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Liquid Phase Parameter Analysis of Methanogenesis in Anaerobic Digestion of Coal Promoted by Kitchen Waste

Qingcai Lv *, Xu Qin, Jinghui Cheng, Jingnan Wang, Liuqi Jia

School of Resources and Environment, Henan Polytechnic University, Jiaozuo 454000, China

*** Corresponding author:** Qingcai Lv

Abstract: In order to study the effect of food and kitchen waste on promoting methane production by collaborative fermentation of coal, this paper selected lignite and food and kitchen waste as the research objects, and carried out the gas production experiment of mixed fermentation of coal and food and kitchen waste with different ratios at 35 °C with mine water as the bacteria source. The results showed that the cumulative CH4 production was the highest in the mixed fermentation with the ratio of 1:4 (coal: kitchen waste). Therefore, exploring the optimal mixture ratio of coal and food waste fermentation can not only effectively improve the gas production effect, but also broaden the diversified utilization ways of coal and food waste, which has a good development potential.

Keywords: Coal; Kitchen Waste; Cooperative Fermentation; Biomethane; Clean Utilization.

1. Introduction

China's energy structure is mainly dominated by fossil energy such as coal, oil and natural gas, accounting for 87% [1]. According to the data released by the Bureau of Statistics, the national coal production will complete 4.56 billion tons in 2022, an increase of 10.5% over the previous year. In recent years, the environmental problems caused by coal use have become more and more obvious, so the development of clean energy is the only way to change our energy structure.

Coal biogas use anaerobic digestion technology to convert part of the organic components of coal into methane [2]. Methane production by anaerobic digestion of coal generally goes through four stages: hydrolysis, acidification, hydrogen production, acetic acid production and methane production, among which the main factors affecting anaerobic digestion are temperature, substrate concentration, solution pH, C/N ratio and inorganic salt. Generally, the main ways to improve the production of coal biomethane are physical methods (grinding, pyrolysis, applied electric field, etc.) [3], chemical methods (potassium permanganate, hydrogen peroxide, sodium hydroxide, etc.) [4,5], biological pretreatment methods (white rot bacteria, bacillus, etc.) [6], and applied organic carbon sources [7]. Although the above methods can improve the efficiency of anaerobic fermentation to a certain extent, due to its high cost and environmental pollution [8], it is urgent to explore the best method to improve the output of coal biomethane. Kitchen waste mainly refers to kitchen waste and table residual waste, which mainly comes from household kitchens, restaurants and other food processing industries [9]. Research shows that with the acceleration of urbanization in China, the growth rate of kitchen waste is far more than 10% [10]. Because kitchen waste is characterized by high moisture, high grease, easy acidification and degradation, unpleasant odor and bacteria breeding [11], if it is not handled properly, it will not only easily cause environmental pollution, but also endanger human health [12]. The main treatment methods of food waste include landfill, incineration, composting, biological feed and anaerobic digestion, among which the application of food waste into biomethane technology has become an effective way to improve the rational utilization of resources. In the process of anaerobic digestion, single kitchen waste is easy to cause systematic acidification due to its own characteristics, resulting in a rapid decrease in pH, which affects the reaction [13,14]. Relevant studies have shown that the combined fermentation of coal and other substrates can regulate C/N [15]. Among them, Zhao et al. [16], after mixing kitchen waste with algae for fermentation, found that the addition of an appropriate amount of kitchen waste could significantly increase the gas production potential. Li Yi et al. [17] found that the mixed fermentation of kitchen waste and cow manure 2.5:1 could improve the optimal fermentation effect, and the methane volume fraction was as high as 62.8%. Chang Cheng et al. [18] found that in the anaerobic fermentation process of 1:4 kitchen waste and residual sludge, microbial degradation ability of sludge was significantly improved, and methane production increased. However, there are few reports on the mixed fermentation of coal and kitchen waste.

