

Data-driven analysis of product interactions during biomass pyrolysis

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Abstract. Pyrolysis technology, crucial for sustainable energy in light of the energy crisis and environmental concerns, was studied using a model compound method involving desulfurization ash with cotton straw and a model compound. This study focused on the catalytic effects of desulfurization ash on the pyrolysis product formation from cotton straw. Key findings include a negative correlation between tar yield and the yields of carbon, water, and syngas, but a positive correlation with other pyrolysis products. Specifically, in the DFA/CE combination, tar and carbon yields were positively correlated, but negatively correlated with syngas and water yields. In DFA/LG, however, tar yield negatively correlated with water and carbon yields. Analysis using visual charts indicated that the H₂ yield in DA/CS significantly fluctuated and positively correlated with the mixing ratio. In DFA/CE, a negative correlation existed between H₂ yield and the combination ratio. For DFA/LG, the trends of CO and CH₄ were consistent with C₂H₆ and H₂, with a stable C₂H₆ rate and CO positively correlating with CO₂. The Lilliefors test, ANOVA, and Spearman's correlation coefficient revealed no significant difference in the yields of pyrolysis products and gases between CE and LG under the same desulfurization ash proportions.

Keywords: Spearman correlation coefficient, Pearson correlation coefficient, ANOVA, frequency analysis

1. Introduction

Biomass is the only renewable organic carbon resource in nature, which is abundant, continuously renewable, and has the advantages of low cost and carbon neutrality^[1]. Many policies have been formulated at home and abroad to promote the wide application of biomass resources, such as China's 14th Five-Year Plan for Renewable Energy, the United States' Higher Blends Infrastructure Incentive Program (HBIIP), and the European Union's Renewable Energy Directive (RED). It is of great significance to study the mechanism and properties of pyrolysis products of materials, as well as the mechanism and role of catalysts in the pyrolysis process, for the efficient utilization and sustainable development of biomass.

In this paper, correlation analysis and analysis of variance are applied to pyrolysis catalysis and new energy development Zhao et al used the Pearson correlation coefficient to analyze the correlation between the total nitrogen concentration in the Great Lake and the relevant operating indicators of the municipal sewage treatment plant^[2]Li et al used the Pearson correlation coefficient to study the correlation between the dual control policy of energy consumption and the energy utilization efficiency of high-energy-consuming industries^[3], and the Spearman correlation coefficient is used for the group, The correlation analysis between the absolute and relative values of the average annual power outage loss load and the system inertia constant of China's power grid is carried out^[4], Xuan et al used the Spearman correlation coefficient for the correlation analysis between river runoff and sediment transport^[5], Cai et al uses ANOVA for die forging die wear study^[6]. Zhang et al used analysis of variance to explore the influence of various influencing factors on the mechanical characteristics of machine-picked cotton^[7].

Cotton stalks, as an agricultural waste rich in cellulose and lignin, were studied for their biomass potential^[8]. The pyrolysis process involved combining desulfurization ash with cotton straw and a

model compound. CE (fiber oligosaccharides) and LG (lignin), representing cellulose and lignin in cotton stalks, were selected as model compounds. This study pyrolyzed these combinations at various ratios to examine the catalytic effect of desulfurization ash on pyrolysis product formation. The analysis included box plot assessments for missing values, Pearson correlation to explore the relationship between pyrolysis combinations, visualization of mixing ratios and gas yields to identify general trends, and frequency analysis to validate these trends. Statistical analysis of pyrolysis products evaluated differences in yields between CE and LG and gas yields. The Lilliefors test checked for normal data distribution, using ANOVA for normally distributed data and Spearman's coefficient for significance analysis otherwise.

