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# Process optimization and study of biogas fermentation with a mixture of duck manure and straw

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ABSTRACT

The agricultural production process generated a lot of straw and other agricultural waste, reasonable use of this part of the biomass energy, which can effectively alleviate part of the energy problem. Taking the poultry feeding industry in the Central Chinese Economic District as a research object, a fermentation test on the mixed raw materials of duck manure and straw was conducted to regulate the proportion of fermenting materials so as to explore their biogas production characteristics. Based on the gas generation rate and cumulative gas production of these mixed raw materials in different proportions and using contrasting tests between fermentation materials mixed to different proportions, the research found that the factors affecting fermentation is temperature followed by inoculation concentration and the concentration of fermentation broth. In view of the factors affecting fermentation with the mixture of duck manure and straw, and the cumulative gas production from raw material mixed in different proportions, optimum temperature for mixed anaerobic fermentation is about 30 °C and the optimum proportion of raw materials is 2.8:1.

## 1. Introduction

With the development of the global economy, population growth, and the improvements in living conditions, mankind is faced with great challenges relating to both energy and the environment. Biogas-generated energy is a type produced by combustible gas arising from microbiological degradation of multiple organic materials under certain temperature, humidity, pH, and anaerobic conditions. It is also a kind of renewable energy source obtained from anaerobic fermentation of the manure arising from the poultry industry and industrial organic waste water and municipal solid waste (MSW) landfill treatment [1–6]. The investigation and application of biogas fermentation technology date from the 1970s. Since then, many scholars have researched the generation of biogas and fermentation technology [7–10]. As early as 1776, Alexander Volte, investigated the gas generated during the rotting of plants at the bottom of lakes and found that methane was contained in the gas thus liberated. In 1875, the Russian scientist, Popof pointed out that the generation of methane arises from microbial fermentation. The microorganisms used for anaerobic decomposition of cellulose were divided into hydrogen-producing bacteria and methane-producing bacteria by B.L. Omelauskie, a microbiologist from Russia. In the 1930s, Buswell et al. analyzed the relationship between anaerobic microorganisms and gas production conditions. Bulk dry anaerobic fermentation technology has been applied in Germany, France, and Algeria since the 1940s [11–15]. In 1974, Methanoges was first proposed by Bryant, who distinguished it from Methanotrophs with methane as its energy source. In the same year, a research team, led by G. Lettinga from Wageningen Agricultural University, Netherlands, developed an up-flow anaerobic sludge blanket [16–18]. In early 2009, the largest biogas device in the world was used in eastern Germany. Biogas technology in China started in the 1930s. The construction of biogas production plants began in the 1950s. After a tortuous development process lasting several decades, biogas production has seen opportunities for rapid improvement. At the end of 2007, more than 26.5 million household biogas digesters had been built and proven techniques were popularized for Chinese biogas production. Chinese annual biogas production exceeded 15.5 billion $m^3$ in rural areas which accounted for 11.4% of the consumption of natural gas in China by the end of 2011. It is expected that the physical quantities of livestock manure and poultry manure from intensive livestock farming in China will reach 2.5 billion and 3.25 billion tons by 2016. These types of manure can produce 150 billion $m^3$ and 195 billion $m^3$ of biogas (equivalent to 240 million and 310 million tons of standard coal, respectively) [19–21].

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In recent years, biogas fermentation technology has developed rapidly and has been an effective method for improving resource utilization of rural animal manure and crop straws [22–28]. Fermentation, with a single material, has been studied extensively and the results applied in day-to-day production. The poultry feeding industry in the Central China Economic District was investigated here through the fermentation testing of mixtures of duck manure and straw. This research regulated the proportions of each fermenting material in its investigation of biogas production characteristics [29].

## 2. Experimental material, instruments and method

Biogas fermentation is a process of material metabolism and energy conversion of microorganisms, during which, energy and substance can be obtained by biogas microorganisms to meet the requirements for their growth and reproduction [30–33]. At the same time, most substances are converted into $CH_4$ and $CO_2$. With the development of China's rural economy and the adjustment of the agricultural sector nationwide, the present poultry feeding industry mainly presents large-scale and intensive development. However, there are overabundant straw resources in production regions for the poultry feeding industry in the Central China Economic District and also some resource and environmental problems arising from the in situ burning of this. Therefore, it is necessary to solve these problems by using a mixture of duck manure and straw for fermentation and by developing and utilizing biomass energy with these new techniques.

