Problem Chosen	2023	Team Control Number
B	ShuWei Cup	2023111421593
	Summary Sheet	

1. Abstract

In this paper, the effective utilization and sustainable development of cotton straw are studied based on the data of pyrolysis products under different catalytic pyrolysis reactions according to the different conditions of each problem.

Data preprocessing. For the data given by the title, no outliers were found. We first plot the dataset given by the general analysis. The Shapiro-Wilk test of the normality test was performed using the dataset, and the judgment questions given by the data set followed a normal distribution. Therefore, by analyzing the judgment results combined with the actual situation, we concluded that the data set has no abnormal data and all follow the normal distribution.

For problem 1: conduct descriptive statistical analysis to obtain basic data information. Drawing the plot of pyrolysis products under different proportions of desulfurization ash, introducing pearson correlation analysis of the yield of different products under different ratios of desulfurization ash. Multiple linear regression model is also established, which can be seen from the above data chart that they all have strong fitting effect.

For question 2: Based on the data provided in Annex 2, we draw images of three thermothermal combinations. Using the images for the analytical discussion. The process of variation at different mixing ratios is explained.

Problem 3: we conducted data visualization analysis and used the T-test method of differential analysis to test the yield of CE and LG pyrolysis products and the yield of pyrolysis gas components.

In view of problem 4, we used the correlation results of problem 1 and problem 2 to construct the relevant linear relationship of different products, as a model of catalytic reaction. Based on this, we established the reaction dynamics to analyze the catalytic reaction mechanism model of desulfurization ash of CE, LG and other model compounds.

For question 5: on the basis of the fourth question, we establish a regression analysis model for prediction. With the least squares method, we can input the value of the product we need to predict the requirement of the mixing ratio.

In conclusion, the process mechanism of biomass pyrolysis catalytic by desulfurization ash is accurately analyzed according to the conditions given by each question. After analysis and verification, the analysis and model of this paper have rationality and certain practical significance.

Key words: data preprocessing pearson correlation analysis linear regression multiple linear regression model response dynamics model regression prediction model

Catalogue

2. Restatement of the problem

The problem background

With the increasing global demand for renewable energy, cotton straw, as an important biomass resource, has attracted much attention recently. Although pyrolysis of cotton straw can produce various forms of renewable energy, the quality and yield of pyrolysis products are affected by various factors such as pyrolysis temperature and catalyst. Therefore, the study of the pyrolysis products of cotton stalk, as well as the mechanism and function of catalyst in the pyrolysis process is of great significance for the effective utilization and sustainable development of cotton stalk.

Problem 1: ① Conduct descriptive statistical analysis for each pyrolysis combination in Annex 1, analyzing the relationship between the yield of pyrolysis products (tar, water, coke slag, syngas) and the mixing ratio of the corresponding thermolysis combination; ② desulfurization ash, as catalyst, plays a role in the reaction of pyrolysis products.

Problem 2: ① Influence of mixing ratio of different pyrolysis products on the yield; ② influence of each group of pyrolysis gas on the yield.

Problem 3: the yield of pyrolysis products of cellulose and lignin is related in the case of the same desulfurization ash content.

Problem 4: Establish the catalytic reaction mechanism model of the desulfurization ash of CE, LG and other model compounds, and establish the reaction kinetic model for analysis.

Problem 5: Use mathematical models or artificial intelligence learning methods to make predictions of the yield or quantity of pyrolysis products under limited data conditions.

3. Problem analysis

Pretreatment

Through data preprocessing, no outliers were found for the data given in the problem. We first plot the dataset given by the general analysis. In the third question, the data set was used to draw the histogram, q-q graph and the Shapiro-Wilk test, and the data set follows normal distribution. Therefore, by analyzing the judgment results combined with the actual situation, we concluded that the data set has no abnormal data and all follow the normal distribution.

1、 Question 1:

According to the Annex 1 data, in order to analyze the relationship of the desulfurization ash content, we performed descriptive statistical analysis to obtain the basic data situation. First, the line diagram of pyrolysis products under different proportions of desulfurized ash is drawn and discussed. To further determine the relationship between the two, we introduced pearson correlation analysis on the yields of different products at different ratios of desulphurash. To see whether there is an important role, we established multiple linear regression models, from the above data chart shows that they all have a strong fitting effect. Therefore, we can conclude that the desulfurization ash has an important role and influence in the pyrolysis reaction of cotton rod, cellulose and lignin.

2. Problem 2: We draw the image of three kinds of thermal solution combination: line diagram and thermal coefficient diagram. The images are used to explore how the mixing ratio affects the yield of each group of pyrolysis gases. We explain the variation process at different mixing ratios through data analysis and visualization of the gas components in each pyrolysis combination, and illustrate the different results produced by each set of pyrolysis gases.

3. Question 3:

After data preprocessing, we tested the data by differential analysis if the data conforms to normal distribution. And can be combined with the normal distribution histogram, PP map or QQ graph for further analysis. In question 3, we deeply analyzed the difference between the yield of cellulose (CE) and lignin (LG) and their gas components under the same proportion of desulfurization fly ash. Through the comprehensive application of statistical testing and multiple regression analysis and the use of various charts.

4. Question 4:

We use the correlation of the problem, the line diagram, construct different product related linear relationship, as a catalytic reaction model, on this basis we establish the reaction dynamics of CE, LG model compounds such as desulfurization ash catalytic reaction mechanism model analysis, can simulate the CE or LG level of kinetic equation and simulate the kinetic equation with the real data.

5. Question 5:

For the last question, based on the fourth question, we built a regression analysis model for prediction. The pyrolysis combination is regarded as the dependent variable, and the pyrolysis product is regarded as the independent variable. Using the least squares method, we can input the value of the products we need so as to predict the demand of the mixing ratio of the pyrolysis combination, and analyze the linear regression prediction model.

4. Model hypothesis

（1） Suppose that the data set accurately represents the various cases of the catalytic reaction of cotton straw pyrolysis.

（2） It is assumed that the catalytic effect of desulfurization ash as a catalyst on all samples is consistent, that is, the catalytic effect is not affected by the characteristics of the sample (such as the origin and type of cotton straw, etc.).
（3） We assume that all the pyrolysis experiments were performed under the same environmental conditions and operating procedure, ensuring the comparability of the results, i. e., that the reaction conditions are stable.
（4）Suppose that the data provided in the topic are complete and accurate.

5. Symbol description

r	Pearson correlation coefficient
Xi，Yi	Sample standard deviation of the sample data
$\bar{X}$,$\bar{Y}$	Sample average of the sample data
k	constant of action
[A]	Reactant concentration

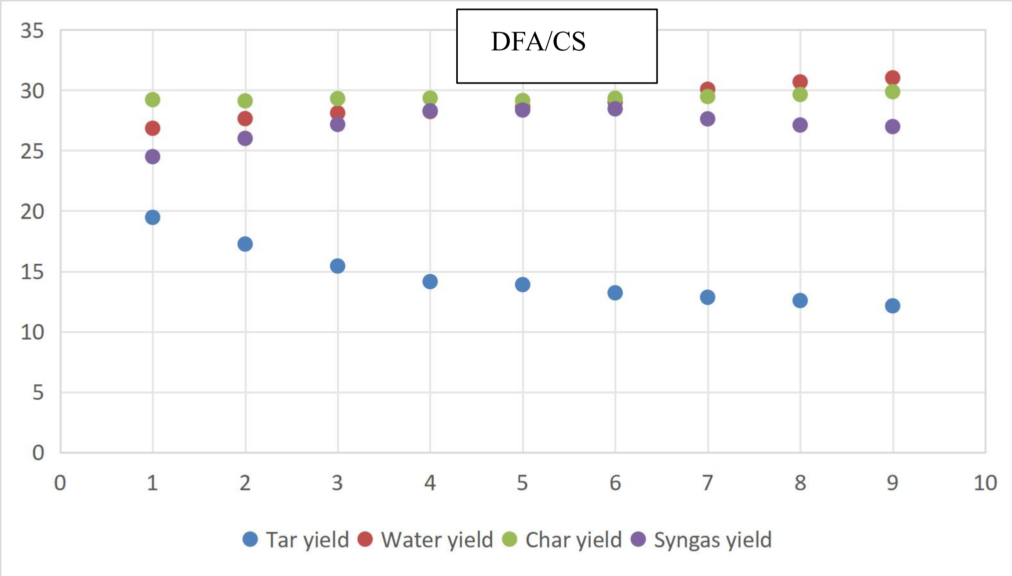
6. Model establishment and solution

Problem a

Data preprocessing

Preprocessing of the experimental data for the desulfurized ash / cotton straw
According to the Annex 1 data, we first conducted a descriptive statistical analysis to obtain the basic data situation

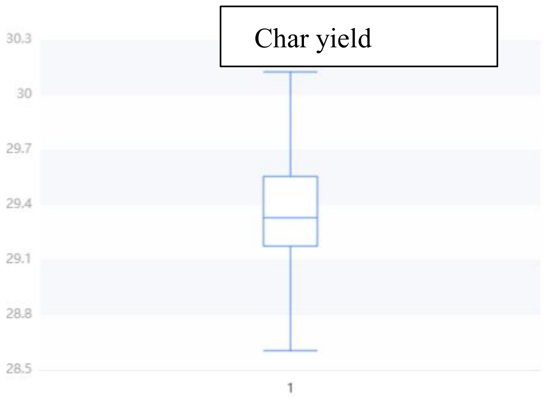
variable name	sample size	maximum	minimum	average	standard deviation	variance	CV
Tar yield	9	19.46	12.13	14.547	2.431	5.909	0.167
Water yield	9	31.02	26.84	28.913	1.415	2.003	0.049
Char yield	9	29.87	29.11	29.379	0.246	0.061	0.008
Syngas yield	9	28.45	24.49	27.161	1.279	1.635	0.047

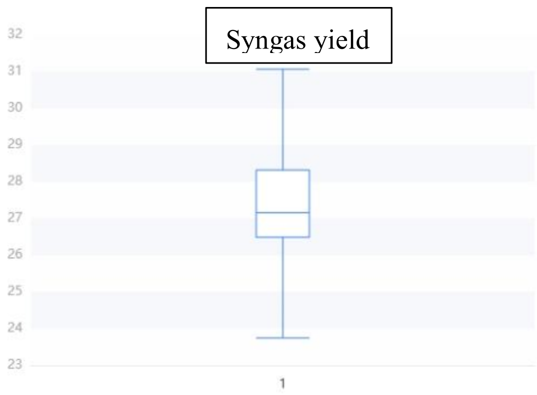


The figure above shows the results of the centralized trend analysis of tar yield, water yield, carbon yield and syngas yield in the form of a scatter plot, which can be used to estimate or predict the population. Forecdiction: tar output, water production, carbon output and syngas output show a regular linear distribution trend, tar output decreases with the increase of desulfurization ash content, and water production, carbon production and syngas output increase slightly with the increase of desulfurization ash content.

Tar yield

water yield



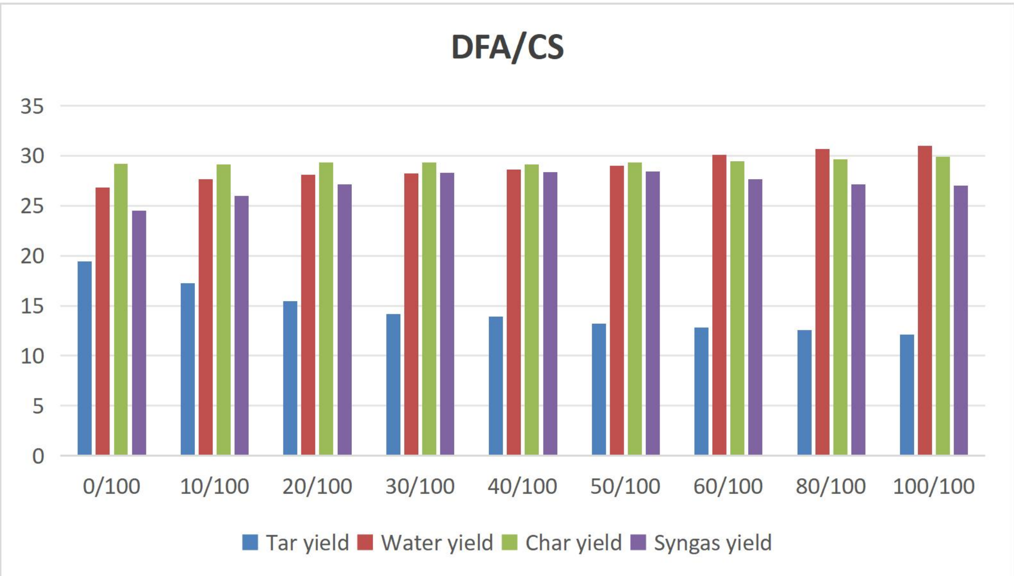


The figure above figure shows the results of discrete trend analysis of tar yield, water production, carbon production and syngas production in the form of box diagram. Forecdiction: tar yield, water yield, carbon yield and syngas yield show a trend of centralized distribution. The upper limit of tar yield is about 22 and the lower limit is about 7.5; water yield, carbon yield, average and upper and lower limit of syngas yield are almost the same.

(See Appendix for analysis of scatter plots and box plots of the other two groups)

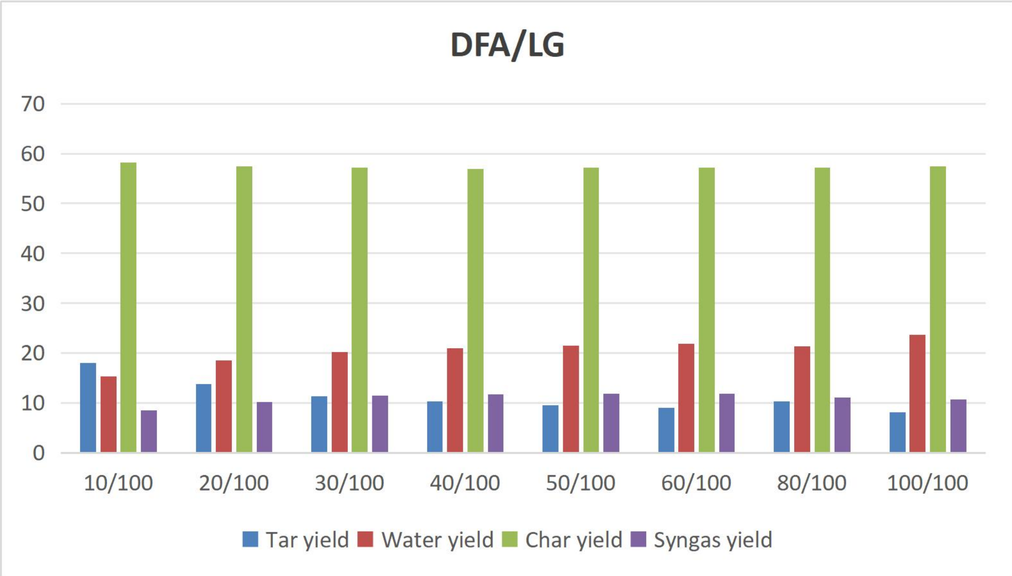
Date analysis

Cotton stalk



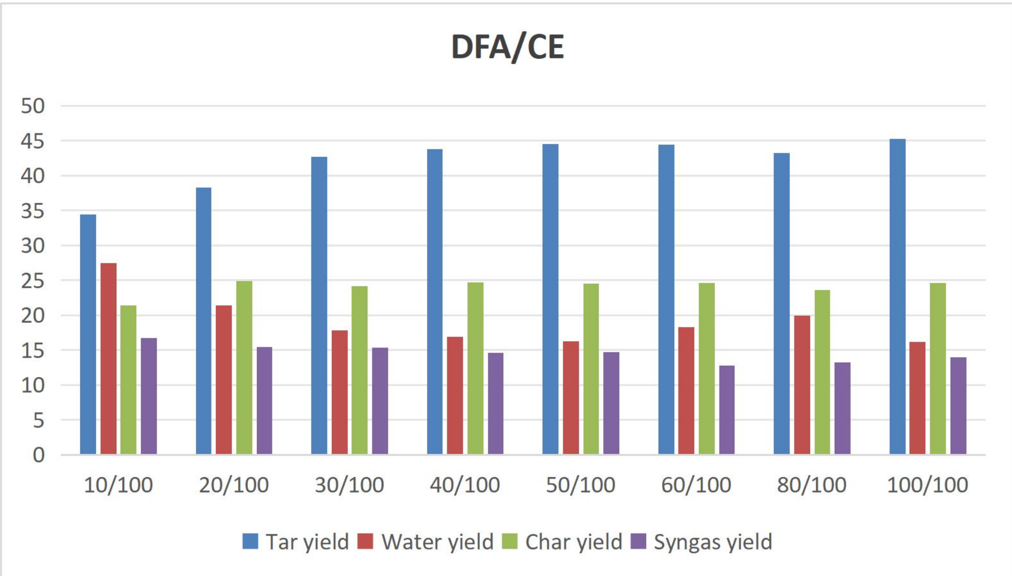
It can be seen that desulphurization ash has a significant impact on the tar yield, which is not obvious to other (water, coke residue, syngas), but the yield of water, coke residue and syngas is high

lignin



It can be seen that the yield of desulfurization ash has a certain impact on tar, water, syngas and coke residue, and the yield of coke residue remains high.

Cellulose



It can be seen that desulfurization ash has a significant impact on the tar yield. The larger the proportion of desulfurization ash, the higher the tar yield, indicating that it is a positive promoting effect. For other (water, coke residue, syngas) is not obvious.