In this paper, different proportions of coal and food waste were mixed and placed in an incubator at 35 °C for anaerobic digestion, and the influence of different proportions of coal and food waste on the gas production potential of coal anaerobic digestion was discussed. By observing the changes of daily gas production, cumulative gas production and CH4 concentration, the optimal mixing ratio of the two substrates was determined. At the same time, combined with the change characteristics of soluble organic matter, COD, coal pore structure and functional groups before and after gas production, the synergic fermentation effect of coal and food waste was comprehensively analyzed. In order to provide a more scientific theoretical basis for broadening the path of mixed fermentation of different substrates.

2. Materials and Methods

2.1. Experimental Materials

The kitchen waste used in the experiment came from a canteen of Henan Polytechnic University and was crushed with a crusher and stored at 4 °C for later use [19]. The coal samples used in the experiment were selected fresh lignite from Inner Mongolia mining area, sealed, stored and returned to the laboratory. Before the experiment, the coal samples were crushed and screened to 60 ~ 80 mesh, and then sealed and stored for later use after autoclerotic sterilization. Elemental analysis and industrial analysis of the coal samples were carried out according to ISO 17247-2013 and ISO 17246-2010 respectively (Table 1). Fresh mine water was collected in sterile glass jars after sterilization and brought back to the laboratory for storage in the refrigerator at 4 °C. Due to the small number of microorganisms in mine water, it was necessary to expand the culture of microorganisms before the experiment.

Table 1. Proximate and ultimate analysis of coal samples

sample	Proximate analysis /%				Ultimate analysis/%				
	M_{ad}	A_{ad}	V_{ad}	FC_{ad}	C_{daf}	H_{daf}	O_{daf}	N_{daf}	S_{daf}
lignite	12.06	13.21	33.56	41.17	71.01	8.91	17.82	1.28	0.98

Note: M, moisture; A, ash yield; V, volatile matter; FC, fixed carbon; ad, air-dry basis; daf, dry ash-free basis; C, carbon; H, hydrogen; N, nitrogen; O, oxygen; S, sulfur

2.2. Enrichment and Culture of Strains

Fresh mine water was collected in sterile glass jars after sterilization, sealed with nitrogen quickly on site, and brought back to the laboratory for storage in a refrigerator at 4 °C. The enrichment and culture of methanogens were completed in the laboratory. The enrichment and culture methods of methanogens are as follows:

1) Methanogenic bacteria enrichment base: Add 1.0 g NH4Cl, 0.1 g MgCl2·6H2O, 0.4 g K2HPO4·3H2O, 0.2 g KH2PO4, 0.2 g Na2S, 2.0 g NaHCO3, 0.001 g C12H7NO4, 0.5 to 1000 mL fresh mine water g C3H7NO2S, 2.0g HCOONa, 2.0g CH3COONa, 1.0g yeast extract, 0.1g tryptone and 10 mL trace element solution.

2) Trace element liquid: Each 1000 mL sterile deionized water is added with 1.5 g amino-triacetic acid, 0.5 g MnSO4·2H2O, 3.0 g MgSO4·7H2O, 0.1 g FeSO4·7H2O, 1.0 g NaCl, 0.1 g CoCl2·6H2O, and CaCl2·2H2O 0.1g, CuSO4·5H2O 0.01g, ZnSO4·7H2O 0.1g, H3BO3 0.01g, AlK (SO4)2 0.01g, NiCl2·6H2O 0.02g, Na2MoO4 0.01g.

3) The prepared methanogenic bacteria enrichment medium was put into a sterile conical bottle, filled with nitrogen for 5 min, quickly sealed, and then placed in a constant temperature incubator, at 35 °C, anaerobic fermentation for 4 days, to obtain methanogenic bacteria enrichment solution.

2.3. Experimental Methods

The experiment of anaerobic fermentation methane production was carried out according to the ratio (coal: meal) of 1:0, 4:1, 2:1, 1:1, 1:2, 1:4, 0:1. The effective volume of the device is 500 mL. The different proportions of configured and enriched strains are poured into the pre-sterilized culture bottle and then stirred evenly. In order to ensure the anaerobic environment, nitrogen is filled for 5 minutes and sealed quickly, and then placed in the constant temperature incubator at 35°C. The gas components were analyzed by gas chromatograph. They can be labeled CK-1-0, CK-4-1, CK-2-1, CK-1-1, CK-1-2, CK-1-4, CK-0-1, respectively.

