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Optimization of Flue Gas Desulphurization Technologies Based on Cloud Model and Kernel Vector Space Model

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ABSTRACT The flue gas desulfurization of coal-fired power plants is currently the main mean to control the emission of sulfur dioxide in China. How to select desulfurization technology that meets both technical and economic requirements becomes the issue of this paper. To deal with problems in evaluating indexes with linguistic evaluation information in the optimization of flue gas desulphurization technologies, a new synthetic evaluation model for flue gas desulphurization technologies based on the cloud model and the kernel vector space method was proposed in this paper. The main contribution of this paper is as follows. First, the comprehensive evaluation index system includes technology, economy, and environmental performance. The technology indicators are qualitative index; economic and environmental indicators belong to quantitative index. In this case, the reasonable transformation from qualitative concepts to quantitative indication was accomplished and the cloud model was used to represent the natural language evaluation information. Second, the subjective weights were determined by the analytic hierarchy process and the objective weights were determined by the entropy method so that the comprehensive weights can be obtained by the method of combining the additional principle with both subjective and objective weights' information. Finally, the priority membership of evaluation objects with the kernel vector space theory was calculated to achieve the optimization of flue gas desulphurization technologies. By comparing and analyzing six different representative flue gas desulphurization technologies, it can be proved that the model has advantages of objectivity, simplicity, effectiveness, and implementation simplicity, and can provide a reliable basis for making a decision in the optimization of flue gas desulphurization technologies.

INDEX TERMS Flue gas desulphurization, kernel vector space, cloud model, proximity analysis, comprehensive evaluation.

I. INTRODUCTION

Currently, desulfurization processes used in coal-fired or oil-fired power stations are various in the world. Notably, some desulfurization processes are relatively mature and have reached the level of industrial application, but some are still in the stage of experimental research. It is of great practical significance to evaluate the desulfurization technologies scientifically and to select the desulfurization technology which is technically reasonable, economically feasible and suitable for cogeneration projects.

The optimization of desulfurization technologies involves many evaluation indexes, which can not be measured by the unified standard of the assessment index system. Xie and Zhang proposed a two-stage fuzzy mathematical model to evaluate the combined performance of SO_2 and NO_x removal technology [1]. By determining factor set, evaluation, evaluation matrix and weight set, 8 important combined removal

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technologies of sulfur dioxide and nitrogen oxide were evaluated, and the evaluation results were given. Chaaban *et al.* proposed the autoregressive economic model to evaluate and compare the three desulfurization schemes considered, so as to determine the most economical and feasible scheme under the consideration of various cost parameters [2]. There are many influencing factors in the choice of desulfurization technology. The key to solving the problem of multi-attribute decision making lies in the fuzzy evaluation and the weight of each attribute. The basic idea of the fuzzy comprehensive evaluation is to give the corresponding weight and consider main indicators that affect the overall performance of the target. The previous study established an evaluation index system for energy saving [3] and emission reduction of thermal power generation technology and constructed a fuzzy comprehensive evaluation model [4]–[10], which could comprehensively evaluate different technologies. The Analytic Hierarchy Process (AHP) is suitable for multi-index decision-making problems with complex hierarchical structure and can deal with qualitative and quantitative factors of decision-making, and can also be used to calculate the weight of multi-index. The Fuzzy Analytic Hierarchy Process (FAHP) was used in the reference [11] to optimize the selection of multi-objective decision-making methods. By establishing evaluation index system and operation state set, introducing AHP-based fuzzy comprehensive evaluation method and set pair analysis method [12]–[13], the state evaluation method of comprehensive evaluation index was established. Liu *et al.* proposed ageing condition assessment model of power equipment [14].

