

# Chemical properties of biochars prepared from corn and wheat straw at different temperatures

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**Abstract.** In this study, biochar produced by anaerobic combustion of wheat straw and corn straw in Henan Province at 300 °C, 500 °C and 700 °C was used. The chemical properties of wheat biochar and corn biochar, such as pH and infrared spectra, were studied with the increase of temperature. The chemical properties of wheat and corn biochars were compared based on the related literatures. It was found that the pH of biochar from wheat straw and corn straw combustion increased with the increase of temperature. Through the analysis of infrared spectra, it was found that the pH change of the two biochars may be related to the content of functional groups in the biochars themselves. With the increase of temperature, the spectra showed that the functional groups of the two biochars, such as hydroxyl and carboxyl, The main reason is that the chemical bonds of the above functional groups are broken with the increase of temperature. Resulting in a decrease in the number of acidic functional groups and an increase in the alkalinity of the biochar.

**Keywords:** wheat stalk, corn stover, biochar, functional grou

## 1. Introduction

### 1.1. Biochar

Biochar refers to carbonaceous materials produced by biomass combustion or pyrolysis under anoxic conditions [1]. Carbon-containing components (carbon black) and non-carbide components (natural organic matter), which have a wide range of sources (such as forest fires and straw burning), and the accumulation of a large number of soil and other environmental substances, have an important impact on the migration and transformation of organic pollutants in the soil. It has large surface area, developed void structure and various oxygen-containing acidic functional groups on the surface, for example, Phenolic hydroxyl, hydroxyl, carboxyl and so on, so that it has a strong adsorption capacity<sup>[2]</sup>. People take advantage of the above properties of biochar and use it for soil improvement, heavy metal adsorption, etc. For example, Brazilians living in the Amazon River Basin have long used a special fertilizer. Biochar can increase agricultural productivity and reduce the need for carbon-intensive fertilizers. Due to the porous structure of the charcoal chips, nutrients and beneficial microorganisms are more likely to accumulate, As a result, the soil becomes fertile, which is conducive to plant growth, increasing yields and making agriculture more sustainable. Absorption of heavy metals mainly refers to the absorption of copper, chromium, mercury and so on.

The main elements of biochar are carbon, oxygen, hydrogen, nitrogen, sulfur and a small amount of trace elements, as well as the rich elements of calcium, potassium and phosphorus in the soil. The carbon content is as high as 60%. Because of the affinity between each carbon atom, it has strong stability at high or low temperatures [3]. Carbonization can effectively increase the content of polycyclic aromatic hydrocarbons in soil and enhance the adsorption. Biochar in which carbon and phosphorus exist in the form of polymers has high-density carbohydrates, which can form inorganic acid salts with other minerals, so the pH of biochar becomes higher and alkaline. If the pyrolysis temperature of the biomass becomes high, The contents of mineral elements such as H, O and S in

biochar prepared at different temperatures showed a decreasing trend. If the types of biomass are different and the pyrolysis methods are different, the surface area of biochar produced will be different. In general, if the pyrolysis temperature increases, the specific surface area of biochar will increase and the water holding capacity of biochar will decrease. Due to the decrease of polar functional groups on the surface, the content of basic groups increases and the number of acidic groups decreases with the increase of pyrolysis temperature, so that the total functional groups decrease, the density of functional groups decreases, and the pH increases<sup>[4]</sup>. Biochars prepared from different biomass at different pyrolysis temperatures have diversity differences and show different environmental effects.

## 1.2. Research background of biochar

In nature, the straw and wood of various plants can be used to prepare biochar. In this experiment, the biochar prepared from wheat and corn straw was used as the research object. Because wheat and corn are the main food crops in China, China is a large agricultural country, in the north of China, wheat is mainly planted, and corn is planted in the whole country. The output of wheat straw and corn straw is very large, and the output of all kinds of crop straw burned or discarded is as high as  $8 \times 10^8$  t every year. The study on the properties of the two biochars is beneficial to the development and utilization of the two agricultural biomasses, turning waste into treasure. Compared with the activated carbon used now, it is an upgraded version, and the application prospect of biochar is very bright. The ideal source of biochar is crop straw, which is renewable and continuously supplied, and is incomparable with other biomass sources.

