted by H. Hamedi et al. in 2011. This research used PSO with the number of particles were 10, learning rate was 1, and iteration of 90. The results are PSO got a better result compared to Sequential quadratic programming [11]. This paper proposes a new mathematical model. Even though the new mathematical model has the R-square score higher than the past model, the oil production from new model is lower than the past model [11]. In 2017, Amega Yasutra and Aris Wakhyudin conducted a study which stated that optimum conditions were achieved at the top of the curve where the gradient was zero. If the gas injected less or exceed the optimal conditions, oil production will be smaller [3]. The method used in that research is GA with a total population of 150, probability of crossover is 0.8 and probability of mutation is 0.2. In this paper, the result from GA has small differences from the result of equal slope [3].

Based on that, this paper tries to use GABC method which is the combined method between ABC and PSO.

2.1. Least square

Oil production based on gas lift techniques depends on the amount of gas injection. GLPC is a curve that represents injected gas and oil production. Every GLPC must have its own mathematical model. Least square is a method for curve fitting where the main concept is to maximize the R-square and minimize the Sum of squares error (SSE) [12]. This paper will be using Least square method to find a mathematical model from GLPC.

2.2. Gbest-guided artificial bee colony

Gbest-guided artificial bee colony (GABC) is a method that combines Artificial bee colony (ABC) and Particle swarm optimization (PSO) [9]. GABC will be divided into three main stages. First stage is to send employed bees to food source and calculate the nectar, second stage is to send onlooker bees to the most abundant food source, and the last stage is to send scouts to find a new food source and hope to find more nectar than the old ones [8]. Food source denotes the solution of the mathematical model or injected gas and the nectar denotes the oil production. According to Karaboga, onlooker bees choose the food source based on
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\[ SM_k = \frac{F F_k}{\sum_{l=1}^{JSM} F F_l} \] (1)

where \( SM_k \) is a food source to be chosen, \( F F_k \) denotes to the amount of nectar from a food source, \( k \) is an iteration when determining the food source to be selected, \( l \) is an integer of \([1, JSM]\), and \( JSM \) denotes to the number of food sources available. Next, scouts will find a new food source based on

\[ SMB_{xy} = P_{xy} + Q(P_{xy} - P_{zy}) + R(BSF_y - P_{xy}) \] (2)

where \( x \in \{1, 2, 3, ..., JEB\}, y \in \{1, 2, 3, ..., D\}, z \in \{1, 2, 3, ..., JEB\}, z \neq x, JEB \) is an amount of employed bees, \( SMB_{xy} \) is a new food source, \( P_{xy} \) is an old food source, \( Q \) denotes to the random uniform between \([-1, 1]\), \( R \) denotes to the random uniform between \([0, C]\), \( C \) is positive constant, \( BSF_y \) is a global solution. This formula tends to escape local optimum and find the optimum global.

3. Proposed method
The proposed method is divided into 3 stages. First, make GLPC for each well from the dataset. Second, create a mathematical model based on each GLPC. Third, construct the GABC algorithm and maximize the mathematical model. The design system can be seen in Figure 1

![Figure 1. Design system.](image)

Gas lift performance curve (GLPC) represent the correlation between gas injection and oil production. \( x \) axis represent the amount of gas being injected while \( y \) axis represent the oil production. An example of GLPC can be seen in Figure 2

Curve fitting is a method to create mathematical model based on a curve. In this paper, curve fitting is used in each GLPC. Based on it, an example of GLPC can be seen in Figure 2 and it resembles polynomial or exponential model. After the mathematical model is made, GABC implementation will maximize the oil production and minimize the use of gas injection based on mathematical model. The equation can be seen in 3 and 4 respectively

\[ GasInjection = \sum_{i=1}^{nWells} (X_i) \] (3)

\[ 0 \leq GasInjection \leq MaximumGas \] (4)

where \( X_i \) denotes to the gas injection in well \( i \), \( nWells \) is the number of well, \( GasInjection \) denotes to the total gas injection and \( MaximumGas \) will be the constraint of limited gas injection.
4. Result and analysis

The dataset used comes from previous research and data synthetic with a total of 10 wells [4]. Dataset containing gas injection and oil production. Oil production is a dependent variable to gas injection. So mathematical model can be formed to represent the effect of gas injection and oil production. The experiments are conducted in 3 cases to find the optimal $C$ where there is no constraint of gas injection, to find the optimal $C$ where maximum gas injected are equal or less than 7500 Thousand Standard Cubic Feet per Day (MSCFD) and to find the optimal $C$ where maximum gas injected are equal or less than 15000 MSCFD. All 3 cases will be compared to ABC algorithm.