Correlation analysis

Based on the above basic data analysis, we have conducted the correlation analysis of the yield of pyrolysis products (tar, water, coke residue, syngas) and the mixing ratio of the corresponding pyrolysis combination

For the above data, we can analyze the Pearson correlation, where the Pearson's

$$r = \frac{\sum_{i=1}^{n}(X_i - \overline{X})(Y_i - \overline{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \overline{X})^2}\sqrt{\sum_{i=1}^{n}(Y_i - \overline{Y})^2}}$$

correlation coefficient is:

X_i, Y_i; $\bar{X}$, $\bar{Y}$ (Where is the sample standard deviation and the sample mean for the sample data, respectively)

Pyrolysis combination: desulfurized ash / cotton straw

(1) Correlation analysis of the mixing ratio of tar yield, water yield, carbon yield, syngas yield and the pyrolysis combination of desulfurization ash / cotton stalk
Based on the following experimental data table, we can get the correlation coefficient between the data

DFA/CS	Tar yield	Water yield	Char yield	Syngas yield
0/100	19.46	26.84	29.21	24.49
10/100	17.25	27.64	29.11	26
20/100	15.43	28.11	29.3	27.16
30/100	14.14	28.23	29.34	28.29
40/100	13.89	28.62	29.14	28.35
50/100	13.21	29.01	29.33	28.45
60/100	12.84	30.07	29.47	27.62
80/100	12.57	30.68	29.64	27.11
100/100	12.13	31.02	29.87	26.98

	DFA/CS	Tar yield
DFA/CS	1(0.000***)	-0.929(0.000***)
Tar yield	-0.929(0.000***)	1(0.000***)

attention : ***、**、*each represent“1%、5%、10%”significance level

	DFA/CS	Water yield
DFA/CS	1(0.000***)	0.985(0.000***)
Water yield	0.985(0.000***)	1(0.000***)

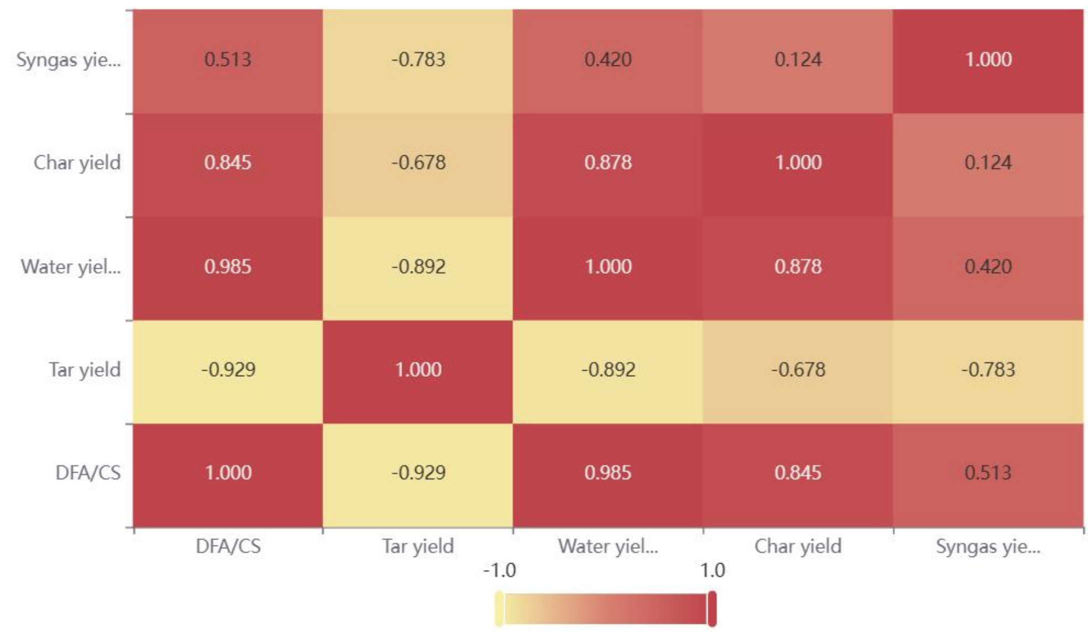
attention : ***、**、*each represent“1%、5%、10%”significance level

	DFA/CS	Char yield
DFA/CS	1(0.000***)	0.845(0.004***)
Char yield	0.845(0.004***)	1(0.000***)

attention : ***、**、*each represent“1%、5%、10%”significance level

	DFA/CS	Syngas yield
DFA/CS	1(0.000***)	0.513(0.158)
Syngas yield	0.513(0.158)	1(0.000***)

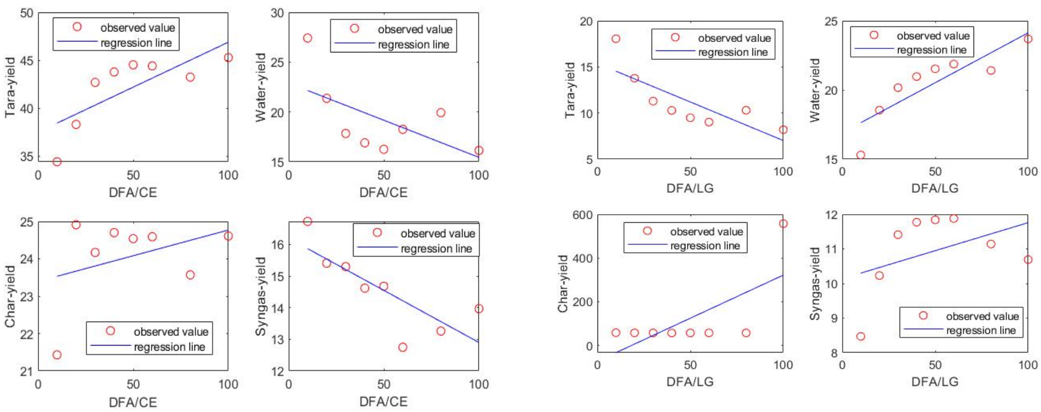
attention : ***、**、*each represent“1%、5%、10%”significance level r1≥ 0.8It can be seen from the table, the absolute value of r1 and the mixing ratio of desulfurization ash / cotton straw combination; the absolute value of r2, the water yield and the mixing ratio of desulfurization ash / cotton straw; the absolute value of r3 and the mixing ratio of desulfurization ash / cotton straw; the absolute value of r4 is less than 0.8, the synthetic gas volume and the mixing ratio of desulfurization ash / cotton straw. Based on the above data, we can give the total thermal coefficient diagram in the case of combined desulfurization ash / cotton straw:

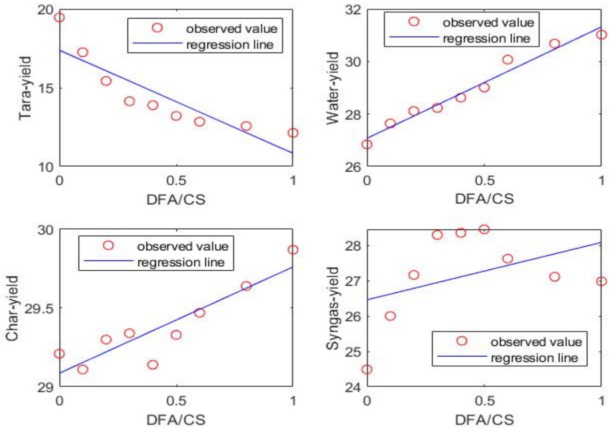


(See the appendix for the other two groups)

Considering the above data, we can conclude that the yield of the pyrolysis product is correlated with the mixing ratio of the pyrolysis combination

Analysis of the multiple linear regression models



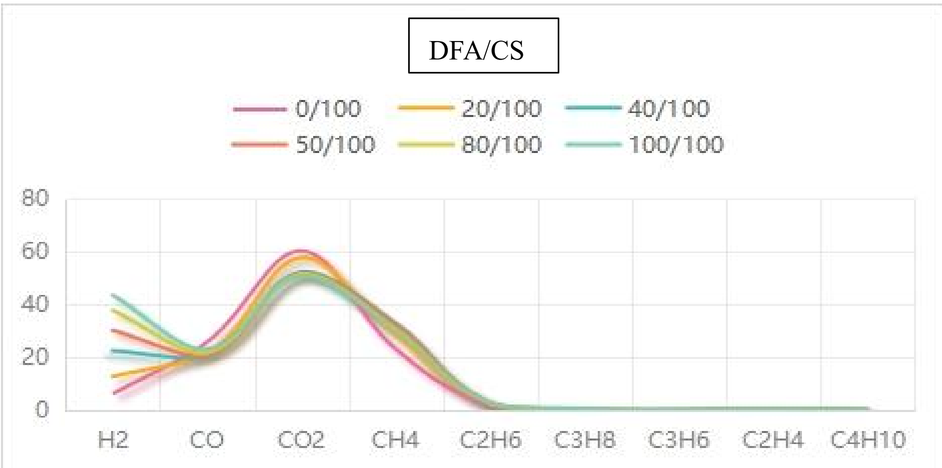


To see whether there is an important role, we established multiple linear regression models, from the above data chart shows that they all have a strong fitting effect. Therefore, we can conclude that the desulfurization ash has an important role and influence in the pyrolysis reaction of cotton rod, cellulose and lignin.

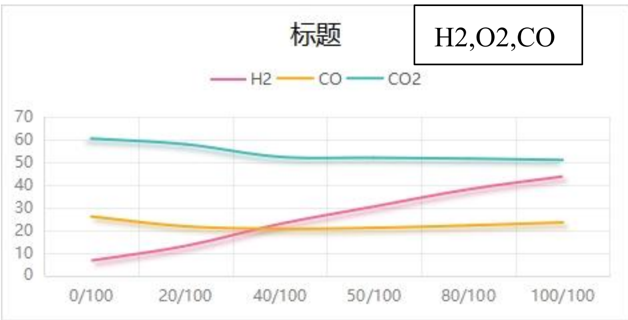
Problem 2

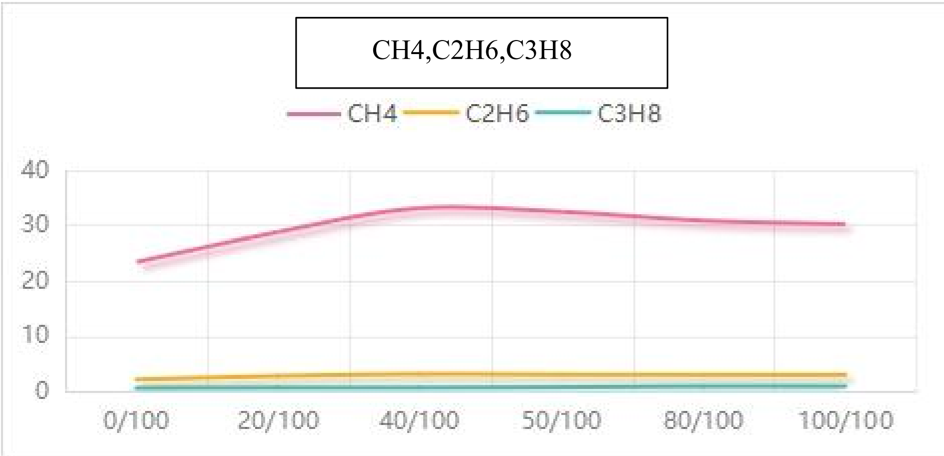
Chart analysis

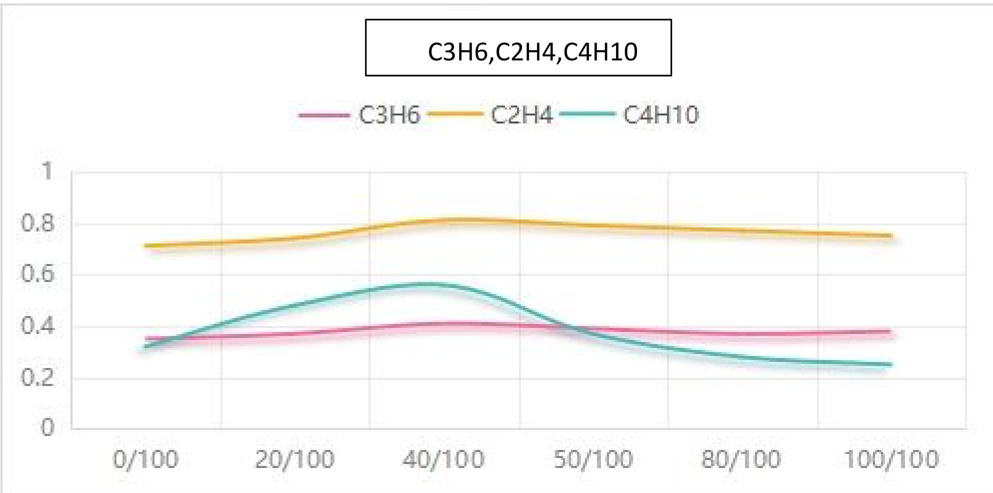
Pyrolysis combination: desulfurized ash / cotton straw



According to the line diagram, in the six gas environments of CO, C2H6, C3H8, C3H6, C2H4, C4H10, the mixing ratio has not much to do with the yield; in the two gas environments of H2, CH4, the higher the desulfurization ash content, the greater the yield; and in the CO2 gas environment, the higher the desulfurization ash content, the smaller the yield.







According to the line diagram, the yield of the pyrolysis product decreases with the increase of desulfurization ash content in CO2 and CO; in the condition of H2, the yield of desulfurization ash increases with the increase of desulfurization ash; in C4H10, in the condition of C2H6 and C3H8.

Correlation coefficient analysis

According to the correlation coefficient table

	DFA/CS	H2	CO	CO2	CH4	C2H6	C3H6	C3H8	C2H4	C4H10
DFA/CS	1(0.000***)	0.998(0.000***)	-0.309(0.552)	-0.901(0.014**)	0.604(0.205)	0.709(0.115)	0.34(0.509)	0.954(0.003***)	0.401(0.431)	-0.505(0.307)

The following is its corresponding thermodynamic coefficient diagram

According to the correlation coefficient, the absolute value of r, H2, CO2 and C3H8, the absolute value of r is less than 0.8, with certain correlation; the absolute value of r in CO, C3H6 and C2H4 is less than 0.5, and the correlation is not strong.

(See Appendix 1 for the remaining data.)

Summary and conclusion of question 2

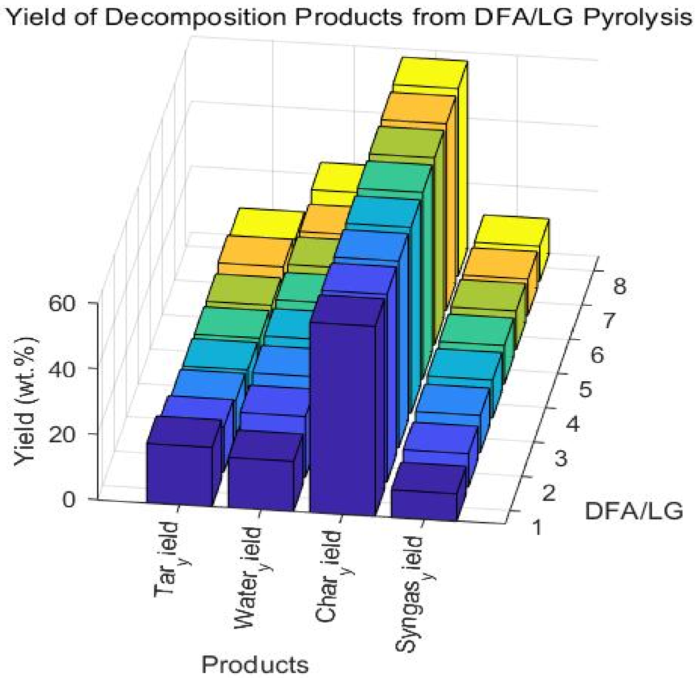
① In the DFA / CS combination, we observed a significant increase in H2 yield with the mixture ratio, while CO and CO2 yields showed a trend of the first increase and then slightly decreased. This may indicate that desulphurization ash promotes changes in gas components, especially in increasing H2 yield.② In the DFA / CE combination, the yield of H2 increased significantly with the mixing proportion, while that of CO and CO2 yield decreased significantly. This trend suggests that desulphized ash may promote the conversion of gas components during cellulose pyrolysis, leading to an increase in H2 yield and a decrease in carbon oxide yield.

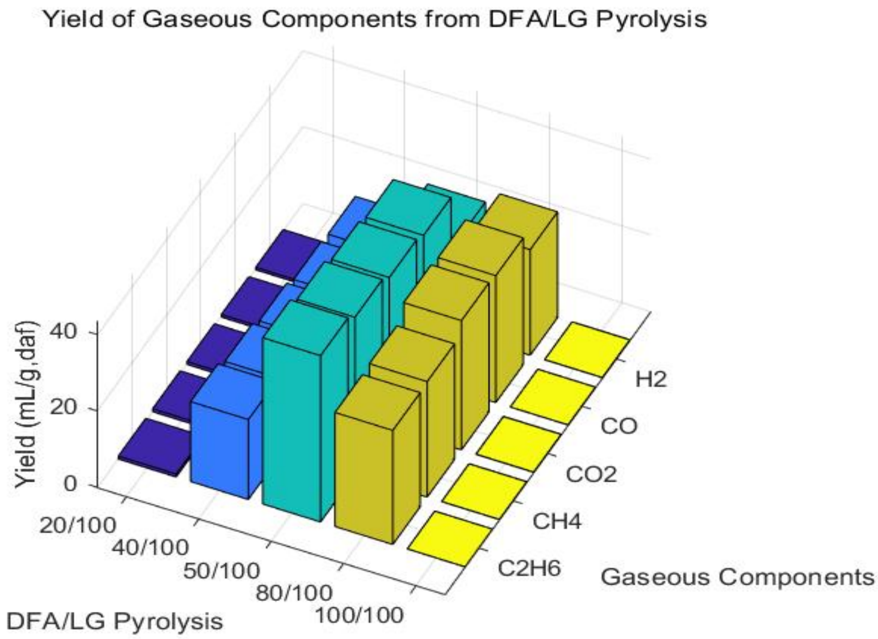
③ In the DFA / LG combination, the yield of H2 increased slightly as the mixing ratio increased, while that of CO and CO2 yield increased significantly. This may reflect the complexity of the lignin pyrolysis and the catalytic effect of the transformation of gas components.

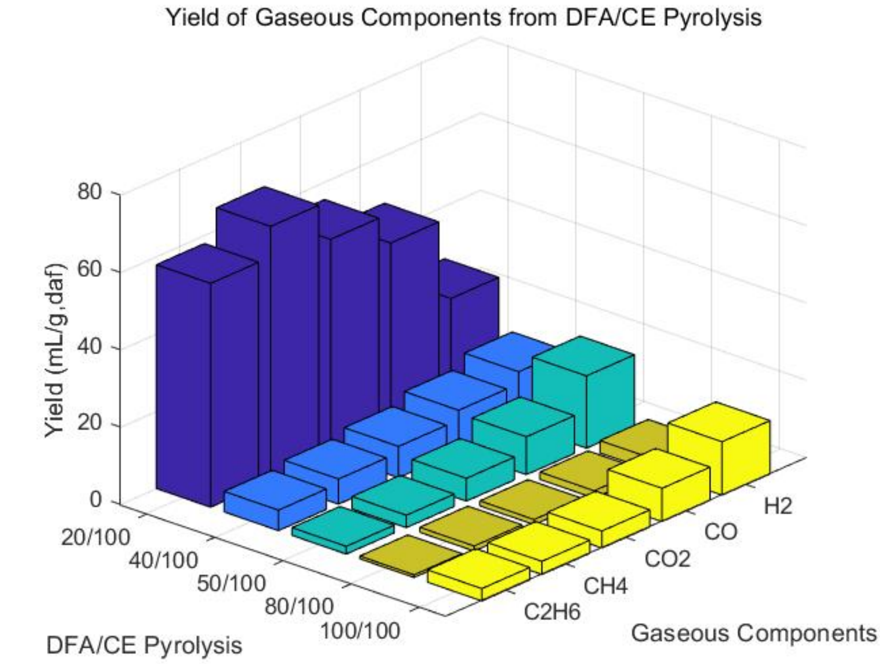
Comprehensive analysis shows that desulfurization ash, as a catalyst, significantly affects the yield of gas components in all three pyrolysis combinations. In particular, the yield of hydrogen was increased in all combinations, suggesting a potential catalytic role of desulfurized ash in promoting hydrogen generation. Moreover, the yield change of carbon oxide indicates that the desulfurization ash affects the gas components in different pyrolysis combinations. These findings are important for understanding the catalytic mechanism of desulfurization ash in biomass pyrolysis and for optimizing the pyrolysis process.

