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Calibrating pipe friction coefficient of the oilfield water injection system based on sensitivity analysis

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

***Corresponding Author:**
Yinfeng Wang
Email: feimeng.wyf@163.com

Abstract: In order to improve the accuracy of hydraulic model for the oilfield water injection network, the model need to be calibrated, so the method of sensitivity analysis was proposed to calibrate pipe friction coefficient in this article. when the node flow and the node pressure were known, the node pressure which affected by the change of the pipe friction coefficient was analyzed, then the pipes of smaller sensitivity were given experience friction value, other pipe friction coefficient was calibrated by the node equations. The method of sensitivity analysis reduced the number of corrected variables and improved the corrected speed, finally the example showed that the corrected node pressure was consistent with the actual node pressure by the method of sensitivity analysis, and illustrated that the method was feasible.
Keywords: oilfield water injection network, pipe friction coefficient, sensitivity analysis

INTRODUCTION

The calculation of hydraulic model for the oilfield water injection network wasn't usually consistent with the actual result, so it is necessary to calibrate the model. the calibration mainly included the node flow estimation and the correction of the pipe friction coefficient, and the basic data of the network had been gradually perfect, the node flow estimation had been more accurate, so the calibration of the pipe friction coefficient is more important. In order to improve accuracy of the calibration, the domestic and foreign scholars have done a lot of research work [1,3], they usually consider from the reasonable layout of testing nodes, reducing the number of calibration variables, increasing calibration data and improving the efficiency of optimization algorithm and so on. Based on reducing the number of calibration variables, this article analyzed the node pressure which affected by changing the pipe friction coefficient, and full used experience values of pipe friction coefficient, then the pipes of smaller sensitivity were given experience values, other pipes were calibrated by the node equations. in this article, an idea network had been tested, and the result was preferable, so the method of sensitivity analysis was feasible.

SENSITIVITY ANALYSIS

Because node pressure was influenced by node flow, pipe friction coefficient, pipe diameter, pipe length and so on, in order to eliminate effects of other parameters, so pipe friction coefficient was separated in this article, and the analysis showed that changing different pipe friction coefficient in network was different for different node pressure; for the same pipe, the pipe friction coefficient was determined by the pipe roughness coefficient, therefore the pipe roughness coefficient determined the node pressure [1,4]. if the roughness coefficient of pipe i changed from n_i to n_i', the pressure of node j changed from H_{ij} to H_{ij}', then for the pressure of node j, the sensitivity of pipe i was

$$X_{ij} = \frac{\left|H_{ij}' - H_{ij}\right| / H_0}{\left|n_i' - n_i\right| / n_i} \quad (1)$$

Where H_0 was artificially set pressure value, the unit was meter.

The sensitivity of all pipes were get by repeating the above process. Because small change of the sensitivity didn't affect the correction results, in order to choose most sensitive pipe, it need to be compared the influence of each pipe friction coefficient for all node pressure, the formula was used as following:

$$X_i = \frac{1}{J}\sum_{i=1}^{J} X_{ij} \quad (2)$$

Where X_i was the sensitivity of pipe i, J was the total number of nodes.

Because the initial pipe friction coefficient and the actual value were large, so it could improve the correction speed and accuracy, that changed from the initial pipe friction coefficient to the experience frictional value. Therefore in this article, the experience frictional value was given the pipe of some smaller sensitivity, and then other pipe friction coefficient was corrected through the node equations.

CALIBRATING PIPE FRICTION COEFFICIENT BASED ON SENSITIVITY ANALYSIS

For the oilfield water injection network which had P pipes, J nodes and L rings, continuous equation of the node was

$$Q_i + \sum q_{ij} = 0 \qquad (3)$$

Where Q_i was the flow of node i, the unit is L/s; q_{ij} was the pipe flow from node i to node j, the unit is L/s .the pressure drop equation was

$$h_{ij} = H_i - H_j = s_{ij} q_{ij}^n \qquad (4)$$

Where H_i, H_j were the pressure of node i, j, the unit was meter; h_{ij} was hydraulic losses from node i to node j, the unit was meter; s_{ij} was pipe friction coefficient from node i to node j, which was shown as following

$$s_{ij} = \frac{10.29 n_{ij}^{\ 2}}{d_{ij}^{\ 5.3}} L_{ij} \qquad (5)$$

Where d_{ij} was the pipe diameter from node i to node j, the unit was meter; L_{ij} was the pipe length from node i to node j, the unit was meters n_{ij} was pipe roughness coefficient from node i to node j.

Through the above analysis, the relation could be obtained between node flow, node pressure, pipe flow and pipe friction coefficient. Because of the unknown number more than the number of equations, the solutions of the node equations were infinite, in order to get the only solution, the node equations need to be supplemented conditions. Because the coefficient matrix of the node equations showed the connection relationship between nodes and pipe, so the structure of the network and the supplementary conditions decided properties of coefficient matrices, and the row vectors of the coefficient matrices were linearly independent, therefore in this article, L pipes of smaller sensitivity was given the experience value, and correction model was obtained as following:

$$\begin{aligned} &\sum_j q_{ij} = Q_i, i = 1, 2, \cdots, N-1 \\ &s.t. \quad n_k = n_0, k = 1, 2, \cdots, L \end{aligned} \qquad (6)$$

Where n_0 which satisfied the following conditions was constant:

(1) L Pipes distributed in each ring, and one friction coefficient of the pipe which was connected by each node was unknown at least, in order to get the reversible coefficient matrix of the node, then the node equations got the only solution.