2.4. Test Method

2.4.1. Gas Component Analysis

Gas chromatograph (Agilent 7890 GC; Agilent Technologies Inc., USA) detected the gas components in the collection bag. The carrier gas of the instrument was helium, the flow rate was 30 mL /min, the column temperature was 80°C, the detector temperature was 100°C, the inlet temperature was 120°C, and the sample volume was 1 mL.

2.4.2. Modified Gompetrz Equation

The modified Gompetrz equation can often be used to predict the methane production capacity of anaerobic fermentation [24,25], which is modeled as follows:

$$P(t) = P_0 \exp\left\{-\exp\left[\frac{R_m e}{P_0}(\lambda - t) + 1\right]\right\} \qquad (1)$$

P(t)- is the cumulative gas production of t d, mL; P0 is the predicted gas production potential, mL; Rm- is the maximum gas production rate, mL/d; λ- is the stagnation time, d; t- is fermentation time, d; e- is a constant, exp (1) =2.71828.

2.4.3. Chemical Oxygen Demand (COD) Test

A D60 multi-parameter water quality detector was used to detect the content of organic matter in the reaction liquid before, during and after the reaction. The liquid to be measured and the premade detection reagent were added to the digestion tube before the test, digested by the DX32 digester and cooled to room temperature, and then the test was started. 3 parallel samples were taken for each group. D60 multi-parameter water quality detector adopts single light speed system, spectral bandwidth is 2 nm, wavelength range is 320 ~ 1100 nm, luminosity range is -0.3 ~ 3A, 0 ~ 200% T, 0 ~ 999.9C, power supply is 10 ~ 240V AC, 50/60 Hz, 70W.

2.4.4. Three-dimensional Fluorescence Test

Three-dimensional fluorescence spectroscopy can characterize the changes and structural characteristics of soluble organic matter (DOM) in the solution, and other physical and chemical properties. The collected liquid at the peak of reaction is diluted by 0.45μm filtration membrane and placed in a refrigerator at 4°C for use. The detection instrument adopts the Japanese F-7000 fluorescence spectrophotometer, the light source is 150 W xenon lamp, the voltage of the photomultiplier tube is 700 V, the excitation wavelength and emission wavelength are 200 ~ 750 nm, and the wavelength scanning speed is 30 nm/min.

2.4.5. Specific Surface Area and Porosity Test

Before and after the reaction, the coal samples were dried in a drying oven at 50°C for 48 h, and then BET specific surface area and porosity analyzer (JB-BK100) was used to perform low-temperature liquid nitrogen adsorption experiments on the dried coal samples. The voltage of the instrument is 220±20 V, the frequency is 50/60 Hz, the maximum power is 300 W, the carrier gas is He, and the test gas is N2.

2.4.6. Infrared Spectrum Test

The coal samples before and after the reaction are dried and screened to less than 150 mesh. The infrared spectrum test is carried out by KBr tablet method. The test instrument is AVATAR 360 Fourier infrared spectrometer, which adopts high efficiency optical components, ceramic light source and high sensitivity detector. The scanning range is 4000-400 cm-1, and the scanning times are 32. The best resolution is 0.4cm-1.

2.4.7. Boehm Titration

Boehm titration method was used to neutralize the acid functional groups on the surface of coal samples by using different concentrations of NaOH, NaHCO3 and Na2CO3, and the content of each acid functional group on the surface of coal was calculated according to the consumption of lye. The concentration of the three-lye used in the experiment was all 0.05mol /L. 1 g of coal sample to be measured was placed in a conical bottle and 25 mL of the above lye was added. After shock and agitation for 24 h, it was filtered, and then 1 g/L methyl red indicator prepared in advance was added and titrated with 0.05mol /L hydrochloric acid. Finally, the content of acid functional groups in coal is calculated according to the consumption of hydrochloric acid.