In GABC and ABC, the upper limit for solution space for each well is set to the most gas injection from each well. It’s because in this paper interpolation least square is used while the lower limit is set to 0. The number of scout bees are set to 500, employed bees are set to 300 and it will go through 200 cycle of exploration and exploitation. One bee represents a solution for all wells.

4.1. Curve fitting

After doing curve fitting for each well, the fittest mathematical model is 10th order polynomial and can be seen in Table 1. It’s because R-square score is higher than the other order polynomial and exponential with 1, while the Sum of squares error (SSE) score is also lower than the others with 34.091.

The equation for 10th order polynomial can be seen in 5 and GLPC result after curve fitting can be seen in Figure 3

$$\text{Pred}_i = \sum_{j=0}^{\text{order}} W_{ij} X_i^{(\text{order} - j)} \quad (5)$$

where $\text{Pred}$ is predicted oil, $W$ denotes for weight, $X$ is the injected gas, $\text{order}$ denotes to the order of polynomial, $i$ denotes to well being predicted, $0 < i \leq \text{nWells}$, and $\text{nWells}$ denotes the number of wells. Weight for each well can be seen in Table 2 and 3 respectively
Table 1. Comparison of curve fitting using polynomial and exponential.

| Order   | R-square   | Sum of squares error |
|---------|------------|----------------------|
| 2nd order polynomial | $9.010 \times 10^{-1}$ | 76540.467 |
| 3rd order polynomial | $9.680 \times 10^{-1}$ | 27288.812 |
| 4th order polynomial | $9.890 \times 10^{-1}$ | 9810.498 |
| 5th order polynomial | $9.970 \times 10^{-1}$ | 3339.374 |
| 6th order polynomial | $9.989 \times 10^{-1}$ | 1135.942 |
| 7th order polynomial | $9.996 \times 10^{-1}$ | 432.043 |
| 8th order polynomial | $9.998 \times 10^{-1}$ | 186.736 |
| 9th order polynomial | $9.999 \times 10^{-1}$ | 81.058 |
| 10th order polynomial | 1 | 34.091 |
| Exponential | $4.483 \times 10^{-1}$ | 379580.500 |

Figure 3. Gas lift performance curve after curve fitting.

Table 2. Weight 0 to weight 5 for each well.

| Well | W0     | W1     | W2     | W3     | W4     | W5     |
|------|--------|--------|--------|--------|--------|--------|
| 1    | -6.448e-31 | 1.386e-26 | -1.285e-22 | 6.734e-19 | -2.198e-15 | 4.643e-12 |
| 2    | -1.336e-31 | 3.093e-27 | -3.092e-23 | 1.749e-19 | -6.166e-16 | 1.411e-12 |
| 3    | -8.357e-30 | 1.149e-25 | -6.806e-22 | 2.276e-18 | -4.740e-15 | 6.417e-12 |
| 4    | -3.703e-29 | 4.741e-25 | -2.617e-21 | 8.150e-18 | -1.576e-14 | 1.965e-11 |
| 5    | -2.658e-28 | 2.834e-24 | -1.304e-20 | 3.387e-17 | -5.475e-14 | 5.722e-11 |
| 6    | -1.4456-30 | 1.385e-26 | -4.470e-23 | 2.360e-20 | 1.971e-16 | 5.246e-13 |
| 7    | 1.445e-29 | -2.190e-25 | 1.437e-21 | -5.358e-18 | 1.247e-14 | 1.872e-11 |
| 8    | 2.601e-30 | -2.417e-26 | 6.215e-23 | 1.007e-19 | 9.301e-16 | 2.144e-12 |
| 9    | -3.431e-29 | 7.625e-26 | 9.151e-23 | -1.293e-19 | 4.240e-16 | 1.048e-13 |
| 10   | 1.898e-29 | -3.948e-26 | -5.058e-23 | 5.936e-20 | 2.135e-16 | -3.539e-14 |

