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The compatibility approach for hazardous waste incineration based on grey relational analysis

Xuedong Liang, Yangyang Xu, Li Yang and Qunxi Gong ¹

Sichuan University, Chengdu 610065, China.

¹ Email: gongqunxi_scu@163.com

Abstract. Incineration compatibility plays an irreplaceable role in the incineration process of hazardous waste. This paper introduces the Grey Relational Analysis (GRA) method for the incineration compatibility to empower each hazardous waste. In order to obtain a reasonable incineration compatibility scheme, an index system was constructed from the calorific value, water content, corrosivity and toxicity which affect the incineration effect, and the method model of incineration compatibility was established by using Grey Relational Analysis, and the relevant cases were analyzed. The research results show that the incineration compatibility scheme based on the Grey Relational Analysis method ensures the stability of incineration and improves the efficiency and quality of incineration under the premise of reducing and harmless hazardous waste.

1. Introduction

Hazardous waste is toxic, flammable, explosive, corrosive, reactive, infectious, radioactive, etc. [1], can cause serious pollution to the air, water and soil, destroy the ecological environment and endanger human health. Among the various existing disposal technologies, the most effective and fastest is the incineration technology, which can treat harmful and toxic components in waste by incineration, thereby realizing the reduction and harmlessness of hazardous waste [2]. Among them, the most important input link is the incineration compatibility of hazardous waste. Reasonable incineration compatibility has a direct impact on the nature of incineration. It has an indirect impact on the consumption of incineration energy and the stability of incineration process. Therefore, the incineration compatibility of hazardous waste plays an irreplaceable role in the incineration process.

However, most factories have relied on the experience of the plant manager or engineer to conduct qualitative analysis when burning compatibility [3], this results in an incineration effect that depends on the accuracy of the experience and judgment of the plant manager or engineer, making it difficult to form a scientific and standard approach. To solve these problems, this paper introduces grey correlation analysis, through quantitative analysis to empowerment for each hazardous waste, then obtain reasonable compatibility program, achieve the reduction and harmless treatment of hazardous waste, ensure the stability of incineration, and improve the efficiency and quality of incineration.

2. Literature review

The word of compatibility comes from traditional Chinese medicine. When the application of a medicinal material is not effective, it is necessary to choose other medicinal materials for reasonable compatibility to achieve better therapeutic effect, and if the compatibility is not appropriate, it will not achieve the purpose of treatment, and may bring other harm [4]. In the process of incinerating



industrial hazardous waste, the word compatibility is quoted [5]. Through the principle of incineration flue gas of harmful substances produced analysis can be drawn from the main source of harmful substances in the flue gas incineration is the incineration of hazardous industrial waste, therefore, in order to achieve qualified flue gas emissions and stable incineration conditions, it is necessary to rationally match the types and quantities of hazardous wastes with complex composition and various forms.

The research on the compatibility of hazardous waste is now mainly divided into two directions. Some scholars focus on the study of compatibility theory: Liu Guoyong [6] proposed the treatment of hazardous industrial hazardous waste incineration for the characteristics of hazardous substances and incineration treatment process, and analyzed the main principles and precautions of compatibility in detail; Lu Saijun, Yan Yiwei et al. [7] discussed the compatibility of hazardous wastes, the overall calorific value, and the weighted average of the elements, which affect the compatibility of materials. Another part of the scholars focus on the exploration of compatibility methods: Xing Yangrong [8] considered the principle and process of hazardous waste incineration reaction, and formed a list of incineration hazardous wastes after physicochemical analysis of incineration hazardous wastes, matching various types of hazardous waste through the list to keep the temperature and smoke composition of the incinerator relatively stable; JiaErheng Ahati et al. [9] studied the compatibility methods and compatibility of various hazardous chemicals in the conditions of meeting the calorific value and load of the incinerator, the calorific content, total moisture content and total sulfur content of the materials after compatibility were determined, and the most suitable combination was found through actual compatibility; Yu Shufen et al [10] developed an expert compatibility system based on SQL Server 2000 database and Delphi language, according to the form, physical properties, compatibility and calorific value of hazardous waste, and treated them separately for hazardous waste compatibility. AK Nema , SK Gupta [11] use formulation to addresses important practical issues like unique characteristics of the hazardous wastes reflecting on waste–waste and waste–technology compatibility. A utility function approach is presented to integrate both cost and risk related objectives.