2. Initial excavation of pyrolysis relationship

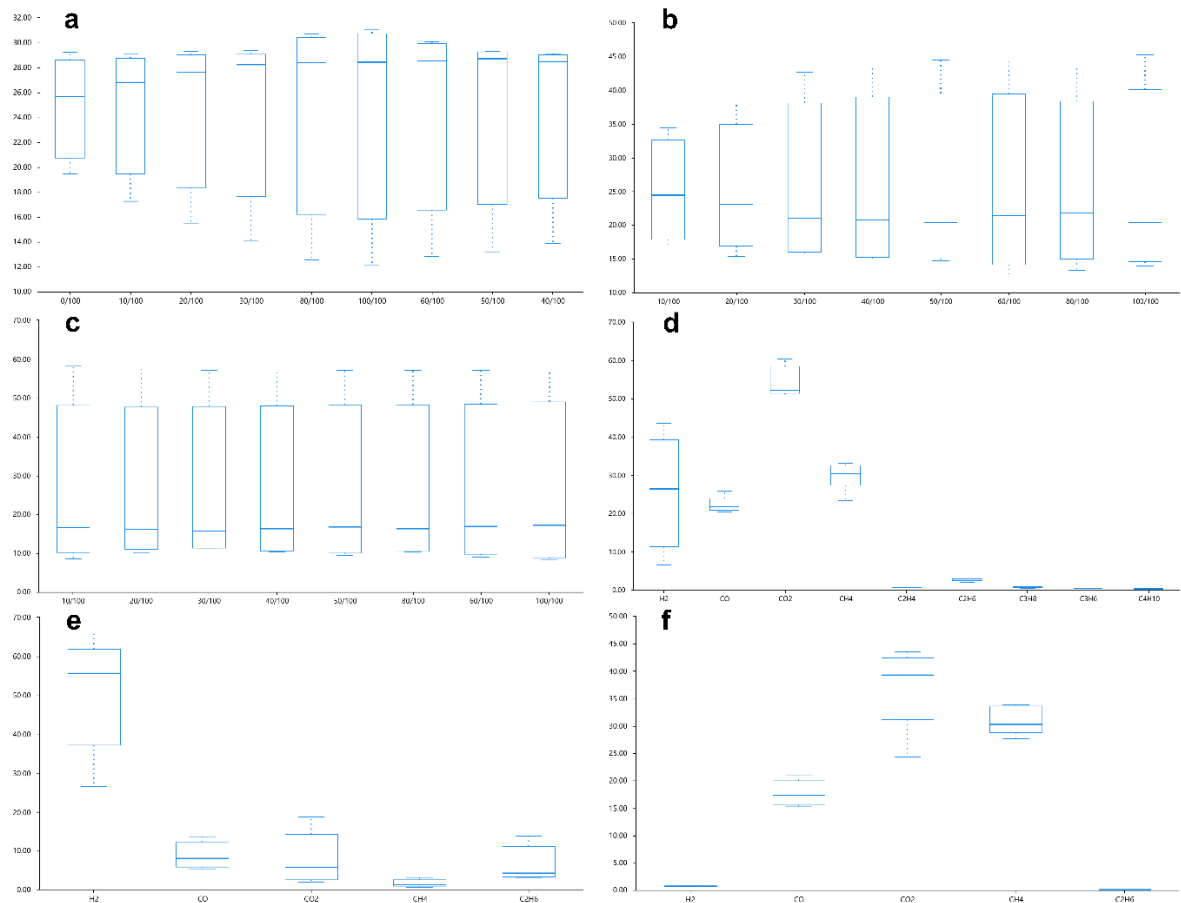


Figure 1. Box plot of the yield of DFA/CE, LG pyrolysis products, and pyrolysis gas As shown in figure 1. Indicates that there are no outliers or missing values in the data.