Nevertheless, the AHP does not consider the effect of individual subjective judgment and preference when constructing comparative judgment matrix. In addition, the above-mentioned methods could not distinguish the uncertainty of data and expert judgment. The artificial neural network method has good fault tolerance and memory association function, and strong adaptive learning function, which can play an effective role in solving the above problems. In the literature [15]–[16], back propagation (BP) neural network was applied to the scheme selection of desulfurization process in cogeneration project, which significantly improved the rationality of the evaluation results. However, the optimization of flue gas desulfurization technologies is a multidimensional objective problem. If the objective function optimized by BP neural network algorithm is in a high-dimensional space and very complex, the convergence speed will inevitably slow down, and the calculation results will also have large errors. The emergence of support vector machine theory perfectly solves this problem. The Support Vector Machine (SVM) theory provides a way to avoid the complexity of high-dimensional space [17]. Its characteristic is to map input data from low-dimensional space to high-dimensional kernel vector space by using kernel function, so as to solve the non-linear problem of low-dimensional space by the linear method in high-dimensional space. Therefore, the kernel vector space method was applied to the optimization of flue gas desulfurization technologies in the article. It perfectly solves the calculation problem of high-dimensional space and significantly improves the efficiency of selection in the optimization of flue gas desulfurization technologies.

In addition to that. The comprehensive evaluation index system of desulfurization technologies schemes only operates at a qualitative aspect, which includes technology, economy, and environmental performance. The traditional expert meeting method is mostly used in the evaluation of desulfurization technologies schemes in China, that is, experts mainly rely on experience to evaluate. And experts can use proficient language to scale values. However, the language is accompanied by greater uncertainty and fuzziness in most cases. A method using the cloud model to reflect the uncertainty of natural and social sciences is very useful for various research fields [18]–[24]. The cloud models can reflect the fuzziness and randomness of concepts. It can be perfectly proved that a cloud model evaluation method is an effective evaluation method [25]. Therefore, this paper proposes an optimal flue gas desulfurization technology based on cloud model and kernel vector space theory. A comprehensive evaluation index system of flue gas desulfurization technologies was set up according to the relevant literature [26]–[28], which took the actual situation of thermal power enterprises into consideration. It not only avoided the uncertainty brought by the evaluation of experts and data but also solved the problem of selecting the flue gas desulfurization scheme affected by multiple evaluation indexes.

The remainder of this paper is summarized as follows. The comprehensive evaluation model of flue gas desulfurization technology was established in Section II. The cloud model to express the natural language assessment information given by the policymakers was used to resolve the problems of qualitative indexes processing in the comprehensive evaluation of the flue gas desulfurization in Section III. A kernel vector space method for flue gas desulfurization technology was proposed, in which the AHP and entropy weight method was used to calculate the weight of each evaluation index information in Section IV. The proposed method was suitable to choose the appropriate flue gas desulfurization technology in Sections V. The conclusions are given in Section VI.

II. THE ESTABLISHMENT OF THE COMPREHENSIVE EVALUATION MODEL OF FLUE GAS DESULFURIZATION TECHNOLOGY

A. DETERMINE THE COMPREHENSIVE EVALUATION INDEX SYSTEM

The flue gas desulfurization technology is influenced by many factors. In this paper, scientificity, independence, operability and so on are principles. The comprehensive evaluation index system of flue gas desulfurization technology which was affected by the coexistence of both qualitative and quantitative factors was constructed on the basis of the existing research results [26]–[28] from the aspect of technical, economic, and environmental protection. Among them, the technical aspects include: process maturity c_1, technical complexity c_2, system upgrade performance c_3, and system negative impact c_4. The economic aspects include: the desulfurization system investment accounts for the proportion of the total power plants investment c_5, the floor space of desulphurization devices where the unit capacity is 300MW c_6, the cost of removing a ton of sulfur dioxide c_7, and power consumption accounts for the proportion of the total generating capacity c_8. The environmental protection aspects include: desulphurization efficiency c_9, and calcium-sulfur mol-ratio c_{10}. As shown in Figure 1.