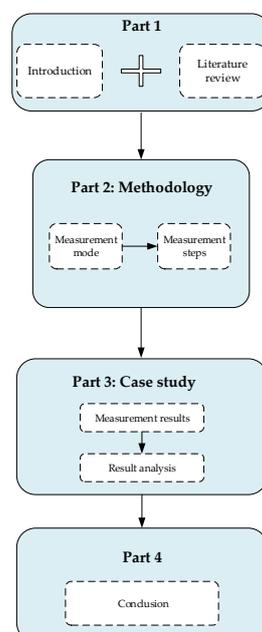


Figure 1. Research framework of the compatibility approach for hazardous waste incineration based on grey relational analysis.

Scholars have done a lot of work in hazardous waste incineration and have achieved remarkable results, however, most of the previous studies were qualitative and lacked quantitative research. In this paper, the grey correlation analysis method is used to study the main factors affecting the incineration of hazardous wastes, under the premise of meeting the compatibility of different hazardous wastes, then determine the weight of different hazardous wastes, find a reasonable incineration compatibility program, and achieve hazardous waste reduction and harmless. Figure 1 shows the detailed study of the frame.

3. Determine the weight by Grey Relational Analysis

The relational analysis in the grey system theory [12] is a new factor analysis method, it mainly analyzes the degree of association of various factors in the system by comparing the geometric relationship of the system data sequence, the value is used to indicate the value of the index value in the sequence to be evaluated close to the corresponding index value in the optimal reference sequence, a larger value indicates a higher degree of closeness [13]. This paper draws on the grey correlation analysis method to weight the indicators. The calculation steps are as follows.

3.1. Data standardization

Considering the hazardous waste set $M = \{M_1, M_2, \dots, M_m\}$, the main factors set affecting the incineration of hazardous waste $T = \{T_1, T_2, \dots, T_n\}$, constructing an indicator matrix A_{ij} .

$$A_{ij} = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix}$$

Standardize the indicator matrix, for the benefit indicator (the larger the indicator value is, the better) and the cost indicator (the larger the index value, the better):

$$\begin{cases} x'_{ij} = \frac{x_{ij} - \min x_i}{\max x_i - \min x_i}, & \text{the benefit indicator} \\ x'_{ij} = \frac{\max x_i - x_{ij}}{\max x_i - \min x_i}, & \text{the cost indicator} \end{cases}$$

Standardized matrix A'_{ij}

$$A'_{ij} = \begin{bmatrix} x'_{11} & x'_{12} & \dots & x'_{1n} \\ x'_{21} & x'_{22} & \dots & x'_{2n} \\ \dots & \dots & \dots & \dots \\ x'_{m1} & x'_{m2} & \dots & x'_{mn} \end{bmatrix}$$

3.2. Determine the reference sequence

In the indicator matrix is a comparison series. Reference sequence:

$$M_0 = \{\gamma_1, \gamma_2, \dots, \gamma_n\}$$

$$\begin{aligned} \gamma_1 &= \max \{x'_{11}, x'_{21}, \dots, x'_{m1}\} \\ \gamma_2 &= \max \{x'_{12}, x'_{22}, \dots, x'_{m2}\} \\ &\dots \\ \gamma_n &= \max \{x'_{1n}, x'_{2n}, \dots, x'_{mn}\} \end{aligned}$$

3.3. Calculate the relational coefficient

Calculate the correlation coefficient of M_j to M_0 for the hazardous waste k using the formula [14] as follows:

$$\theta_j(k) = \frac{\min_j \min_k |M_0(k) - M_j(k)| + \rho \max_j \max_k |M_0(k) - M_j(k)|}{|M_0(k) - M_j(k)| + \rho \max_j \max_k |M_0(k) - M_j(k)|} \tag{1}$$

Where ρ is the resolution coefficient, which can reduce the influence of the extreme value on the calculation, $\rho \in [0,1]$, generally takes $\rho \leq 0.5$, and $\rho=0.5$ in the method.

3.4. Calculate the degree of association

The degree of association is the embodiment of the relationship between the reference sequence and the comparison sequence. The calculation formula is as follows:

$$m_j = \frac{1}{m} \sum_{k=1}^m \theta_j(k) \tag{2}$$

3.5. calculate the weight

Calculate the weights using the formula below:

$$W_j = \frac{m_j}{\sum_{j=1}^m m_j} \tag{3}$$

4. Compatibility of hazardous waste

After determining the weighting of each type of hazardous waste, the method of compatibility of hazardous waste is as follows:

$$M_1W_1 + M_2W_2 + \dots + M_mW_m = \sum \sum MW \tag{4}$$

The amount of hazardous waste in the incineration compatibility is: M_1, M_2, \dots, M_m , this will give you a steady state:

$$T_{T_i} = \sum_{j=1}^m \sum_{i=1}^n T_i M_j \tag{5}$$

5. Case study

There is a hazardous waste disposal company, assuming 10 kinds of hazardous wastes can be burned in the warehouse $M=\{M_1, M_2, \dots, M_{10}\}$, consider the four indicators of calorific value, water content, corrosion and toxicity of each hazardous waste $T=\{T_1, T_2, \dots, T_4\}$, now considering the incineration of hazardous waste, it is first necessary to determine the hazardous waste compatibility scheme for incineration.

