

The Optimized Operation Of the Oilfield Water Injection System Based on Complex Method

Yinfeng Wang, Yuxue Wang

School of mathematics and statistics, Northeast Petroleum University, Daqing 163318, China.

***Corresponding Author:**

Yinfeng Wang

Email: feimeng.wyf@163.com

Abstract: The optimized operation model of the oilfield water injection system which optimized to the water injection station was established in this paper, and the objective function of the model made minimum energy consumption of the water injection station, the constraint of the model made hydraulic balance of the system, the balance of water consumption and the balance of injection pressure. The complex method was used to solve the model in this paper, the feasibility of the algorithm was verified by an oilfield water injection system, and better optimization results were obtained.

Keywords: the oilfield water injection system; the complex algorithm; optimization

INTRODUCTION

The oilfield water injection was a wide range of oilfield development and secondary oil recovery at home and abroad, but after the oilfield development to middle, power consumption had accounted for oilfield water injection more than 40% of the total power consumption, and with the increase of water cut in the crude, power consumption would be increased dramatically, so how to make operation optimization of oilfield water injection system had become a problem that needed to solve urgently in oil field production. The operation optimization of the oilfield water injection system was a problem that determined the opening and operating parameters of injection pumps in the given situation, so that the system could meet the requirements of injection system and reduce energy consumption. This paper studied the operation optimization of the oilfield water injection system, solved the constrained optimization problem by complex algorithm, and obtained good optimization results.

THE COMPLEX ALGORITHM

Complex was the polyhedron which was composed of $n+1 \leq k \leq 2n$ vertexes in n dimensional space. The idea of the complex algorithm[3,4, 5] was from the simplex algorithm of unconstrained optimization, the iterative process of the complex algorithm was as follow: first k vertexes were chosen as the vertexes of the initial complex in the feasible region, then the objective function value of the chosen vertexes were compared, at last the worst vertex which had the largest objective function value was removed, and the new complex was composed of reflection point of the worst vertex and other vertexes. Repeat the above process, the process made that the position of the complex get closer to the optimal point. If convergence precision was reached, then the vertex of the smallest objective function value was taken for the approximate optimal vertex in the last complex. Complex Algorithm[3,4,5] was as follows:

(1) Given the number of the variable n , variable range $a_i, b_i (i = 1, 2, \dots, n)$, the number of the complex vertexes k , required accuracy ε, δ ;

(2) Generated the initial complex;

(i) Generated the first vertex $X^{(1)}$ of the initial complex, checked $X^{(1)}$ whether it was feasible, if not feasible, regenerate random the first vertex $X^{(1)}$, until $X^{(1)}$ was feasible;

(ii) Randomly generated other vertexes $X^{(2)}, X^{(3)}, \dots, X^{(k)}$ of the initial complex, checked the feasibility of $k-1$ vertexes; if $X^{(q+1)}$ was not in the feasible region, then it would be transferred to the feasible region, the method was as follows: found the center of q vertexes which were in the feasible region as follows:

$$X^{(D)} = \frac{1}{q} \sum_{j=1}^q X^{(j)}$$

Produced new $X^{(q+1)}$ according to the following formula

$$X^{(q+1)} = X^{(D)} + 0.5(X^{(q+1)} - X^{(D)})$$

If $X^{(q+1)}$ was not feasible, iterated again according to the above formula, until $X^{(q+1)}$ was feasible; in sequence to check for $X^{(q+2)}, L, X^{(k)}$, if one was not feasible, it would be called in the feasible region according to the above method; the initial complex was formed in the feasible region, until all vertexes were feasible.

(3) Calculated objective function values of each vertex in the complex, found out the worst vertex $X^{(H)}$ and the best vertex $X^{(L)}$ according to the following formula.

$$X^{(H)} : f(X^{(H)}) = \max \{ f(X^{(j)}), j = 1, 2, L, k \}$$

$$X^{(L)} : f(X^{(L)}) = \min \{ f(X^{(j)}), j = 1, 2, L, k \}$$

turned to step (8).

(4) Calculated the center of other vertexes except the worst vertex according to the following formula;

$$X^{(C)} = \frac{1}{k-1} \sum_{j=1}^k X^{(j)} \quad j \neq H$$

(5) Checked the feasibility of $X^{(C)}$, if $X^{(C)}$ was not feasible, then returned to step (2); If $X^{(C)}$ was possible, turned to step (6);

(6) Calculated mapping point $X^{(R)} = X^{(C)} + \alpha(X^{(C)} - X^{(H)})$, $\alpha = 1.3$, checked whether $X^{(R)}$ was in the feasible region; if $X^{(R)}$ was in the feasible region, turned to step (7); Otherwise, recalculated the mapping point $X^{(R)}$, if the new mapping point was still not in the feasible region, repeat the above process.

(7) Compared the objective function value of the mapping point and the worst vertex, formed a new complex. if $f(X^{(R)}) < f(X^{(H)})$, then $X^{(H)} = X^{(R)}$, formed a new complex, returned to step (3); otherwise $\alpha = 0.5\alpha$, returned to step (6); after several iterations, if $\alpha < \delta = 10^{-5}$, and the mapping point couldn't be better than the worst vertex, found out the worse vertex in the complex, namely

$$X^{(SH)} : f(X^{(SH)}) = \max \{ f(X^{(j)}), j = 1, 2, L, k, j \neq H \}$$

and $X^{(H)} = X^{(SH)}$, turned to step (4);

(8) Checked whether it met the terminating condition, if satisfied $\left\{ \frac{1}{k} \sum_{j=1}^k [f(X^{(j)}) - f(X^{(L)})]^2 \right\}^{\frac{1}{2}} \leq \varepsilon$, and

then $X^* = X^{(L)}$, $f(X^*) = f(X^{(L)})$, output the optimal solution; Otherwise, return to step (3).