The research on biochar was relatively early, mainly reaching an unprecedented climax in the 1980s. Before that, Japanese researcher Ogawa [5], Describing biochar as a fire fertilizer that increases soil fertility, Trimble later discovered that biochar used as a crop fertilizer can increase crop yields. As the chemical and physical properties of biochar continue to be recognized and confirmed by scientists, international research on biochar has reached an unprecedented height. Earlier studies were mainly based on its structural properties, for example, Karaosmanoglu et al. studied the relationship between temperature and heating rate and the yield and structure of biochar prepared by pyrolysis of rape straw. In recent years, influenced by the greenhouse effect, the study of biochar has become a hot spot, for example, some scholars published an article in Nature saying that the effect of biochar on the environment is a "carbon negative" process. This statement has aroused a certain range of discussion [6]. Subsequently, some people commented in Nature that biochar can also improve soil fertility and has a wide range of application prospects. In addition, the adsorption of heavy metals has also been carried out. In China, the earliest study of biochar was the development and utilization of black charcoal soil by ancient Chinese ancestors in the 18th century. 2,500 years ago in the Amazon, The black charcoal soil there is evidence of the earliest use of biochar. Biochar can improve soil solidification, soil fertility, environmental pollution, waste management, renewable energy and climate change, which has attracted great attention of scholars in the field of environment.

Agricultural biomass as one of the raw materials for preparing biochar. For example, wheat straw and corn straw [7, 8]. In human production and life, the utilization rate is very low, generally returned to the field by burning or burying, and a small part of it is used as fuel. The annual output of these crop straws is very large, but the utilization rate is very small, forming a huge contrast. Statistics from the Food and Agriculture Organization of the United Nations show that 66% of the world's crop straw fibers are not recycled. It rots directly in the field, and a small amount of crop straw is used as fuel. About 19% of them are used as building materials or covering materials, about 12% are used as feed for herbivorous livestock, and about 3% can be used as raw materials for handicrafts. There are few projects that really form the resource utilization technology for the industrial production of straw fiber materials. In our country, About 20% of the straw can be used as feed for livestock, 70% of the straw can be used as fuel, and the ash after burning can be scattered into the field as fertilizer, or burned and returned to the field on the spot, or directly turned into the field to fertilize the field, and another 10% of straw can be put into industrial production. In most areas of China, straw is not fully utilized. If we can find a way, It can not only save resources, but also protect the environment. Now there is

such a method, that is, to convert the straw of various crops into biochar, so as to improve the utilization rate of crop straw. Otherwise, the large yield and low utilization rate of crop straw are regrettable. Therefore, seeking a high efficient application of biochar has become a research hotspot<sup>[9, 10]</sup>.

For example, Pu Lijun<sup>[11]</sup>The preparation of biochar and its adsorption of copper ions were studied, because copper wastewater is very harmful to human health, and the adsorption of copper ions by ordinary activated carbon is not strong. Dong Yunting studied the structural characteristics of biochar and its combined algae remediation of water body, and discussed the combined remediation effect of biochar and algae on water body [12]. Most of their research has been on biochar adsorption. In recent years, the research abroad mainly focuses on the increase of crop yield by biochar. Eunice Badu [13] Et al. studied the effects of biochar and nitrogen fertilizer on maize yield, Schillem<sup>[14]</sup>Liu Yingying has studied the effects of biochar and nitrogen fertilizer on wheat growth, and also studied the utilization of biochar in material recovery<sup>[15]</sup>. Compounds, artificial sweeteners, and perfluoroalkyl substances are extracted from water using a passive treatment system containing zero-valent iron and biochar.

In recent years, excessive nitrogen (N) and phosphorus (P) in the environment have seriously affected the environment and human health. Biochar has the advantages of high efficiency, flexibility, good economic and environmental benefits. It is a product produced by the pyrolysis of crops, wood and so on under anaerobic conditions. The pore structure of raw materials has the characteristics of strong adsorption capacity, low solubility, stable chemical properties, rich pore structure and large specific surface area, Yingjie Dai [13]. The research status of biochar adsorption of N and P was reviewed, and 26 aspects were described. The influencing factors and adsorption mechanism of nitrogen and phosphorus, the application of biochar as fertilizer in soil adsorption of nitrogen and phosphorus, and the application of biochar in engineering treatment were introduced, and the economic and environmental benefits of biochar were analyzed. Based on the summary of the current 29 research results, the future development of biochar adsorption of N and P was discussed, as well as 30 issues that need to be considered in the future development process. Muhammad [16] Biochar modification technology has been paid more and more attention because of its advantages in environment, agronomy and economy.