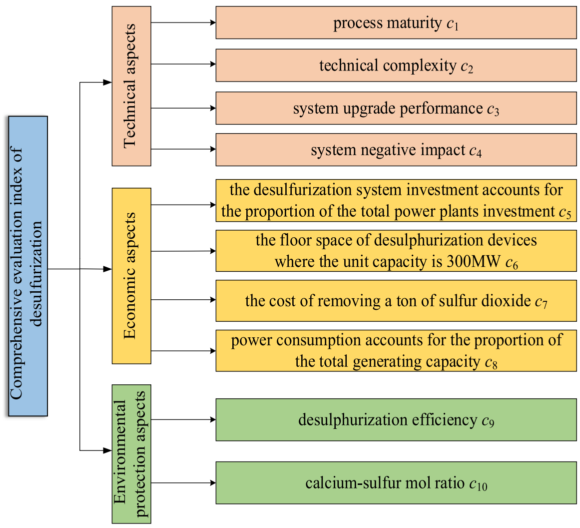

FIGURE 1. Comprehensive evaluation index of desulfurization.

B. DETERMINATION OF THE EVALUATION INDEX WEIGHT

The weight coefficient of each evaluation index in the comprehensive evaluation index system of flue gas desulfurization technology has a great effect on the final evaluation results. In this paper, when the AHP is used to determine the subjective weight of each index [28], the entropy weight method is used to determine the objective weight of each index, and the synthesis weights can be obtained by applying the principle of the integration means of addition. Because the AHP can introduce expert experience as well as personal preference information, while the entropy weight method can objectively and fully reflect the inherent information of desulfurization technology, the combined method can overcome the shortcomings of one single method and make the evaluation result more scientific and reasonable.

Assuming that using AHP to determine the subjective weight vector for W_S, and entropy weight method is used to determine the objective weight vector W_O. Through the integration means of addition, it is concluded that the final synthesis weights can be expressed by using the formulas below:

$$W = aW_S + bW_O \tag{1}$$

$$\begin{cases} a = \dfrac{1}{m-1}[(1P_1 + 2P_2 + \cdots + mP_m) - \dfrac{m+1}{m}] \\ b = 1 - a \end{cases} \tag{2}$$

where P_i is the corresponding components that the subjective weight vectors were sorted in ascending order, and m is the number of evaluating indexes.

C. STANDARDIZED PROCESSING

In account of different physical meaning and dimension information of each evaluation index, the evaluation index of different dimension and different order of magnitude can be correlated and analyzed. It is necessary to transform each index into dimensionless data of similar order of magnitude by standardization. Generally, there are initialization operator, mean operator and interval operator. In this paper, the average operator is used to sum up the sequence to be evaluated and the interval operator is used. When the average values of the 10 indexes corresponding to the reference sequence have obtained, the mean images of each quantity could be obtained by dividing the characteristic quantities of the 10 indexes in the six sequences by the corresponding average values.

$$\overline{X_i} = \frac{1}{6}\sum_{k=1}^{6} x_i(k), \quad k = 1, 2, 3, \ldots, 6 \tag{3}$$

III. UTILIZING CLOUD MODEL TO REALIZE QUANTITATIVE TRANSFORMATION OF THE QUALITATIVE INDEXES

The cloud model is kind of a mathematical model describing the uncertainty between the qualitative concept and its numerical description. It integrates both fuzziness and randomness and realizes the mutual mapping between qualitative and quantitative factors. Digital characteristics of the cloud are denoted by three parameters: expected value Ex, entropy En, and super entropy He. Notably, the expected value is the center of the property concept in the theory of domain, and the most representative of attribute concept. Entropy is the measure of the property concept fuzzy degree, which reflects the numerical range accepted by property concept. Hyper entropy reflects the degree of discrete cloud droplets, revealing the correlation between the randomness and the fuzziness of the attribute concept.

In the comprehensive evaluation index system of flue gas desulfurization technology, there are both qualitative indexes and quantitative indexes. In order to treat all indexes comprehensively through scientific computing, qualitative indicators must be converted into numerical form so that the quantitative evaluation index system will be established eventually. The qualitative indexes C_1 was divided into five levels: lab scale experiment, pilot-scale experiment, industrial demonstration, industrial application, and commercialization. C_2 is divided into simple, simpler, medium, more complex, and complex 5 levels. C_3 is divided into bad, worse, medium, better, and good 5 levels. C_4 is divided into small, smaller, medium, bigger, and big 5 levels [27].