3. Results and Discussion

3.1. Difference Analysis of Gas Production in Anaerobic Fermentation under Different Ratio Conditions

The results of daily gas production and cumulative gas production in anaerobic digestion experiments with a single substrate (coal or meal) and different proportions of substrates are shown in Fig1. As can be seen from FIG. 1 (b), the increase in the proportion of food and kitchen waste contributes to the increase of the total gas production of anaerobic digestion and the extension of the entire gas production cycle. The gas production of the anaerobic digestion systems CK-1-0, CK-2-1 and CK-4-1 basically ended on the 18th day. However, the anaerobic digestion systems of CK-1-1, CK-1-2 and CK-1-4 basically reached the end of gas production on the 40th day. Combined with FIG.1 (b) and (d), it can be seen that methane production in blank group accounts for 40.13% of cumulative gas production, while CK-1-1 has the highest cumulative gas production, reaching 2886 mL, followed by CK-1-4, but its cumulative methane production is higher than that of CK-1-1. The cumulative methane production of CK-1-4 is 1725.2 mL, and the methane volume fraction is 60.96%, which is about 5.8% higher than that of CK-1-1. By comparing various gas production parameters of anaerobic digestion with different ratios, it can be seen that CK-1-4 has the highest biomethane production and the best gas production effect.

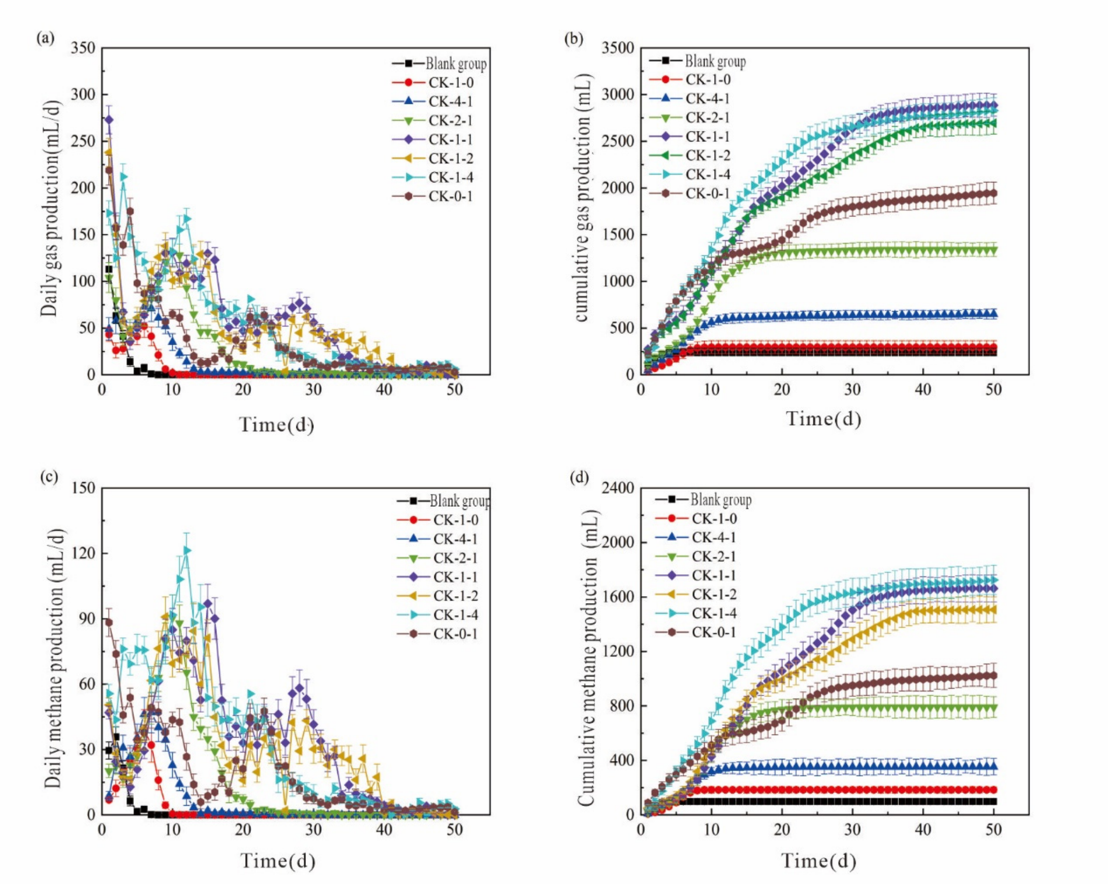

Fig 1. Effects of different ratios on gas production by mixed fermentation (a)Daily gas production (b)Cumulative gas production (c)Daily methane production (d)Cumulative methane production