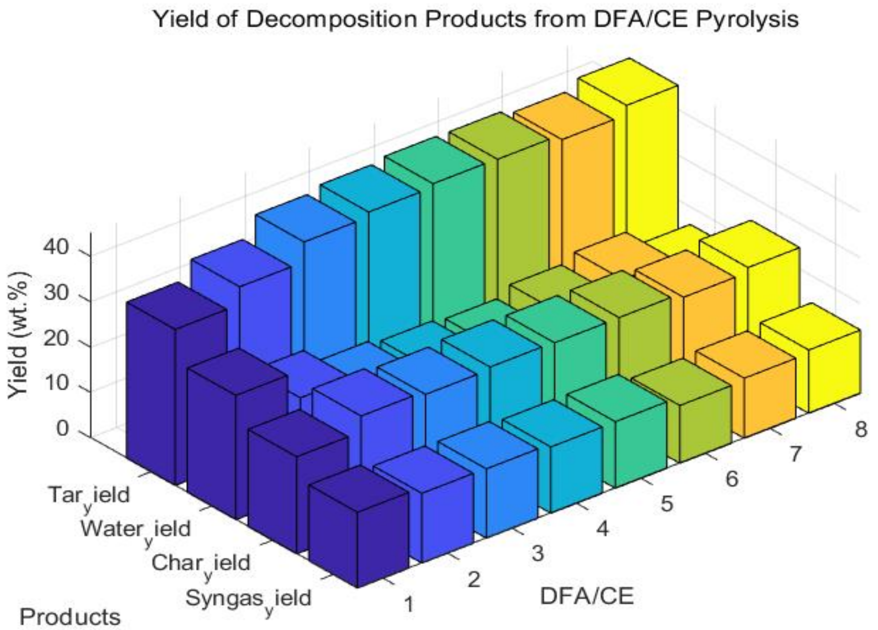
Problem 3

Visualization and analysis of the data
According to the problem to establish a 3 D bar statistical chart for observation









The above figure clearly shows that CE and LG have obvious differences in the yield of pyrolysis products and the yield of pyrolysis gas components, but further data analysis is required

Pyrolysis product: tar

Normal distribution test

Whether there is a significant difference in the yield of pyrolysis products of CE and LG and the yield of pyrolysis gas components under the same proportion of desulfurization ash catalysis, we used the T test method of difference analysis.

Before performing the T test, we advanced the normality test to check whether the data fit to the normal distribution

Generally, there are two test methods for normal distribution, one is Shapiro-Wilk test, which is suitable for small sample data (sample size 5000); the other is Kolmogorov Smirnov test, which is suitable for large sample data (sample size> 5000). Therefore, for this sample, we conduct S-W test.

If significant (P <0.05), the null hypothesis is rejected (the data meets the normal distribution), the data does not meet the normal distribution, and otherwise the data meets the normal distribution.

PS: Usually, it is difficult to meet the test in realistic research cases. If the absolute value of sample kurtosis is less than 10 and the absolute value of skewness is less than 3, it can be described as normal distribution histogram, PP graph or QQ graph.

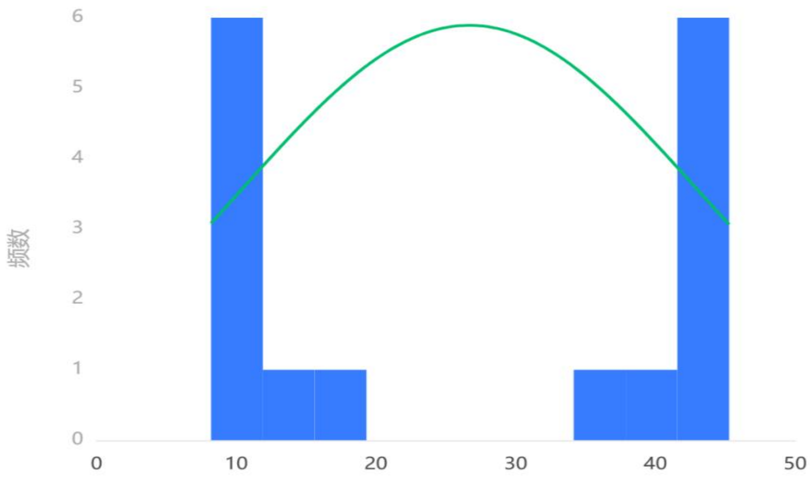
For the tar yield in the yield of the pyrolysis products, the T-test gives the following data

Results of the normality test

variable	sample size	median	average	standard deviation	skewness	kurtosis	S-W checkout
Tar yield	16	26.24	26.691	16.251	0.019	-2.132	0.776(0.001***)

Tar yield was tested using S-W test with significance P-value of 0.001, showing significance at the level and rejecting the null hypothesis, so the data did not satisfy the normal distribution. The absolute value of kurtosis (-2.132) is less than 10, and the absolute value of skewness (0.019) is less than 3, which can be further analyzed with normal distribution histogram, PP map or QQ graph

Histogram of the normality test



The figure above figure shows the results of the normality test of variable tar yield data. If the normal graph basically presents a bell shape (high in the middle, low at both ends), it indicates that the data is not absolutely normal, but is basically accepted as normal distribution.

Homogeneity test of variance

	Species (standard deviation)		F	P
	DFA/CE Tar yield(n=8)	DFA/LG Tar yield(n=8)		
Tar yield	3.764	3.207	0.269	0.612

The results of the homogeneity of variance test showed that for the tar yield, the significance P-value of 0.612 does not show significance at the level, and the null hypothesis cannot be rejected, so the data satisfies the homogeneity of variance

Table of T-test analysis results for independent samples

variable name	variable value	sample size	average	standard deviation	T -test	mean difference	Cohen's d value
Tar yield	DFA/CE Tar yield	8	42.082	3.764	T=17.608 P=0.000***	T=17.608 P=0.000***	8.804
	DFA/LG Tar yield	8	11.3	3.207			
	total	16	26.691	16.251			

Analysis the charts:

DFA/CE Tar yield, The average value of DFA / LG Tar yield in tar yield is respectively: 42.082/11.3; Since satisfying the homogeneity of variance, Using the independent sample T-test, The P-value of the significance result was 0.000 * * *, Thus, the results were statistically significant, Note that the DFA / CE Tar yield, DFA / LG Tar yield has a significant difference in the tar yield; The Cohen's d value of the difference magnitude is: 8.804, The difference is very large (0.20, 0.50 and 0.80 correspond to small, medium, and large critical points, respectively).

(Desdesulfurization ash and cellulose, desulfurization ash and lignin are the same as above, see the appendix for complete analysis)

Pyrolysis gas components: yieldH_2

H_2 For the yield in the pyrolysis gas fraction, the T-test gives the following data

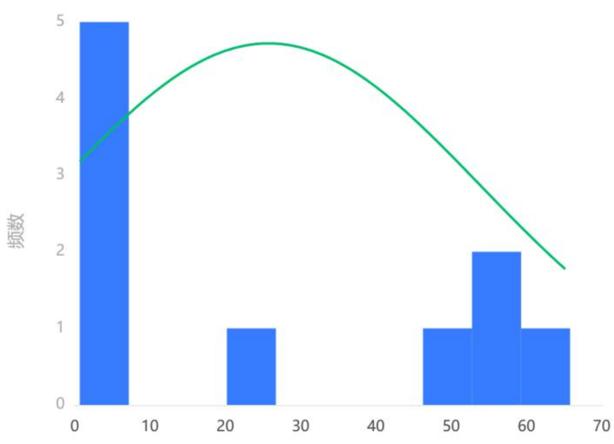
Normal test

Results of the normality test

variable	sample size	median	average	standard deviation	skewness	kurtosis	S-W checkout
H2 yield	10	13.705	25.747	28.165	0.353	-2.042	0.782(0.009***)

H2 yield was tested by S-W test with significance P-value of 0.009, showing significance at level and rejecting the null hypothesis, so the data did not satisfy the normal distribution. The absolute value of kurtosis (-2.042) is less than 10, and the absolute value of skewness (0.353) is less than 3, which can be further analyzed with normal distribution histogram, PP map or QQ graph.

Histogram of the normality test



The figure above graph shows the results of the normality test of the variable H2 yield data. If the normal graph basically presents a bell shape (high in the middle, low at both ends), it indicates that the data is not absolutely normal, but is basically acceptable as normal distribution

Homogeneity test of variance

	Species (standard deviation)		F	P
	DFA/CE(n=5)	DFA/LG (n=5)		
H2 yield	14.942	0.058	7.592	0.025**

The results of the homogeneity of variance test showed that for H2 yield, the significance P-value is 0.025 * *, showing significance at the level, rejecting the null hypothesis, and therefore the data did not satisfy the homogeneity of variance

Table of T-test analysis results for independent samples

variable name	variable value	sample size	average	standard deviation	T -test	mean difference	Cohen's d value
H2 yield	DFA/CE	5	50.74	14.942	T=7.48 P=0.000***	T=7.48 P=0.002***	4.731
	DFA/LG	5	0.754	0.058			
	total	10	25.747	28.165			

The means of DFA / CE and DFA / LG in H2 yield were 50.74/0.754; since the homogeneity of variance is not satisfied, Welch's T test, the P value of significance was 0.002 * * * indicating significant difference between CE and LG. The difference amplitude Cohen's d value was 4.731, and the difference range is very large (0.20,0.50 and 0.80 correspond to small, medium and large critical points, respectively)

(Desulfurash and CO, CO2, CH4, C2H6 analysis method as above, see the appendix for complete analysis)

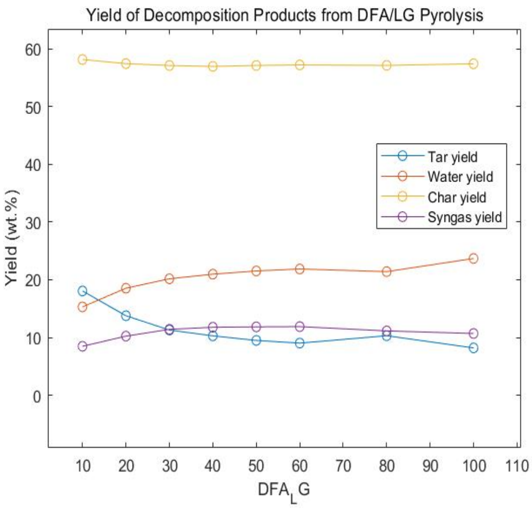
Question 3 summary and conclusion

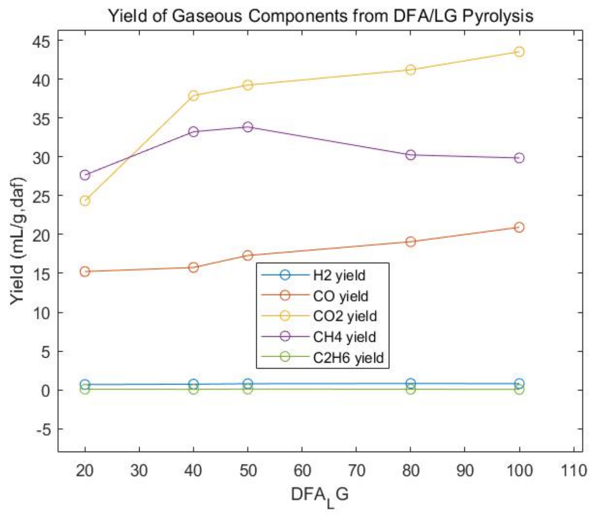
In question 3, we deeply analyzed the difference between the yield of cellulose (CE) and lignin (LG) and their gas components under the same proportion of desulfurization fly ash. Through comprehensive application of statistical test and multiple regression analysis, and through the advanced chart visual observation, in the same proportion of desulfurization ash catalytic, CE and LG pyrolysis gas component yield have significant influence, part has a certain influence, this significant difference may result from their essential differences in chemical structure, need to be discussed from the chemical reaction principle and catalytic reaction mechanism for further. And these significant effects can be clearly seen through the chart.

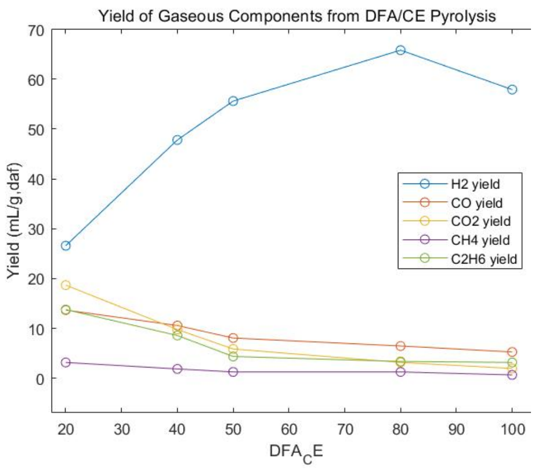
Problem four

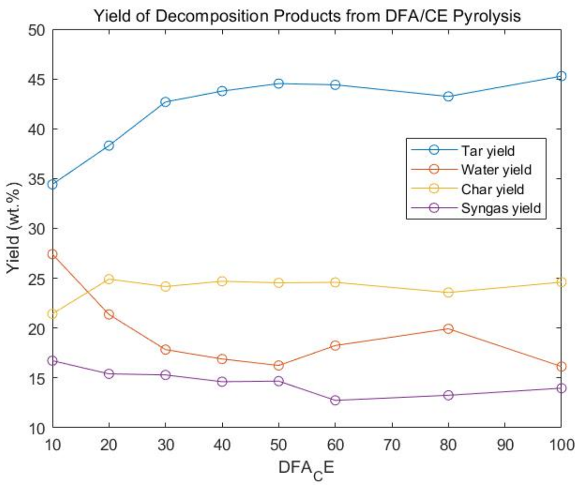
Model building

Question 4 requires us to establish the reaction dynamics to analyze the catalytic reaction mechanism model of the model compounds such as CE and LG









It can be seen from the correlation comparison of the experimental data in the above four graphs and questions (1) that the ratio of the yield of the product and the thermal solution combination is linear, so we can assume that the rea ction series is the first-level reaction, and the first-order reaction rate equation can be written as

$$\frac{d[A]}{dt} = k[A]$$

Where k is the reaction rate constant, [A] is the concentration of reactants, an d the number of CE and LG will gradually decrease with time, so we can thi nk that [A] and CE are proportional to LG.

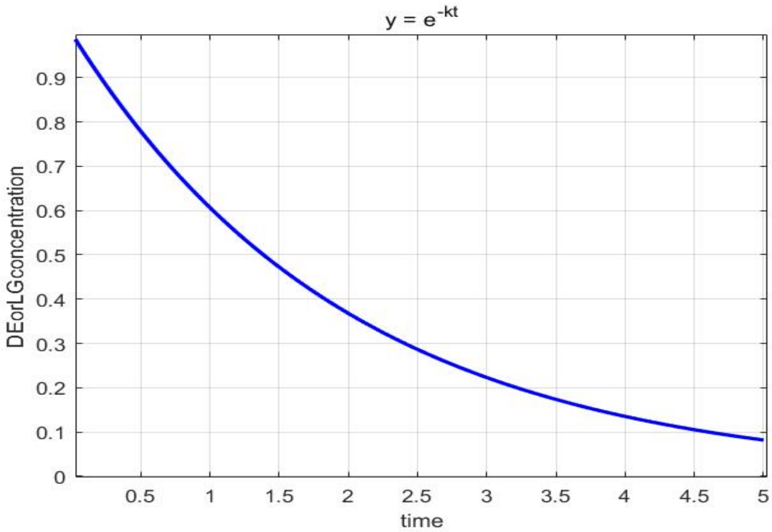
The solution of the model

Use the separation variable method and find the integral$\int \frac{1}{[A]} = \int -kdt$

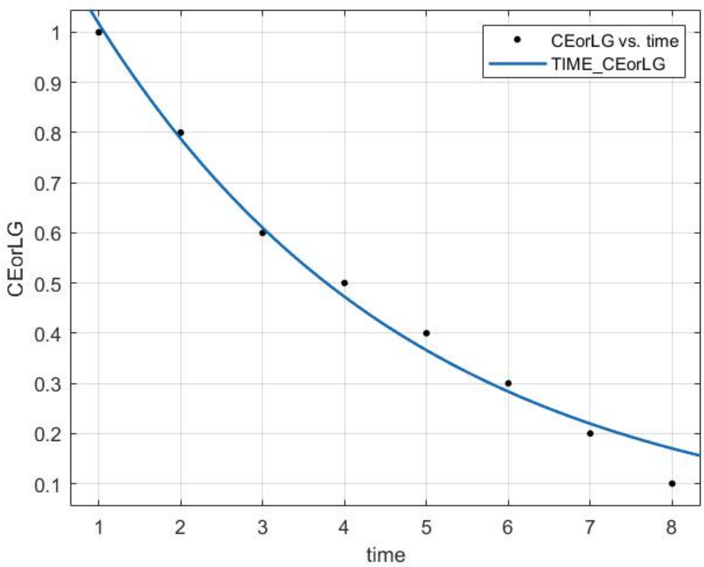
ln [A] =− ktI. e., namely, [A] =e^{-kt}

We take the x-axis as the time, take 1,2,3,4,5 unit times, and the y-axis as the CE or LG concentration, assuming that the concentration also decreases from, plot the function image of [A] =,e^{-kt}

The following below shows the first order kinetic equations of the simulated CE or LG



The kinetic equations of this simulation were fitted to the real data



This get the reaction rate k: 0.2555

e^{-kt}For this, [A] = is written as

$$[A]=e^{-0.2555t}$$

This formula reflects the dependence of the concentration over time. Together with the analysis of question 1, it does indicate that DFA plays a significant role in the pyrolysis reaction of CE and LG.

Problem five

ideas of solving a problem

For the last question, we can treat the pyrolysis combination as the dependent variable, and the pyrolysis product as the independent variable. Using the least squares method, we can input the value of the product we need so as to predict the demand of the mixing ratio of the thermosolution combination.

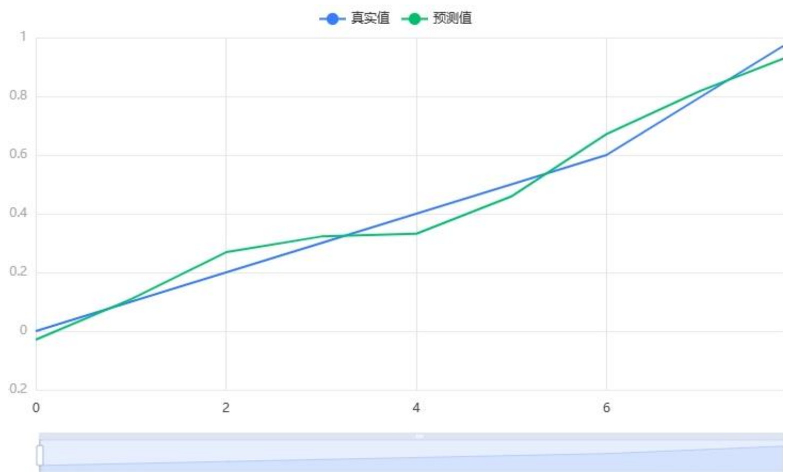
Model building

We used the pyrolysis combined desulfurization ash / cotton stalk as an example for linear regression prediction model analysis

Linear regression analysis results in n=9									
	Non-standardized coefficients		Standardization coefficient	t	P	VIF	R^2	adjust R^2	F
	B	standard error	Beta						
constant	-0.001	0	-	-1.784	0.135	-	0.976	0.961	F=66.907 P=0.000***
Tar production	-0.139	0.061	-1.032	-2.283	0.071*				
water yield	0.036	0.103	0.156	0.351	0.740				
Carbon production	0.16	0.174	0.12	0.921	0.399				
Synthetic gas production	-0.121	0.05	-0.472	-2.409	0.061*				
Dependent variable: desulfurization ash / cotton straw									

The analysis of the results of the F test can be obtained, a significance P-value of 0.000 * * *, significant at the level, the null hypothesis of regression coefficient of 0 is rejected, so the model basically meets the requirements. For the variable collinearity performance, the VIF value of variable tar yield, water yield, carbon yield and syngas yield is greater than 10, and there is a collinear relationship, simple removal of the collinar independent variable or ridge regression or gradual regression. We can obtain the model formula: y= -0.001-0.139 * Tar production + 0.036 * water yield + 0.16 * carbon production-0.121 * syngas production.

