Application of AHP in scheme comparison and selection of improvement of high-sour gas field's potential capacity

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Abstract

In order to promote the exploration and development of natural gas resources in the eastern part of Sichuan, and to supplement the gas in West-east Pipeline Project. It is urgent to improve potential capacity of high sour gas field. Based on the present situation of ground gathering and transportation in east Sichuan, three schemes of improvement of high-sour gas field's potential capacity are proposed. Based on the principle of multiple objective decision analysis and analytic hierarchy process, an optimization model for scheme comparison and selection is established. The weight of evaluation index was obtained by arithmetic mean method, then the judgment matrix is established. The comprehensive evaluation indexes are calculated and sorted, and the subjective indexes are expressed in quantitative form and compared quantitatively. It overcomes the shortcoming of the traditional scheme selection by comparing the advantages and disadvantages. Finally, building a new desulphurization unit based on A2 dehydration station is recommended. Under the premise of ensuring safe operation, to maximize the potential capacity of high sour gas field in east region of Sichuan.

Keywords

High-sour gas field; Potential capacity; Analytic hierarchy process; Scheme comparison and selection.

1. Introduction

In recent years, with the production of low sulfur gas fields such as carboniferous system entering a declining period, the number of new wells with high sulfur gas have increased in east region of Sichuan in PetroChina Southwest Oil and Gasfield Company.

At present, the raw gas pipe network and purification plants along the pipe line do not adapt, and the total sulfur in downstream purification plants exceeds the standard. As a result, some high sour gas wells were shut down, and the downstream purification plants could not deal with high sour raw gas and was shut down [1]. In view of the above situation, the potential capacity of high sour gas field in east region of Sichuan is optimized to increase the output of high sour gas field, and the downstream purification plants is able to operate under full load for a long time and improve economic benefits.

In the early 1970s AHP (The Analytic Hierarchy Process) was presented by T.L.Saaty, a professor at the University of Pittsburgh. Its principle is to stratify the decision-making thinking of complex systems, then the quantitative and qualitative factors are combined in the process of optimization analysis, using the mathematical method to calculate the relative weight of all factors. Finally, the optimal scheme is selected by comparison [2]. Based on the principle of multiple objective decision analysis and analytic hierarchy process, an optimization model for scheme comparison and selection is established. The weight of evaluation index was obtained by arithmetic mean method. The judgment matrix is established, the comprehensive evaluation indexes are calculated and sorted, and the subjective indexes are expressed in quantitative form and compared quantitatively. It overcomes the shortcoming of the traditional scheme selection by comparing the advantages and disadvantages.

2. A brief introduction to the schemes of improvement of potential capacity of high sour gas field

2.1 Operation status of high sour gas field and ground gathering and transportation system

The potential capacity of high sour gas field in a block is estimated to be $125\times10^4m^3/d$ in the eastern part of Sichuan, and H_2S content and CO_2 content of raw gas in some gas reservoirs are as high as $93g/m^3$ and $89g/m^3$ respectively. At present, the area is surrounded by purification plants A, B, C and D. See table 1.1 for specific operating parameters.

There are two dehydration stations A1 and A2 on the main pipeline of gas gathering system, which mainly transport the wet raw gas of this block into the main pipeline of gas gathering system after dewatering.

The gas gathering pipeline between this block and A1 dehydration station (line A) and the gas gathering pipeline between A1 dehydration station and A2 dehydration station (line B) were reformed in 2016 to meet the relevant standards of ground gathering and transportation system with high H_2S content. See figure.1.1 for the schematic diagram of a block ground gathering and transportation system.

Table 1.1 Operation status of each purification plant.(As of May,2017)

Name	Processing capacity $10^4m^3/d$	design parameter g/m^3		Actual processing capacity $10^4m^3/d$
		H_2S content	CO_2 content	
A	200	30-77	50-137	155
B	300	7-9	30-40	280
	300	7-9	30-40	shutdowns
C	400	5-10	≤30	270
	200	5-10	≤30	shutdowns
	80	20-75	≤30	shutdowns
D	400	4-6	≤30	shutdowns

2.2 Schemes of improvement of high sour gas field’s potential capacity

Based on the current operation status of high sour gas field and ground gathering and transportation system in this block, on the premise of ensuring safe operation. In order to maximize the production capacity of high sour gas field in east region of Sichuan. Therefore, three schemes of improvement of high sour gas field’s potential capacity are proposed.