### 2.1. Experimental material

Fresh duck manure collected from the breeding and processing industry of Cherry Valley Ducks in the Central China Economic District, and newly harvested rice straw (without roots) obtained from the scientific and educational park for the poultry feeding industry were adopted as raw materials for fermentation in these experiments [34,35]. After natural air-drying, the straws were chopped into sections measuring 30 mm in length. They were then soaked in water and biogas slurry and stored for later use. Afterwards, these materials were blended in proportions of 1:1, 1.8:1, 2.8:1, and 3.8:1 based on their dry mass. The biogas slurry (water content of 84.1%) from final-stage fermentation, taken from a normal biogas digester used in the poultry feeding industry in the Central China Economic District, was used as the inoculation. In these experiments, fresh duck manure and the reserved straw were poured into glassware and sealed for composting for four to six days. They were then moved to a fermenting container, the biogas produced was collected in a gas-collecting bottle.

### 2.2. Experimental apparatus

The fermentation equipment, with water-discharging and gas-producing attributes, was made by Key Laboratory of Renewable Energy of Ministry of Agriculture, Henan Agricultural University, China. It contained fermentation equipment (a fermenting container with a volume of 5 L), water-discharging and gas-producing equipment (a gas collecting bottle with a volume of 1 L and a water collecting bottle with a volume of 1 L). An electric blender (JJ-IA Type operating at 3000 rpm) and a PC-1000 digital display temperature controller were fixed on the fermentation container. Additionally, a sample connection was set at the bottom of the fermentation container. The experimental device can be seen in Fig. 1.

### 2.3. Experimental method

There are many factors influencing the fermentation process. Among which, the total solids concentration, the amount of inoculation, and fermentation temperature affecting biogas fermentation were explored here [36–40]. Daily gas production was obtained by measuring the volume of water discharged into the gas collecting bottle and the influence of those aforementioned factors was analyzed to obtain the optimal combination of fermentation conditions [41–43]. The fermentation raw materials were fresh duck manure and reserved straw. The groups treated with alkali were: R1, R2, R3, R4, R5, R6, R7, R8, and R9; while control groups without alkali treatment were: U1, U2, U3, U4, U5, U6, U7, U8, and U9. They were placed into thermostat-controlled incubators, separately. Then, after adjusting the temperature, the experiments were conducted.

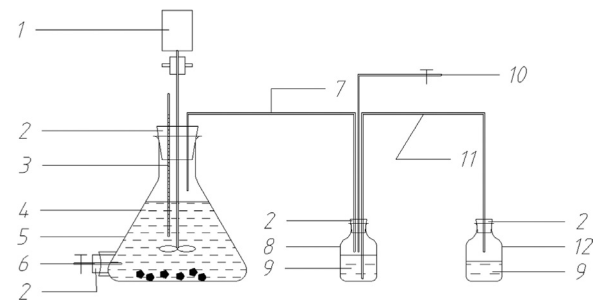


**Fig. 1.** Experimental device for anaerobic fermentation. 1-Stirred vessel, 2-the rubber plug, 3-temperature controller, 4-fermented liquid, 5-fermented container, 6.-sampling port, 7-the gas-conducting tube, 8-collecting gas bottle, 9-water, 10-gas port, 11-the water-conducting tube and 12-collecting water bottle.

The method of gas recovery by water drainage was used. Daily gas production was recorded regularly to investigate the changes of the gas generation rate and cumulative gas production from each group with the same concentration of fermentation broth, different inoculation concentrations, and all fermentation temperatures [44–47]. The contrasting tests between fermentation raw materials mixed in different proportions were also performed. Based on these experiments, the parameters for biogas fermentation were studied to optimally control the ratio of fermenting materials [48,49].

### 2.4. Experimental design

Firstly, the treatment group with raw materials in proportion 2.8:1 was used for analysis. The straw was pre-treated with alkali liquor (i.e. the sodium hydroxide solution). Its concentration was 6% and the water content was 78%: it was inoculated for six days. After alkali pre-treatment, the straw was mixed with fresh duck manure. The fermentation effects were compared with those of the mixture of fresh duck manure and straw without treatment. Secondly, contrasting tests for groups with different proportions of raw materials (fresh duck manure and pre-treated straw) were conducted [50].

## 3. Results and analysis

### 3.1. Changes in gas production with fermentation time

Under different fermentation conditions, the daily biogas production of each treatment group and a control group were measured based on the gas production during fermentation as collected through the method of gas recovery by water drainage, i.e. by measuring the water discharged into the gas collecting bottle. Table 1 shows the cumulative gas production of the treatment group and a control group whose proportions of raw material were 2.8:1. The change in cumulative gas production with fermentation time is indicated in Fig. 2.

The research showed that the constituent structure of the straw changed after alkali pre-treatment, especially with regard to hemicellulose degradation therein. Compared with the control groups, gas production increased significantly and the fermentation time was also reduced. When the alkalinity was 6%, straw fermentation produced the most biogas. Gas production was little influenced by fluctuations when the water content was between 60% and 68%. When the water content