Studies to date have shown that vermicomposting has good physicochemical properties, namely, high porosity, surface area, number of functional groups, and cation exchange capacity (CEC). These properties combine composting with major nutrient cycling, facilitate microbial activity during composting, and improve the reproductive capacity of earthworms during composting. The addition of biochar and the composting of pests during the composting process improved the chemical properties of the waste. Sri Shalini S Palanivelu K [17] The generation of biomass waste is increasing dramatically, and the greenhouse gases emitted from biomass combustion have a serious impact on the environment and people's health. It has a high organic carbon content and can be reused/repurposed for other uses, useful products that contribute to climate change mitigation (e.g. biochar) [18]. Biochar, a renewable carbon, is becoming increasingly important, opening up a field of research that explores the properties and stability of biochar, its wide range of applications, impacts on soils, characteristics of biochar-soil matrices, techno-economic details, carbon-nitrogen interactions, and emission control. This reviews the opportunities for biomass waste to be used for biochar production, Thermochemical reactions of various preparations and their mechanisms are summarized for the application of biochar in soil improvement, climate change, energy production, and environmental remediation. The influence of physical and chemical parameters (temperature, heating rate, chemical composition, etc.) On the production of biochar will contribute to the stability of the industry. The production of biochar, syngas, and bio-oil from low-temperature (heating), microwave-assisted pyrolysis, hydrothermal carbonization, pyrolysis (fast, slow, flash), gasification, and combustion processes remains to be developed. CO<sub>2</sub>, CH<sub>4</sub>, NO<sub>2</sub>, emissions from different soil types and carbon sequestration by biochar addition were all accomplished here. The modification and activation of biochar have been studied in recent years because of its role in improving the quality of

biochar and expanding its application. The production of biochar from biomass waste is highlighted. Biochar, as an alternative to fossil fuels, will be a promising solution for waste management, bioenergy and climate change [19].

Biochar is an important biomaterial for mitigating environmental and agricultural problems. The complex outdoor environment (including exposure to solar radiation) has a great impact on the structure of biochar, which can affect its function when used outdoors. The aim of this study was to understand the physical and chemical changes that occur in the different end products of kinetic bamboo biochar (BB) in relation to the temperature of exposure to harmful radiation. Chemical properties of bamboo-derived biochars (BBs) from accelerated weathering were studied by measuring chemical elements, ash content, BET specific surface area, infrared spectroscopy and X-ray photoelectron spectroscopy. Thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) were used to determine the change of functional groups, the change of element species distribution on the surface of BBs and the difference of thermochemical properties. The results of this test show that the BBs change significantly after 400 H of accelerated weathering [20]. The content of C and N in the BBs decreased, while the content of O increased. The mean change in color and the residual fraction of BBs were 1.02% and 1.58%, respectively. The average growth rate of the O/C ratio (by elemental analysis, C and O<sub>2</sub>) was 17.04%, 13.88% and 86.63%, respectively. These results suggest that BBs undergo a series of photooxidation reactions when exposed to UV radiation. Increasing surface oxygen-containing functional groups can improve the surface activity of BB in soil improvement application, pollutant degradation efficiency and biodegradation.

Biochar is a cost-effective and versatile carbon material that can be used to immobilize heavy metals (HM) in soil. So far, the fixation of different heavy metals by various biochars is very good. However, little is known about the release conditions of immobilized heavy metals. As the released heavy metals may pose a threat to the soil environment, it is essential to understand the biological release patterns. Biochar can adsorb heavy metals in soil. Cadmium pollution in soil has attracted worldwide attention, and sulfur and modified biochar (SBC) can combine the advantages of biochar and sulfur remediation of cadmium. Biochar from agricultural waste is feasible because of its low cost. However, little research has been done on the effects of sulfur. Dun Chen [21] The immobilization mechanism of original wheat straw biochar (BC) and Cd, and the immobilization of Cd on sulfur modified biochar (SBC) and common biochar were studied. Elemental and SEM analysis confirmed that sulfur could be successfully loaded on the original biochar. The analysis confirmed that the adsorption mechanism of cadmium on biochar and modified biochar was quite different. In particular, the adsorption of Cd on biochar was due to the interaction of Cd(OH)<sub>3</sub> and CdCO<sub>3</sub> with carbonyl and carboxyl groups, while on the modified biochar, the adsorption was mainly due to the formation and interaction of CdS and CdHS with organic sulfides.