Fitting the renderings



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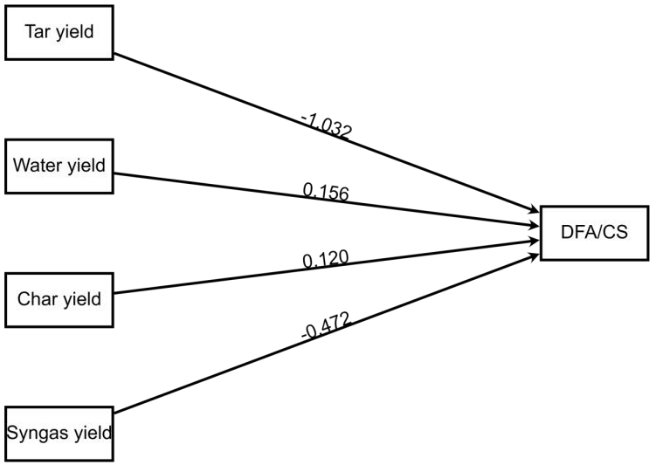
Model path diagram



The figure above shows the results of this model in the form of a path diagram, mainly including the coefficients of the model, which is used to analyze the influence relationship of X on Y.

model prediction

variable	coefficient	test value
constant	-0.0006407524873402988	1
Tar production	-0.13919756984982345	
water yield	0.03608933724871699	
Carbon production	0.16015693246278695	
Synthetic gas production	-0.12112394859571146	

Predicted results-	-0.0006407524873402988

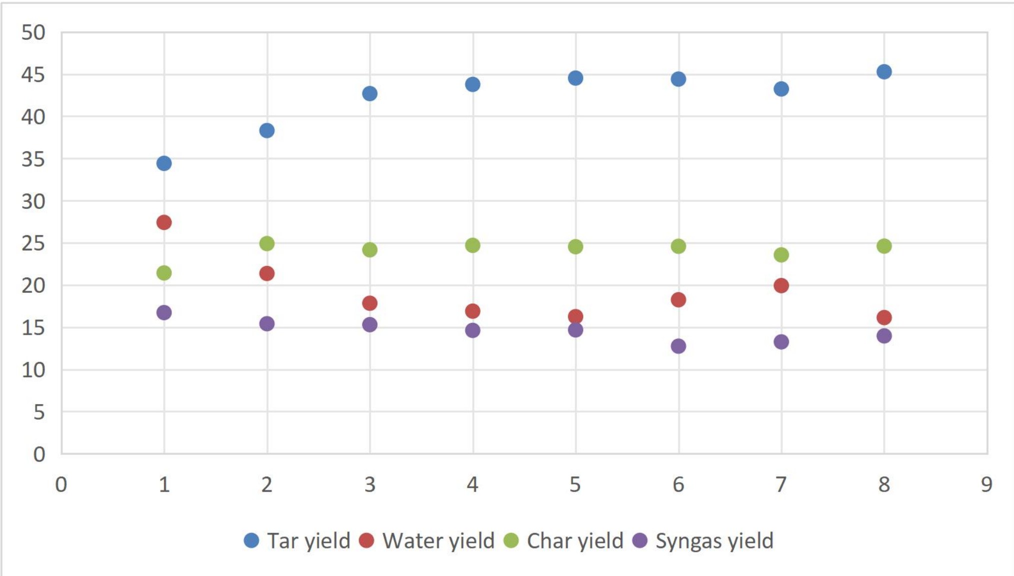
Appendix 1

Question 1 Pretreatment of desulfized ash / cellulose and desulfurized ash / lignin data

Desulfurized ash and cellulose

variable name	sample size	maximum	minimum	average	standard deviation	median	variance	CV

Tar yield	8	45.28	34.42	42.082	3.764	43.51	14.167	0.089
Water yield	8	27.42	16.14	19.262	3.759	18.045	14.127	0.195
Char yield	8	24.91	21.43	24.065	1.141	24.565	1.302	0.047
Syngas yield	8	16.73	12.75	14.59	1.271	14.65	1.615	0.087



The figure above shows the results of the centralized trend analysis of tar yield, water yield, carbon yield and syngas yield in the form of a scatter plot, which can be used to estimate or predict the population. Forecdiction: tar output, water output, carbon output and syngas output show a relatively regular linear distribution trend, tar output increases with the increase of desulfurization ash content, and water output, carbon output and syngas output fluctuate slightly with the increase of desulfurization ash content.

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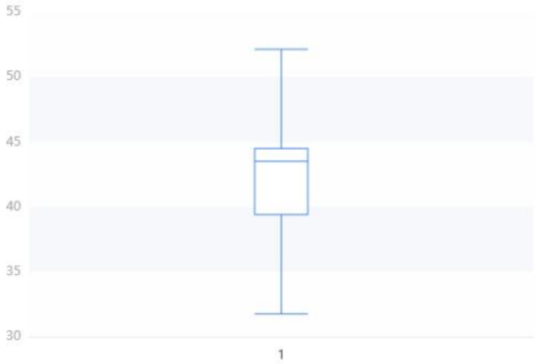
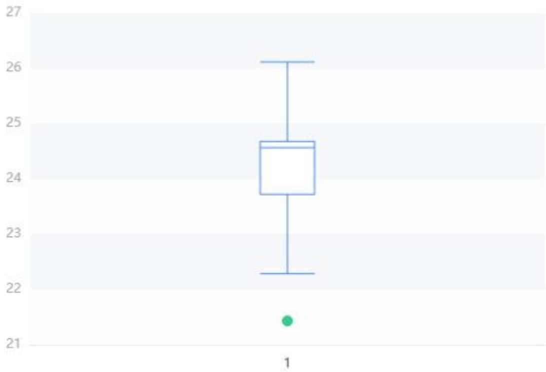
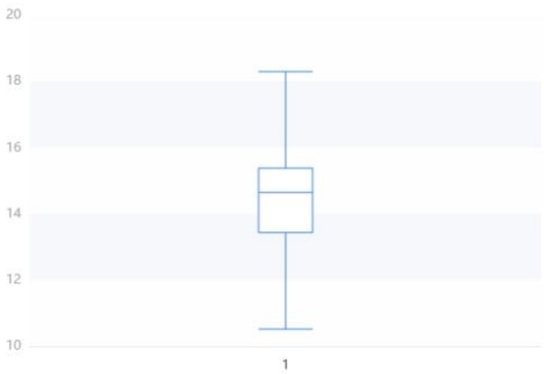


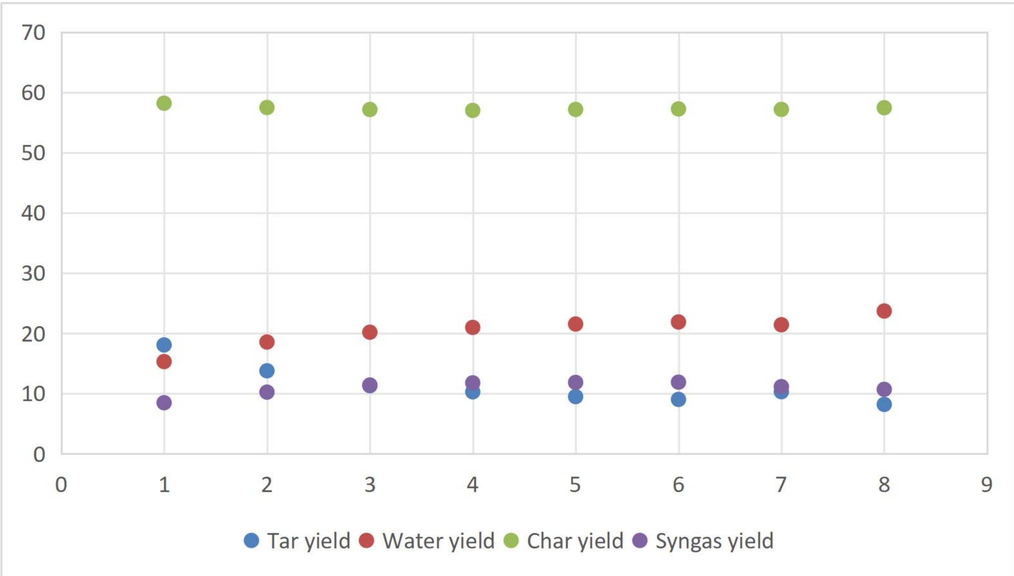




The figure above figure shows the results of discrete trend analysis of tar yield, water production, carbon production and syngas production in the form of box diagram. Forecdiction: tar production, water production, carbon production and syngas production show a trend of centralized distribution; the upper limit of tar production is about 53 and the lower limit is about 32; water production, carbon production and upper limit are almost the same; the upper limit of syngas production is about 18.1 and the lower limit is about 10.5.

Desulfurized ash and lignin

variable name	sample size	maximum	minimum	average	standard deviation	median	variance	CV
Tar yield	8	18.06	8.19	11.3	3.207	10.29	10.284	0.284
Water yield	8	23.69	15.3	20.435	2.539	21.19	6.446	0.124
Char yield	8	58.17	56.98	57.336	0.373	57.19	0.139	0.007
Syngas yield	8	11.88	8.47	10.929	1.153	11.275	1.33	0.106



The figure above shows the results of the centralized trend analysis of tar yield, water yield, carbon yield and syngas yield in the form of a scatter plot, which can be used to estimate or predict the population. Prediction: tar yield, water yield, carbon production and syngas production show a regular linear distribution, while tar yield decreases with the increase of desulfurized ash content; carbon yield and syngas production are basically unchanged with the increase of desulphized ash content; water yield increases slightly with the increase of desulfurized ash content.

The figure above figure shows the results of discrete trend analysis of tar yield, water production, carbon production and syngas production in the form of box diagram. Forecdiction: Tar output, water production, carbon production and syngas output show a trend of centralized distribution, and the maximum difference between the upper and lower limits of tar output is about 16.

Question 1 Analysis of data on desulfurization ash / cellulose and desulfurization ash / lignin

Pyrolysis combination: desulfurized ash / cellulose

(1) Correlation analysis of the mixing ratio of tar yield, water yield, carbon yield, syngas yield and the pyrolysis combination of desulfurization ash / cellulose

DFA/CE	Tar yield	Water yield	Char yield	Syngas yield
10/100	34.42	27.42	21.43	16.73
20/100	38.31	21.37	24.91	15.41

30/100	42.69	17.84	24.17	15.3
40/100	43.78	16.9	24.7	14.62
50/100	44.53	16.25	24.54	14.68
60/100	44.41	18.25	24.59	12.75
80/100	43.24	19.93	23.57	13.26
100/100	45.28	16.14	24.61	13.97

From this form, we can get the corresponding correlation coefficient table:

	DFA/CE	Tar yield
DFA/CE	1(0.000***)	0.826(0.012**)
Tar yield	0.826(0.012**)	1(0.000***)

attention ： ***、**、*each represent“1%、5%、

	DFA/CE	Water yield
DFA/CE	1(0.000***)	-0.664(0.073*)
Water yield	-0.664(0.073*)	1(0.000***)

attention ： ***、**、*each represent“1%、5%、
10%”significance level

	DFA/CE	Char yield
DFA/CE	1(0.000***)	0.426(0.293)
Char yield	0.426(0.293)	1(0.000***)

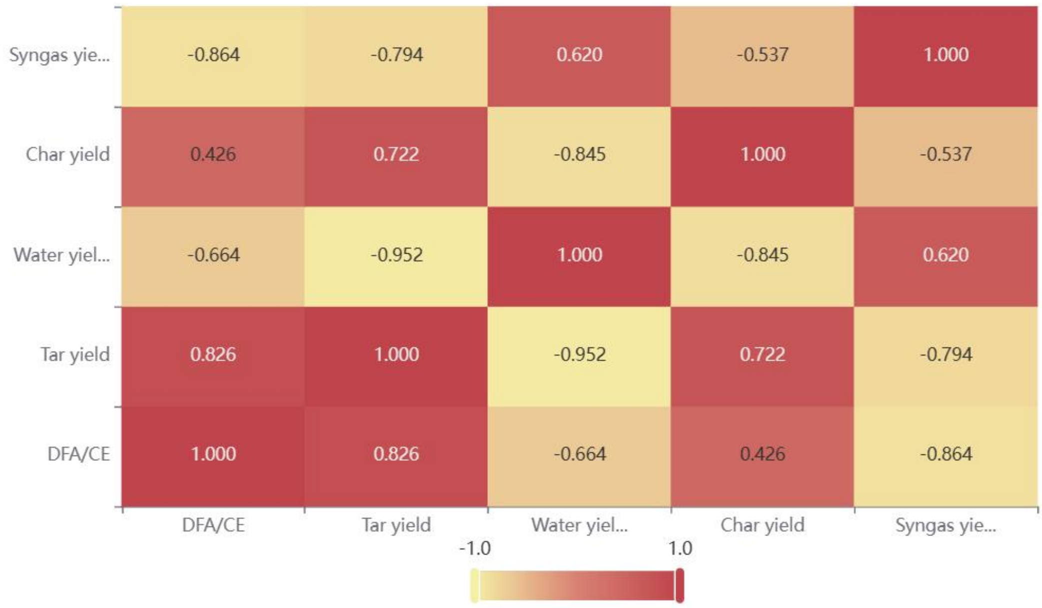
attention ： ***、**、*each represent“1%、5%、
10%”significance level
10%”significance level

	DFA/CE	Syngas yield
DFA/CE	1(0.000***)	-0.864(0.006***)
Syngas yield	-0.864(0.006***)	1(0.000***)

attention ： ***、**、*each represent“1%、5%、
10%”significance level

≥ 0.8 It can be seen from the table, the absolute value of r1 is strongly correlated with the mixing ratio of desulphization ash / cellulose; the absolute value of r2 is greater than 0.5 and less than 0.8, so the water yield and the mixing ratio of desulphization ash / cellulose have a certain correlation; the absolute value of r3 is less than 0.5, so the mixing ratio of carbon yield and desulfurization ash / cellulose is not strong; the absolute value of r4, so the synthetic gas production is strongly correlated with the mixing ratio of desulphization ash / cellulose. ≥ 0.8

Based on the above data, we can present the total diagram of thermal coefficient in the combination of desulphization ash / cellulose:



Pyrolysis combination: desulfurized ash / lignin

(1) Correlation analysis of the mixing ratio of tar yield, water yield, carbon yield, syngas yield and the pyrolysis ratio of desulfurization ash / lignin combination

DFA/LG	Tar yield	Water yield	Char yield	Syngas yield
10/100	18.06	15.3	58.17	8.47
20/100	13.77	18.54	57.46	10.23
30/100	11.29	20.17	57.13	11.41
40/100	10.28	20.97	56.98	11.77
50/100	9.49	21.53	57.14	11.84
60/100	9.02	21.87	57.23	11.88
80/100	10.3	21.41	57.15	11.14
100/100	8.19	23.69	57.43	10.69

From this form, we can get the corresponding correlation coefficient table:

	DFA/LG	Tar yield
DFA/LG	1(0.000***)	-0.855(0.007***)
Tar yield	-0.855(0.007***)	1(0.000***)

attention ： ***、**、*each represent“1%、5%、10%”significance level

	DFA/LG	Water yield
DFA/LG	1(0.000***)	0.904(0.002***)

Water yield	0.904(0.002***)	1(0.000***)

attention ：***、**、*each represent“1%、5%、10%”significance level

	DFA/LG	Char yield
DFA/LG	1(0.000***)	-0.49(0.217)
Char yield	-0.49(0.217)	1(0.000***)

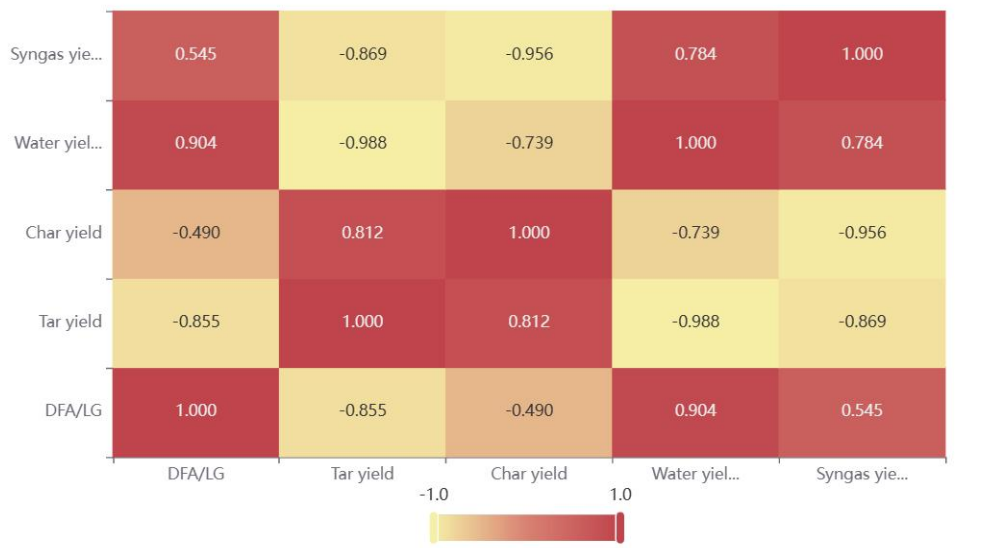
attention ：***、**、*each represent“1%、5%、10%”significance level

	DFA/LG	Syngas yield
DFA/LG	1(0.000***)	0.545(0.162)
Syngas yield	0.545(0.162)	1(0.000***)

attention ：***、**、*each represent“1%、5%、10%”significance level

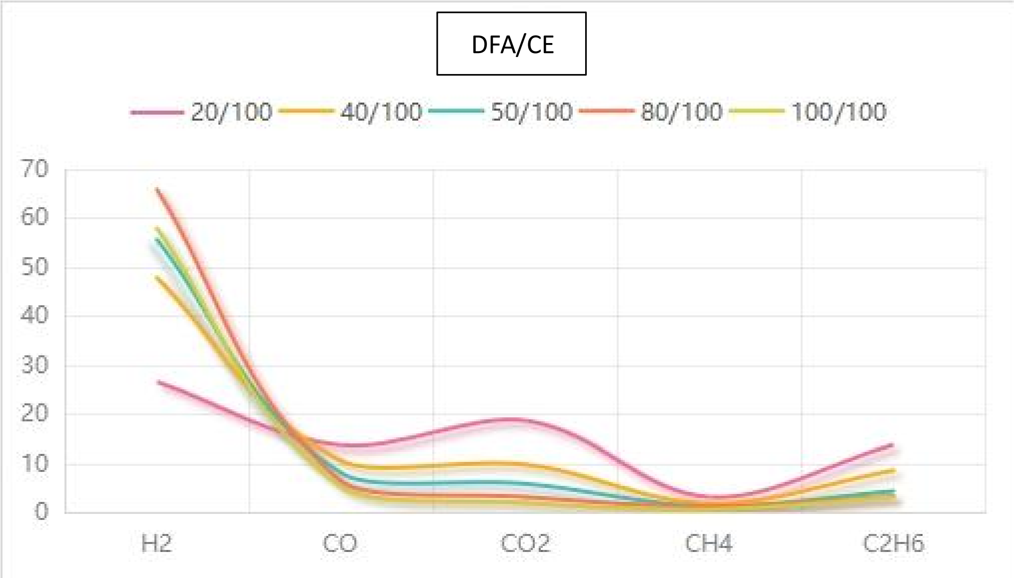
$\geq 0.8 \geq 0.8$ It can be seen from the table, the absolute value of r1 has the strong correlation between tar yield and the mixing ratio of desulfurization ash / lignin combination; the absolute value of r2 between the water yield and the mixing ratio of desulfurization ash / lignin combination; the absolute value of r3 is less than 0.5, so the mixing ratio of carbon yield and the mixing ratio of desulfurization ash / lignin combination is not strong; the absolute value of r4 is less than 0.8, so the mixing ratio of synthetic gas volume and the mixing ratio of desulfurization ash / lignin combination.

