

# Biogas slurry pricing method based on nutrient content

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**Abstract:** In order to promote biogas-slurry commercialization, A method was put forward to value biogas slurry based on its nutrient contents. Firstly, element contents of biogas slurry were measured; Secondly, each element was valued based on its market price, and then traffic cost, using cost and market effect were taken into account, the pricing method of biogas slurry was obtained lastly. This method could be useful in practical production. Taking cattle manure raw material biogas slurry and corn stalk raw material biogas slurry for example, their prices were 38.50 yuan RMB per ton and 28.80 yuan RMB per ton. This paper will be useful for recognizing the value of biogas projects, ensuring biogas project running, and instructing the cyclic utilization of biomass resources in China.

## 1. Introduction

With the development of the large-scale livestock breeding industry, simultaneous development of large and medium sized biogas projects were recognized by the government as an efficient measure to relieve energy pressure, while reducing livestock manure treatment. According to statistics, until the end of 2013, 99625 large, and medium sized biogas projects have been conducted in China.<sup>[1]</sup> Estimated with current growth, the production of biogas slurry in China (including biogas residue) could reach 600 million tons per year. Operation of the built-up biogas projects revealed that the fermentation residues produced by the biogas project-biogas slurry has features of concentration, large quantity, and continuity; therefore, digestion is difficult within small-radius regions. This problem has already restricted the confidence of biogas project owners, consequently hindering biogas development and utilization. How to effectively recycle and utilize biogas slurry has already developed into one of the major problems in the construction of large biogas projects.<sup>[2]</sup>

Currently, long-term extensive utilization of chemical fertilizer has led to rural land consolidation, deteriorating soil quality, continuously decreasing soil fertility, and gradually deteriorating agricultural product quality. Simultaneously, large-scale utilization of chemical fertilizer also caused serious soil and water pollution, and that would endanger human health and destroy human living environment<sup>[3]</sup>. Biogas residue and slurry contain the necessary nutrients for plant growth<sup>[4]</sup>, and are also rich in organic substances beneficial for soil improvement, and small molecular humus, which is easily absorbed by plants<sup>[5]</sup>. Biogas residue and slurry are both of positive significance for the improvement of crop production and quality, and also beneficial to maintain and enhance soil fertility<sup>[6-8]</sup>. Therefore, use as fertilizer is the most important application of biogas residue and slurry<sup>[9-10]</sup>. Fully utilizing biogas slurry resources has positive significance to promote the development of the biogas industry in China, to ensuring the sustainable development of agriculture, to enhancing the recycling and utilization efficiency of biomass resources, and improving the energy and resource structures of China.

Utilization of biogas slurry as fertilizer has a long history already, however, the main study of biogas



slurry application as fertilizer still focuses on the utilization effect of biogas slurry, including improving crop productivity, promoting product quality, increasing crop resistance, and enhancing soil quality and fertility<sup>[11-14]</sup>. Since biogas slurry as a type of fertilizer resource with a relatively large application market, the commercialization of biogas slurry is imperative.

To better guide the allocation and utilization of biogas slurry, it is very important to fully understand the properties of the biogas slurry, clarify the value of biogas slurry, and to provide quantifiable references. To carry out and promote the commercialization of biogas slurry, the determination of an appropriate price for biogas slurry is a necessary aspect of investigation<sup>[15]</sup>. Although people realized the value of biogas slurry and began to pay attention to the recycling and utilization problem of biomass resources, no study exists to date about the price determination of biogas slurry for both the domestic and the international market. Based on premises of using biogas slurry as fertilizer and the comprehensive consideration of transportation and utilization cost of biogas slurry, this study provides a set of biogas slurry pricing methods and further elaborates the practical application of this method using examples such as the analysis of nutrient contents of biogas slurry.

## 2. Method presentation

Starting from the nutrient content of biogas slurry and appropriately considering the market values of the corresponding nutrient elements and market factors, a nutrient content price determination method of biogas slurry was developed that can be used in the actual production process. This method included three main steps: determination of varieties and contents of main nutrients in biogas slurry, calculation of the price of individual nutrients and price determination of biogas slurry.