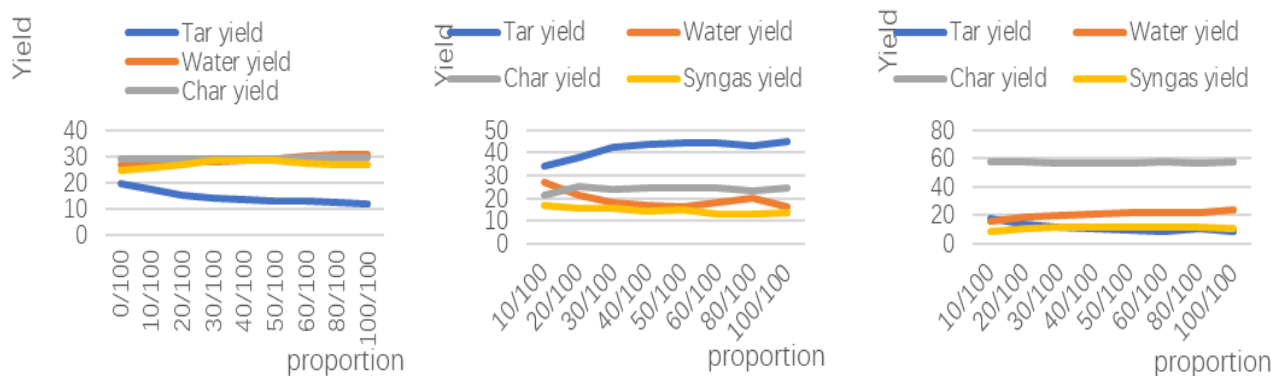


Figure 2. DA/CS, DFA/CE, DFA/LG pyrolysis combination ratio

As shown in figure 2. In DA/CS, the tar yield was negatively correlated with the pyrolysis ratio, the carbon yield and water yield were positively correlated with the pyrolysis ratio, the syngas yield had an optimal solution ratio of 50/100, and in DFA/CE, the tar yield was positively correlated with the pyrolysis ratio, the carbon yield remained stable, and the mixing ratio with the highest yield of water yield was between 50/100 and 80/100. Among DFA/LG, there was a positive correlation between water yield and pyrolysis combination, and the pyrolysis mixing ratio had no obvious effect on the yield of syngas and carbon production but was negatively correlated with tar yield.

There are no outliers in the data, and a line chart is drawn to explore the effect of the pyrolysis ratio on each pyrolysis product.

Then, the correlation analysis, the Pearson correlation coefficient analyzes the correlation between tar yield, water yield, carbon yield, and syngas yield.

In Table 1, the Pearson correlation coefficient between tar yield and synthesizer is less than zero for each pyrolysis combination, indicating that there is a negative correlation between tar yield and syngas for any set of pyrolysis combinations. There was a negative correlation between tar yield and water yield in DFA/CS and DFA/CE, but a positive correlation in DFA/LG, and a negative correlation between tar yield and carbon yield in DFA/CS and DFA/LG, and a positive correlation in DFA/CE.

Table 1. Pearson correlation coefficient of each pyrolysis combination

	Tar production	Carbon yield	Water production	synthesis gas
Tar production	1	-.678*	-.892**	-.783*
Carbon yield	-.678*	1	.878**	0.124
Water production	-.892**	.878**	1	0.42
synthesis gas	-.783*	0.124	0.42	1

3. Exploration of the effect of mixing ratio on pyrolysis gas

Firstly, the fluctuation of pyrolysis gas generated by each heat combination under different proportions was explored.

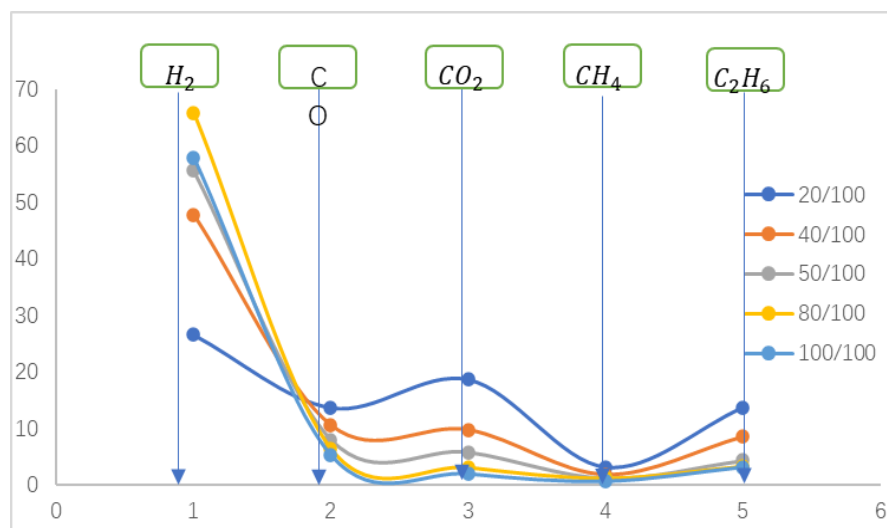


Figure 3. DFA/CS combination ratio and pyrolysis gas yield

As shown in figure 3. For DA/CS pyrolysis mixing, the changing trend is the same when the mixing ratio is between 0/100 and 20/100 when the mixing ratio of the pyrolysis combination is between 40/100 and 100/100, the pyrolysis combination has the same change trend, in these pyrolysis combination ratios, the H₂ yield fluctuates with the mixing ratio is more obvious, and it is positively correlated, with the continuous decrease of the mixing ratio of pyrolysis combination, in 20/100 and 40/100, reaching a peak, the yield of pyrolysis gas on the left side of the peak increases with the increase of the mixing ratio, and the pyrolysis gas on the right side of the peak decreases with the increase of the proportion, when the ratio reaches 60/100, the yield of pyrolysis gas tends to be flat.

