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Enhanced split-phase resource utilization of kitchen waste by thermal pre-treatment

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ABSTRACT

Our society currently faces the twin challenges of resource reclamation from rapidly escalating KW (kitchen waste) and increasingly expensive depletion costs and restrictive disposal legislation due to environmental impacts and fast depleting global resources necessitate action. This work studied the influence of thermal hydrolysis on the utilization of KW based on the principle of split phase processing, including solid phase for pig feed, liquid phase for anaerobic digestion and floating oil for biodiesel. It shows that the solid phase of KW after thermal treatment could satisfy the nutrition content requirements as raw materials for pig feed. The efficiency of the subsequent anaerobic digestion of liquid phase increased for KW pretreated at 120 °C and higher methane production and soluble chemical oxygen demand reduction were achieved after a pretreatment time of 40 min. Composition analysis of floating oil during thermal hydrolysis indicates that unsaturated fatty acid accounts for more than 61% and the main ingredients are monounsaturated fatty acid (more than 36%). All parameters important for biodiesel quality except the acid value could satisfy the biodiesel requirements according to the European standard. From overall analysis, the thermal pre-treatment was profitable with output value of $ 57.52 ton^{-1} KW.

1. Introduction

More than 30 million tons of KW (kitchen wastes) are produced in China every year. Approximately 80% of the collected KW has been directly utilized as feedstuff in pig farms in China, which is facing strict restrictions by China's Ministry of Agriculture due to concerns of foot and mouth disease, and raw materials for illegal extraction of hogwash oil, which is unsanitary and can cause serious illness. In addition, the universal concern on environmental protection, resource utilization and food safety has brought increasing research on KW processing technology.

Due to high moisture and salt content, there are two potential problems on the incineration of KW, including extra energy consumption, and generation and release of toxic pollutants to the environment. Such negative aspects coupled with high oil content, KW does not favor the compost process [1], thus restricts their application in fertilizer utilization. In addition, AD (anaerobic digestion) can be used to convert organics into biogas for energy recovery and achieve waste reduction [2,3]. When KW is treated anaerobically as a single substrate, common problems would appear during conventional AD because of their high oil content and the presence of macromolecular compounds, including the accumulation of lactic acid at an early stage of the digestion process resulting in a sudden pH drop and inhibitory levels of ammonia, sulphide and long-chain fatty acids due to the high protein and fat content [4]. These factors usually impede digestion stability, thus restricting the application of AD. Besides, the lack of efficient technology for disposal of biogas residues, the secondary pollutant during anaerobic digestion, also limits the application of anaerobic digestion in the recycling of KW.

In the technical aspect, numerous pretreatment methods and new process techniques, for example co-digestion with substrates

Abbreviations: KW, kitchen waste; AD, anaerobic digestion; CF, crude fiber; CP, crude protein; EE, ether extract; Ash, crude ash; NFE, nitrogen free extract; SCOD, soluble chemical oxygen demand; GE, gross energy; DE, digestible energy; ME, metabolizable energy; NE, net energy; AA, Amino acids; DAA, dispensable AA; IDAA, indispensable AA; Ala, alanine; Asp, Aspartic acid; Glu, Glutamic acid; Gly, Glycine; Pro, Proline; Ser, Serine; Tyr, Tyrosine; Thr, Threonine; Val, Valine; ILe, Isoleucine; Leu, Leucine; Phe, Phenylalanine; His, Histidine; Lys, Lysine; Arg, Arginine; VFA, volatile fatty acids; BMP, biochemical methane potential; FA, fatty acids; DU, degree of unsaturation; LCSF, long chain saturated factor; SFA, saturated fatty acids; UFA, unsaturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids.

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containing high levels of ammonium nitrogen and alkalinity have been proposed to improve the physical and chemical properties of organic waste to enhance the solubilisation of organic particulates and promote biogas production [5,6]. Among these methods, thermal treatment has been demonstrated to be an effective method to provide better phase separation, higher hydrolysis rate of complex particulate organic substrates and apparent sterilization effects, thus improving the subsequent disposal, such as enhancing the efficiency of anaerobic digestion process [7]. In addition, thermal pretreatment of KW could meet these requirements of guarantying the effect of disinfection sterilization, avoid the premise of exogenous pollution and improve the recovery rate of useful resource [8], such as nutrients and lipids when using as pig and other animal feed due to the enormous demand [9,10], and could also enhance the production of waste edible oils, which could not only be used as the raw oil for biodiesel production [11], but also effectively alleviate biological inhibiting reactions induced by the high concentrations of oil and grease in KW [12].