The purpose of this research is to maximize $Pred_i$ so more oil can be produced and to
minimize the $X_i$ so less gas injection is used for each $i$. It can be seen in equation 6

$$Q_{\text{gas}} = \text{MAX}( \sum_{i=1}^{n\text{Wells}} Pred_i)$$

where $Q_{\text{gas}}$ denotes to sum of all oil production in each well.

4.2. Gbest-guided artificial bee colony

Results from the experiments show that the optimum oil production in each well, best C value in each case and the comparison between GABC and ABC. Optimal oil production in a day can be seen in Table 4 where maximum of 7500 MSCFD gas injection can produce 4812.877 Barrel oil per day (Bopd), while maximum 15000 MSCFD of gas injection will get about 5107.873 Bopd, and the unlimited gas injection can produce 5142.156 Bopd. The best C value for every case is 2.

| Well | $W_6$ | $W_7$ | $W_8$ | $W_9$ | $W_{10}$ |
|------|-------|-------|-------|-------|---------|
| 1    | -6.422e-09 | 5.794e-06 | $-3.000 \times 10^{-3}$ | 1.305 | 436.878 |
| 2    | -2.131e-09 | 2.139e-06 | $-1.500 \times 10^{-3}$ | 0.721 | 458.512 |
| 3    | -5.767e-09 | 3.498e-06 | $2.000 \times 10^{-3}$ | 0.459 | 174.659 |
| 4    | -1.599e-08 | 8.53e-06  | $-3.000 \times 10^{-3}$ | 0.813 | 269.364 |
| 5    | -3.916e-08 | 1.762e-05 | $5.000 \times 10^{-4}$ | 1.210 | 319.706 |
| 6    | 5.307-10    | -1.161e-07 | $-2.000 \times 10^{-4}$ | 0.289 | 199.999 |
| 7    | 1.808e-08   | -1.073e-05 | $3.000 \times 10^{-3}$ | 0.025 | 299.999 |
| 8    | -2.603e-09  | 1.812e-06 | $-8.000 \times 10^{-4}$ | 0.325 | 100 |
| 9    | 1.544e-09   | -1.854e-06 | $3.000 \times 10^{-4}$ | 0.605 | 299.999 |
| 10   | -7.323e-10  | 9.565e-07 | $-6.000 \times 10^{-4}$ | 0.306 | 499.999 |

Table 3. Weight 6 to weight 10 for each well.

| C    | 7500 MSCFD | 15000 MSCFD | Unlimited Gas Injection |
|------|------------|-------------|------------------------|
| 0.5  | 4805.538   | 5059.127    | 5132.399               |
| 1    | 4797.516   | 5071.466    | 5141.484               |
| 1.5  | 4811.998   | 5075.737    | 5138.772               |
| 2    | 4812.877   | 5107.873    | 5142.156               |
| 2.5  | 4781.721   | 5090.469    | 5129.323               |
| 3    | 4799.476   | 5066.691    | 5125.047               |
| 3.5  | 4775.977   | 5067.275    | 5131.488               |
| 4    | 4785.080   | 5073.997    | 5128.189               |
| 4.5  | 4764.851   | 5071.910    | 5121.054               |
| 5    | 4799.020   | 5059.376    | 5130.787               |

Table 4. Oil produced in every well.