The golden section method is adopted—the qualitative evaluation such as good, better, medium, bad, and worse were used for five types of cloud models. During the process of the specific application, the indexes that good for benefit-oriented are high or reasonable, but the cost index could be very low or unreasonable. The rest of the comment set is similar.

Middle cloud is assumed to be $C_0(E_{x0}, E_{n0}, \mathrm{H}_{e0})$, the clouds adjacent to its left and right side are $C_{-1}(E_{x-1}, E_{n-1}, \mathrm{H}_{e-1})$, $C_{+1}(E_{x+1}, E_{n+1}, \mathrm{H}_{e+1})$, $C_{-2}(E_{x-2}, E_{n-2}, \mathrm{H}_{e-2})$, $C_0(E_{x+2}, E_{n+2}, \mathrm{H}_{e+2})$.

Among them:

$$\begin{cases} E_{x0} = (x_{\min} + x_{\max})/2 \\ E_{x-2} = x_{\min} \\ E_{x+2} = x_{\max} \\ E_{x-1} = E_{x0} - 0.382(x_{\min} + x_{\max})/2 \\ E_{x+1} = E_{x0} + 0.382(x_{\min} + x_{\max})/2 \end{cases} \tag{4}$$

$$\begin{cases} E_{n-1} = E_{n+1} = 0.382(x_{\max} - x_{\min})/6 \\ E_n = 0.618E_{n+1} \\ E_{n-2} = E_{n+2} = E_{n+1}/0.618 \end{cases} \tag{5}$$

$$\begin{cases} H_{e-1} = H_{e+1} = H_{e0}/0.618 \\ H_{e-2} = H_{e+2} = H_{e+1}/0.618 \end{cases} \tag{6}$$

The effective domain is defined to [0,1], H_{e0} is given to 0.006, the calculations show that: good for corresponding model is (1,0.104,0.016), better for corresponding model is (0.691,0.064,0.010), medium for corresponding model is (0.5,0.039,0.006), worse for corresponding model is (0.309, 0.064, 0.010), and bad for corresponding model is (0,0.104,0.016). As shown in Figure 2.

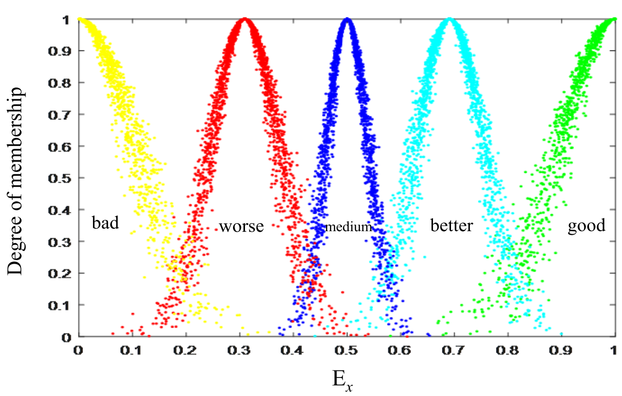

FIGURE 2. Clou model.

Through the language evaluation of h experts on qualitative indicators, each value of the language evaluation has a corresponding cloud model. h values of the language evaluation can be expressed as a comprehensive cloud model. Among them:

$$E_x = \frac{E_{x1}E_{n1} + E_{x2}E_{n2} + \cdots + E_{xh}E_{nh}}{E_{n1} + E_{n2} + \cdots + E_{nh}} \tag{7}$$

$$E_n = E_{n1} + E_{n2} + \cdots + E_{nh} \tag{8}$$

IV. THE KERNEL VECTOR SPACE METHOD

It is assumed that the n evaluation index values of m types of flue gas desulfurization technologies constitute the initial decision matrix $\boldsymbol{D}(d_{ij})_{n\times m}$. Because of differences in physical meaning and the dimension information that every evaluation index has, in order to make the evaluation index of different dimension and different order of magnitude can be correlated and analyzed, it is necessary to make every evaluation index into dimensionless data of similar order of magnitude by standardization processing, and the decision matrix $\boldsymbol{G}(g_{ij})_{n\times m}$ can be built after standardization processing.