In solving the above problems, certain assumptions need to be met: The hazardous wastes burned meet the compatibility, that is, the acidic and alkaline materials cannot be fed together; the materials

that are mixed with each other to generate heat and gas cannot be put together; the materials that react with water cannot be directly compatible.

5.1. Initial data

The initial data sheet is as follows Table 1:

Table 1. The table of initial data.

	1	2	3	4	5	6	7	8	9	10
T1	12000	14000	15000	14000	9000	12000	14000	13000	8900	11000
T2	15	25	17	20	25	23	22	21	19	18
T3	6	1	5	9	7	4	4	6	2	7
T4	3	2	4	6	4	4	5	7	6	2

The unit of T1 is KJ/KG, T3 and T4 were evaluated using the 1~9 scale method. Standardize Table 1 to obtain a new indicator value Table 2.

Table 2. The table of standardized data.

	1	2	3	4	5	6	7	8	9	10
T1	0.5082	0.8361	1.0000	0.8361	0.0164	0.5082	0.8361	0.6721	0.0000	0.3443
T2	1.0000	0.0000	0.8000	0.5000	0.0000	0.2000	0.3000	0.4000	0.6000	0.7000
T3	0.3750	1.0000	0.5000	0.0000	0.2500	0.6250	0.6250	0.3750	0.8750	0.2500
T4	0.8000	1.0000	0.6000	0.2000	0.6000	0.6000	0.4000	0.0000	0.2000	1.0000

5.2. calculate the weight of M_j

Calculate the relational coefficient according to the relational coefficient formula, and get Table 3:

Table 3. The table of relational coefficient.

	1	2	3	4	5	6	7	8	9	10
T1	0.5041	0.7531	1.0000	0.7531	0.3370	0.5041	0.7531	0.6040	0.3333	0.4326
T2	1.0000	0.3333	0.7143	0.5000	0.3333	0.3846	0.4167	0.4545	0.5556	0.6250
T3	0.4444	1.0000	0.5000	0.3333	0.4000	0.5714	0.5714	0.4444	0.8000	0.4000
T4	0.7143	1.0000	0.5556	0.3846	0.5556	0.5556	0.4545	0.3333	0.3846	1.0000

From Table 3, the relational is calculated according to the correlation degree calculation formula (2):

$$m_j = \{2.6629, 3.0864, 2.7698, 1.9710, 1.6259, 2.0157, 2.1957, 1.8363, 2.0735, 2.4576\}$$

Finally, the relational degree obtained is normalized, and the weight of each hazardous waste is:

$$W_j = \{0.1173, 0.1360, 0.1220, 0.0868, 0.0716, 0.0888, 0.0967, 0.0809, 0.0914, 0.1083\}$$

5.3. determine compatibility program

After obtaining the compatibility weight of each type of hazardous waste, the compatibility scheme of each hazardous waste in the incineration process can be obtained. The amount of each hazardous waste per kilogram of mixed waste is

$$M_j = \{0.1173, 0.1360, 0.1220, 0.0868, 0.0716, 0.0888, 0.0967, 0.0809, 0.0914, 0.1083\}$$

The indicators for the mixed waste incineration program are: T1=12479.80 KJ/KG、T2=20.23%, T3=4.90, T4=4.09

6. Conclusions

Reasonable incineration compatibility can make combustion stable and detoxification thorough. At the same time, it can save combustion fuel, protect refractory materials and prolong the service life of incineration facilities. It is of theoretical and engineering significance to study the compatibility of hazardous waste incineration based on grey correlation. Through research, the following conclusions are drawn:

- (1) By introducing the grey correlation analysis method for incineration compatibility, a quantitative compatibility method model was established to make the incineration compatibility achieve breakthroughs from experience to science, and the compatibility method was more scientific and standardized;
- (2) The method was verified by case and a reasonable incineration compatibility scheme was obtained to prove the effectiveness of the method.

Further research work will introduce the concept of information entropy and conduct in-depth research on the weighting methods in the model.

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