Based on the above data, we can give the total diagram of the thermal coefficient in the combination of desulfurization ash / lignin:

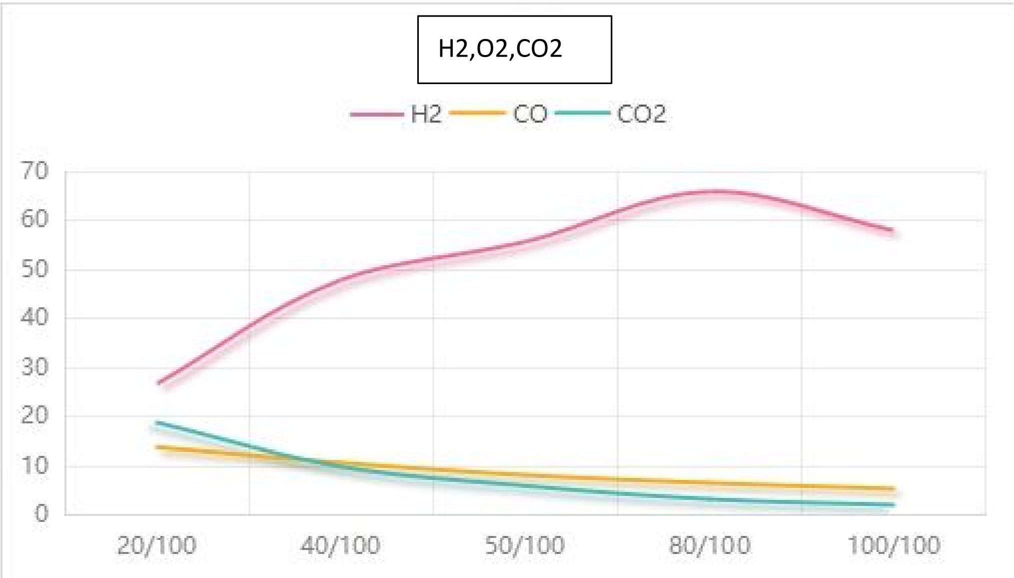


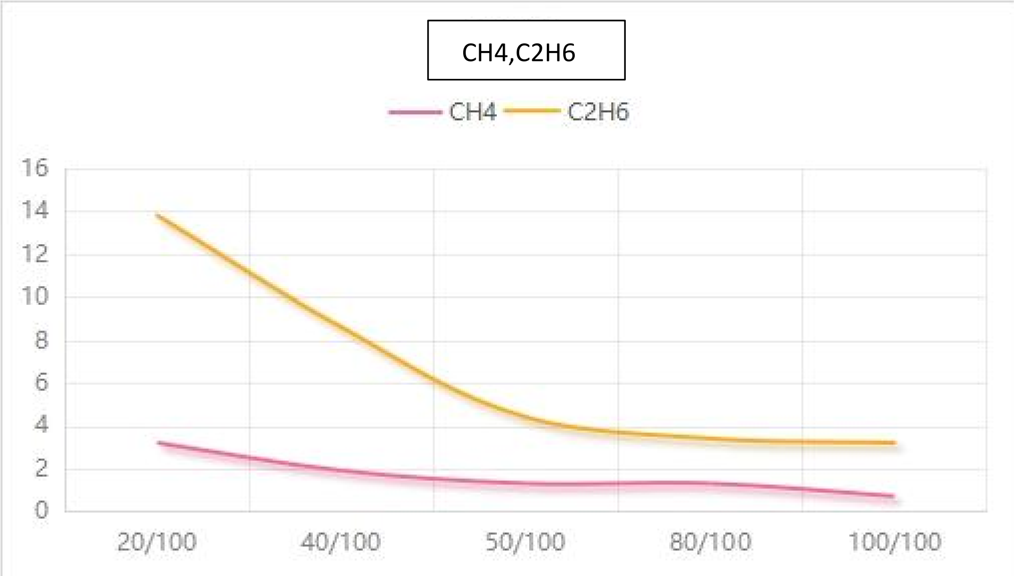
Question 2 Analysis of desulfurization ash / cellulose and desulfurization ash / lignin data

。Pyrolysis combination: desulfurized ash / cellulose



According to the line diagram, in the CH4 gas environment, the mixing ratio is not much related to the yield; the higher the H2 ash content, the higher the yield; in the CO, CO2 and C2H6 gases, the higher the ash content, the smaller the yield.

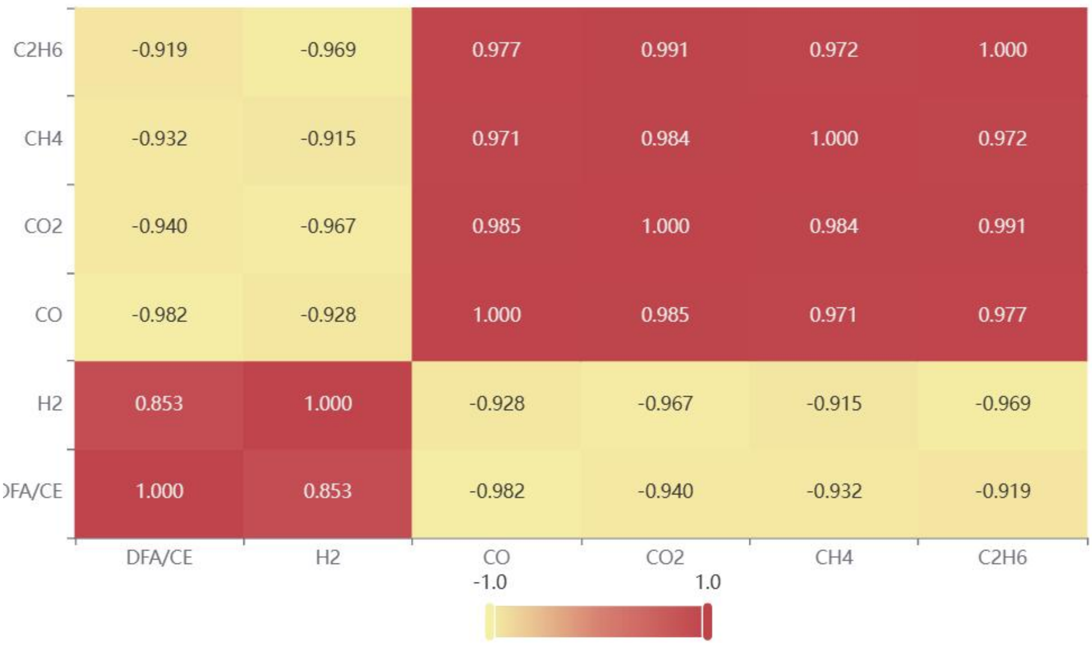




According to the line, with the increase of desulfurization ash, the yield of CO, CO2, C2H6 and CH4 decreases; under H2, the yield of desulfurization ash decreases.
According to the correlation coefficient table

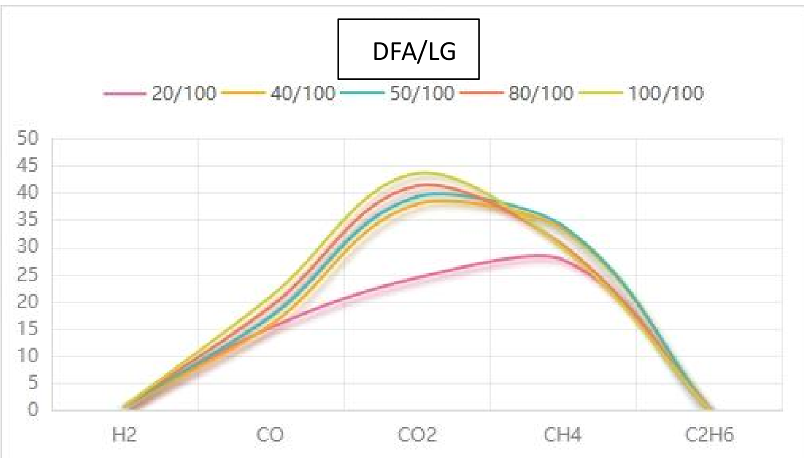
	DFA/CE	H2	CO	CO2	CH4	C2H6
DFA/CE	1(0.000***)	0.853(0.066*)	-0.982(0.003***)	-0.94(0.018**)	-0.932(0.021**)	-0.919(0.027**)
H2	0.853(0.066*)	1(0.000***)	-0.928(0.023**)	-0.967(0.007***)	-0.915(0.029**)	-0.969(0.007***)
CO	-0.982(0.003***)	-0.928(0.023**)	1(0.000***)	0.985(0.002***)	0.971(0.006***)	0.977(0.004***)
CO2	-0.94(0.018**)	-0.967(0.007***)	0.985(0.002***)	1(0.000***)	0.984(0.002***)	0.991(0.001***)
CH4	-0.932(0.021**)	-0.915(0.029**)	0.971(0.006***)	0.984(0.002***)	1(0.000***)	0.972(0.006***)
C2H6	-0.919(0.027**)	-0.969(0.007***)	0.977(0.004***)	0.991(0.001***)	0.972(0.006***)	1(0.000***)

The following is its corresponding thermodynamic coefficient diagram

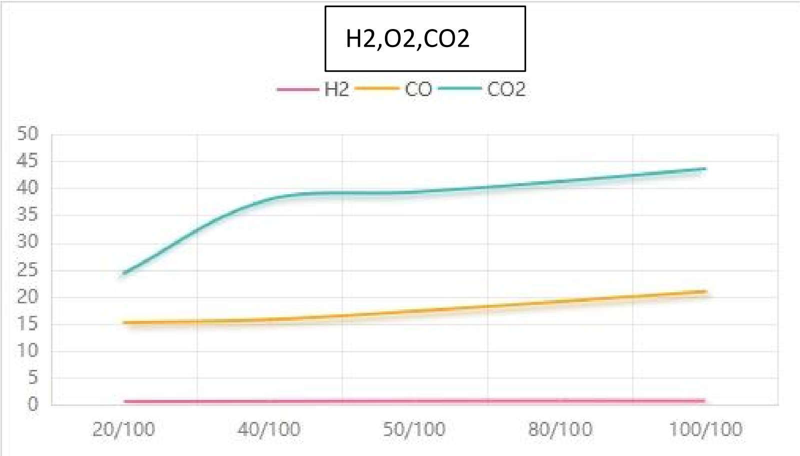


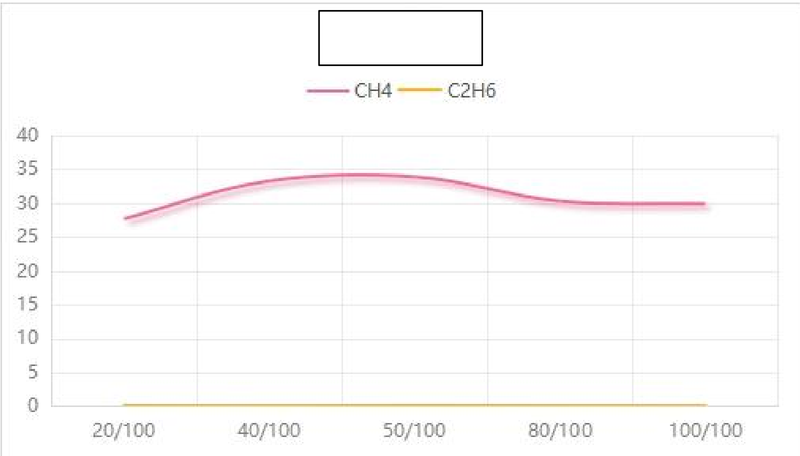
According to the correlation coefficient table, with the increase of the desulfurization ash content, the absolute value of r of H2, CO, CO2, CH4 and C2H6 is greater than 0.8, which has a strong correlation.

Pyrolysis combination: desulfurized ash / lignin



According to the line diagram, in H2 and C2H6, the mixing ratio is not related to the yield; in CO, CO2 and CH4, the higher the ash content.



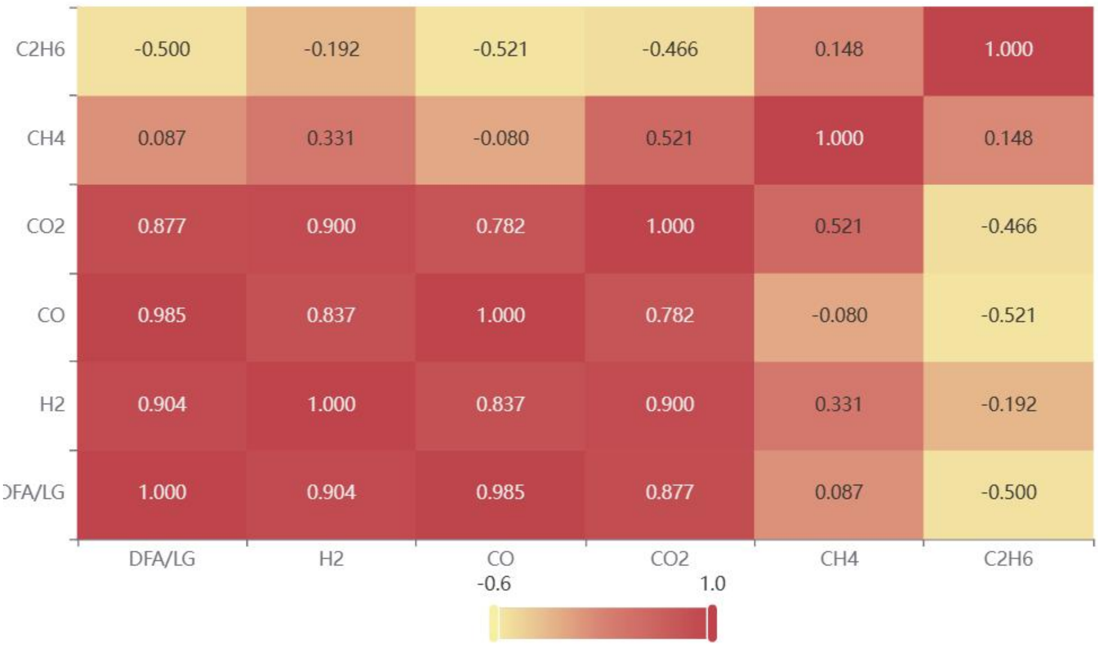


According to the line chart, the yield of pyrolysis products increases with the increase of CO and CO2; in the condition of H2 and C2H6, the increase is basically unchanged.

According to the correlation coefficient table

	DFA/LG	H2	CO	CO2	CH4	C2H6
DFA/LG	1(0.000***)	0.904(0.035**)	0.985(0.002***)	0.877(0.051*)	0.087(0.889)	-0.5(0.391)
H2	0.904(0.035**)	1(0.000***)	0.837(0.077*)	0.9(0.037**)	0.331(0.586)	-0.192(0.757)
CO	0.985(0.002***)	0.837(0.077*)	1(0.000***)	0.782(0.118)	-0.08(0.898)	-0.521(0.368)
CO2	0.877(0.051*)	0.9(0.037**)	0.782(0.118)	1(0.000***)	0.521(0.368)	-0.466(0.429)
CH4	0.087(0.889)	0.331(0.586)	-0.08(0.898)	0.521(0.368)	1(0.000***)	0.148(0.812)
C2H6	-0.5(0.391)	-0.192(0.757)	-0.521(0.368)	-0.466(0.429)	0.148(0.812)	1(0.000***)

The following is its corresponding thermodynamic coefficient diagram



According to the correlation coefficient table, with the increase of desulfurization ash content, the absolute value of r is greater than 0.8, with strong correlation; the absolute value of r in CH4 gas environment is similar to 0, which basically has no correlation; the absolute value of C2H6 gas environment r is greater than 0.5 and less than 0.8, with certain correlation.