2.2.1 Scheme 1—Reconstruction and extension of purification plant A

Purification plant A is located near this block and mainly deals with raw gas with high sulfur content. Therefore, it is proposed to expand the original desulphurization and sulfur recovery device at the same address, increase its treatment capacity to $300\times10^4m^3/d$, and add tail gas treatment device. Through the transformation, it can deal with raw gas with high sulfur content which cannot be utilized in the production capacity of this block.

2.2.2 Scheme 2—Construction of skid-mounted desulphurization equipment at gas well head.

It is proposed to adopt skid-mounted desulphurization equipment at high sour gas well head, and to select MDEA solutions and LO-CAT technology to deal with high sour raw gas. To a large extent this scheme can reduce the area of land expropriation and time of construction, according to development time of gas well to realize rolling development. Skid-mounted desulphurization equipment has the virtue of convenient installation and transportation, and a set of skid-mounted desulphurization equipment can realize the biggest capacity of $36\times10^4m^3/d$.

2.2.3 Scheme 3—A new desulphurization unit is built based on A2 dehydration station

According to the current operation status of high sour gas field and ground gathering and transportation system in this block, only purification plant B, C and D have the ability to deals with raw gas of low sulfur. The main pipeline of gas gathering system of line A and line B were reformed in 2016 in accordance with the relevant standards of ground gathering and transportation system of high H2S gas field, so a new purification device based on A2 dewatering station is proposed under the condition of not changing the existing gas gathering system. The high sour raw gas was processed into low sulfur raw gas, then low sulfur raw gas will flow to purification plant B, C and D. It has the advantage of reducing the pipeline of sour gas load and improvement of potential capacity of high sour gas field.