The results obtained from GABC will be compared to ABC in each case (7500 MSCFD, 15000 MSCFD, and unlimited gas injection). GABC has a better result in every case where the produced oil are 4812.877 Bopd, 5107.873 Bopd, 5142.156 Bopd. Compared to them, ABC only
get 4768.478 Bopd, 5067.960 Bopd, and 5116.22 Bopd respectively. Table 5 shows that GABC has more oil production and can maximize the use of gas injection compared to ABC algorithm.

| CASE         | GABC           | ABC            |
|--------------|----------------|----------------|
| Gas Injection (MSCFD) | Oil Production (Bopd) | Gas Injection (MSCFD) | Oil Production (Bopd) |
| 7500 MSCFD   | 7472.534       | 7435.425       | 4812.877          | 4768.478 |
| 15000 MSCFD  | 14245.643      | 14159.053      | 5107.873          | 5067.960 |
| Unlimited Gas| 21566.555      | 20269.002      | 5142.156          | 5116.220 |

Table 6 shows the detail of gas injection and oil production in every well of each case. Unlimited gas injection has more oil production but also more gas injection, while maximum 7500 of gas injection only uses 7472.534 MSCFD and maximum 15000 of gas injection only uses 14245.643 MSCFD. It’s because GLPC resembles polynomial mathematical model where it can be seen in Figure 3

| Well | 7500 Gas Injection | Oil Production (Bopd) | 15000 Gas Injection | Oil Production (Bopd) | Unlimited Gas Injection | Oil Production (Bopd) |
|------|--------------------|-----------------------|---------------------|-----------------------|-------------------------|-----------------------|
| 1    | 794.357            | 712.400               | 1730.994            | 744.674               | 3892.451                | 749.921               |
| 2    | 678.048            | 643.881               | 2261.047            | 697.130               | 3186.032                | 702.326               |
| 3    | 550.687            | 255.314               | 1017.012            | 265.962               | 1960.363                | 270.255               |
| 4    | 483.940            | 397.660               | 916.427             | 416.641               | 1716.644                | 424.047               |
| 5    | 248.856            | 453.814               | 1423.777            | 520.251               | 1295.734                | 519.386               |
| 6    | 1047.258           | 359.157               | 1814.462            | 401.831               | 2640.803                | 406.549               |
| 7    | 1208.765           | 621.944               | 1973.461            | 649.792               | 2498.052                | 649.998               |
| 8    | 1194.116           | 198.657               | 1187.224            | 198.523               | 2535.095                | 208.720               |
| 9    | 1081.299           | 629.366               | 1192.424            | 628.262               | 1005.711                | 626.338               |
| 10   | 185.208            | 540.684               | 728.815             | 584.807               | 835.670                 | 584.616               |
| Total| 7472.534           | 4812.877              | 14245.643           | 5107.873              | 21566.555               | 5142.156              |

The optimum gas injection in each well can produce more oil. In case of 7500 MSCFD, it can be used in long term production because it’s not much different from 15000 MSCFD and unlimited gas. Gas injection is not cheap, so if used continuously without thinking what will happen later, the company using gas lift method will experience loss. But, if it’s used in short term for faster production unlimited gas allocation would be better than the other cases. Least square method is used to find the mathematical model from GLPC and 10th order polynomial is selected because R-square score equal to 1 and SSE score is 34.091. Using high order polynomial can make the mathematical model fitter than exponential or low order polynomial. GABC can optimize wells at once so it can save time for the production. GABC has a better performance than ABC, so the oil production can be optimal in every case. The optimal condition of C value in GABC is 2, because when finding a new solution, it shouldn’t deviate too far from the best solution and can reach a best solution faster.
5. Conclusion
It can be concluded that GABC perform better performance than ABC algorithm in each case with 4812.877 Bopd, 5107.873 Bopd, 5142.156 Bopd, with the limited gas injection used in case of 7500 MSCFD, 15000 MSCFD and unlimited gas injection is 7472.534 MSCFD, 14245.643 MSCFD and 21566.555 MSCFD respectively. When conducting experiments, all optimal oil production obtained when C in GABC is equal to 2. Case of limited 7500 MSCFD gas injection will be better to be used in long term production while unlimited gas injection in short term production. Contribution of this research is to find the fittest mathematical model and implement GABC to find the maximum value of mathematical model. For further research, authors recommend to optimize the Least square method to find the most suitable mathematical model even though R-square score is equal to 1, but the SSE score is still high with 34.091. Furthermore, find the most suitable parameters for number of employed bees, scouts and number of cycle GABC. It’s because in this paper the parameters are set manually.

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