According to the policy perspective on promoting the recycling application and resource saving of KW, developing resource-saving and environment-friendly society as well as circular economy and protecting the ecological environment in both China (FAGAIHUANZI [2010] No. 1020) and other countries due to environmental impacts and fast depleting global resources necessitate action [13–15], it is required especially in China that the construction of pilot projects should be conducted overall planning and combinational optimization to enhance resource-oriented utilization and harmless treatment of three phases in KW, including oil, solid and liquid phase (FAGAIHUANZI [2010] No. 1020). Because of policy encouragement, environmental concern and economic incentives by local and central governments in China, more diverse methods after thermal pretreatment should be developed as the amount of KW production increases rapidly. Besides, basing on the increasing universal concern on safety, energy and environmental preservation, finding proper and effective disposal methods of KW for energy production and solution for KW treatment and valorization, enhancing biogas production and reducing the amount of final residue is extremely important [16,17]. In addition, basing on technological limitations and knowledge-based processing and efficient and cost-competitive ways converting KW into valuable products, the objective of this study is to estimate and analyze the impacts of the split-phase processing with thermal hydrolysis of KW.

In this regard, this paper aims at a comprehensive study on the solubilisation effects of organic compounds in three phases (solid, liquid and oil phase) of KW, and the recovery rate of floating oil and nutritional components, such as protein and amino acid, during different thermal pretreatments. Furthermore, the potential of floating oil to produce biodiesel, solid phase to produce pig feed after thermal drying process, and liquid phase to produce biogas under mesophilic anaerobic digestion condition (35 °C) from KW is evaluated. This study is unique in that it proposes a split-phase processing method to maximize the recycling utilization of KW and analyzes process that produces resources comprehensively from KW, while comparison of results in this study highlights the significant impact of thermal hydrolysis degrees. Results and conclusions presented are intended to contribute to processing knowledge of KW in the areas of biomethane, pig feed and biodiesel production, waste management and related policy.

2. Materials and methods

2.1. Kitchen waste

The characteristics of KW (kitchen waste) are closely relevant to local living standards, eating habits, etc. In particular, according to investigations carried out in some cities in China, it could be found that food waste and bones accounted for more than 90% in KW, while the other proportions were mainly paper, plastic, wood, metal, etc. And the characteristics of KW include high moisture content (70%–87%), high organic content (80%–93%, dry basis), and the content of oil ranged from 2% to 3% with the salt content as approximately 1%. Moreover, the volatile solid content in KW was also pretty high (75%–90%, dry basis) and some nutrient content, such as crude protein and crude fat, showed no significant difference from the typical feed, i.e. soybean, corn and etc.

Table 1(a) shows the basic characteristics of KW and the characteristics of KW collected from a canteen in Tsinghua University were conformed to the current situation of basic components of KW in China. Specifically, the major components were carbohydrates derived from bread, cooked noodles and rice; proteins and fat from different types of meat and fish. The KW was mixed with a kitchen blender to ensure uniform and representative experimental materials. It was then crushed into particles with an average size of 1–2 mm and stored at 4 °C in a refrigerator.

2.2. Reactors and processing method

A thermal hydrolysis reactor was used to perform the pretreatment of KW; a semi-continuously operating continuously-stirred flow tank reactor was used to study the effect of thermal

Table 1
(a). Characteristics of the KW. (b). Characteristics of the instruments used in this study.

(a)

Parameters	KW
pH	6.50 ± 0.2
Total solids (%)	18.7 ± 1.2
Volatile solids (%, wet basis)	17.5 ± 1.4
Proteins (%, wet basis)	2.8 ± 0.2
Lipids (%, wet basis)	3.7% ± 0.3
Carbon (%, dry basis)	46.1 ± 1.6
Hydrogen (%, dry basis)	6.9 ± 0.2
Oxygen (%, dry basis)	37.8 ± 1.6
Nitrogen (%, dry basis)	3.2 ± 0.4
Sulfur (%, dry basis)	0.3 ± 0.01

(b)

Item	Specification	Parameter in this study
Thermal hydrolysis reactor	Effective volume: 20 L Highest pressure: 2.0 MPa Highest temperature: 220 °C	90–140 °C
Three-phase separator	Power: 220 V, 50 HZ Max RCF: 4650 g Highest speed: 5500 rpm Rotating accuracy: ±50 rpm Duration: 0–99 min	5000 rpm
Transesterification system	Power: 220 V, 50 Hz Temperature range: RT – 100 °C Temperature accuracy: ±1 °C	Moisture removal: 105 °C Reaction time, 1 h Reaction temperature: 60 °C
Thermal drying system	Power: 220 V, 50 HZ Temperature range: RT – 250 °C Temperature accuracy: ±1 °C	Temperature: 105 °C
Anaerobic digester	Power: 220 V, 50–60 Hz Temperature range: RT – 100 °C Temperature accuracy: ±0.5 °C Working volume: 250 mL	Temperature: 35 °C Feed: Inoculum = 1:5 (volume)