According to the characteristics of each attribute of each feasible project, Multiple Criteria Decision Making (MCDM) not only can help the decision-maker to rank each practicable scheme, but also evaluate and select a scheme that conforms to the ideal of the decision-maker. The aim of MCDM is to find sufficiently good alternative(s) from a collection of alternatives, which attains the goal of each criterion. So we proposed the kernel vector space method and cloud model to solve the MCDM problem that the optimization of flue gas desulphurization technologies belongs to. The kernel vector space is a kind of kernel clustering idea based on clustering method. Compared with the space vector model, the kernel vector space can optimize the calculation process and make the calculation process simpler. In view of the advantages of the kernel vector space, this method is chosen to deal with practical problems. To simplify the operation, we assume that the samples to be evaluated are mapped to the high-dimensional feature space by the non-linear kernel function, the distance between the samples and the samples is further. Nonlinear kernels transform the inner product operation of m-dimensional high-dimensional space into the kernel function calculation of n-dimensional low-dimensional input space, which ingeniously solves the problem of "dimension disaster" in high-dimensional feature space, thus laying a theoretical foundation for solving complex problems in high-dimensional feature space. For the choice of the kernel function, according to the experience, we choose the most popular Gauss kernel function. Its corresponding feature space is infinite dimension, and the finite sample is definitely linear separable in the feature space. Assuming that the sample is hyperspherical in the input space, the scale parameter in the Gauss function can be the reciprocal of the hyperspherical radius, and its expression is shown in the formula (9).

$$Ker(x, y) = \exp\left(-\frac{\|x-y\|^2}{2\sigma^2}\right) \tag{9}$$

where σ >0 is the scale function of Gauss function; x, y are space vectors. The sample to be evaluated is expressed as a vector R of n-dimensional space coordinate system $(r_1, r_2, \ldots, r_n)$ by mathematical method, and then the reference limits of each evaluation index are determined. According to the optimum principle, the optimum value of each index is selected as the standard reference value in M models. The reference limits are also expressed as the vector R_i of n-dimensional space coordinate system $(r_{i1}, r_{i2}, \ldots, r_{in})$

after mathematical treatment. If two directions are taken in n-dimensional space, the reference limits are also expressed as the vector of n-dimensional space coordinate system. Quantities have common endpoints. The sample space vector and the standard reference vector are mapped to the kernel vector space by using the Gauss kernel function, and then the angle cosine of the two lines in the kernel space can be obtained.

$$\cos\theta_i = \frac{Ker\,(R, R_i)}{\sqrt{\mathrm{Ker}(R,R)}\sqrt{Ker\,(R_i,R_i)}} \tag{10}$$

Considering the difference caused by the different weights among the indicators, the weighted cosine values of the vector line segments in the kernel space affected by the weights of the indicators are regarded as the degree of sample approaching the standard state level, that is, the degree of approaching.

$$\cos\theta_i = \frac{Ker\,(RW, R_iW)}{\sqrt{\mathrm{Ker}(RW,RW)}\sqrt{Ker\,(R_iW,R_iW)}} \tag{11}$$

By calculating the closeness degree, the evaluation results of flue gas desulfurization technology can be obtained according to the principle of closeness selection. The closeness degree is the best technology of flue gas desulfurization. So the methodology flowchart of the article is shown in Figure 3.

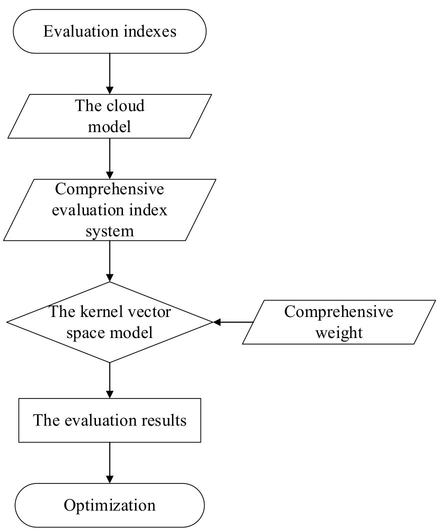

FIGURE 3. The flowchart of optimization of flue gas desulfurization.