### 1.3. Research prospect of biochar

Biochar is a low-cost, porous, carbon-rich material with great adsorbability and support matrix potential due to its high surface activity and large specific surface area [22]. High ion exchange capacity. Metal nanomaterials are solid nanoparticles with high reactivity, high surface area, and high surface energy. Metal nanomaterials will lose their excellent physical and chemical properties due to their aggregation and passivation. Carbon-rich biochar can be used to overcome these disadvantages of metal nanomaterials. Combines the advantages of the biochar, the metal nano material, Supporting metal nanomaterials in porous and stabilized biochar creates a new biochar-supported metal nanoparticles (MNPs @ BC) [23]. Therefore, metal nanoparticles can be used to design appropriate properties of metal nanoparticles, stabilize anchored metal nanoparticles, promote catalytic/redox reactions at the biochar-metal interface, and maximize the efficiency of biochar and metal nanomaterials in environmental applications. In the context of global research, the problem of soil pollution has become more serious. Biochar can effectively improve soil, which makes experts pay more attention to the research of biochar. According to the relevant literature reports, biochar has a strong adsorption capacity, according to its nature, it can improve the utilization of nitrogen and

phosphorus in soil, and fix nitrogen and phosphorus in soil. In addition, biochar can improve soil structure and reduce N and P transport with soil media. Trick cites most of the researchers' results and explains the effects of different biochars. Biochar can promote the adsorption, transformation and leaching of nitrogen and phosphorus. The application prospect of biochar in soil environmental management and environmental sustainable development will be strengthened in the future.

## 2. Research Materials and Methods

### 2.1. Materials and apparatus

Experimental apparatus:

**Table 1.** Table of experimental instruments

Specifications of experimental instruments	
Box-type Resistance Crusher	Furnace Shanghai Guanding Co., Ltd. Jiangyin Crushing Machinery Manufacturing Co., Ltd.
Thermogravimetric Analyzer	Shanghai Yinuo Precision Instrument Co., Ltd.
Fourier transform infrared spectrometer	Tianjin Jingtuo Instrument Equipment Co., Ltd.
PH Meter	Wuhan Gilder Technology Co., Ltd.
Constant Temperature Oscillator	Shanghai Hetian Low Speed Centrifuge Co., Ltd.
Sample holder	Shanghai Boxun Industrial Co., Ltd. Medical Equipment Factory
200 Mesh Sieve	Guangzhou Jiameihua Laboratory Equipment Co., Ltd. Kunming Xinmiao Sieve Mesh Factory
Electronic Balance Lesder	Electronic Balance Factory
Alumina crucible	Changxing Shengfa Refractories Co., Ltd.
Tangshan Kaiping	Tongsheng Chemical Porcelain Factory
Beaker	Tianchang Tianhu Analytical Instrument Co., Ltd.

Experimental drug:

**Table 2.** Table of experimental drugs

Experimental drug	Specification
Wheat Straw	1kg
Corn stalks	1kg
KBr	Analytically pure
Deionized water	10L

## 2.2. Experimental method and data processing

### 2.2.1 Preparation of biochar

**Table 3.** Preparation steps of biochar

Experimental steps	Experimental method
1. Rinse	Wheat straw was washed twice with tap water and deionized water in order to remove residual dust on the surface.
2. Drying and crushing	Drying in an oven, crushing with a crusher, placing in a brown bottle, and labeling for later use.
3. Sieve	Weigh about 20 G of 60-mesh biomass powder into a 100 mL crucible, compact and cover
4. Cracking	Pyrolysis was carried out in a muffle furnace filled with nitrogen and limited oxygen at a certain temperature (300, 500, 700 °C) for 30 min. After cooling to room temperature, it was taken out, ground with a mortar, sieved with a 60-mesh sieve, and packed in a brown bottle for subsequent characterization experiments.
5. Mark	A series of biochar samples made from wheat straw are labeled as XM 300, xm500 and xm700, where XM represents the wheat straw and the following number represents the pyrolysis temperature used. Corn biochar is also named by this method, for example, ym300 refers to the corn biochar sample prepared at 300 °C
6. Parallel sample	Parallel samples were prepared at the same time as each sample preparation