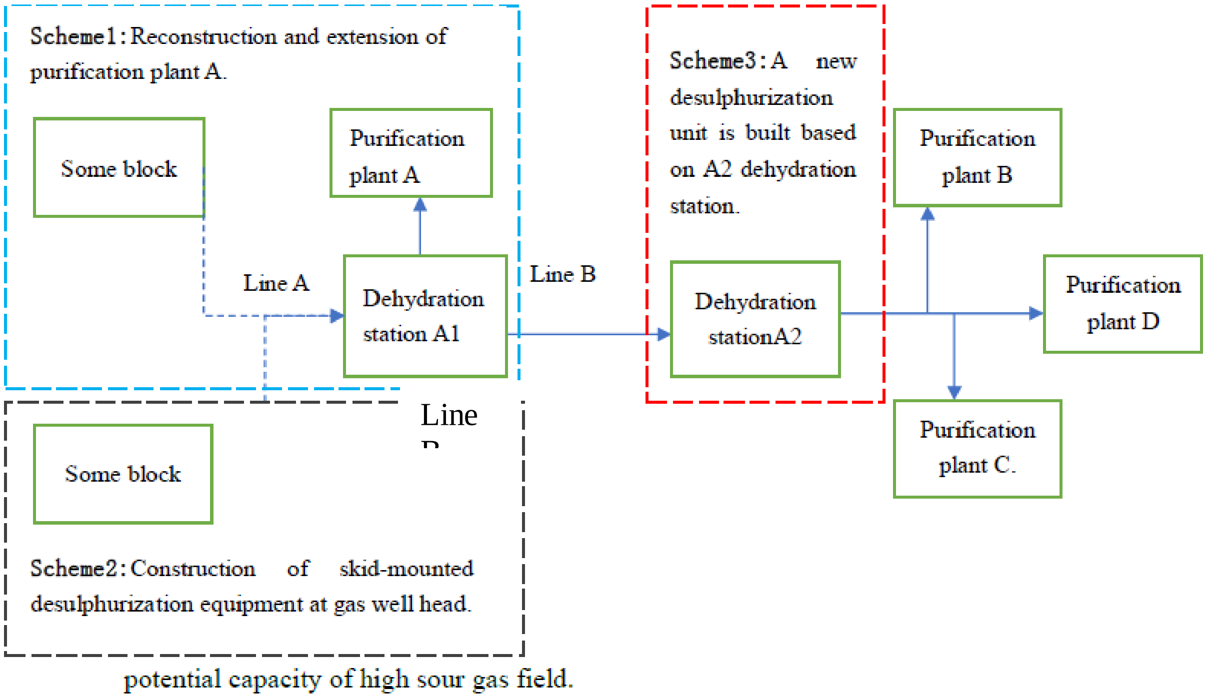

Figure 1.1 The schematic diagram of some block ground gathering and transportation system

The comprehensive comparison of various schemes is shown in table 1.2.

Table 1.2 Comprehensive comparison table of various schemes

Evaluation indexes	Schemes		
	Schemes 1	Schemes 2	Schemes 3
Construction period	Large	Small	Medium
Project investment	Large	Medium	Small
Impact of construction process on production	Large	Medium	Small
Impact on the local government planning	Large	Small	Medium
Scheme effectiveness	Large	Small	Medium

3. Schemes comparison and selection

3.1 Build the optimization model of improvement of high-sour gas field's potential capacity

There are many factors influencing the choice of schemes, and there is also an interaction between them [3]. This paper mainly determines the following five evaluation indexes: construction period A1, project investment A2, impact of construction process on production A3, impact on the local government planning A4, and scheme effectiveness A5. Through the analysis of the factors of each scheme, the hierarchy chart of schemes is constructed. As shown in figure 2.1.

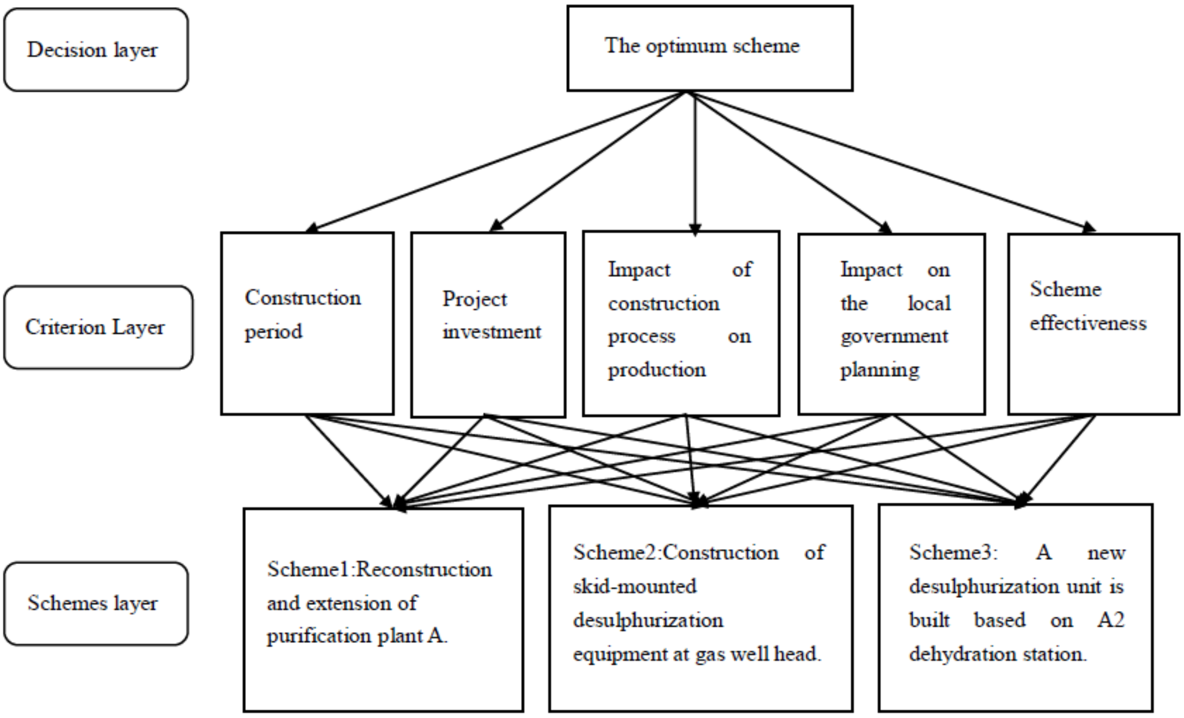

Fig. 2.1 The hierarchy diagram of schemes

The optimization model of improvement of high-sour gas field's potential capacity:

$$U_i = \sum_{j=1}^{n} k_{ij} \times w_j$$

In the formula:

U_i—The result of the ith scheme;

k_{ij}—Evaluation value of ith scheme in evaluation index j;

w_j—The weight value of the jth evaluation index in the criterion layer.

3.2 Determine the weight of evaluation indexes

When optimizing the scheme, the weight value of each evaluation index should be determined first. The slight difference in weight value setting will have a great impact on the overall scheme comparison result [4]. Therefore, the determination of reasonable evaluation index weight value has a decisive role. At present, in the field of engineering, the weight of evaluation index is mainly determined by binomial coefficient method, Delphi method and analytic hierarchy process (AHP). Analytic hierarchy process (AHP) includes geometric average method, arithmetic average method, eigenvector method and least square method [5]. In this paper, the arithmetic mean method of analytic hierarchy process (AHP) is used to determine the weight of evaluation index of schemes.

Luo zhengqing et al. in their early studies on scale method, believed that both the three-scale method and the nine-scale method could maintain order under a single criterion, but the latter method had higher accuracy [6]. Therefore, this paper adopts the nine-scale method recommended by professor

Saaty of the university of Pittsburgh in the United States. Among the five influencing factors, only two of them are compared at a time, and the following agreement is made [7]:

Table 2.1 Gradation scale for quantitative comparison of alternatives

Option	Numerical value(s)
Equal	1
Marginally strong	3
Strong	5
Very strong	7
Extremely strong	9
Intermediate values to reflect fuzzy inputs	2,4,6,8
Reflecting dominance of second alternative compared with the first	Reciprocals

(1)According to table 1.2 and table 2.1, two factors were compared to obtain the comparison matrix:

$$\mathrm{A} = a_{ij} = \begin{bmatrix} A & A_1 & A_2 & A_3 & A_4 & A_5 \\ A_1 & 1 & 1/4 & 1/3 & 1/4 & 1/5 \\ A_2 & 4 & 1 & 2 & 3 & 1/3 \\ A_3 & 3 & 1/2 & 1 & 2 & 1/3 \\ A_4 & 4 & 1/3 & 1/2 & 1 & 1/4 \\ A_5 & 5 & 3 & 3 & 4 & 1 \end{bmatrix}$$

(2)Normalize A by column:

$$\mathrm{A}' = \begin{bmatrix} 0.0588 & 0.0492 & 0.0488 & 0.0244 & 0.0945 \\ 0.2353 & 0.1967 & 0.2927 & 0.2927 & 0.1575 \\ 0.1765 & 0.0984 & 0.1463 & 0.1951 & 0.1575 \\ 0.2353 & 0.0656 & 0.0732 & 0.0976 & 0.1181 \\ 0.2941 & 0.5902 & 0.4390 & 0.3902 & 0.4724 \end{bmatrix}$$

(3)Add A' to the rows:

$$\mathrm{A}'' = \begin{bmatrix} 0.2757 \\ 1.1749 \\ 0.7738 \\ 0.5897 \\ 2.1860 \end{bmatrix}$$

(4)Normalize A'' by column:

$$\mathrm{A}''' = \begin{bmatrix} 0.0551 \\ 0.2350 \\ 0.1548 \\ 0.1179 \\ 0.4372 \end{bmatrix}$$

(5)Calculation of consistency ratio:

$$\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(Aw)_i}{w_i} = \frac{1}{5}\left|\frac{0.2824}{0.0551} + \frac{1.2646}{0.2350} + \frac{0.8193}{0.1548} + \frac{0.6035}{0.1179} + \frac{2.3538}{0.4372}\right| = 5.2596$$

$$\mathrm{CI} = \frac{\lambda_{max} - n}{n - 1} = 0.06491$$

$$\mathrm{CR} = \frac{CI}{RI} = \frac{0.001}{1.12} = 0.0580 < 0.1$$

In the formula:

λ_{max}—The maximum eigenvalue of A;

CI—Conformance index;

RI—Average random consistency index，take 1.12 when n = 5.