3.2. Kinetic Analysis of Methanogenesis

the modified Gompetrz model to fitting cumulative produced from anaerobic digestion system and the related parameters as shown in figure 2. As can be seen from FIG. 2, the trend of cumulative methane production curves of anaerobic digestion with different ratios of coal and kitchen waste is significantly different. The blank group basically stops gas production on the 5th day, and the CK-1-0 group also stops gas production on or around the 10th day, while the longest gas production period is close to 50 days. It can be seen that except for CK-0-1, with the increase of the proportion of kitchen waste, not only the total gas production increases, but also the methane production lag period is prolonged. Through the analysis of fitting parameters, it can be seen that the correlation coefficients R2 of each group obtained by fitting the modified Gompertz equation are all greater than 0.98, indicating that the modified Gompertz model can better reflect the anaerobic digestion process of methane production after mixing different proportions of coal and kitchen waste. P0 and Rm are related to the proportion of coal and food waste added. When CK-1-4, the gas production potential reaches the highest, and is 1712.7 mL, which is basically consistent with the actual cumulative gas production P(t). By comparing the gas production potential of CK-4-1, CK-2-1, CK-1-2 and CK-1-4, it can be seen that the gas production potential of anaerobic digestion with food waste as the main coal as the auxiliary is higher than that of anaerobic digestion with food waste as the auxiliary coal.

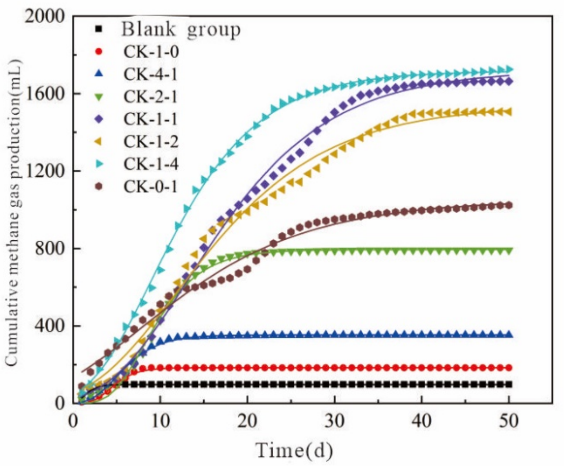

Fig 2. Cumulative methane production curve from modified Gompertz model

CK-1-4, which has the highest gas production potential, is 4.85, 2.16 and 1.13 times of CK-4-1, CK-2-1 and CK-1-2, respectively. The gas production rate of each group ranged from 35.84 to 91.10 mL /d, and the gas production rate could be used as a marker to measure the gas production potential and microbial activity in the anaerobic digestion system [22]. As can be seen from Fig 1, the gas production rate of CK-1-4 was 91.10 mL

3.3. Analysis of Soluble Organic Matter

According to the gas production effect in Fig 1, it can be seen that CK-1-4 has the best gas production effect. Therefore, the liquid phase of groups CK-1-0, CK-1-4, and CK-0-1 at the peak of gas production is taken and the change characteristics of soluble organic matter are detected by fluorescence spectrophotometer, and the results are shown in Figure 3. The fluorescence region can be divided into 5 parts [23] according to the relevant research results of fluorescence spectral partitioning. The fluorescence peaks of aromatic protein substances in zone I (Ex/Em is (200-250 nm)/(280-330 nm)) and tryptophan protein substances in zone II (Ex/Em is (200-250 nm)/(330-380), respectively The fluorescence peaks of fulvic acid humus in region III (Ex/Em is (200-250 nm)/(380-450 nm)), and the fluorescence peaks of microbial metabolic protein substances in region IV (Ex/Em is (250-400 nm)/(280-380) The fluorescence peaks of humic acids in zone V (Ex/Em is (250 ~ 400 nm)/(380 ~ 500 nm)). As can be seen from FIG. 3 (a), (b) and (c), there are mainly four kinds of peaks in the liquid phase of anaerobic digestion methanogenesis of CK-1-0, CK1-4 and CK-0-1. The fluorescence peaks of aromatic protein substances in zone I, tryptophan protein substances in zone II, fulvillitic acid substances in zone III and soluble microbial metabolites in zone IV were respectively found. In Fig 3 (a), the strongest fluorescence peak in the liquid phase of CK-1-0 anaerobic digestion was found in zone III. It shows that microorganisms can decompose humus organic matter in coal into many difficult to decompose fulvic acid and other macromolecular organic matter [24,25] in the process of anaerobic digestion