### 2.1 Determination of the varieties and contents of main nutrients of biogas slurry

Biogas slurry was extracted after complete anaerobic fermentation and the biogas residue was filtered via filter press. If the biogas slurry had been standing for a long time, it should be stirred to homogeneity prior to sampling and testing. Biogas slurry sampling should be representative and 3-5 parallel samples with the same quantity are taken in general. These are then mixed into one sample for utilization and determination. Biogas slurry is the residual substance after anaerobic fermentation and is usually neutral or slightly alkaline (pH value generally ranges between 7.0-7.5), which is suitable for utilization as fertilizer for most plants. Although biogas slurry contains more than 20 types of nutrient elements that are necessary for plant growth, there is no operability and practicability to manifest the values of all nutrient elements. Therefore, according to the properties of biogas slurry and considering a realistic situation, four indicators including organic substance, total nitrogen, total phosphorus, and total potassium were chosen and their contents in biogas slurry were determined, respectively.

#### 2.1.1 Determination of the organic substance in biogas slurry

The organic substance in biogas slurry was determined via titration after oil-bath; i.e., heating by oil-bath followed by application of the potassium dichromate volumetric method. The specific determination method used a measuring cylinder or coarse porous straw to draw 10 mL homogeneously mixed biogas slurry, which was added into a 500 mL volumetric flask to a constant volume and homogeneously mixed, forming the test solution. 5 mL of the prepared solution were drawn to control the content of organic carbon to below 8 mg; 5 mL of 0.8 M potassium dichromate ( $\frac{1}{6} \text{K}_2\text{Cr}_2\text{O}_7$ ) solution were added as well as 5 mL concentrated sulfuric acid, followed by boiling for 5 min in an oil-bath between 170-180 °C. Other specific determination steps were identical to those for the general determination of organic substance in soil.<sup>[16]</sup> The organic substance content of biogas slurry was defined as  $\eta_{OM}$ .

#### 2.1.2 Determination of the total nitrogen content of biogas slurry

Total nitrogen was determined using the Kjeldah method after digestion with sulfuric acid-potassium dichromate. The specific procedure used a measuring cylinder or coarse porous straw to draw 10 mL homogeneously mixed biogas slurry, then added into a 1000 mL volumetric flask to a constant volume and mixed to homogeneity, thus forming the test solution. 5 mL of the prepared solution were drawn to control the content of total nitrogen to be below 1 mg; then, 2 g accelerator and 5 mL concentrated

sulfuric acid were added, the mixture was shaken to homogeneity and digested on an ectothermic electric furnace. The further determination procedure was identical to the determination of total nitrogen in soil using the Kjeldah method. The total nitrogen content in biogas slurry was defined as  $\eta_N$ .

### 2.1.3 Determination of the total phosphorus content in biogas slurry

The total phosphorus content in biogas slurry was determined via  $H_2SO_4$ - $H_2O_2$  digestion and the vanadium-ammonium Molybdate-colorimetry method. The specific procedure drew 1 mL homogeneously mixed biogas slurry and added this into a digestion tube, adding 10 mL concentrated sulfuric acid, and shaking homogeneously (overnight). A bent-necked funnel covered the bottle, it was slowly heated on the electric furnace until the concentrated sulfuric acid began to decompose and white smoke began to rise, at which point, the temperature was gradually increased. When the solution was uniformly brownish black, the digestion tube was taken off, the mixture was slightly cooled and the bent-necked funnel was lifted out. Then, 10 drops of  $H_2O_2$  were added and the digestion tube was continuously shaken and reheated (to slightly boiling) for 10-20 min; then, the digestion tube was taken off and the mixture was slightly cooled before 5~10 drops of  $H_2O_2$  were added. This procedure was repeated several times until the digestion liquid became colorless or clear and bright, then reheated for 5-10 min to completely remove all  $H_2O_2$ ; then, the digestion tube was taken off and cooled, the funnel was washed with water, and the washing liquor was added into the bottle. Then, the digestion liquid was transferred into the volumetric flask, set to constant volume, and either remained still or was filtrate. The supernatant liquid was removed for total phosphorus content determination. The specific procedure was identical to the determination of effective phosphorus content in soil. The total phosphorus content in biogas slurry was defined as  $\eta_P$ .

### 2.1.4 Determination of total potassium content in biogas slurry

The total potassium content in the biogas slurry was determined via flame photometry. The utilized test solution was identical to that used for the total phosphorus determination as described in section 1.1.3. All further specific procedures were identical to that for the determination of effective potassium content in soil. The total potassium content in biogas slurry was defined as  $\eta_K$ .

## 2.2 Price calculation of individual nutrients

Organic substance, elemental nitrogen, elemental phosphorus, and elemental potassium were the four indicators that were used to determine the price of biogas slurry. For each nutrient, a type of commercialized fertilizer should be set as reference, i.e., the reference fertilizer. The price of each nutrient was calculated based on the market selling price of the reference fertilizer. The market selling price of this reference fertilizer was obtained via market survey. Although the selling price of organic fertilizers differed slightly across the country, a relatively reasonable and unified price could be obtained.