The combination of problem three pyrolysis products and pyrolysis gas

thermal decomposition product

Pyrolysis products: water yield

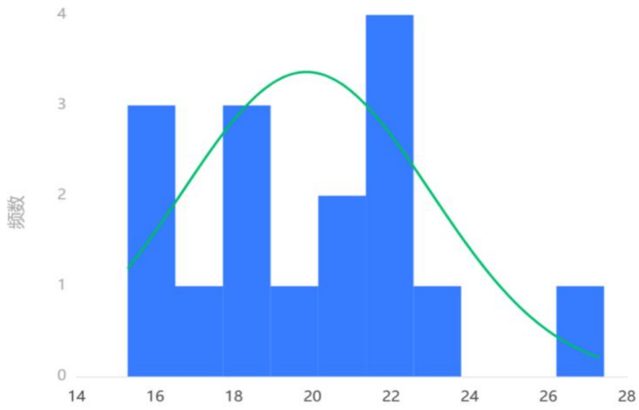
For the water yield in the yield of the pyrolysis products, the T-test gives the following data

Results of the normality test

variable	sample size	median	average	standard deviation	skewness	kurtosis	S-W checkout
water yield	16	20.05	19.849	3.157	0.68	0.732	0.948(0.461)

The aquatic rate was tested by S-W test, and the significance P-value was 0.461, which did not show significance at the level, and the null hypothesis cannot be rejected, so the data met the normal distribution

Histogram of the normality test



The figure above graph shows the results of the normality test of the variable aquatic rate data. If the normal graph basically presents a bell shape (high in the middle, low at both ends), it indicates that although the data is not absolutely normal, it is basically accepted as normal distribution

homogeneity test of variance

	Species (standard deviation)		F	P
	DFA/CE Water yield(n=8)	DFA/LG Water yield(n=8)		
water yield	3.759	2.539	0.803	0.385

The results of the homogeneity of variance test showed that for the aquatic rate, the significance P-value was 0.385, which does not show significance at the level, and the null hypothesis cannot be rejected, so the data satisfied the homogeneity of variance

Table of T-test analysis results for independent samples

variable name	variable value	sample size	average	standard deviation	T -test	mean difference	Cohen's d value
water yield	DFA/CE Water yield	8	19.262	3.759	T=-0.731 P=0.477	T=-0.731 P=0.478	0.366
	DFA/LG Water yield	8	20.435	2.539			

variable name	variable value	sample size	average	standard deviation	T -test	mean difference	Cohen's d value
	total	16	19.849	3.157			

DFA/CE Water yield, The mean value of DFA / LG Water yield in aquatic product rate is: 19.262/20.435; Since satisfying the homogeneity of variance, Using the independent-sample T-test, The significance result P-value was 0.477, Thus, the statistical results were not significant, Note that the DFA / CE Water yield, DFA / LG Water yield has not significantly difference in aquatic rate; The Cohen's d value is 0.366, The difference range is small (0.20, 0.50 and 0.80 correspond to small, medium, and large critical points, respectively)

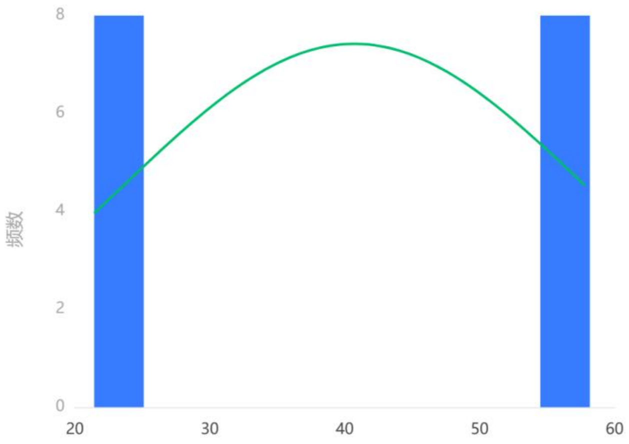
Pyrolysis products: coke production volume

For the coke production in the yield of pyrolysis products, the T test of the following data

Results of the normality test

variable	sample size	median	average	standard deviation	skewness	kurtosis	S-W checkout
mixing ratio	16	0.45	0.488	0.294	0.463	-0.796	0.933(0.272)
coke yield	16	40.945	40.701	17.201	-0.006	-2.294	0.681(0.000***)

Coke yield was tested by S-W test with significance P-value of 0.0, significance at the level, the null hypothesis was rejected, so the data did not satisfy the normal distribution. The absolute value of kurtosis (-2.294) is less than 10, and the absolute value of skewness (-0.006) is less than 3, which can be further analyzed with normal distribution histogram, PP map or QQ graph.



The figure above shows the results of the normality test of the variable coke yield data. If the normal figure basically presents a bell shape (high in the middle, low at both ends), it indicates that although the data is not absolutely normal, it is basically accepted as a normal distribution

homogeneity test of variance

	Species (standard deviation)		F	P
	DFA/CE Char yield(n=8)	DFA/LG Char yield(n=8)		
coke yield	1.141	0.373	3.262	0.092*

The results of the homogeneity of variance test show that for the coke yield, the significance P-value is 0.092 *, which does not show significance on the level, and the null hypothesis cannot be rejected, so the data satisfies the homogeneity of variance

Table of T-test analysis results for independent samples

variable name	variable value	sample size	average	standard deviation	T -test	mean difference	Cohen's d value
coke yield	DFA/CE Char yield	8	24.065	1.141	T=-78.39 P=0.000***	T=-78.39 P=0.000***	39.195
	DFA/LG Char yield	8	57.336	0.373			
	total	16	40.701	17.201			

DFA/CE Char yield, The average value of DFA / LG Char yield in coke yield is respectively: 24.065/57.336; Since satisfying the homogeneity of variance, Using the independent-sample T-test, The P-value of the significance result was 0.000 * * *, Thus, the results were statistically significant, Note that the CE Char yield, LG Char yield There are significant differences in the coke yield; The Cohen's d value of the difference is 39.195, The difference is very large (0.20, 0.50 and 0.80 correspond to small, medium, and large critical points, respectively)

Pyrolysis product: Synthetic gas production

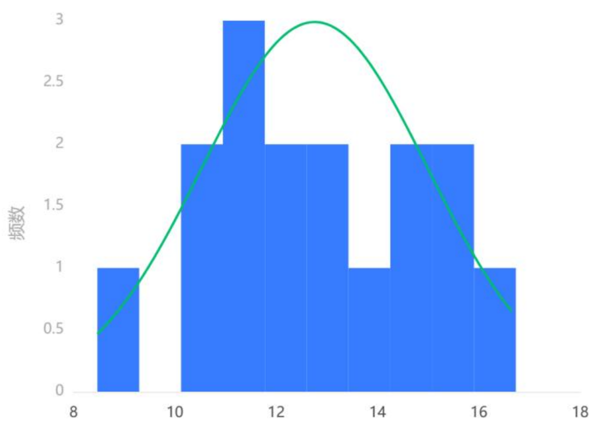
For the syngas production in the yield of pyrolysis products, the T-test of the same proportion of desulfurization ash produced the following data

Results of the normality test

variable	sample size	median	average	standard deviation	skewness	kurtosis	S-W checkout
mixing ratio	16	0.45	0.488	0.294	0.463	-0.796	0.933(0.272)
Mixture yield	16	12.315	12.759	2.225	0	-0.545	0.977(0.935)

The mixed gas yield was tested by the S-W test with a significance P-value of 0.935, not significant at the level, and the null hypothesis cannot be rejected, so the data satisfied the normal distribution.

Histogram of the normality test



The figure above figure shows the results of the normality test of the variable mixed gas yield data. If the normal graph basically shows a bell shape (high in the middle, low at both ends), it indicates that the data is not absolutely normal, but is basically acceptable as normal distribution

homogeneity test of variance

	Species (standard deviation)	F	P

	DFA/CE Syngas yield(n=8)	DFA/LG Syngas yield(n=8)		
Mixture yield	1.271	1.153	0.071	0.794

The results of the homogeneity of variance test showed that for the mixed gas yield, the P-value of significance was 0.794 and did not show significance at the level, and the null hypothesis cannot be rejected, so the data satisfied the homogeneity of variance

Table of T-test analysis results for independent samples

variable name	variable value	sample size	average	standard deviation	T -test	mean difference	Cohen's d value
Mixture yield	DFA/CE Syngas yield	8	14.59	1.271	T=6.035 P=0.000***	T=6.035 P=0.000***	3.017
	DFA/LG Syngas yield	8	10.929	1.153			
	total	16	12.759	2.225			

DFA/CE Syngas yield, The mean value of DFA / LG Syngas yield in the mixed gas yield is respectively: 14.59/10.929; Since satisfying the homogeneity of variance, Using the independent-sample T-test, The P-value of the significance result was 0.000 * * *, Thus, the results were statistically significant, Note that the CE Syngas yield, LG Syngas yield There are significant differences in the mixed gas yield; Cohen's d value of the difference magnitude: 3.017, The difference is very large (0.20, 0.50 and 0.80 correspond to small, medium, and large critical points, respectively).

Pyrolysis gas combination

Pyrolysis gas components: yieldCO

CO For the yield in the pyrolysis gas fraction, the T-test gives the following data

Results of the normality test

variable	sample size	median	average	standard deviation	skewness	kurtosis	S-W checkout
CO yield	10	14.465	13.25	5.397	-0.198	-1.307	0.949(0.659)

CO yield was tested by S-W test with significance P-value of 0.659, which did not show significance at the level, and the null hypothesis cannot be rejected, so the data satisfied the normal distribution.

Histogram of the normality test

The figure above shows the results of normality test of the variable CO yield If the normal graph basically presents a shape (high in the low at both ends), it that although the data absolutely normal, it basically acceptable normal distribution

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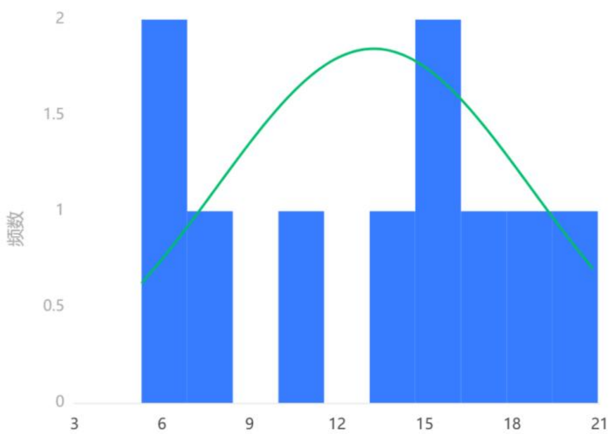


homogeneity test of variance

	Species (standard deviation)		F	P
	DFA/CE(n=5)	DFA/LG (n=5)		
CO yield	3.364	2.365	0.796	0.398

The results of the homogeneity of variance test showed that for CO yield, the P-value of significance was 0.398, not significant at the level, and the null hypothesis cannot be rejected, so the data satisfied the homogeneity of variance

Table of T-test analysis results for independent samples

variable name	variable value	sample size	average	standard deviation	T -test	mean difference	Cohen's d value
CO yield	DFA/CE	5	8.84	3.364	T=-4.797 P=0.001***	T=-4.797 P=0.002***	3.034
	DFA/LG	5	17.661	2.365			
	total	10	13.25	5.397			

DFA / CE, DFA / LG mean in CO yield were 8.84 / 17.661 respectively; due to the homogeneity of variance, T-test and the significance P-value was 0.001 * * *, so the statistical result was significant, indicating that DFA / CE, DFA / LG had a significant difference in CO yield; the difference Cohen's d value was 3.034 (0.20,0.50 and 0.80 correspond to small, medium, and large critical points respectively).

Pyrolysis gas components: yieldCO_2

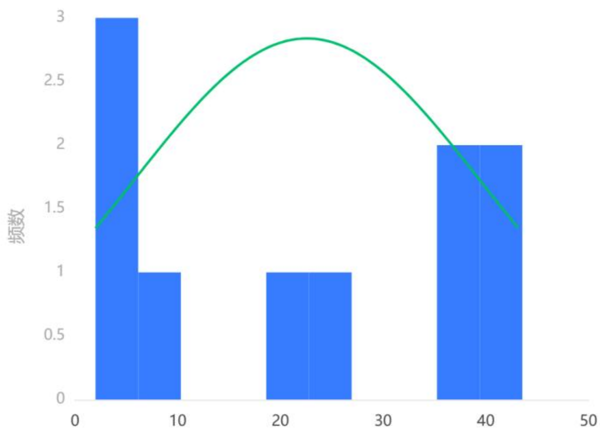
CO_2 For the yield in the pyrolysis gas fraction, the T-test gives the following data

Results of the normality test

variable	sample size	median	average	standard deviation	skewness	kurtosis	S-W checkout
CO2 yield	10	21.525	22.591	16.866	0.032	-1.987	0.87(0.099*)

CO2 The yield was tested by S-W test, and the significance P-value of 0.099 does not show significance at the level, and the null hypothesis cannot be rejected, so the data met the normal distribution.

Histogram of the normality test



The figure above shows

the results of the normality test of the variable CO2 yield data. If the normal graph basically presents a bell shape (high in the middle, low at both ends), it indicates that although the data is not absolutely normal, it is basically acceptable as a normal distribution

homogeneity test of variance

	Species (standard deviation)		F	P
	DFA/CE(n=5)	DFA/LG (n=5)		
CO2 yield	6.73	7.526	0.001	0.971

The results of the homogeneity of variance test showed that for the CO2 yield, the P-value of significance was 0.971, which did not show significance at the level, and the null hypothesis cannot be rejected, so the data satisfied the homogeneity of variance

Table of T-test analysis results for independent samples

variable name	variable value	sample size	average	standard deviation	T -test	mean difference	Cohen's d value
CO2 yield	DFA/CE	5	7.92	6.73	T=-6.499 P=0.000***	T=-6.499 P=0.000***	4.11
	DFA/LG	5	37.262	7.526			
	total	10	22.591	16.866			

DFA / CE, DFA / LG mean CO2 yield: 7.92 / 37.262 respectively; due to the homogeneity of variance, the T-test and the significance P value is 0.000 * * *, so the statistical results are significant, indicating that DFA / CE and DFA / LG are significant; Cohen's d value is 4.11, very large (0.20,0.50 and 0.80 correspond to small, medium and large critical points respectively).

Pyrolysis gas components: yieldCH_4

CH_4 For the yield in the pyrolysis gas fraction, the T-test gives the following data

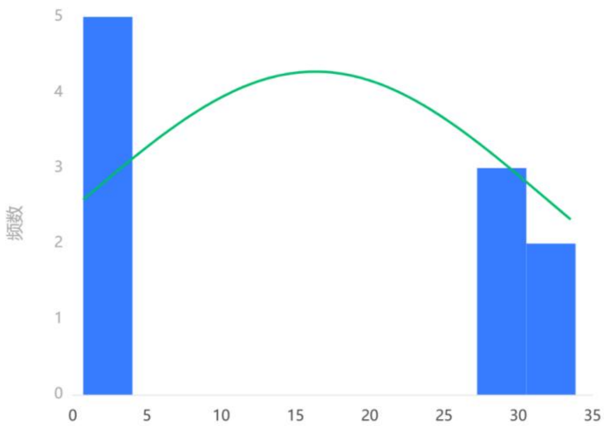
Results of the normality test

variable	sample size	median	average	standard deviation	skewness	kurtosis	S-W	checkout

variable	sample size	median	average	standard deviation	skewness	kurtosis	S-W checkout
CH4 yield	10	15.435	16.331	15.55	0.037	-2.477	0.741(0.003***)

CH4 The yield was tested by S-W test, with a significance P-value of 0.003, showing significance at the level, rejecting the null hypothesis, so the data did not satisfy the normal distribution. The absolute value of kurtosis (-2.477) is less than 10, and the absolute value of skewness (0.037) is less than 3, which can be further analyzed with normal distribution histogram, PP map or QQ graph.

Histogram of the normality test



The figure above shows the results of the normality test of the variable CH4 yield data. If the normal graph basically presents a bell shape (high in the middle, low at both ends), it indicates that although the data is not absolutely normal, it is basically acceptable as a normal distribution

homogeneity test of variance

	Species (standard deviation)		F	P
	DFA/CE(n=5)	DFA/LG (n=5)		
CH4 yield	0.95	2.557	6.032	0.040**

The results of the homogeneity of variance test showed that for the CH4 yield, the P-value of significance was 0.040 * *, showing significance at the level, rejecting the null hypothesis, and thus the data did not satisfy the homogeneity of variance

Table of T-test analysis results for independent samples

variable name	variable value	sample size	average	standard deviation	T -test	mean difference	Cohen's d value
CH4 yield	DFA/CE	5	1.68	0.95	T=-24.021 P=0.000***	T=-24.021 P=0.000***	15.192
	DFA/LG	5	30.982	2.557			
	total	10	16.331	15.55			

The means of DFA / CE and DFA / LG in CH4 yield were 1.68 / 30.982; since the homogeneity of variance is not satisfied, the P value is 0.000 * * *; the statistical result is significant, indicating that DFA / CE and DFA / LG are significantly different in CH4 yield; the difference amplitude Cohen's d value is 15.192, which is very large (0.20,0.50 and 0.80 correspond to small, medium and large critical points respectively).

Pyrolysis gas components: yieldC_2H_6

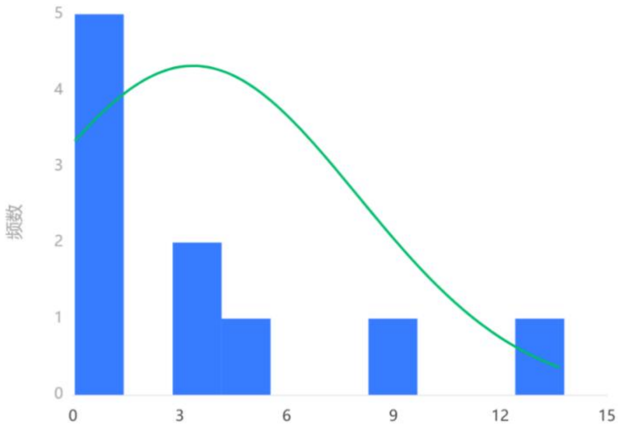
H_2 For the yield in the pyrolysis gas fraction, the T-test gives the following data

Results of the normality test

variable	sample size	median	average	standard deviation	skewness	kurtosis	S-W checkout
C2H6 yield	10	1.645	3.375	4.615	1.549	1.99	0.771(0.006***)

C2H6 The yield was tested by S-W test, with a significance P-value of 0.006, showing significance at the level, rejecting the null hypothesis, so the data did not satisfy the normal distribution. The absolute value of kurtosis (1.99) is less than 10, and the absolute value of skewness (1.549) is less than 3, which can be further analyzed with normal distribution histogram, PP map or QQ graph

Histogram of the normality test



The figure above shows the results of the normality test of the variable C2H6 yield data. If the normal graph basically presents a bell shape (high in the middle, low at both ends), it indicates that although the data is not absolutely normal, it is basically acceptable as a normal distribution

homogeneity test of variance

	Species (standard deviation)		F	P
	DFA/CE(n=5)	DFA/LG (n=5)		
C2H6 yield	4.54	0.016	15.217	0.005***

The results of the homogeneity of variance test showed that for the C2H6 yield, the P-value of significance was 0.005 * * *, showing significance at the level, rejecting the null hypothesis, and thus the data did not satisfy the homogeneity of variance

Table of T-test analysis results for independent samples

variable name	variable value	sample size	average	standard deviation	T -test	mean difference	Cohen's d value
C2H6 yield	DFA/CE	5	6.68	4.54	T=3.256 P=0.012**	T=3.256 P=0.031**	6.61
	DFA/LG	5	0.07	0.016			
	total	10	3.375	4.615			

DFA / CE, DFA / LG C2H6 yield mean 6.68 / 0.07 respectively; since the homogeneity of variance was not satisfied, Welch's T test, the P value of significance was 0.031 * *, so statistical results are significant, indicating that DFA / CE, DFA / LG is significantly different in C2H6 yield; the difference amplitude Cohen's d value was 2.059, the difference is very large (0.20,0.50 and 0.80 correspond to small, medium, and large critical points respectively).