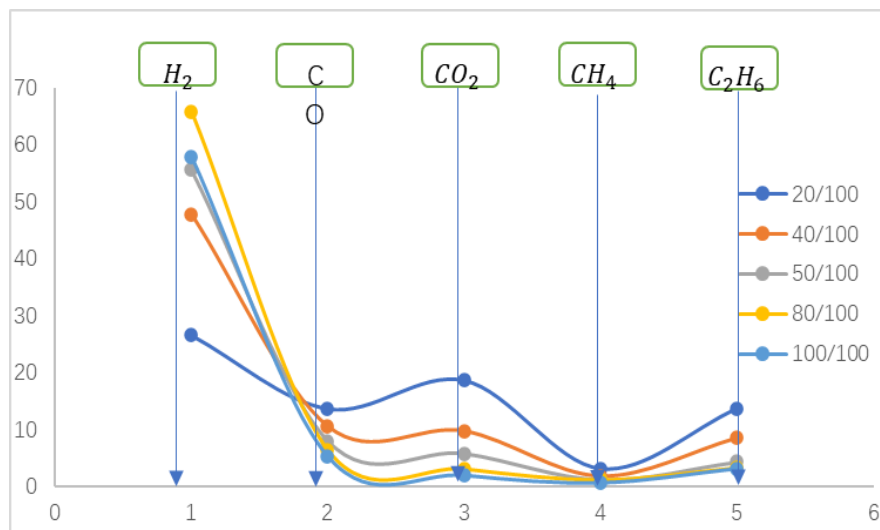


Figure 4. DFA/CE combination ratio and pyrolysis gas yield

As shown in figure 4. There was a positive correlation between H₂ and pyrolysis ratio, and CO, CO₂, CH₄, and C₂H₆ showed the same change trend, and all showed negative correlation, indicating that under the influence of the mixing ratio, the generation of each pyrolysis gas fluctuated significantly, and the mixing ratio had a significant effect on the pyrolysis gas.

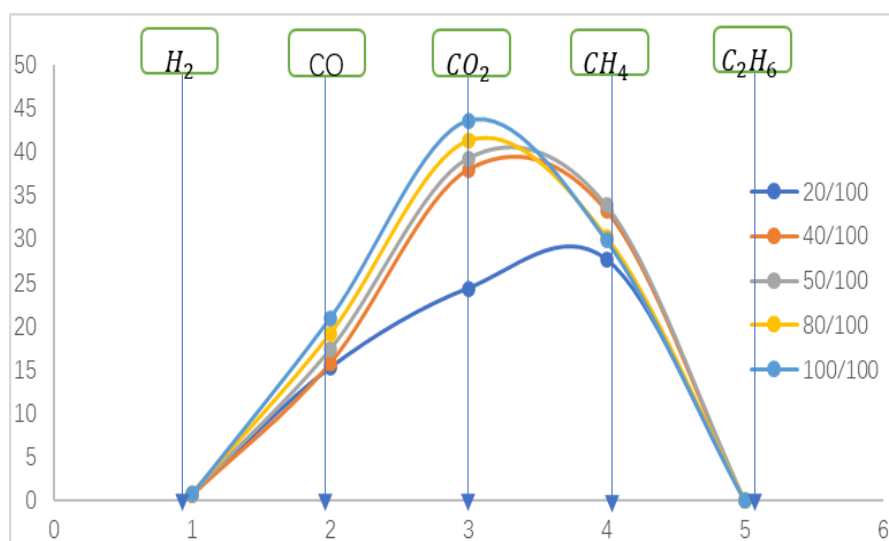


Figure 5. DFA/LG combination ratio and pyrolysis gas yield

As shown in figure 5. The changing trend of H₂ and C₂H₆ was the same, and the mixing ratio did not affect the two, indicating that DFA could not play a catalytic role in the formation of these two pyrolysis gases of LG, and CO and CO₂ were positively correlated with the mixing ratio, indicating that DFA had a promoting effect on the formation of two gases, and the optimal ratio of CH₄ was 50/100, which increased with the increase of the proportion on the left side of the ratio and decreased with the increase of the proportion on the right side of the ratio.

Then, the variation trend of each pyrolysis gas under different proportions was further explored.