V. APPLICATION EXAMPLES

For ease of analysis and comparison, in this paper, 6 typical flue gas desulfurization technologies were selected for calculation, such as: limestone wet process of desulfurization technology M_1, spraying calcium inside the furnace tail humidifying method M_2, rotating spray drying method M_3, simple wet constructed M_4, wet ammonia method M_5, and electron beam method M_6. Natural language assessment was conducted by 4 experts to evaluate the qualitative indicators of the schemes. Qualitative index evaluation information is obtained as shown in Table 1, each row in the table represents an expert's evaluation of the qualitative indicators of the corresponding scheme.

TABLE 1. Evaluation results of qualitative index.

Desulfurization technology	c_1	c_2	c_3	c_4
M_1	commercialization	simple	good	smaller
	commercialization	simple	good	small
	commercialization	simple	good	small
	commercialization	simple	good	smaller
M_2	industrial application	simpler	better	bigger
	industrial demonstration	simple	medium	medium
	industrial demonstration	simple	better	bigger
	industrial application	simple	medium	medium
M_3	industrial demonstration	simpler	medium	bigger
	industrial application	simpler	worse	medium
	industrial demonstration	simpler	medium	bigger
	industrial application	simpler	worse	medium
M_4	industrial demonstration	simple	medium	smaller
	industrial demonstration	simple	better	smaller
	industrial demonstration	simpler	medium	smaller
	industrial demonstration	simpler	better	smaller
M_5	industrial application	more complex	good	medium
	industrial application	more complex	medium	smaller
	industrial application	medium	good	smaller
	industrial application	medium	medium	medium
M_6	industrial demonstration	more complex	medium	smaller
	industrial demonstration	medium	worse	medium
	industrial demonstration	medium	worse	smaller
	industrial demonstration	more complex	medium	medium

TABLE 2. Original decision matrix.

Index	M_1	M_2	M_3	M_4	M_5	M_6
c_1	1.000 0	0.618 1	0.618 1	0.500 0	0.690 0	0.500 0
c_2	1.000 0	0.881 9	0.690 0	0.881 9	0.381 3	0.381 3
c_3	1.000 0	0.618 1	0.381 3	0.618 1	0.863 6	0.381 3
c_4	0.881 9	0.381 3	0.381 3	0.690 0	0.618 1	0.618 1
c_5/%	15.5	10.0	11.0	9.5	17.5	15.0
c_6/m^2	4 000	1750	2 750	2750	4 000	6 000
c_7/yuan	1 150	900	1 050	900	1 500	1 500
c_8/%	1.75	0.75	1.00	1.00	1.40	2.25
C_9/%	95.0	57.5	72.5	75.0	92.0	90.0
c_{10}	1.05	2.00	1.50	1.10	1.10	1.25

According to the nature of each index, the decision matrix after standardization and normalization is obtained by using the formula (3) as shown in Table 3.

While using AHP to get subjective weights, the objective weight is obtained by using the entropy weight method together with the decision matrix after standardized treatment. Take it into the formula (1) and (2) to get the comprehensive weight, results are shown in Table 4 and Figure 4.

TABLE 3. Initial decision matrix after standardization and normalization.

Index	M_1	M_2	M_3	M_4	M_5	M_6
c_1	1.868 9	-0.196 2	-0.196 2	-0.834 6	0.192 7	-0.834 6
c_2	1.108 9	0.668 3	-0.047 5	0.668 3	-1.198 9	-1.198 9
c_3	1.420 9	-0.102 3	-1.046 7	-0.102 3	0.877 0	-1.046 7
c_4	1.496 1	-1.115 4	-1.115 4	0.495 0	0.119 8	0.119 8
c_5/%	0.724 2	-0.923 7	-0.624 2	-1.073 6	1.323 0	0.574 3
c_6/m^2	0.310 1	-1.212 1	-0.535 5	-0.535 5	0.310 1	1.662 9
c_7/yuan	-0.060 6	-0.969 4	-0.424 1	-0.969 4	1.211 8	1.211 8
c_8/%	0.697 4	-1.0831	-0.638 1	-0.638 1	0.074 1	1.587 7
C_9/%	1.009 3	-1.571 3	-0.539 0	-0.367 0	0.802 7	0.665 4
c_{10}	-0.774 8	1.823 5	0.455 7	-0.638 3	-0.638 3	-0.227 8

TABLE 4. Weight of evaluation index.