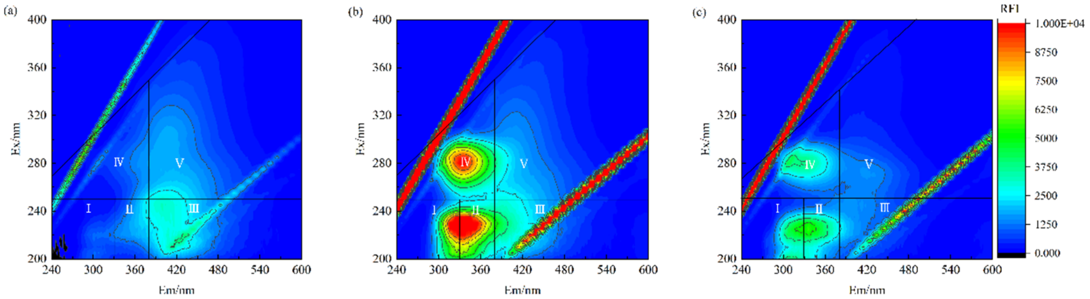

Fig 3. Three- dimensional fluorescence spectra of soluble organic natter at the peak of gas production (a)CK-1-0(b)CK-1-4(c)CK-0-1

3.4. Variation Characteristics of COD in Anaerobic Fermentation Process

COD can be used to characterize the amount of reducing substances that can be oxidized during anaerobic digestion, and the greater the value, the greater the concentration of soluble organic matter in the fermentation system [28]. The change characteristics of COD in anaerobic digestion process of mixed coal and kitchen waste in different proportions are shown in Table 2. As can be seen from Table 2, the COD value of the enriched cultured bacterial solution before the experiment was 313.25 mg/L, but after anaerobic digestion, the COD value of all groups increased at the peak of gas production, among which the COD value of groups CK-1-4 was the highest, and was 807.48 mg/L, 2.58 times that of before the experiment. This is because the microbial activity in CK-1-4 is stronger than that in other groups, so in the process of anaerobic digestion, microorganisms will degrade macromolecular complex substances in the system more fully into organic acids, sugars, lipids and other soluble organic matter. In the later stage of anaerobic digestion, the COD of the system decreases. Combined with the results of gas production, it can be seen that microorganisms in the fermentation system will continuously participate in various metabolic activities in the stages of hydrolysis, acidification and acetic acid production, and finally consume organic matter in the solution to produce methane, thus reducing the COD value in the system. The changes of COD are shown in Table 2. Combined with Fig 1, it can be seen that CK-1-4 has the best gas production effect, and at the peak of gas production, CK-1-4 has the highest daily gas production, indicating that the high concentration of soluble organic matter in the system can be fully utilized by microorganisms to convert into methane

Table 2. Changes of COD in liquid phase during anaerobic fermentation

samples	before the experiment (mg/L)	Peak gas production period (mg/L)	End gas production (mg/L)
CK-1-0	313.25	324.82	143.94
CK-4-1		379.46	291.1
CK-2-1		392.89	330.72
CK-1-1		699.25	357.15
CK-1-2		670.36	349.93
CK-1-4		807.48	296.96
CK-0-1		748.19	346.10