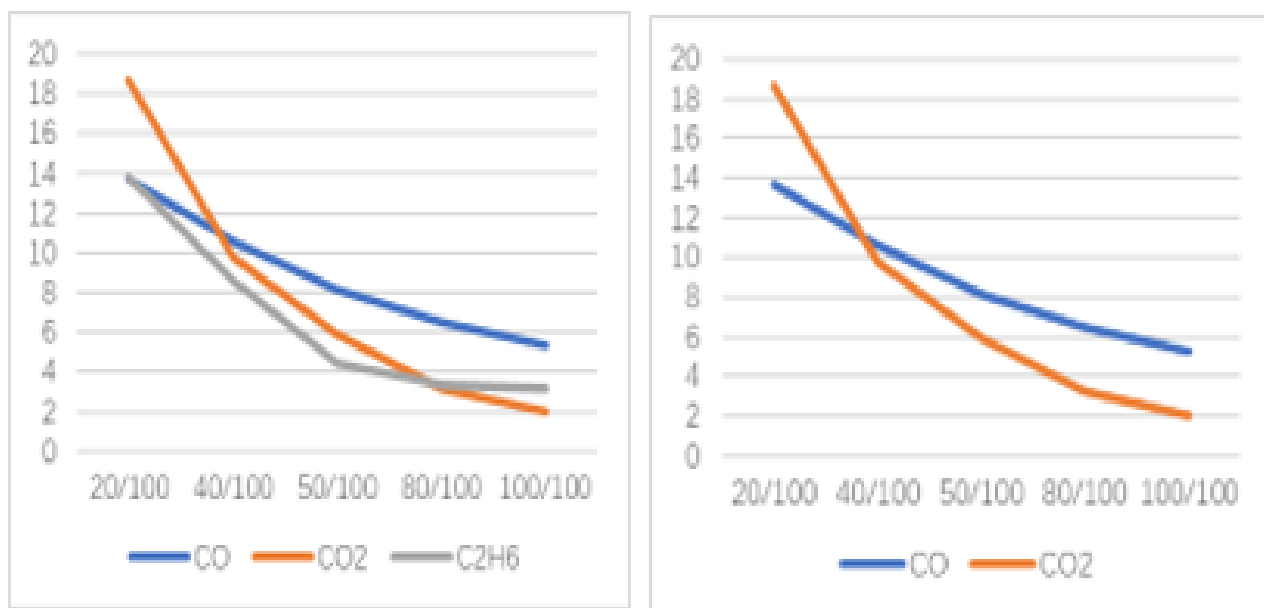


Figure 6. Change in DFA/CE pyrolysis gas yield

As shown in figure 6. The yield of CH₄ decreased with the increase of the ratio, and the yield of H₂ increased first and then decreased with the increase of the ratio, and the optimal ratio of H₂ was 80/100. The pyrolysis gas yields of CO and CO₂ decreased with the increase of the ratio, and the slope of CO₂ was larger than that of CO, indicating that the CO₂ decreased faster when the mixing ratio was equal to the gradient. The optimal ratio of C₂H₆ pyrolysis gas yield was 50/100.

Then, the frequency analysis was carried out to verify whether the results of the above pyrolysis combination on the pyrolysis gas yield were reliable.