### 2.2.1 Price of organic substances

Organic fertilizer is a commercialized fertilizer that provides organic substance as a main nutrient. Organic fertilizer that mainly provides organic substance had a price range of 500-800 yuan. For the price determination, the value  $E_{OM}$  could be calculated according to an estimation of experts. The organic substance content of organic fertilizer generally ranged above 25% and was identified as  $\partial_{OM}$ .

Therefore, the price of organic substance could be calculated with the equation  $\rho_{OM} = \frac{E_{OM}}{\partial_{OM}}$  and uses a unit of yuan/t.

### 2.2.2 Price of elemental nitrogen

Urea is a fertilizer that provides elemental nitrogen as the main nutrient. The selling price of urea ranged from 1500-1800 yuan. For the price determination, a value  $E_N$  could be calculated according to an estimation of experts. The nitrogen content in urea was defined as  $\partial_N$  (generally 4-6%). Hence, the

price of elemental nitrogen could be calculated via  $\rho_N = \frac{E_N}{\partial_N}$ , and the unit was yuan/t.

### 2.2.3 Price of elemental phosphorus

Diammonium phosphate was the fertilizer that provided elemental phosphorus as the main nutrient. Although diammonium phosphate contains two main nutrient elements (nitrogen and phosphorus), the price of elemental nitrogen could be determined (see section 1.2.2); thus, the price of elemental phosphorus could be calculated. The selling price of diammonium phosphate was about 3000 yuan. For price determination, a value  $E_P$  could be calculated according to an estimation of experts. The nitrogen content in diammonium was defined as  $\partial_N$  (generally above 18%). The phosphorus content was defined as  $\partial_P$  (generally above 6%). The price of elemental phosphorus could be calculated via  $\rho_P = \frac{(E_P - \partial_N \times \rho_N)}{\partial_P}$  and the unit was yuan/t.

### 2.2.4 Price of elemental potassium

Potassium chloride was the fertilizer that provided elemental potassium as the main nutrient. The selling price of potassium chloride was around 3500 yuan. For the price determination, the value  $E_K$  could be calculated according to an estimation of experts. The potassium content of potassium chloride was defined as  $\partial_K$  (generally 60%). Therefore, the price of potassium could be calculated via  $\rho_K = \frac{E_K}{\partial_K}$  and the unit was yuan/t.

## 2.3 Price determination of biogas slurry

After content determinations of organic substance, total nitrogen, total phosphorus, and total potassium, the value of each nutrient in the biogas slurry could be calculated according to the price of the respective nutrient. The fertilizer value of biogas slurry was calculated with the addition of four items, and after dividing by the quantity of biogas slurry, a value per unit was obtained, i.e., the price of biogas slurry. Of course, this price could only be obtained when biogas slurry was utilized as fertilizer. Therefore, it was necessary to consider factors such as the actual demand of biogas slurry, transportation costs, and utilization costs.

The specific calculation equation for the price of biogas slurry was:

$$P = [(\rho_{OM} \cdot \eta_{OM} + \rho_N \cdot \eta_N + \rho_P \cdot \eta_P + \rho_K \cdot \eta_K) - P_M - P_U] \cdot \delta \quad (1)$$

In the above equation (1), P was the price of biogas slurry (yuan/t);

$P_M$  was the added transportation cost of biogas slurry compared to other fertilizers (yuan/t);

$P_U$  was the added utilization cost of biogas slurry compared to other fertilizers (yuan/t);

$\delta$  was the practical popularity of biogas slurry compared to other fertilizers (%).

## 3. Application example of this method

According to the methodology above, prices were determined of a type of biogas slurry that uses cow dung as raw material as well as a type of biogas slurry that uses straw. Furthermore, both users and owners of the biogas slurry unanimously recognized these prices.

The utilized biogas slurry was collected from the biogas digester of a farmer in Sijia village, Gaoguanzhai town, Zhangqiu city in Jinan, using cow dung as main raw material. The biogas slurry was settled longer than 72 h, and filtered through a 1 mm mesh sieve for further utilization, which was stirred homogeneously during use. The determination of the main nutrients in the biogas slurry is shown in Table 1.

Table 1 Nutritional contents of biogas slurry

Organic substance (%)	Total nitrogen (%)	Total phosphorus (%)	Total potassium (%)
3.213	0.117	0.074	0.096

Note: The solid substance content of biogas slurry was 9.81%.

