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# Design and efficiency analysis of biogas engineering for the mixture of kitchen waste and garden waste

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***Abstract*—In view of the characteristics of food waste, large volume and constant output in universities,taking a Chinese University as an example, we explored the centralized mode of kitchen waste biogas disposal in universities.The anaerobic fermentation technology is the core of the design,and the ""canteen + garden"" engineering mode is adopted, converting organic waste into energy and organic fertilizer through this process. According to the daily average throughput of 5t, a continuous stirred tank reactor (CSTR) 300m3 is needed.The results show that an average annual treatment capacity is 1200t mixed organic wastes, the annual output of organic fertilizer raw materials such as biogas slurry and biogas residue is 370.8t and annual biogas output is 144,000m3. Biogas supplies the canteen, biogas slurry produces organic fertilizer, and the treated biogas slurry is discharged. This scheme can effectively improve the environment of the campus and establish the basic mode of circular agriculture.**

***Keywords—Anaerobic Digestion; Kitchen Waste; Garden Waste; Biogas Engineering; Methane***

## I. Introduction

The double crises of energy and environment have brought the research and development of renewable energy to an unprecedented height and prompted the rapid development of large and medium-sized biogas projects in China in recent years. At current stage, China's large and medium-sized biogas projects mainly use livestock and poultry manure, industrial organic wastewater and municipal living sludge as raw materials, but there are seldom biogas projects that use kitchen waste as raw material. Kitchen waste is a typical urban organic waste. Kitchen waste's solid residue is rich in animal and plant fats, carbohydrates, proteins and other organic substances, showing the characteristics of "Two Highs and Two Lows", namely high water content, high organic matter, low quality and low heat value. The traditional waste disposal methods such as incineration, land filling, mechanical crushing, are not suitable for kitchen waste disposal. Most of the modern kitchen waste are treated by biological treatment, including aerobic and anaerobic treatment, but the aerobic composting of kitchen waste has disadvantages such as slow temperature increasing, low volumetric efficiency, poor particle stability and the process of composting will release $CH_4$ and $N_2O$ [1~2]. Production of biogas by anaerobic fermentation can't only improve the resource utilization level of kitchen waste, but also to achieve the dual benefits in economy and environment, currently it is the mainstream technology in kitchen waste recycling. Anaerobic fermentation technology is the degradation and stabilization of organic matter by microorganisms under anaerobic conditions, which is accompanied by the production of biogas (the main components are methane and carbon dioxide). Anaerobic fermentation, as an effective means for the resource utilization of waste, attracts more and more attention with the dual advantages of pollution control and energy recovery [3].

The kitchen waste generated by the canteens in colleges and universities has the characteristics of constant output, large output, concentrated output time and relatively single components. According to the statistics [4], from September to December 2016, there are 37,092,000 students enrolled in regular colleges and universities in China, if calculated on the basis of about 0.1kg of kitchen waste per person per day, the annual (based on 300 days) output is at least 1.1 million t. Some researchers mixed kitchen waste with garden garbage for laboratory-scale combined fermentation experiments (Table 1); the experiments show that the synergistic and complementary effects of combined fermentation can achieve better gas production. Take a Chinese university as an example, this design explores the ways of concentration biogasification, harmless and resource utilization of kitchen waste in colleges and universities in order to improve the campus environment and establish the basic pattern of campus's ecological cycle.

Table I . Methane yields from mono-digestion of food waste and co-digettion of folld waste with other substrates [5-7]

| Feedstocks | OLR /$gVS·L^{-1}$ | Temperature /℃ | Yield /$mL·gVS^{-1}$ | Concentration /% |
|---|---|---|---|---|
| Kitchen waste | 6.8 | 50 | 435 | 73.1 |
| Kitchen waste | 16.0 | 50 | 518 | 66.1 |
| Kitchen waste | 12.5 | 35 | 245 | 56.9 |
| Kitchen waste and garden waste | 6.5 | 50 | 430 | 60.0 |
| Kitchen waste and garden waste | 12.5 | 35 | 185 | 51.7 |
| Kitchen waste and garden waste | 46.1 | 37 | 272 | 69.4 |

## II. Characteristics of Feedstocks

The main components of kitchen waste are fat; carbohydrate and protein, the theoretical yields of $CH_4$ at standard temperature and standard pressure were respectively 0.99 $L\cdot g^{-1}$, 0.42 $L\cdot g^{-1}$ and 0.63 $L\cdot g^{-1}$. The $CH_4$ production potential of fat is higher than that of carbohydrate and protein. There are researchers who conducted an experimental study on $CH_4$ production potential of kitchen waste and found that the $CH_4$ production potential of meat, cellulose, rice, cabbage and mixed wastes were respectively 482, 356, 294, 277 and 472 $mL\cdot gVS^{-1}$. Under the optimal conditions, the output can account for 0.82, 0.92, 0.72, 0.73 and 0.86 of the theoretical stoichiometric $CH_4$ output, indicating that under the suitable anaerobic system conditions, about 86% of carbon in the kitchen waste can be converted into $CH_4$ [8]. However, due to the high biodegradability of kitchen waste and its relatively low carbon/nitrogen (C/N) ratio, there has a range of potential inhibitors encountered in fermentation of single kitchen waste, including the volatile fatty acids produced by the rapid degradation of starch and ammoniacal nitrogen produced by protein degradation [9].