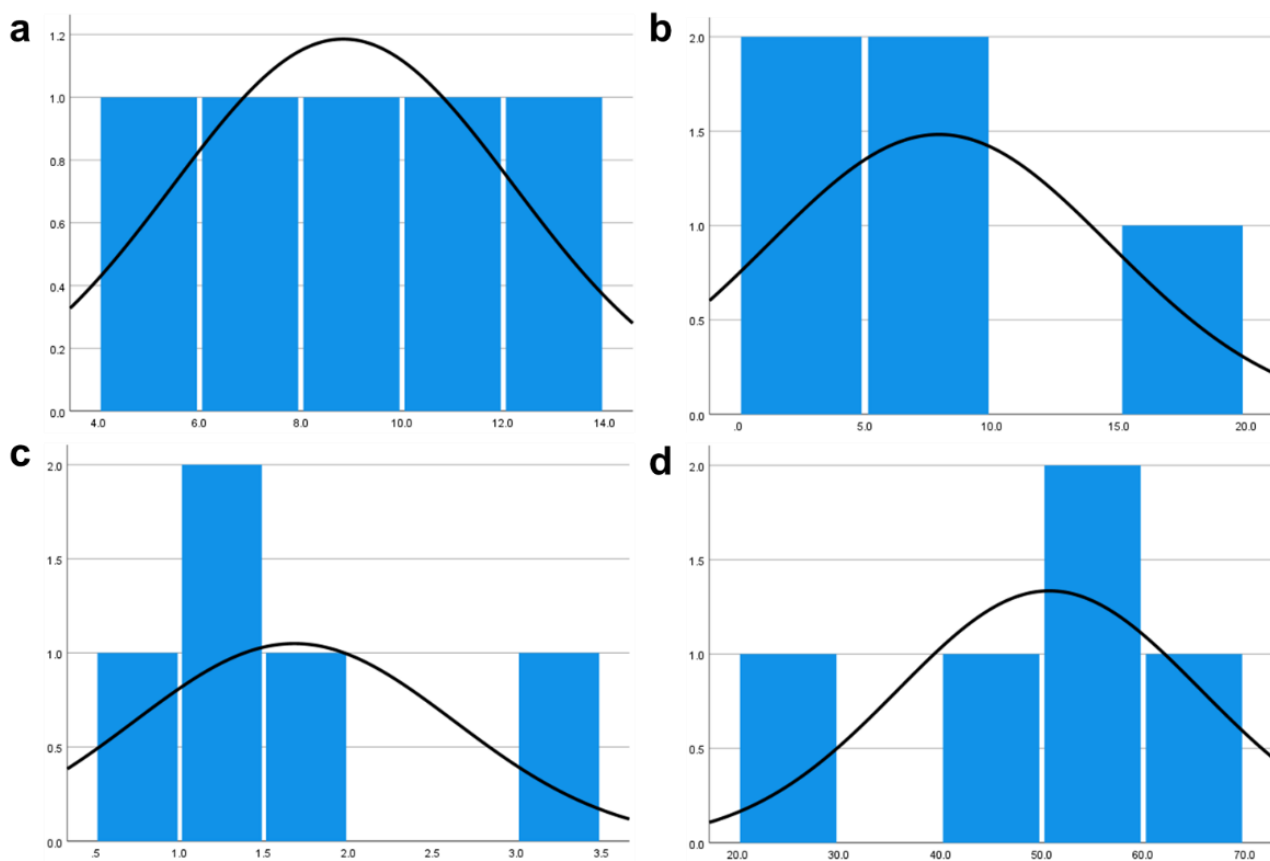


Figure 7. DFA/CE frequency diagram

a: H₂ **b:** CO **c:** CH₄ **d:** C₂H₆

As shown in figure 7.DFA/CE, with the gradual increase of the proportion of the combination of the proportion, the yield of the pyrolysis gas of CO and CO₂ showed a negative correlation, the yield of C₂H₆ decreased first and then flattened to nearly the same with the increase of the proportion, the yield of CH₄ decreased with the increase of the mixing ratio of the pyrolysis combination, and the yield of H₂ increased with the increase of the mixing ratio of the pyrolysis combination, and then showed a downward trend.

It is consistent with the above analysis results, and the results are reliable.

4. Statistical analysis of pyrolysis products

To explore the differences in the yields of CE and LG pyrolysis products, the yields of CE and LG pyrolysis products and the differences in the composition of pyrolysis gas were analyzed under the same ratio. Tables 4 and 5 are the product yield and pyrolysis gas yield of CE and LG under different ratios, respectively.

Table 2. CE, LG product yields

10/100		20/100		30/100		40/100		50/100		60/100		80/100		100/100	
CE	LG	CE	LG	CE	LG	CE	LG	CE	LG	CE	LG	CE	LG	CE	LG
34.42	18.06	38.31	13.77	42.69	11.29	43.78	10.28	44.53	9.49	44.41	9.02	43.24	10.3	45.28	8.19
27.42	15.3	21.37	18.54	17.84	20.17	16.9	20.97	16.25	21.53	18.25	21.87	19.93	21.41	16.14	23.69

Table 3. Pyrolysis gas yield of CE and LG

20/100		40/100		50/100		80/100		100/100	
CE	LG	CE	LG	CE	LG	CE	LG	CE	LG
26.6	0.67	47.8	0.72	55	0.78	65	0.81	57	0.79
13.7	15.23	10.6	15.76	8.1	17.305	6.5	19.075	5.3	20.935
18.7	24.35	9.8	37.91	5.9	39.26	3.2	41.23	2	43.56
3.2	27.67	1.9	33.25	1.3	33.86	1.3	30.26	0.7	29.87
13.8	0.08	8.6	0.06	4.4	0.09	3.4	0.07	3.2	0.05

In table 2 and 3, Firstly, the Lilliefors test is used to return a test decision for the null hypothesis, which is that the data of vector x are from the distribution in the normal distribution family, and the return result h is 0 to indicate that it conforms to the normal distribution, 1 means it does not conform to it, and Table 4 and Table 5 are the normal test tables of CE, LG product yield and pyrolysis gas yield.