Price determination of organic substance, nitrogen, phosphorus, and potassium referred to organic fertilizer, urea, diammonium phosphate, and potassium chloride, respectively. The provisional price, obtained via market research and its transformation are shown in Table 2.

Table 2 Unit price of nutritional contents and reference fertilizer

Reference fertilizer	Market price E/yuan/t	Effective nutrient	Nutrient content $\delta$ /%	Unit price of nutrient $\rho$ /yuan/t
Organic fertilizer	600	Organic substance	30	2000
Urea	1800	Total nitrogen	46	3910
Diammonium phosphate	3000	Total nitrogen	18	3910
		Phosphorus	46	4990
Potassium chloride	3500	Potassium	60	5830

Note: The market price was determined according to the market selling price at that time. Pure nitrogen, pure phosphorus, and pure potassium were all consistent with nutrient content identification in determination and analysis presented here. Diammonium phosphate contained two nutrient elements, nitrogen and phosphorus and the price of nitrogen was determined first, deducing the value of nitrogen afterwards to calculate the price of phosphorus.

The transportation cost of biogas slurry was calculated according to transportation of 5 t per trip, resulting in a transportation cost of about 100 yuan within a generally meaningful distance and range, which was relatively high. Therefore, it was necessary to reduce the price per ton by 20 yuan for price calculation of biogas slurry; the transportation cost of common fertilizer could be ignored. Hence,  $P_M = 20$  yuan/t.

The utilization cost of biogas slurry was slightly higher compared to common fertilizers. The labor cost was calculated as 50 yuan under the condition that half a day of labor was required to pour 5 t of biogas slurry. As a result, the price of biogas slurry should be reduced by 10 yuan per ton. Hence,  $P_U = 10$  yuan/t.

The popularity of biogas slurry by consumers was relatively high, mainly due to the comprehensive nutrients in biogas slurry and the relatively strong fast-acting properties. In addition, it could significantly improve the soil properties and promote the taste of agricultural products. However, considering the limitation factors such as farming time and monotonous utilization mode, as well as a lack of scale of the local fruit and vegetable products and general market capacity, a value of 80% was used herein.

The price of biogas slurry was calculated according to equation (1)

$$P = [(\rho_{OM} \cdot \eta_{OM} + \rho_N \cdot \eta_N + \rho_P \cdot \eta_P + \rho_K \cdot \eta_K) - P_M - P_U] \cdot \delta = [(200 \times 3.213\% + 3910 \times 0.117\% + 4990 \times 0.074\% + 5830 \times 0.096\%) - 20 - 10] \times 0.8$$

=38.499≈38.50

Hence, price of the biogas slurry was determined as 38.50 yuan/t.

#### 4. Conclusion

With the construction and operation of large and medium biogas projects in China, biogas slurry has become a main representative of "farm manure". From the viewpoint of cyclic utilization of agricultural resources, utilization of biogas slurry as fertilizer has become the consensus of biogas operators, agricultural producers, and other related personnel. However, this industry is still in its infancy, and the investigation depth of studies about utilization as fertilizer requires further strengthening. At present, most reports still focus on the utilization efficiency aspect. However, due to the uncertainty of the tested material (biogas slurry and residue), the result and reproducibility of these reports were poor, thus providing weak reference value. Particularly at present, there is no authoritative uniform scale for the concept of biogas slurry. A referable standard should be formed towards definition, components, elemental content, and physical and chemical properties of biogas slurry, which will facilitate a standard development of this industry.

Utilization of biogas slurry as fertilizer is an important part of the cyclic utilization of biomass resources, and has relatively high economic interest, combined with ecological and social benefits. Biogas owners hope to sell biogas slurry as commodity. However, due to limitation by problems such as high cost and inconvenience of transportation, uncontrollable time of fertilizer-requirements, and poor stability of biogas slurry fertilizer efficiency, agreement with scattered farmers is hard to achieve. Hence, in order to make a profit, they can only seek for large-scale planting zones; however, a beneficial coordination between them still requires the intervention of authoritative departments to fairly and reasonably determine both value and pricing issues of biogas slurry.

No report exists to date on the pricing of biogas slurry. In this study, a method for the price determination of biogas slurry was provided according to the contents of main nutrients. If biogas slurry is utilized as raw material for the production of other products, it is possible to use the idea provided in this study, and choose indicators appropriate to the product requirement to adjust the determined price. This study also provides a reference for the adjustment of national policy and for the cyclic utilization of biomass resources.

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