Garden garbage is an important part of campus solid waste and can be produced and used throughout the year.Garden waste includes, for example, mowed grasses, stubbles, weeds, fallen leaves, fruit husks, vines, twigs and other wastes. The main components of its organic matters are cellulosic carbohydrates, in addition, including a small amount of crude protein and crude fat. Single fermentation of lignocellulosic garden waste also faces challenges, including lack of nutrients, slow start-up and long residence time [10]. The adoption of mixed fermentation process is expected to achieve better methane production performance. Mixed fermentation can increase nutrient balance, dilute inhibitory compounds, and improve organic degradation and biogas production through synergistic and complementary effects. As a result, the mixed anaerobic fermentation can be a viable solution for centralized treatment of kitchen waste and garden waste. Table 2 shows the various indicators of kitchen waste and garden waste.

Table II. CHARACTERISTICS OF KITCHEN WASTE AND GARDEN WASTE

| Items | kitchen waste | garden waste |
|---|---|---|
| TS /%,w.b. | 26.9±0.3 | 86.8±0.3 |
| VS /%,w.b. | 25.2±0.3 | 74.3±0.9 |
| VS/TS /% | 93.6±0.5 | 85.7±1.2 |
| C /%,d.b. | 46.3±0.7 | 45.3±0.3 |
| N /%,d.b. | 2.1±0.2 | 1.1±0.1 |
| C/N | 22.0±1.1 | 41.2±1.3 |
| pH | 4.51±0.01 | ND |
| TAN/$mg\cdot L^{-1}$,w.b. | ND | ND |
| Cellulose/%,d.b. | ND | 32.1±0.9 |
| Hemicellulose/%,d.b. | ND | 23.7±0.7 |
| Lignin/%,d.b. | ND | 14.1±0.7 |

Notes: w.b., web base; d.b.,dry base; ND, not determin.

This design uses "canteen + garden" treatment mode; take anaerobic fermentation technology as the core, the mixed fermentation of kitchen waste and garden waste is used to produce biogas. There have 500 mu of farmland around the site of this project, of which the available area is about 350 mu, it can completely accommodate and treat the organic fertilizer such as biogas residue and slurry and avoid secondary pollution. The produced biogas can generate electricity through the generator set, and the electric energy can be used for biogas project's own temperature-keeping heating and canteen's electricity supply.

The main advantages of the "canteen + garden" treatment mode are: this mode has certain potential for promotion, the campus with agricultural area can accommodate and use the organic fertilizer produced by anaerobic fermentation and realize the recycling and use of organic waste produced by campus; for the campus that can't accommodate and use, the organic fertilizer can be granulated for sales to reduce pollution and generate certain economic benefits. The generated biogas can be used as clean energy to reduce energy consumption.

## III. DESIGN OF ANAEROBIC DIGESTION PROCESS

### A. *Anaerobic Fermentation Process*

This project is designed as an industrial production process of continuous feeding. The chopsticks, meal boxes, large bones and other solids that are large and difficult for degradation are removed from kitchen waste through screening and manual sorting; then pulverize and mix waste, and transfer it into acidification regulation pool. After acidification adjustment, the mixed raw material is pumped into an anaerobic fermentation tank. Anaerobic reaction tank is equipped with a central axis stirring device; the material in the tank is in a fully mixed state. The biogas produced by the project is processed by the biogas purification device, stored and provided to generator set for electricity generation, the produced electric energy is supplied to the canteen on the one hand and used for heat production on the other hand to meet the heating and heat preservation needs of the biogas project itself. Produced biogas slurry and biogas residue are transferred into temporary storage tank for sedimentation and storage, biogas slurry is recovered into the liquid feed system for recycling, the remaining biogas slurry and biogas residue are used as raw materials for the production of organic fertilizer, organic fertilizer is used as garden plants' fertilizer. Process flow chart is shown in Fig. 1.