Index	Subjective weight	Objective weight	Comprehensive weight
c_1	0.141 3	0.166 9	0.150 3
c_2	0.040 7	0.118 9	0.068 0
c_3	0.075 7	0.135 0	0.096 4
c_4	0.075 7	0.125 6	0.093 1
c_5/%	0.121 2	0.085 1	0.108 6
c_6/m^2	0.030 3	0.061 6	0.041 3
c_7/yuan	0.121 2	0.117 5	0.119 9
c_8/%	0.060 6	0.066 3	0.062 6
C_9/%	0.222 2	0.056 3	0.164 2
c_{10}	0.111 1	0.066 8	0.095 6

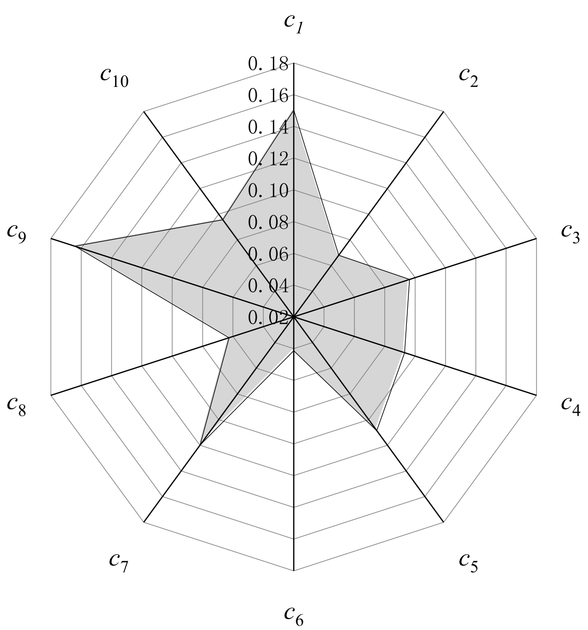

FIGURE 4. Comprehensive weights of various evaluation indicators.

Among them: process maturity c_1, technical complexity c_2, system upgrade performance c_3, and system negative impact c_4. the desulfurization system investment accounts for the proportion of the total power plants investment c_5, the floor space of desulphurization devices where the unit capacity is 300MW c_6, the cost of removing a ton of sulfur dioxide c_7, and power consumption accounts for the proportion of the total generating capacity c_8. desulphurization efficiency c_9, and calcium-sulfur mol-ratio c_{10}.

According to the formula, the closeness between the schemes and the standard reference schemes is calculated. The results are shown in Table 5.

TABLE 5. The proximity of evaluation schemes.

Desulfurization technology	*proximity*
M_1	0.950 2
M_2	0.874 3
M_3	0.910 1
M_4	0.900 0
M_5	0.904 4
M_6	0.850 9

The optimal membership degrees of each desulfurization technology scheme were sorted. The result is $u_1 > u_3 > u_5 > u_4 > u_2 > u_6$, so the first type of desulfurization technology is the relative optimal scheme. This is consistent with the results of the fuzzy comprehensive evaluation [27] and gray level analysis [28].

By using the method mentioned in this paper, 6 different desulfurization technologies were evaluated from the aspects of technical character, economical character, and environmental protection, respectively. The conclusion is that: from the technical aspect, the optimal scheme is M_1; from the economic aspect, the optimal scheme is M_2; from the environmental protection aspect, the optimal scheme is M_1. It can be seen that the resulting optimal scheme of the flue gas desulfurization technology is not the same when evaluating with different aspects. Thus, it is necessary to take various factors into account when evaluating different flue gas desulfurization technologies, so that the optimal scheme can be obtained comprehensively, synthetically, and systematically.