Appendix 2

```
% Question 1 Multiple linear regression MATLAB code implementation
% argument
DFA_CS = [0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.8, 1];

% dependent variable
Tara_yield = [19.46, 17.25, 15.43, 14.14, 13.89, 13.21, 12.84, 12.57, 12.13];
Water_yield = [26.84, 27.64, 28.11, 28.23, 28.62, 29.01, 30.07, 30.68, 31.02];
Char_yield = [29.21, 29.11, 29.3, 29.34, 29.14, 29.33, 29.47, 29.64, 29.87];
Syngas_yield = [24.49, 26, 27.16, 28.29, 28.35, 28.45, 27.62, 27.11, 26.98];

% Build the design matrix
X = [ones(length(DFA_CS), 1), DFA_CS'];

% The dependent variables were merged into a matrix
Y = [Tara_yield', Water_yield', Char_yield', Syngas_yield'];

% multiple linear regression
B = X\Y;

% predicted value
Y_pred = X * B;

% Calculate the R square
Y_mean = mean(Y);
SS_tot = sum((Y - Y_mean).^2);
SS_res = sum((Y - Y_pred).^2);
R_squared = 1 - (SS_res./SS_tot);

% graphing
figure;
subplot(2,2,1);
plot(DFA_CS, Tara_yield, 'ro', DFA_CS, Y_pred(:,1), 'b-');
xlabel('DFA/CS');
ylabel('Tara-yield');
legend('observed value', 'regression line');

subplot(2,2,2);
plot(DFA_CS, Water_yield, 'ro', DFA_CS, Y_pred(:,2), 'b-');
xlabel('DFA/CS');
```

```
ylabel('Water-yield');
legend('observed value', 'regression line');

subplot(2,2,3);
plot(DFA_CS, Char_yield, 'ro', DFA_CS, Y_pred(:,3), 'b-');
xlabel('DFA/CS');
ylabel('Char-yield');
legend('observed value', 'regression line');

subplot(2,2,4);
plot(DFA_CS, Syngas_yield, 'ro', DFA_CS, Y_pred(:,4), 'b-');
xlabel('DFA/CS');
ylabel('Syngas-yield');
legend('observed value', 'regression line');

The% shows the R square
Disp (['R squared value:', num2str (R_squared)]);


% argument
DFA_CE = [10 20 30 40 50 60 80 100];

% dependent variable
Tara_yield = [34.42 38.31 42.69 43.78 44.53 44.41 43.24 45.28];
Water_yield = [27.42 21.37 17.84 16.9 16.25 18.25 19.93 16.14];
Char_yield = [21.43 24.91 24.17 24.7 24.54 24.59 23.57 24.61];
Syngas_yield = [16.73 15.41 15.3 14.62 14.68 12.75 13.26 13.97];

% Build the design matrix
X = [ones(length(DFA_CE), 1), DFA_CE'];

% The dependent variables were merged into a matrix
Y = [Tara_yield', Water_yield', Char_yield', Syngas_yield'];

% multiple linear regression
B = X\Y;

% predicted value
Y_pred = X * B;

% Calculate the R square
Y_mean = mean(Y);
SS_tot = sum((Y - Y_mean).^2);
SS_res = sum((Y - Y_pred).^2);
```

```
R_squared = 1 - (SS_res./SS_tot);

% graphing
figure;
subplot(2,2,1);
plot(DFA_CE, Tara_yield, 'ro', DFA_CE, Y_pred(:,1), 'b-');
xlabel('DFA/CE');
ylabel('Tara-yield');
legend('observed value', 'regression line');

subplot(2,2,2);
plot(DFA_CE, Water_yield, 'ro', DFA_CE, Y_pred(:,2), 'b-');
xlabel('DFA/CE');
ylabel('Water-yield');
legend('observed value', 'regression line');

subplot(2,2,3);
plot(DFA_CE, Char_yield, 'ro', DFA_CE, Y_pred(:,3), 'b-');
xlabel('DFA/CE');
ylabel('Char-yield');
legend('observed value', 'regression line');

subplot(2,2,4);
plot(DFA_CE, Syngas_yield, 'ro', DFA_CE, Y_pred(:,4), 'b-');
xlabel('DFA/CE');
ylabel('Syngas-yield');
legend('observed value', 'regression line');

The% shows the R square
Disp (['R squared value:', num2str (R_squared)]);



% argument
DFA_LG= [10 20 30 40 50 60 80 100];

% dependent variable
Tara_yield = [18.06 13.77 11.29 10.28 9.49 9.02 10.3 8.19];
Water_yield = [15.3 18.54 20.17 20.97 21.53 21.87 21.41 23.69];
Char_yield = [58.17 57.46 57.13 56.98 57.14 57.23 57.15 557.43];
Syngas_yield = [8.47 10.23 11.41 11.77 11.84 11.88 11.14 10.69];

% Build the design matrix
X = [ones(length(DFA_LG), 1), DFA_LG'];
```

```
% The dependent variables were merged into a matrix
Y = [Tara_yield', Water_yield', Char_yield', Syngas_yield'];

% multiple linear regression
B = X\Y;

% predicted value
Y_pred = X * B;

% Calculate the R square
Y_mean = mean(Y);
SS_tot = sum((Y - Y_mean).^2);
SS_res = sum((Y - Y_pred).^2);
R_squared = 1 - (SS_res./SS_tot);

% graphing
figure;
subplot(2,2,1);
plot(DFA_LG, Tara_yield, 'ro', DFA_LG, Y_pred(:,1), 'b-');
xlabel('DFA/LG');
ylabel('Tara-yield');
legend('observed value', 'regression line');

subplot(2,2,2);
plot(DFA_LG, Water_yield, 'ro', DFA_LG, Y_pred(:,2), 'b-');
xlabel('DFA/LG');
ylabel('Water-yield');
legend('observed value', 'regression line');

subplot(2,2,3);
plot(DFA_LG, Char_yield, 'ro', DFA_LG, Y_pred(:,3), 'b-');
xlabel('DFA/LG');
ylabel('Char-yield');
legend('observed value', 'regression line');

subplot(2,2,4);
plot(DFA_LG, Syngas_yield, 'ro', DFA_LG, Y_pred(:,4), 'b-');
xlabel('DFA/LG');
ylabel('Syngas-yield');
legend('observed value', 'regression line');

The% shows the R square
Disp (['R squared value:', num2str (R_squared)]);
```

```
% DFA-ce \ DFA _ CE \ DFA _ LG material yield scatter plot MATLAB code
implementation
% data preparation
DFA_CS=[0 10 20 30 40 50 60 90 100];
tar_yield=[19.46 17.25 15.43 14.14 13.89 13.21 12.84 12.57 12.13];
water_yield=[26.84 27.64 28.11 28.23 28.62 29.01 30.07 30.68 31.02];
char_yield=[29.21 29.11 29.3 29.34 29.14 29.33 29.47 29.64 29.87];
syngas_yield=[24.49 26 27.16 28.29 28.35 28.45 27.62 27.11 26.98];

Md_tar=fitlm(DFA_CS,tar_yield);
Md_water=fitlm(DFA_CS,water_yield);
Md_char=fitlm(DFA_CS,char_yield);
Md_syngas=fitlm(DFA_CS,syngas_yield);

disp('Linear Regression Statistics for Tar Yield');
disp(Md_tar);
disp('Linear Regression Stasistics for Water Yield');
disp(Md_water);
disp('Linear Regression Stasistics for Char Yield');
disp(Md_char);
disp('Linear Regression Stasistics for Syngas Yield');
figure
subplot(2,2,1)
scatter(DFA_CS,tar_yield,'o','filled');
legend('DFA_CS_tar_yield')

hold on ;
subplot(2,2,2)
scatter(DFA_CS,water_yield,'o','filled');
legend('DFA_CS_water_yield')

hold on
subplot(2,2,3)
scatter(DFA_CS,char_yield,'o','filled');
legend('DFA_CS_char_yield')

hold on
subplot(2,2,4)
scatter(DFA_CS,syngas_yield,'o','filled');
legend('DFA_CS_syngas_yield');
```

```
% data preparation
DFA_CE=[10 20 30 40 50 60 80 100];
tar_yield=[34.42 38.31 42.69 43.78 44.53 44.41 43.24 45.28];
water_yield=[27.42 21.37 17.84 16.9 16.25 18.25 19.93 16.14];
char_yield=[21.43 24.91    24.17 24.7 24.54 24.59 23.57 24.61];
syngas_yield=[16.73 15.41 15.3 14.62 14.68 12.75 13.26 13.97];

Md_tar=fitlm(DFA_CE,tar_yield);
Md_water=fitlm(DFA_CE,water_yield);
Md_char=fitlm(DFA_CE,char_yield);
Md_syngas=fitlm(DFA_CE,syngas_yield);
disp('Linear Regression Statistics for Tar Yield');
disp(Md_tar);
disp('Linear Regression Stasistics for Water Yield');
disp(Md_water);
disp('Linear Regression Stasistics for Char Yield');
disp(Md_char);
disp('Linear Regression Stasistics for Syngas Yield');

figure
subplot(2,2,1)
scatter(DFA_CE,tar_yield,'o','filled');
legend('DFA_CE_tar_yield')

hold on ;
subplot(2,2,2)
scatter(DFA_CE,water_yield,'o','filled');
legend('DFA_CE_water_yield')

hold on
subplot(2,2,3)
scatter(DFA_CE,char_yield,'o','filled');
legend('DFA_CE_char_yield')

hold on
subplot(2,2,4)
scatter(DFA_CE,syngas_yield,'o','filled');
legend('DFA_CE_syngas_yield');

% data preparation
DFA_LG=[10 20 30 40 50 60 80 100];
tar_yield=[18.06 13.77 11.29 10.28 9.49 9.02 10.3 8.19];
water_yield=[15.3 18.54 20.17 20.97 221.53 21.87 21.41 23.69];
char_yield=[58.17 57.46 57.13 56.98 57.14 57.23 57.15 57.43];
```

```
syngas_yield=[8.47 10.23 11.41 11.77 11.84 11.88 11.14 10.69];

Md_tar=fitlm(DFA_CE,tar_yield);
Md_water=fitlm(DFA_CE,water_yield);
Md_char=fitlm(DFA_CE,char_yield);
Md_syngas=fitlm(DFA_CE,syngas_yield);
disp('Linear Regression Statistics for Tar Yield');
disp(Md_tar);
disp('Linear Regression Stasistics for Water Yield');
disp(Md_water);
disp('Linear Regression Stasistics for Char Yield');
disp(Md_char);
disp('Linear Regression Stasistics for Syngas Yield');

figure
subplot(2,2,1)
scatter(DFA_LG ,tar_yield,'o','filled');
legend('DFA_LG_tar_yield')

hold on
subplot(2,2,2)
scatter(DFA_LG,water_yield,'o','filled');
legend('DFA_LG_water_yield')

hold on
subplot(2,2,3)
scatter(DFA_LG,char_yield,'o','filled');
legend('DFA_LG_char_yield')

hold on
subplot(2,2,4)
scatter(DFA_LG,syngas_yield,'o','filled');
legend('DFA_LG_syngas_yield')

print('plot.1', '-dpng');




% 3 D bar statistics graph MATLAB code implementation for question 3

% Define data
```

```
DFA_CE_H2 = [26.6, 47.8, 55.6, 65.8, 57.9];
DFA_CE_CO = [13.7, 10.6, 8.1, 6.5, 5.3];
DFA_CE_CO2 = [18.7, 9.8, 5.9, 3.2, 2];
DFA_CE_CH4 = [3.2, 1.9, 1.3, 1.3, 0.7];
DFA_CE_C2H6 = [13.8, 8.6, 4.4, 3.4, 3.2];
DFA_LG_H2 = [0.67, 0.72, 0.78, 0.81, 0.79];
DFA_LG_CO = [15.23, 15.76, 17.305, 19.075, 20.935];
DFA_LG_CO2 = [24.35, 37.91, 39.26, 41.23, 43.56];
DFA_LG_CH4 = [27.67, 33.25, 33.86, 30.26, 29.87];
DFA_LG_C2H6 = [0.08, 0.06, 0.09, 0.07, 0.05];
% Draw the curve


figure;
bar3([DFA_CE_H2', DFA_CE_CO', DFA_CE_CO2', DFA_CE_CH4',
DFA_CE_C2H6']);
xticks(1:5);
xticklabels({'20/100', '40/100', '50/100', '80/100', '100/100'});
yticks(1:5); yticklabels({'H2', 'CO', 'CO2', 'CH4', 'C2H6'});
xlabel('DFA/CE Pyrolysis');
ylabel('Gaseous Components');
zlabel('Yield (mL/g,daf)');
title('Yield of Gaseous Components from DFA/CE Pyrolysis');

figure;
bar3([DFA_LG_H2', DFA_LG_CO', DFA_LG_CO2', DFA_LG_CH4',
DFA_LG_C2H6']);
xticks(1:5);
xticklabels({'20/100', '40/100', '50/100', '80/100', '100/100'});
yticks(1:5);
yticklabels({'H2', 'CO', 'CO2', 'CH4', 'C2H6'});
xlabel('DFA/LG Pyrolysis');
ylabel('Gaseous Components');
zlabel('Yield (mL/g,daf)');
title('Yield of Gaseous Components from DFA/LG Pyrolysis');

figure;
Tab2 = [34.42 38.31 42.69 43.78 44.53 44.41 43.24 45.28;
27.42 21.37 17.84 16.9 16.25 18.25 19.93 16.14;
21.43 24.91 24.17 24.7 24.54 24.59 23.57 24.61;
16.73 15.41 15.3 14.62 14.68 12.75 13.26 13.97];
y_labels = {'Tar_yield', 'Water_yield', 'Char_yield', 'Syngas_yield'};
```

```
bar3(Tab2);
title('Yield of Decomposition Products from DFA/CE Pyrolysis');
xlabel('DFA/CE');
ylabel('Products');
zlabel('Yield (wt.%)');
set(gca,'yticklabel',y_labels);

figure;
Tab3 = [18.06 13.77 11.29 10.28 9.49 9.02 10.3 8.19;
15.3 18.54 20.17 20.97 21.53 21.87 21.41 23.69;
58.17 57.46 57.13 56.98 57.14 57.23 57.15 57.43;
8.47 10.23 11.41 11.77 11.84 11.88 11.14 10.69];
y_labels = {'Tar_yield', 'Water_yield', 'Char_yield', 'Syngas_yield'};
bar3(Tab3);
title('Yield of Decomposition Products from DFA/LG Pyrolysis');
xlabel('DFA/LG');
ylabel('Products');
zlabel('Yield (wt.%)');
set(gca,'yticklabel',y_labels);




% 3 D kernel density graph MATLAB code implementation for question 4
% DFA _ LG gas
x = [20, 40, 50, 80, 100]; % DFA/LG
y = [0.67, 15.23, 24.35, 27.67, 0.08; % H2
0.72, 15.76, 37.91, 33.25, 0.06; % CO
0.78, 17.305, 39.26, 33.86, 0.09; % CO2
0.81, 19.075, 41.23, 30.26, 0.07; % CH4
0.79, 20.935, 43.56, 29.87, 0.05]; % C2H6
[X,Y] = meshgrid(x, 1:size(y, 1));
F = mvksdensity([X(:), y(:)], [X(:), y(:)], 'Bandwidth', [5, 5], 'Kernel', 'normpdf');

surf(X, Y, reshape(F, size(X)));
xlabel('DFA/LG');
ylabel('compound');
zlabel('kernel density estimation');
title('Three-dimensional mao of kernel density estimation');
set(gca, 'YTick', 1:size(y, 1), 'YTickLabel', {'H2','CO','CO2','CH4','C2H6'});
colorbar;
```

```
% DFA _ CE gas
x = [20, 40, 50, 80, 100]; % DFA/CE
y = [26.6, 13.7,18.7,3.2,13.8; % H2
47.8, 10.6, 9.8, 1.9, 8.6; % CO
55.6,8.1,5.9, 1.3, 4.4; % CO2
65.8, 6.5,3.2, 1.3, 3.4; % CH4
57.9, 5.3, 2, 0.7, 3.2]; % C2H6
[X,Y] = meshgrid(x, 1:size(y, 1));
F = mvksdensity([X(:), y(:)], [X(:), y(:)], 'Bandwidth', [5, 5], 'Kernel', 'normpdf');

surf(X, Y, reshape(F, size(X)));
xlabel('DFA/CE');
ylabel('compound');
zlabel('kernel density estimation');
title('Three-dimensional mao of kernel density estimation');
set(gca, 'YTick', 1:size(y, 1), 'YTickLabel', {'H2','CO','CO2','CH4','C2H6'});
colorbar




% DFA _ LG material
x = [10, 20, 30, 40, 50, 60, 80, 100]; % DFA/LG
y = [18.06, 13.77, 11.29, 10.28, 9.49, 9.02, 10.3, 8.19; % Tar_yield
15.3, 18.54, 20.17, 20.97, 21.53, 21.87, 21.41, 23.69; % Water_yield
58.17, 57.46, 57.13, 56.98, 57.14, 57.23, 57.15, 57.43; % Char_yield
8.47, 10.23, 11.41, 11.77, 11.84, 11.88, 11.14, 10.69]; % Syngas_yield
[X,Y] = meshgrid(x, 1:size(y, 1));
F = mvksdensity([X(:), y(:)], [X(:), y(:)], 'Bandwidth', [5, 5], 'Kernel', 'normpdf');
surf(X, Y, reshape(F, size(X)));
xlabel('DFA/LG');
ylabel('compound');
zlabel('kernel density estimation');
title('Three-dimensional mao of kernel density estimation');
set(gca, 'YTick', 1:size(y, 1), 'YTickLabel',
{'Tar_yield','Water_yield','Char_yield','Syngas_yield'});


% DFA _ CE material
x = [10, 20, 30, 40, 50, 60, 80, 100]; % DFA/CE
y = [34.42, 38.31, 42.69, 43.78, 44.53, 44.41, 43.24, 45.28; % Tar_yield
27.42, 21.37, 17.84, 16.9, 16.25, 18.25, 19.93, 16.14; % Water_yield
21.43, 24.91, 24.17, 24.7, 24.54, 24.59, 23.57, 24.61; % Char_yield
```