After the anaerobic fermentation starts, according to the design of the scheduled treatment amount, the new fermentation raw materials are added on a daily basis, while drain the biogas slurry of the same amount. Except for accident, maintenance or repair, fermentation device will not drain material in large quantity. Using this fermentation process, the quantity and quality of material fluid in the biogas digester basically remains stable, and the gas production is also well balanced. Due to continuous fermentation, this process requires adequate fermentation raw materials supply to prevent the decreasing of biogas digester's utilization rate caused by large replacement of raw materials, so that the raw material digestion capacity and gas production capacity will be greatly improved.

The project uses medium-temperature fermentation process to produce biogas, and the temperature of fermentation liquid is maintained within the range of (35±3) ℃. Compared with the high-temperature fermentation, the digestion speed of this process is slightly slower and the gas production rate is lower, but the energy consumption of maintaining medium-temperature fermentation is less, the biogas fermentation can be maintained at a relatively high level, the gas production speed is relatively faster, gas production is also more balanced, the liquid material basically will not crust, it can ensure the perennial steady operation.

### B. Operating Parameters

According to the characteristics of anaerobic reaction of mixed kitchen waste and agricultural organic wastes, CSTR anaerobic reactor is used according to design. It is a simple mixed anaerobic reactor that is suitable for materials with high content of suspending solids. Anaerobic reaction tank is equipped with a central axis stirring device to ensure that the material in the tank is in a fully mixed state. In the anaerobic fermentation reaction system, proper stirring and mixing can make the endoenzymes and exoenzymes of the microorganism in the bioreactor fully contact and mix with the substrate, which help the normal process of substances conversion and transfer in the anaerobic reactor and to some extent guarantee the uniform distribution of temperature and material concentration in the reaction system. At the same time, they also avoid the accumulation of organic acids in some areas and improve the gas generation performance of the anaerobic system.

For the project design, fermentation material fluid's TS concentration is 8%; hydraulic retention time (HRT) is 20d. The total volume of the anaerobic reactor is calculated by the following formula: $V = KQ\cdot HRT$, where: V is the total volume of the reactor; K is the ratio coefficient of effective volume to total volume; Q is the wastewater flow rate ($m^3\cdot d^{-1}$); HRT is hydraulic retention time (d). The daily feed (Q) is about 5t, calculated according to 8% feed TS concentration, to ensure the stable operation of the treatment project, assume HRT (T) is 20d and K is 1.2, then the total volume of CSTR reactor is $300m^3$.

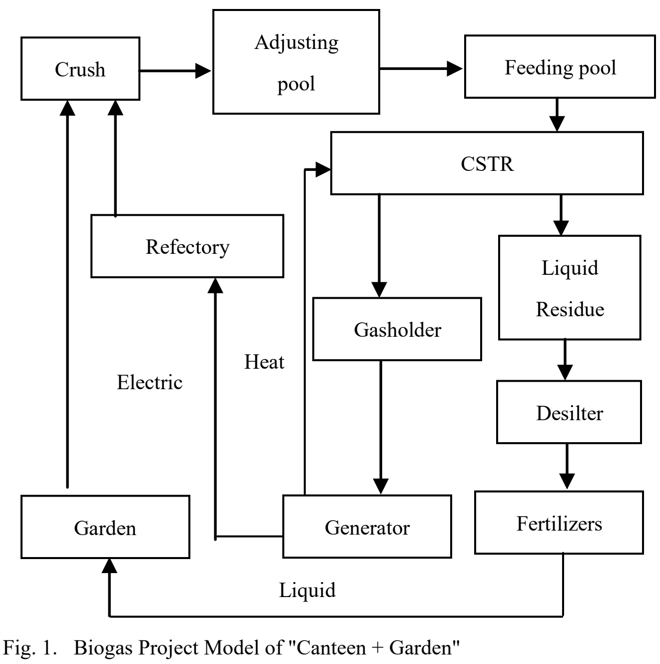


Fig. 1. Biogas Project Model of "Canteen + Garden"

### C. Material Balance Analysis

The average daily amount of kitchen waste of the student canteen in the university where this project locates is 3.5 tons and the total solid content (TS) is 8%~10%. The daily organic waste generated in gardens and farm areas is about 1.5t and the total solids (TS) content is 22~30%.

Based on 5 tons daily processing capacity of organic mixed waste, 92% of water content and 8% of solid waste content in the mixed waste, if the mixed waste is completely added into the mixing stirrer for full mixing, the system can produce $600m^3$ of biogas and 1.545 tons of biogas residue and slurry per day.