THE ESTABLISHMENT OF THE MODEL AND THE PROCESSING OF CONSTRAINT CONDITION

The purpose of the optimized operation of the oilfield water injection system was minimum energy consumption of the system, when the opening and the quantity of each pump were determined. At present there were two main optimization models, one was optimized to water injection pump station, and then optimized to every pump; another was directly optimized to every pump. This paper used the first optimization model, and optimized results of the pump would be calculated according to the data of the pump station.

The model [1,2] of optimized to the pump station was as follows.

$$\min f(u) = \alpha \sum_{i=1}^m P_i u_i$$

$$\text{s.t.} \begin{cases} u_i' - Q_i - \sum_{j \in I_i} s_{ij} \operatorname{sgn}(p_i - p_j) |p_i - p_j|^{1/\alpha} = 0, & i = 1, L, n-1 \\ \sum_{i \in X} u_i = \sum_{i=1}^n Q_i \\ p_i' - p_i^{\min} \geq 0 & i = 1, L, n_p \\ u_i^{\min} \leq u_i \leq u_i^{\max} & i \in X \end{cases}$$

Where α was conversion factor, m was the number of the water injection pump station, P_i was the node pressure of water injection pump station i , the unit was m; u_i was the flow of water injection pump station i , the unit was m^3/s ; n was the number of the node; p_i was the pressure of node i , the unit was m; u_i' was the injection rate of node i , the unit was m^3/s ; Q_i was the water consumption of node i , the unit was m^3/s ; p_i' was the node pressure of water injection well i , the unit was m; n_p was the number of the water injection well; X was the number of the water injection pump station.

The processing of constraint condition

(1) Constraint condition $u_i' - Q_i - \sum_{j \in I_i} s_{ij} \operatorname{sgn}(p_i - p_j) |p_i - p_j|^{1/\alpha} = 0$ and $p_i' \geq p_i^{\min}$ which had been

satisfied in the static simulation algorithm were not considered separately.

(2) Because the position of each vertex represented the displacement of water injection pump station in the complex algorithm, so constraint condition $\sum_{i \in X} u_i = \sum_{i=1}^n Q_i$ was translated into $\sum_{i=1}^n Q_i - u_m^{\max} \leq \sum_{l=1}^{m-1} \mu_l < \sum_{i=1}^n Q_i$ which could constrain the displacement of $m-1$ pump stations and determinate the displacement of the last pump station by $\mu_m = \sum_{i=1}^n Q_i - \sum_{l=1}^{m-1} \mu_l$, where $\mu_m = \sum_{i=1}^n Q_i - \sum_{l=1}^{m-1} \mu_l$ ensured that the system's total water supply was equal to the total water injection of injection Wells.

SIMULATION EXAMPLE

The water injection system of an oilfield which was as an example was checked calculation. The water injection system had seven water injection stations, 98 nodes, 131 pipelines, and the total water injection of the water injection system was $2136m^3/h$. The complex algorithm was solved the model, where the number of the variables was $n = 6$, the number of the vertexes was $k = 2n = 12$, changing range of the variables was $[200, 500]$, the reflection coefficient was $\alpha = 1.3$, the stop condition was $\frac{1}{k} \sum_{j=1}^k [f(X^{(j)}) - f(X^{(L)})] \leq \varepsilon$. Optimization results of the pump displacement was showed in table 1 by the complex algorithm, and the objective function value of the system was $228621kw \cdot h/d$ by the data of table 1, the objective function value was $238651kw \cdot h/d$ by the actual production displacement, the above results showed that the objective function value which was calculated by the complex algorithm decreased $10030kw \cdot d/h$, and the results of the complex algorithm was superior to the results of the pattern search algorithm[6].

Table 1 Optimization results of the pump displacement (m^3/d)

1	2	3	4	5	6	7
305.56	240.75	330.59	340.72	260.66	204.88	453.31

CONCLUSION

The optimization of the oilfield water injection system was important for reducing energy consumption of water injection, improving production efficiency and so on, so this paper studied the operation optimization of the oilfield water injection system and established the model of the operation optimization, the complex algorithm was solved the model, and this paper gave the method which reduced infeasible solution by satisfied the pump displacement and maintaining water balance. For example, an oilfield water injection system was validated the algorithm which got the good results, and the result illustrated that this method was feasible.

REFERENCES

1. Zeng Wen, Liu Yang, Wei Lixin, Yang Jianjun, Zhang Yunjun; Optimization of oilfield injection system based on improved genetic algorithm, Journal of Daqing Petroleum Institute, 2004; 28(6): 51-54.
2. Liu Chunlan; Research on optimization methods in oilfield water injection system based on Ant-Particle algorithm. Daqing Petroleum Institute, 2010.
3. Wang Siren; The introduction of the complex method and its appliance. Jiangxi hydraulic technology. 1995;21(2): 93-97.
4. He Bingyu; The application of Complex method in parameters optimization of water quality model. Journal of Xinjiang University (natural sciences), 1996; 13(4): 75-79.
5. Wang Fulin; Initial complex problems of the complex method. Journal of zhejiang agricultural university, 1996; 22(1): 73-76.
6. Wang yuxue, Liu Chunlan, Wang Yinfeng, Zhou Shaohua; Optimization in oilfield water injection system based on algorithm of ant colony-particle swarm method. Journal of Daqing Petroleum Institute, 2010; 34(2): 73-76.