3.5. Change Characteristics of Coal Pore Structure

According to the classification of the International Union of Pure and Applied Chemistry (IUPAC), coal pore size can be divided into three types, namely large pore size (pore size > 50 nm), medium pore size (pore size between 2 and 50 nm) and micro-pore size (pore size < 2 nm) [29]. The experimental results of low temperature liquid nitrogen adsorption after anaerobic digestion of mixed coal and kitchen waste with different ratios are shown in Table 3. The specific surface area, total pore volume, average pore size of mesoporous and macroporous coal and micropore size of CK-1-0 after anaerobic digestion are 6.45 m2/g, 0.05 cm3/g, 8.49 nm and 1.44 nm, respectively. With the increase of the proportion of food and kitchen waste, the specific surface area, total pore volume and micropore diameter of coal after anaerobic digestion gradually increase, while the average pore diameter of mesoporous and macroporous coal decreases (Table 3). Among them, the pore structure of CK-1-4 changes most obviously compared with that of CK-1-0. The specific surface area, total pore volume and micropore diameter of CK-1-0 are increased by 0.80 times, 2.20 times and 0.12 times, respectively, but the average pore size of mesoporous and macropore is decreased by 0.68 times. Due to the degradation of macromolecular organic matter in coal to small molecular matter by microorganisms in the anaerobic digestion process of mixing coal and kitchen waste, the number and pore size of micropores in coal gradually increase with the shedding of these organic matter. In addition, some metabolites are produced during the growth and reproduction of the microbial community, which occupy the mesoporous and macroporous areas of the coal, resulting in the reduction of its pore size. With the increase of the proportion of food and kitchen waste, the microbial activity in the system is enhanced, the micropore pore size increases, and the average pore size of mesoporous and macropore decreases. In addition, because micropores are the main contributor of specific surface area [30,31], the specific surface area of coal after anaerobic digestion by mixing coal and food and kitchen waste increases.

Table 3. BET specific surface area test results

mark number	BET (m^2/g)	total pore volume (cm^3/g)	Average pore diameter of mesoporous and macroporous (nm)	micropore pore size (nm)
CK-1-0	6.452	0.053	8.488	1.436
CK-4-1	7.047	0.053	7.770	1.543
CK-1-1	9.646	0.065	7.211	1.552
CK-1-4	11.588	0.157	5.061	1.607

3.6. Infrared Analysis

CK-1-0, CK-1-4 and raw coal without anaerobic digestion were tested by infrared spectrum, and the results were shown in Fig4. According to the position, type and intensity of the absorption peak in the infrared spectrum, the attribution, type and content of the absorption band of oxygen-containing functional groups on the surface of coal can be determined [32]. Generally can be divided into wave number band of 3685 ~ 3000 cm - 1 free hydroxyl stretching vibration, wave number 3000 ~ 2700 cm $^{-1}$ fat hydrocarbon stretching vibration, wave number 1800 ~ 1000 cm - 1 oxygen containing functional groups with vibration and wave number 900 ~ 700 cm - 1 aromatics (C - H) vibration with four areas. As can be seen from Fig 4, the main infrared absorption peaks of the maceral components of the three groups of coal samples show a similar trend, in which the absorption peaks at the wave numbers 3600 cm-1, 1600 cm-1 and 1050 cm-1 show obvious stretching vibration. The wave number 3600 cm-1 is located in the elastic vibration region of free hydroxyl group, which contains hydroxyl group formed by free association or ether bond. The wave number 1600 cm-1 and 1050 cm-1 are both located in the vibration region of oxygen-containing functional groups. The wave number 1600 cm-1 mainly corresponds to the stretching vibration peak of carboxyl group, and the wave number 1050 cm-1 mainly corresponds to the stretching vibration peak of fatty acid ester or lactone group. In the process of anaerobic digestion, microorganisms will use various oxygen-containing functional groups (carboxyl group, lactone group, etc.) in coal to participate in various metabolism, so the corresponding infrared characteristic absorption summit in coal will appear obvious stretching vibration. Moreover, according to the above analysis of soluble organic matter, it can be seen that the microbial activity in the anaerobic digestion process of coal and kitchen waste alone is lower than that in the anaerobic digestion of CK-1-4, and the degradation of coal is insufficient. Therefore, the stretching vibration of the infrared characteristic absorption peak is slightly weaker than that of CK-1-4, and the gas production effect is also lower than that of CK-1-4