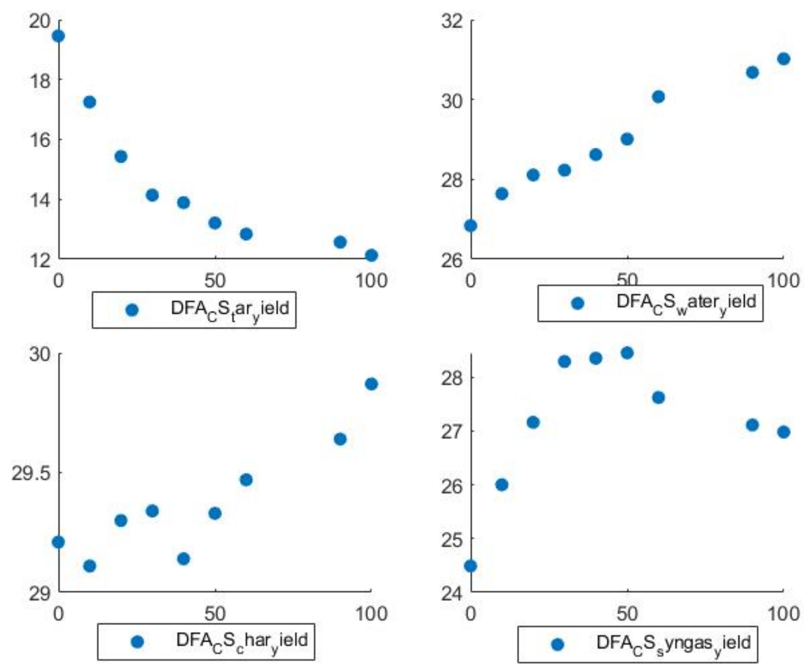
```
16.73, 15.41, 15.3, 14.62, 14.68, 12.75, 13.26, 13.97]; % Syngas_yield
[X,Y] = meshgrid(x, 1:size(y, 1));
F = mvksdensity([X(:), y(:)], [X(:), y(:)], 'Bandwidth', [5, 5], 'Kernel', 'normpdf');
surf(X, Y, reshape(F, size(X)));
xlabel('DFA/CE');
ylabel('compound');
zlabel('kernel density estimation');
title('Three-dimensional mao of kernel density estimation');
set(gca, 'YTick', 1:size(y, 1), 'YTickLabel',
{'Tar_yield','Water_yield','Char_yield','Syngas_yield'});
colorbar;


% Question 4 curve MATLAB code implementation
% Code 1
DFA _ CE = [10,20,30,40,50,60,80,100];% DFA _ CE serves as the abscissa
Tar_yield = [34.42, 38.31, 42.69, 43.78, 44.53, 44.41, 43.24, 45.28];
Water_yield = [27.42, 21.37, 17.84, 16.9, 16.25, 18.25, 19.93, 16.14];
Char_yield = [21.43, 24.91, 24.17, 24.7, 24.54, 24.59, 23.57, 24.61];
Syngas_yield = [16.73, 15.41, 15.3, 14.62, 14.68, 12.75, 13.26, 13.97];
% Draw the curve
plot(DFA_CE, Tar_yield, '-o', 'DisplayName', 'Tar yield');
hold on ;
plot(DFA_CE, Water_yield, '-o', 'DisplayName', 'Water yield');
plot(DFA_CE, Char_yield, '-o', 'DisplayName', 'Char yield');
plot(DFA_CE, Syngas_yield, '-o', 'DisplayName', 'Syngas yield');
hold off ;
% Add a title and a label
xlabel('DFA_CE');
ylabel('Yield (wt.%)');
title('Yield of Decomposition Products from DFA/CE Pyrolysis');
legend('Location', 'best');


% Code 2
DFA _ LG = [10,20,30,40,50,60,80,100];% DFA _ LG serves as the abscissa
Tar_yield = [18.06, 13.77, 11.29, 10.28, 9.49, 9.02, 10.3, 8.19];
Water_yield = [15.3, 18.54, 20.17, 20.97, 21.53, 21.87, 21.41, 23.69];
Char_yield = [58.17, 57.46, 57.13, 56.98, 57.14, 57.23, 57.15, 57.43];
Syngas_yield = [8.47, 10.23, 11.41, 11.77, 11.84, 11.88, 11.14, 10.69];
% Draw the curve
plot(DFA_LG, Tar_yield, '-o', 'DisplayName', 'Tar yield');
hold on ;
plot(DFA_LG, Water_yield, '-o', 'DisplayName', 'Water yield');
```

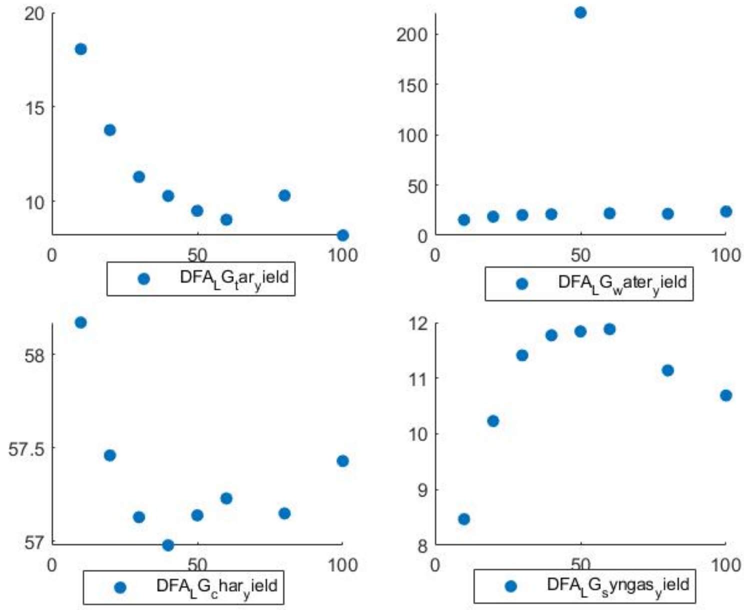
```
plot(DFA_LG, Char_yield, '-o', 'DisplayName', 'Char yield');
plot(DFA_LG, Syngas_yield, '-o', 'DisplayName', 'Syngas yield');
hold off ;
% Add a title and a label
xlabel('DFA_LG');
ylabel('Yield (wt.%)');
title('Yield of Decomposition Products from DFA/LG Pyrolysis');
legend('Location', 'best');


% Code 3
DFA _ CE = [20,40,50,80,100];% DFA _ CE is as the abscissa
H2_yield = [26.6, 47.8, 55.6, 65.8, 57.9];
CO_yield = [13.7, 10.6, 8.1, 6.5, 5.3];
CO2_yield = [18.7, 9.8, 5.9, 3.2, 2];
CH4_yield = [3.2, 1.9, 1.3, 1.3, 0.7];
C2H6_yield = [13.8, 8.6, 4.4, 3.4, 3.2];
% Draw the curve
plot(DFA_CE, H2_yield, '-o', 'DisplayName', 'H2 yield');
hold on ;
plot(DFA_CE, CO_yield, '-o', 'DisplayName', 'CO yield');
plot(DFA_CE, CO2_yield, '-o', 'DisplayName', 'CO2 yield');
plot(DFA_CE, CH4_yield, '-o', 'DisplayName', 'CH4 yield');
plot(DFA_CE, C2H6_yield, '-o', 'DisplayName', 'C2H6 yield');
hold off ;
% Add a title and a label
xlabel('DFA_CE');
ylabel('Yield (mL/g,daf)');
title('Yield of Gaseous Components from DFA/CE Pyrolysis');
legend('Location', 'best');


% Code 4
DFA _ LG = [20,40,50,80,100];% DFA _ LG serves as the abscissa
H2_yield = [0.67, 0.72, 0.78, 0.81, 0.79];
CO_yield = [15.23, 15.76, 17.305, 19.075, 20.935];
CO2_yield = [24.35, 37.91, 39.26, 41.23, 43.56];
CH4_yield = [27.67, 33.25, 33.86, 30.26, 29.87];
C2H6_yield = [0.08, 0.06, 0.09, 0.07, 0.05];
% Draw the curve
plot(DFA_LG, H2_yield, '-o', 'DisplayName', 'H2 yield');
hold on ;
plot(DFA_LG, CO_yield, '-o', 'DisplayName', 'CO yield');
```

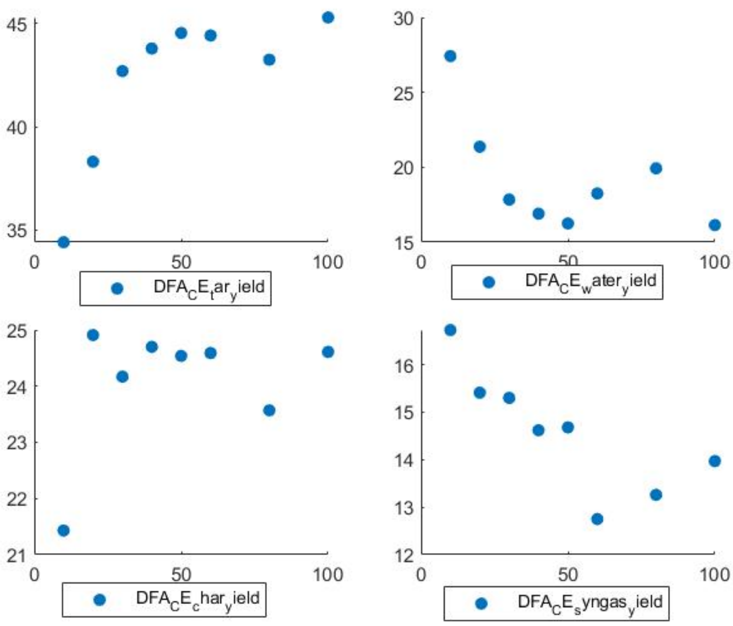
```
plot(DFA_LG, CO2_yield, '-o', 'DisplayName', 'CO2 yield');
plot(DFA_LG, CH4_yield, '-o', 'DisplayName', 'CH4 yield');
plot(DFA_LG, C2H6_yield, '-o', 'DisplayName', 'C2H6 yield');
hold off ;
% Add a title and a label
xlabel('DFA_LG');
ylabel('Yield (mL/g,daf)');
title('Yield of Gaseous Components from DFA/LG Pyrolysis');
legend('Location', 'best');
```

Appendix 3

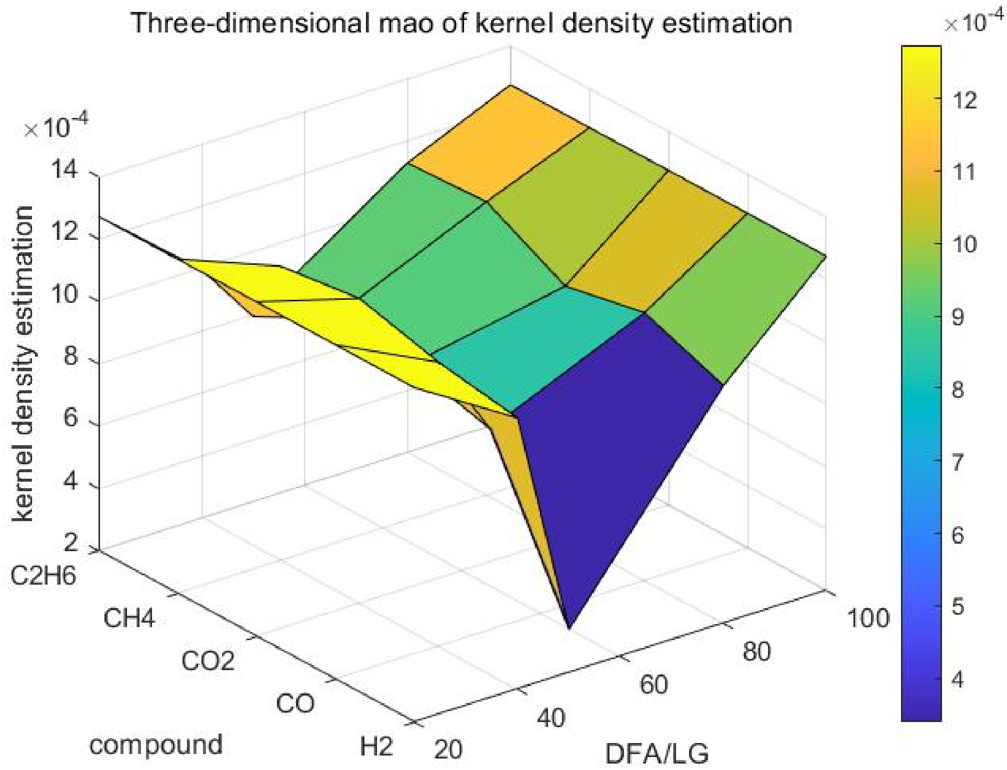
```
% DFA-ce \ DFA _ CE \ DFA _ LG material yield scatter plot MATLAB code
implementation
```



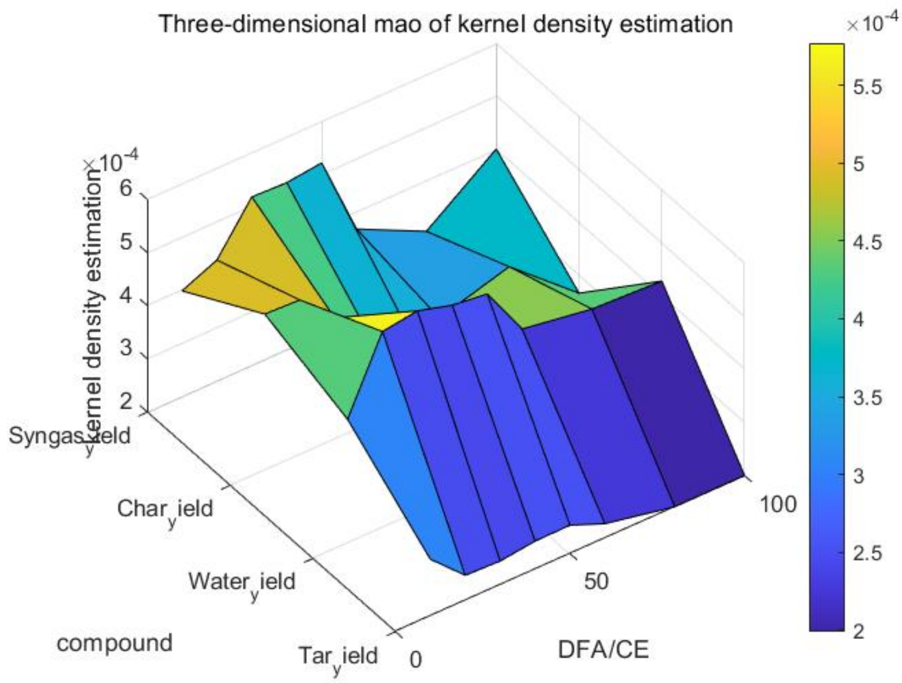




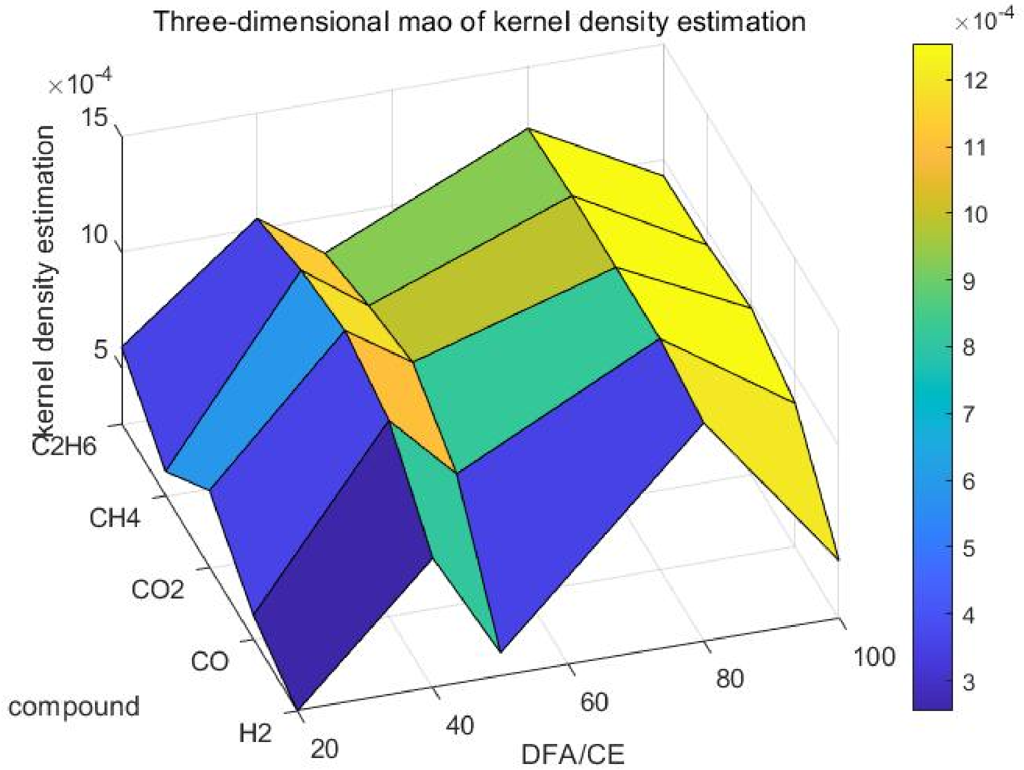
% 3 D kernel density graph MATLAB code implementation for question 4

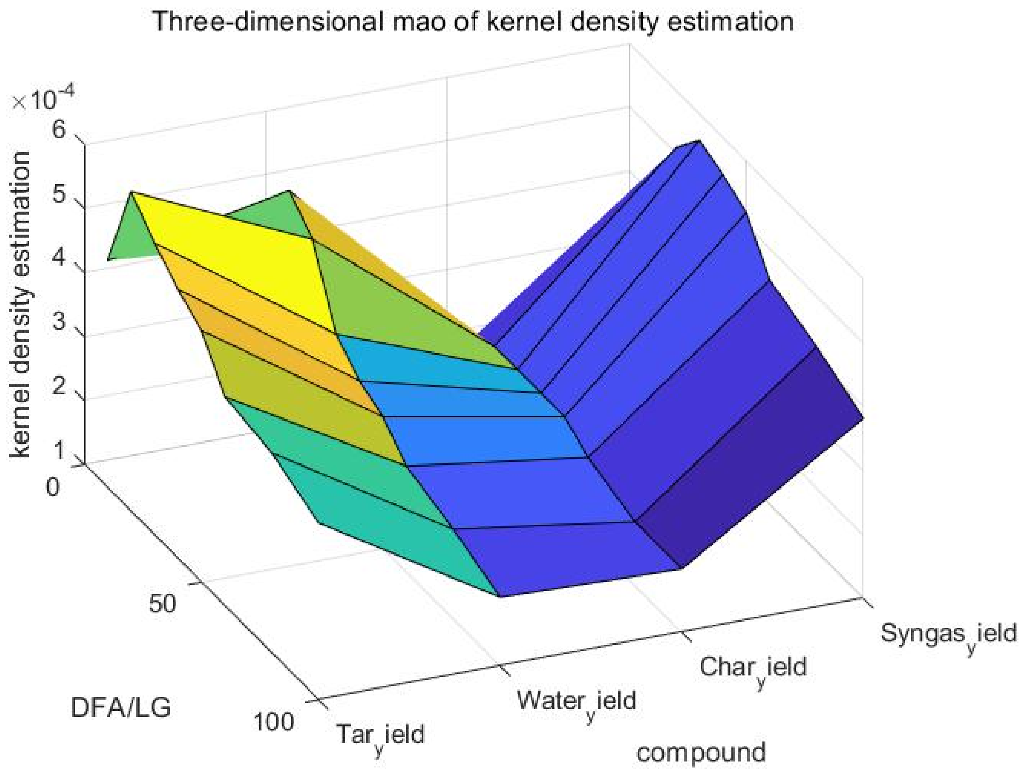


Three-dimensional mao of kernel density estimation
kernel density estimation
×10^-4
compound
C2H6
CH4
CO2
CO
H2
DFA/LG
20
40
60
80
100



Three-dimensional mao of kernel density estimation
kernel density estimation
×10^-4
compound
Syngas_yield
Char_yield
Water_yield
Tar_yield
DFA/CE
0
50
100


Three-dimensional mao of kernel density estimation
×10^-4
15
10
5
kernel density estimation
C2H6
CH4
CO2
CO
H2
compound
20
40
60
80
100
DFA/CE
×10^-4
12
11
10
9
8
7
6
5
4
3


Three-dimensional mao of kernel density estimation
×10^-4
6
5
4
3
2
1
0
kernel density estimation
50
100
DFA/LG
Tar_yield
Water_yield
Char_yield
Syngas_yield
compound