**Table 4.** Temperature Table for Preparation of Wheat and Corn Biochar

Biochar	Pyrolysis temperature			Parallel sample		
Wheat biochar	300°C	500°C	700°C	300°C	500°C	700°C
Corn biochar	300°C	500°C	700°C	300°C	500°C	700°C

### 2.2.4 Infrared analysis

The infrared spectrum of biochar was measured by Fourier transform infrared spectrometer, and the samples were prepared by KBr tableting. The scanning wavenumber range is 400-4000 cm<sup>-1</sup>, the resolution is 1.0 cm<sup>-1</sup>, 64 scans are accumulated, the test temperature is 25 °C, and the relative humidity is 35% -45%.

**Table 5.** Experimental Steps of Infrared Analysis

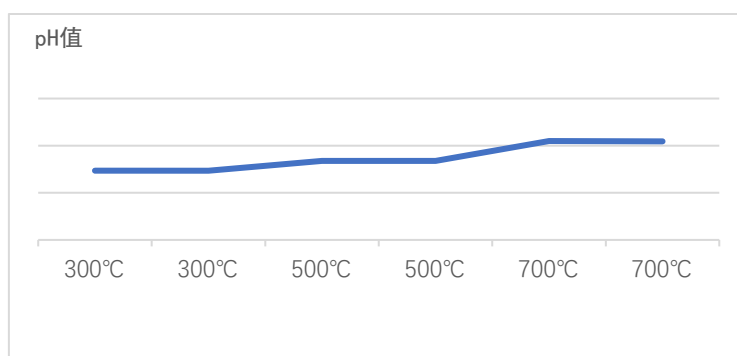
Experimental steps	Experimental method
1. Test sample preparation	Firstly, analytically pure (preferably single crystal fragments) KBr is fully ground in an agate mortar until the particle size is less than 2 μm (usually 200 mesh sieve) and placed in a dryer for later use
2. Grind and mix	Take a certain amount of sample (generally 2-5mg) and ground and sieved KBr powder (100-120mg) according to the proportion (if it is quantitative analysis, it should be weighed accurately) and put them into an agate mortar to fully grind and mix until there is no obvious sample particles in the mixture. The above operation should be carried out in an infrared drying oven to prevent KBr from absorbing water.
3. Molding	First install the base, mold cavity and mold core, carefully transfer the ground powder to the bottom surface of the mold cavity with a stainless steel spatula, and scrape it flat with a slightly higher center.
4. The sample is flattened	Carefully put in the plunger. Flatten the sample and turn it slightly for a few times to distribute the powder evenly. Carefully cover the plunger with sealing ring and pressure ring, and fix it on the hydraulic press. Connect the vacuum tube, turn on the vacuum pump, and vacuumize for about 5min to remove the water vapor and air in the mold cavity and the sample.
5. Remove the sample	Rotate the handle to gradually pressurize 7500 kg/cm <sup>2</sup> , and remove the vacuum tube for about 1-2min to slowly release the pressure. Take out the die, remove the base, turn the diaphragm upside down, support the collar on the outer ring of the plunger, and extrude the sample. It was carefully removed with stainless steel tweezers, placed on a sample holder, and its spectrum was recorded.

### 3. Results and analysis

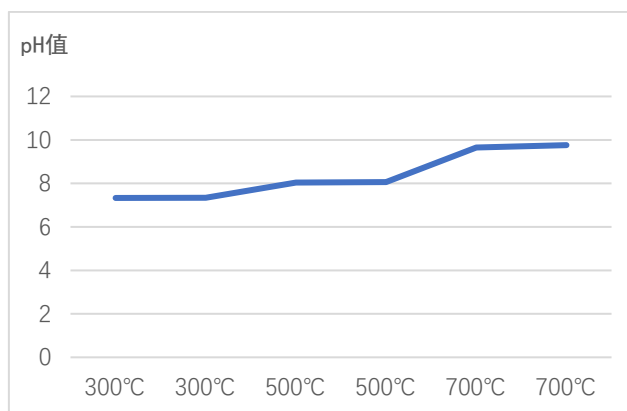
#### 3.1. Yield

The yield of wheat biochar and corn biochar decreased when the temperature of biochar preparation increased from 300 °C to 700 °C. The main reason is that the temperature increases gradually, the degree of biomass carbonization increases, and the yield of biochar decreases gradually.