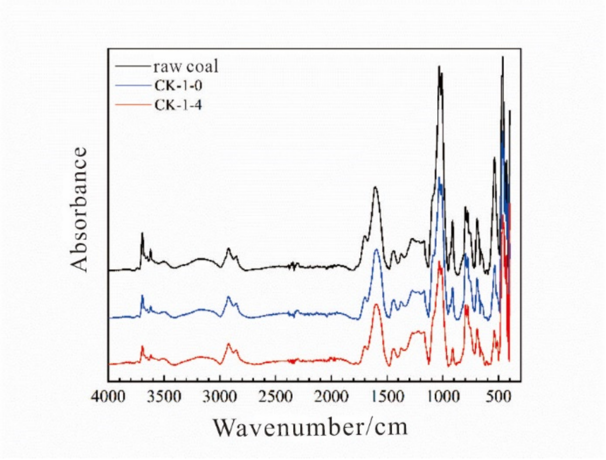

Fig 4. Infrared spectral changes of coal before and after mixed fermentation

3.7. Change Characteristics of Acidic Functional Groups in Boehm Titration

Boehm titration method was used to calculate the content of acidic oxygen-containing functional groups on the surface of coal after anaerobic digestion. The results are shown in Table 4. The acidic oxygen-containing functional groups detected by Boehm titration are carboxyl group (-COOH), phenolic hydroxyl group (-OH) and lactone group in coal. As can be seen from Table 4, the total amount of acidic functional groups of macerals of raw coal is 0.1875 mmol/g, higher than that of CK-1-0 and CK-1-4, but the total amount of acidic oxygen-containing functional groups of maceral after anaerobic digestion of CK-1-0 is higher than that of CK-1-4, 0.1858 mmol/g and 0.1740 mmol/g, respectively. Moreover, the acidic oxygen-containing functional groups of the three groups of maceral followed the following order: carboxyl group > lactone group > phenolic hydroxyl group. In summary, it can be seen that in the anaerobic digestion process, the acidic oxygen-containing functional groups (lactone, carboxyl, etc.)/side chains in the coal structure are converted into methane by microorganisms, and the microbial activity of CK-1-4 is higher, the gas production effect is better, and the total amount of acidic functional groups is slightly lower, which is basically consistent with the change trend of the characteristic absorption peak of acidic oxygen-containing functional groups in the infrared spectrum.

Table 4. Variation of acidic oxygen-containing functional groups in coal based on Boehm titration

samples	molality(mmol/g)			
	carboxyl	butylidene	phenolic hydroxyl group	gross
raw coal	0.1089	0.0782	0.0004	0.1875
CK-1-0	0.1029	0.0681	0.0148	0.1858
CK-1-4	0.0925	0.0534	0.0281	0.1740

4. Conclusion

In the process of mixed anaerobic digestion with different ratios of coal and food waste, the anaerobic digestion period was prolonged with the increase of the proportion of food waste, and the gas production effect became better. When the ratio of coal and food waste in mixed fermentation was 1:4 (coal: food waste), the cumulative methane production was the highest, and was 1725.2 mL. At the peak of gas production, the fluorescence intensity of soluble organic matter in 1:4 (coal: food waste) was the strongest, and the COD in the fermentation liquid of each group increased first and then decreased. At the end of gas production, the COD degradation effect of 1:4 (coal: food waste) was the best. With the increase of the proportion of food waste, the specific surface area, pore volume and micropore diameter of coal increase gradually, while the average pore diameter of mesoporous and macropore decreases. Various functional groups in coal participate in the growth and metabolism of microorganisms and fall off, resulting in obvious stretching vibration of their corresponding absorption peaks, and the content of acidic oxygen-containing functional groups (hydroxyl, carboxyl and lactone groups) is reduced, among which 1:4 (coal: kitchen waste) has the best gas production effect, and its acidic oxygen-containing functional groups also change most obviously.

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