Table 4. Normal distribution test of CE and LG product yields

CE	H	p	LG	h	p
0/100	0	0.5	10/100	0	0.055973
20/100	0	0.5	20/100	0	0.064012
30/100	0	0.32055	30/100	0	0.114828
40/100	0	0.46279	40/100	0	0.145506
50/100	0	0.409216	50/100	0	0.170972
60/100	0	0.424167	60/100	0	0.188312
80/100	0	0.23713	80/100	0	0.165539
100/100	0	0.434785	100/100	0	0.341277

Table 5. Normal test of pyrolysis gas yield of CE and LG

CE	h	p	LG	h	p
20/100	0	0.5	20/100	0	0.437425
40/100	1	0.005472	40/100	0	0.5
50/100	1	0.003482	50/100	0	0.5
80/100	1	0.001458	80/100	0	0.5
100/100	1	0.001352	100/100	0	0.493391

In table 4 and 5, The yields of CE and LG products were normally distributed, and the analysis of variance was used to judge the difference^[9] The yield of pyrolysis gas does not conform to the normal state, and the Spearman correlation coefficient is used to judge the difference between the two^[10].

The analysis of variance showed that $p < 0.05$ was an unlikely event with significant differences, and $p > 0.05$ was possible with no significant differences, and the test results in Table 6 were obtained

Table 6. Analysis of variance of CE, LG on product yield

	10/100	20/100	30/100	40/100	50/100	60/100	80/100	100/100
p	1	1	1	1	1	1	1	1

As shown in table 6, The p-values were all greater than 0.05, indicating that there was no significant difference in the yield of pyrolysis products between CE and LG

Then, whether there is a significant difference in the yield of CE and LG pyrolysis gas, and the test results in Table 7 are obtained by using the Spearman correlation coefficient

Table 7. Spearman correlation coefficients for CE and LG at various proportions

	20/100	40/100	50/100	80/100	100/100
Distinctiveness	0.381	0.747	0.747	0.285	0.285
r_s	-0.5	-0.2	-0.2	-0.6	-0.6

As shown in table 7, r_s is the correlation coefficient, the p-value indicates irrelevance, the smaller the absolute value of r_s , the larger the p-value, $p > 0.05$, indicating that there is no significant difference, and vice versa, the values of r_s in 20/100, 40/100 and 50/100 are all less than or equal to 0.5, and the significance of all mixing ratios in the table is greater than 0.05, so there is no significant difference in the pyrolysis gas yield of CE and LG in each ratio.

Therefore, there was no significant difference between the yield of pyrolysis products and the yield of pyrolysis gas between CE and LG thermal combinations.

5. Conclusions

Through the above studies, it was concluded that under CA/CS, the tar yield was negatively correlated with the carbon yield, the water yield, and the syngas yield, and the other pyrolysis products were all in a competitive tube, DFA/CE, the tar yield was positively correlated with the carbon yield, and negatively correlated with the syngas yield and water production, and in the DFA/LG, the tar yield was negatively correlated with the water yield, and the syngas yield was negatively correlated with the carbon yield. The yield of the DA/CS pyrolysis combination changed significantly with the mixing ratio, D FA/CE, with the correlation of the combination ratio, CO, and showed a negative correlation, and the CO₂ ratio of DFA/LG CH₄ C₂H₆, and medium heat combination had no effect on the yield of the two and was used H₂ C₂H₆ The Lilliefors test, combined with ANOVA and Spearman's correlation coefficient, showed that there was no significant difference between the yields of CE and LG pyrolysis products and the yield of pyrolysis gases under the catalysis of desulfurization ash in the same proportion.

This paper provides a research idea for pyrolysis catalytic products and new energy development, which is of practical significance the model is generalizable, which can not only shorten the time of

other experiments in this field, and improve the experimental efficiency, but also reflect the trend of the change of the product with the mixing ratio, and lay a foundation for the research on new energy development.

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