(2) When the ring of the network was convex polygons, any chosen pipe could make that the coefficient matrix was reversible, and the node equations had unique solution. When the ring of the network was concave polygon, in order to get reversible coefficient matrix, both sides of concave polygon couldn't be chosen, and the pipe arrangement needs to be noticed.

The algorithm of the model is as following

Step1：Calculate all pipe sensitivity;

Step2：Select the pipe of the smallest sensitivity in each ring , and record the ring number;

Step3：choose L pipes by condition (1) and (2), and the pipes were given empirical value;

Step4：solve other pipe friction coefficient by the node equations.

SIMULATION EXAMPLE

In this article, the ideal network was shown in figure 1. the network had 9 nodes, 12 pipes and 4 rings, the basis data of the network was shown in table 1,and the last column of table 1 was the true value of all pipe roughness.

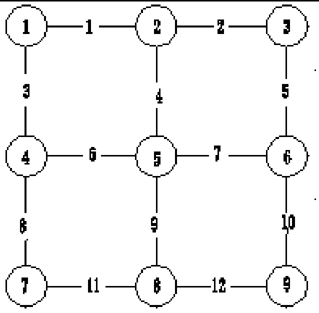

Fig-1: The ideal network

Table 1: The basis data of the ideal network

Node number	Node flow (m^3/h)	Node pressure (m)	pipe number	Upstream node	Downstream node	Pipe diameter (m)	Pipe length (m)	n_{ij}
1	-184.4	15.4	1	1	2	0.2	3000	0.013
2	-180.9	15.3	2	2	3	0.15	1800	0.014
3	-133.6	15.2	3	1	4	0.2	3000	0.014
4	-53.7	15.1	4	2	5	0.2	1000	0.013
5	30.9	15	5	3	6	0.2	1500	0.013
6	112.9	14.9	6	4	5	0.2	1200	0.015
7	-28.4	14.8	7	5	6	0.15	1500	0.013
8	231.4	14.5	8	4	7	0.15	1300	0.016
9	205.8	14.2	9	5	8	0.2	1400	0.013
			10	6	9	0.15	1500	0.015
			11	7	8	0.15	1000	0.013
			12	8	9	0.15	1000	0.013

In the network of figure 1, the pressure of node 5 was given constant. According to the empirical data, the pipe roughness coefficient often valued between 0.013 and 0.018, so in order to research the influence of different pipe friction coefficient for the node pressure, the pipe roughness coefficient was changed from 0.013 to 0.018, then the sensitivity of each pipe was calculated by the formula (2) and shown in the second column of table 2; the pipes of the smallest sensitivity was chosen in each ring of the network, then the chosen pipes were adjusted by the conditions of (1) and (2), until the coefficient matrix of the node equations was reversible, the pipes of meted the conditions were given the actual values which were shown in the third column of table 2. According to the above conditions, the friction coefficient of other pipes was calculated by the model (6) and shown in the fifth column of table 2, the calculated friction coefficient was consistent with the actual values, according to above data, the calculated node pressure which was shown in the seventh column of table 2 was consistent with the actual node pressure, so the model was feasible.

Table-2: The results

Sl. No.	**Sensitivity value**	**Experience**	**Found**	**Calculated**	**Node number**	**Calculated pressure**	**Known pressure**
1	0.0379	0.013	0.013	0.013	1	15.4	15.4
2	0.0595	0.014	0.014	0.014	2	15.3	15.3
3	0.129		0.014	0.014	3	15.2	15.2
4	0.178		0.013	0.013	4	15.1	15.1
5	0.209		0.013	0.013	5	15	15
6	0.0684	0.015	0.015	0.015	6	14.9	14.9
7	0.0883	0.013	0.013	0.013	7	14.9	14.8
8	0.1303		0.016	0.016	8	14.6	14.5
9	0.4955		0.013	0.013	9	14.3	14.2
10	0.8149		0.015	0.015			
11	0.2853		0.013	0.013			
12	0.5028		0.013	0.013			

The pipes which were chosen by sensitivity analysis were given empirical friction coefficient, and the empirical values were shown in the second column of table 3, then other pipe friction coefficient was calculated and shown in fourth column of table 3, it had small deviation between the actual values and the calculated values, but according to above data, the calculated node pressure which was shown in the sixth column of table was consistent with the known node pressure.

Table-3: The results

Sl. No.	Experience	Found	Calculated	Node number	Calculated pressure	Known pressure
1	0.015	0.013	0.015	1	15.4	15.4
2	0.015	0.014	0.015	2	15.3	15.3
3		0.014	0.013	3	15.2	15.2
4		0.013	0.013	4	15.1	15.1
5		0.013	0.013	5	15	15
6	0.015	0.015	0.014	6	14.7	14.9
7	0.015	0.013	0.015	7	14.8	14.8
8		0.016	0.015	8	14.9	14.5
9		0.013	0.013	9	14.7	14.2
10		0.015	0.016			
11		0.013	0.013			
12		0.013	0.013			

CONCLUSION

In the condition of node flow and node pressure which were known, this article researched the correction method of the pipe friction coefficient. In this article, the pipe friction coefficient of smaller sensitivity was given experience value; other pipe friction coefficient was calibrated by the node equations. For example, an ideal network was validated the algorithm which got the good results, and the result illustrated that this method was feasible.

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