#### 3.2. Determination and analysis of pH



**Fig. 1** Variation of pH of wheat biochar with temperature at different temperatures



**Fig. 2** Change of pH with Temperature of Corn Biochar at Different Temperatures

It can be seen from the broken line chart of the determination of the pH of the biochar that the pH of the wheat biochar and the corn biochar gradually increases with the increase of temperature, and when the pH rises to about 10, the pH does not change any more. The reasons for the above experimental phenomena are as follows: the peak absorption of the prepared biochars of the two materials is basically the same at the same temperature, And the same type of surface groups, aromatic ring structures are formed during pyrolysis, the pyrolysis temperature of aromatic compounds increases with increasing temperature. With the pyrolysis of the two materials, the functional groups on the surface of biochar also changed, mainly the alkane groups disappeared with the increase of pyrolysis temperature, and the methyl (-CH<sub>3</sub>) and methylene (-CH<sub>2</sub>) groups also disappeared gradually. The degree of aromaticity of the aromatic compounds also increases. The results of Bohem titration showed that the total amount of surface functional groups and the amount of basic functional groups were relatively high at all pyrolysis temperatures, while the amount of acidic functional groups was less than that of basic functional groups at all pyrolysis temperatures. With the increase of pyrolysis temperature, the surface functional groups of the biochars prepared by the two materials changed similarly. The total amount of surface functional groups decreases, the content of acidic functional groups decreases, and the content of alkaline functional groups increases, so the pH value increases. At the same time, because the content of acidic groups such as -oh decreases with the increase of temperature, the alkalinity increases and the pH increases.

### 3.3. Infrared spectrum analysis

Combined with the functional group comparison table found in the literature, we can have a simple interpretation of the atlas.

Infrared spectrum analysis of corn biochar. At 300 °C, corn biochar mainly contains functional groups such as -oh, -C = O, -C-O, -C-O-C-, -Si-O-Si-, and the abundance is relatively large. At 500 °C, the infrared spectrum of corn biochar also contained functional groups such as -oh, -C = O, -C-O, -C-O-C-, -Si-O-Si-, but the abundance was lower than that at 300 °C. When the temperature rises to 700 °C, the infrared spectrum of corn biochar shows that: The abundance of functional groups is lower, and the abundance of -oh is almost gone. The main reason is that with the increase of temperature, the chemical bonds of some functional groups are broken, which reduces the abundance of these groups. At the same time, the decrease of the abundance of acidic groups leads to the increase of pH value.

Looking at the infrared analysis of wheat biochar, the change of functional groups of wheat biochar has the same trend as that of corn biochar, and the types of functional groups are the same, but there are some differences in abundance. The cause of this phenomenon is similar to that of corn biochar.

## 4. Discussion and conclusion

This experiment mainly discussed the preparation process of wheat biochar and corn biochar, the change process of yield with temperature, the change process of pH with temperature, and the analysis of two kinds of biochar by infrared spectroscopy. Through this experiment, we can draw the following conclusions:

The chemical properties of wheat biochar and corn biochar are quite similar, and there is little difference in the yield of their preparation. Wheat and corn are the main food crops in China, and the amount of waste such as wheat straw and corn straw is very large every year. These two kinds of straw can be used to prepare biochar, which can be used to improve soil and adsorb heavy metals.

The pH value of wheat biochar and corn biochar increased gradually with the increase of temperature. From about 5 to about 10, we can use the chemical properties of biochar to properly adjust the temperature to prepare biochar with different temperatures and functions. Biochar with a pH below 7 can be used to improve alkaline soils. Biochar with a pH above 7 can be used to improve acid soils.

The changes of chemical properties of biochar, such as pH value, are closely related to the changes of functional groups on the surface of biochar, which can be explained by infrared spectra. The figure shows that with the increase of temperature, the abundance of some acidic groups, such as -oh, decreases gradually, and the number of acidic groups decreases, so the pH increases.

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