Biogas residue is a kind of semi-solid remaining material after biogas fermentation. It is rich in organic matter, humic acid, amino acid, nitrogen, phosphorus, potassium and trace elements and is a kind of high-quality fast-acting organic fertilizer. The biogas slurry and residue produced by the biogas project can be used as organic fertilizer for greenhouse production in the agricultural park. The annual output of biogas slurry and biogas residue is 370.8t. Based on 8t fertilization per mu of farmland per year, produced fertilizer can meet the needs of 46mu of farmland.

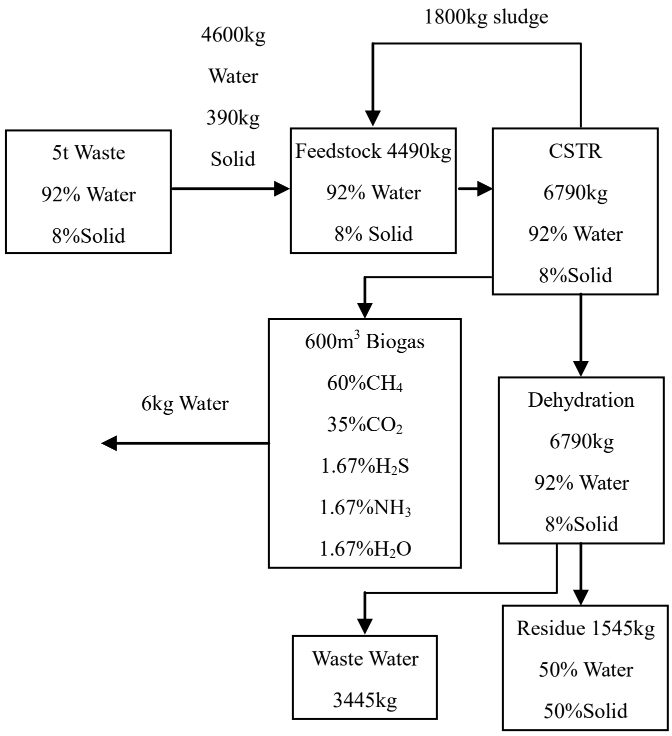


Fig. 2. Material Balance of the Campus Biogas Engineering

### D. Energy Balance Analysis

The main component of biogas is methane ($CH_4$); it contains 50%~80% methane. The heat value of each cubic meter of pure methane is 34,000 kJ, the heat value of each cubic meter of biogas is about 20800~23600 kJ. That is, the heat value of one cubic meter of biogas after complete combustion is equivalent to 0.7 kilograms of anthracite. Compared with other gases, it has a better antiknock performance and is an excellent clean fuel.

Based on daily production capacity of 600m³ biogas and 60% of $CH_4$ concentration, it can generate 3660kWh electric energy, in addition to 36.6kWh of wasted energy, of which

2190kWh is used for heat production, 1433.4kWh is used for canteen's power supply.

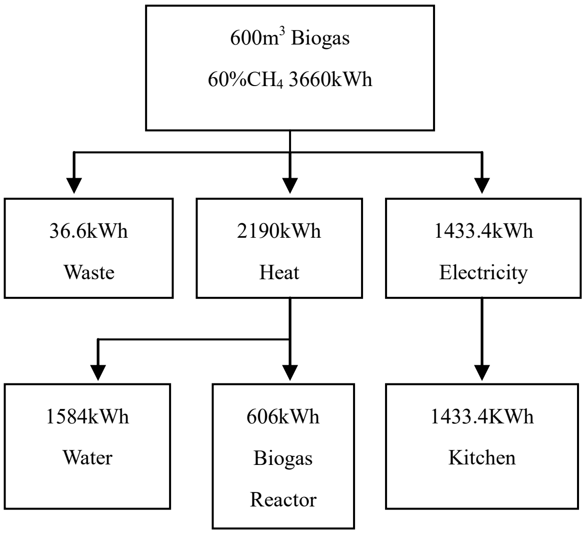


Fig. 3. Energy Balance of the Campus Biogas Engineering

## IV. CONCLUSION

Take anaerobic fermentation technology as core, "canteen + garden" biogas project model achieves the harmless treatment and resource utilization; and realizes the effect of energy saving for the campus, it has a certain potential for promotion. After mixed anaerobic fermentation process, kitchen and garden organic waste can be effectively converted into biogas, organic fertilizer and other resources. According to the calculation based on the designed treatment capacity, this project uses a $300m^3$ full-mixed anaerobic reactor with an average annual treatment capacity of 1200t mixed organic wastes, the annual output of organic fertilizer raw materials such as biogas slurry and biogas residue is 370.8t and annual biogas output is $144{,}000m^3$. Biogas can be used for electricity supply for campus canteens and biogas project's heat preservation after conversion into electricity; biogas slurry and biogas residue can be used as organic fertilizer for agricultural park or sold to others to eliminate secondary pollution.

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