By using the method of literature [27] – [28] to analyze the example, the final statistical result is shown in Table 6.

TABLE 6. Comparison of the evaluation results.

Desulfurization technology	literature[27]	literature[28]	This article
M_1	0.180 0	0.831 2	0.950 2
M_2	0.170 0	0.765 3	0.874 3
M_3	0.159 0	0.732 9	0.910 1
M_4	0.162 0	0.820 2	0.900 0
M_5	0.157 0	0.754 6	0.904 4
M_6	0.172 0	0.692 7	0.850 9

From the results of Figure 5, we can see that the proximity degree of the model proposed in this paper is significantly greater than that of the fuzzy comprehensive evaluation model and the gray analytic hierarchy process model, which makes the evaluation results more reasonable and credible.

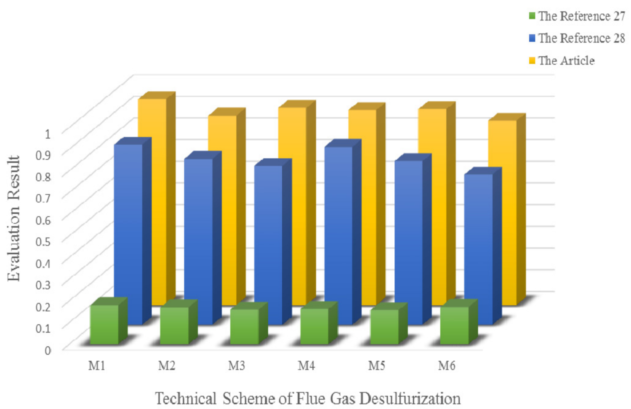

FIGURE 5. Comparison of rating results.

The decision-making results of the fuzzy comprehensive evaluation method depend largely on the selection of the membership function of each evaluation index, and its processing method is difficult to unify. Grey AHP uses the principle of maximum correlation degree to determine the quality of the scheme, which is prone to the problem that the correlation difference is small, and it is difficult to make an accurate judgment. The method mentioned in this paper has a solid mathematical foundation, simple implementation and easy programming. In addition, the degree of closeness between each scheme and the optimal one also provides directions and ideas for the improvement of all schemes to the optimal one.

VI. CONCLUSIONS

The decision-making model proposed in this paper is more in line with the actual situation in China. When installing or building a new desulfurization system in the cogeneration projects, it can be used as a relatively simple comprehensive evaluation tool of reference for thermal power enterprises to screen the most reasonable desulfurization process scheme which is economically, technically feasible and environmentally friendly. The optimal technical model of flue gas desulfurization provides a strong guarantee, which further promotes the practical application of desulfurization technology in new cogeneration projects and has a good value in practicality. The achievements are shown as follows.

(1) The cloud model is used to solve the problems of representing qualitative evaluation index quantitatively in the optimization of flue gas desulfurization technology and as a result, the quantitative decision information is realized completely. In this way, the technology performance was described as the quantitative decision information that can be used in evaluation and calculation just as economic and environmental index. By introducing the experience of experts from the desulfurization field through natural language, it does not only confirm the common-sense thinking, but also reflects the characteristics of the optimal flue gas desulfurization technology.

(2) The subjective weight of each index is determined by the AHP. The entropy weight method is used to determine the objective weight of each index. And the synthesis weights can be obtained by applying the principle of the integration means of addition. The combination weighting method comprehensively considers the influence of both subjective factors and objective information, which makes the final evaluation result more scientific and reasonable.

(3) The kernel vector space method is used to analyze the relationship between the sub-indexes in the evaluation index system. That avoids the one-sidedness of the decision making that uses only a single index evaluation value for each scheme. All aspects of the evaluation information are taken into account so that the reliability of the decision model is improved. It has been proved that the kernel vector space method and the cloud model have a great effect in handling MCDM issue. Besides, the concept of proximity is introduced and compared with the traditional method, the decision proximity of the proposed model is larger than that of the traditional method, which further provides direction and ideas for transforming the selected scheme to the optimal one.

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