Saaty suggests the value of CR should be less than 0.1, it meets the requirements of consistency test. Therefore, the weight of each evaluation index is taken as follows:

$$w_i = (w_1, w_2, w_3, w_4, w_5) = (0.0551, 0.2350, 0.1548, 0.1197, 0.4372)$$

3.3 Establish judgment matrix

When different evaluation dimensions exist simultaneously in the same project evaluation model, in order to make comparison and selection of schemes under the same standard conditions, each evaluation indexes are converted into proper dimensionless indexes [8]. Evaluation indexes are usually divided into two categories. One is the profitability index, and the larger the value is, the more beneficial it will be to the scheme, such as the scheme effectiveness. The larger the value of another kind of index is, the more unfavorable it is to the scheme. It is called loss index, such as the impact of construction process on production.

(1)Calculation of profitability index:

$$P_{ij} = \frac{D_{ij} - D_{jmin}}{D_{jmax} - D_{jmin}}$$

(2)Calculation of loss index:

$$P_{ij} = \frac{D_{jmax} - D_{ij}}{D_{jmax} - D_{jmin}}$$

In the formula:

D_{ij}—The calculated value of the jth evaluation index in the ith scheme;

D_{jmax}、D_{jmin}—The maximum and minimum values of the jth evaluation index in the evaluation system;

P_{ij}—The value of the jth evaluation index in the ith scheme after non-dimensional disposal.

Both qualitative and quantitative indicators are included in the schemes. Therefore, this paper adopts the following evaluation indexes to calculate the values to reflect the differences between them. See table 2.2 for specific categories.

Table 2.2 The calculated value of the evaluation index

Classify	Extremely strong	Very strong	Strong	Marginally strong	Equal
Score	9	7	5	3	1

According to table 2.1, table 2.2, calculation formula of benefit index, calculation formula of loss index and calculation value table of evaluation index, judgment matrix can be calculated:

$$K = \begin{vmatrix} 0.25 & 0.25 & 0.25 & 0.25 & 0.75 \\ 0.75 & 0.50 & 0.75 & 0.50 & 0.25 \\ 0.50 & 0.75 & 0.50 & 0.75 & 0.50 \end{vmatrix}$$

3.4 Calculate the comprehensive evaluation index

$$U_i = \sum_{j=1}^{n} k_{ij} \times w_j$$

$$U = \begin{vmatrix} 0.25 & 0.25 & 0.25 & 0.25 & 0.75 \\ 0.75 & 0.50 & 0.75 & 0.50 & 0.25 \\ 0.50 & 0.75 & 0.50 & 0.75 & 0.50 \end{vmatrix} \times \begin{vmatrix} 0.0551 \\ 0.2350 \\ 0.1548 \\ 0.1179 \\ 0.4372 \end{vmatrix} = (0.4686, 0.4432, 0.5882)$$

Through the comparison and selection of the three schemes by using the analytic hierarchy process, we get $u_3 > u_1 > u_2$. That is, scheme 3 is the optimal scheme. The calculated results by using the analytic hierarchy process is consistent with on-site recommendation scheme, and the results are reliable.

4. Conclusion

(1) This paper uses the nine-scale method in the analytic hierarchy process to calculate the weight of evaluation index. This method has higher precision, meets the requirement of consistency check, and reduces the influence of decision maker's subjective factors on the optimization process.

(2) The results show that the analytic hierarchy process (AHP) is used to reach the same conclusion as the traditional optimization method, which provides decision-makers with more scientific data support.

(3) The construction period, project investment, impact of construction process on production, impact on the local government planning, and scheme effectiveness have been comprehensively compared. Scheme 3 is recommended, namely, a new desulphurization unit is built based on A2 dehydration station. The potential capacity of high sour gas field can be maximized in east region of Sichuan.

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