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Research article

Faecal sludge treatment and utilization by hydrothermal carbonization

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ABSTRACT

Hydrothermal carbonization (HTC) is a thermal conversion process that can be applied to convert faecal sludge into carbonaceous solids, called hydrochar. In this study, the technical feasibility of hydrochar production by HTC of faecal sludge was investigated. Experimental results showed energy contents of the produced hydrochar to be about 19–20 MJ/kg, comparable to natural coals and therefore usable as a solid fuel. The produced hydrochar contained a carbon content of approximately 40%wt, which could be processed further to make it suitable as an anode in batteries. The produced hydrochar also had adsorption characteristics for removing heavy metals and micropollutants in wastewater. Liquid by-products obtained from the HTC process were found to contain high concentrations of organic matter, while the amount of gas produced was 10 L-gas/kg-FS with CO_2 is the main component. The bio-methane potential tests of this liquid product suggested the methane production of about 2.0 L-CH_4 per kg-faecal sludge could be obtained.

1. Introduction

Most developing countries do not have sewer systems with centralized treatment for wastewater treatment. Human excreta containing faeces and urine is commonly disposed into septic tanks, cesspools or pit latrines. The accumulated sludge from these systems, so called faecal sludge (FS), is periodically removed and usually discharged into nearby canals, land and paddy fields. Modern agriculture and irrigation are the major applications of wastewater treatment (Valipour, 2015, 2016; Viero and Valipour, 2017). Because FS generally contains high concentrations of organic matter and pathogens, to avoid serious environmental and health risk problems, it is not recommended for use in agriculture and irrigation. Typical FS treatment technologies, such as drying beds, constructed wetlands, composting, and digestion, are well known, but they do not solve the environmental and health problems, effectively.

Hydrothermal carbonization (HTC) is a thermal conversion process that can be applied to convert FS into carbonaceous solids, called "Hydrochar", within a short period of time (1–5 h) at a relatively low temperature range of 180–250 °C and corresponding pressures of 20–30 bar (Fakkaew et al., 2015a, 2015b). The main advantage of HTC over other thermal conversion technologies, such as pyrolysis, gasification and incineration, is its ability to convert wet FS to become hydrochar with relatively high yields without preliminary dewatering and drying (Libra et al., 2011), which, consequently, requires less energy.

Previous studies found that the chemical structure and energy content of the produced hydrochar were similar to natural coal, making it suitable for use as a solid fuel in conventional combustion processes. However, hydrochar, a carbonaceous material, could be utilized as a value-added product. This study investigated the technical feasibility of hydrochar production by HTC of FS. Products from the HTC process, including the hydrochar as well as liquid and gas products, were analyzed to identify their physical and chemical characteristics with an emphasis on applicability. Treatment options to utilize the HTC product as value-added products and to minimize potential environmental impacts were evaluated.

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2. Materials and methods

2.1. FS samples and HTC reactor

FS, the accumulated sludge in septic tanks, cesspools and pit latrines, was collected from a municipal emptying truck that serviced residential areas in Pathumtani, located near Bangkok, Thailand. The moisture content of the collected FS samples, originally measuring approximately 95%wt, was adjusted to approximately 80%wt using water bath evaporation before feeding to the HTC reactor. A 1-L high-pressure HTC reactor made of stainless steel and equipped with a pressure gauge, thermocouple and gas collection ports, was used in this study (Fig. 1). An electric heater equipped with a control panel was used to adjust the temperature and reaction time of the HTC reactor.

2.2. HTC experiment

Each HTC experiment was performed in triplicate with 350 mL FS samples, operating conditions were controlled at temperatures of 250 °C and reaction time of 5 h. The pressure generated was monitored and recorded during HTC operation. After the desired temperatures and reaction times of each experiment were reached, the HTC reactor was quickly cooled using water in a cooling bucket at the cooling rate of 45 °C/minute to stop the reactions. After the HTC reactor was cooled to ambient temperature, the gas samples were collected. The carbonized FS remaining in the HTC reactor was separated into solid (hydrochar) and liquid products using vacuum filtration (Whatman filter paper, 1.2 μm). The produced hydrochar was subsequently dried in an oven at 105 °C for at least 12 h to remove the remaining moisture. The hydrochar and the liquid and gas samples were analyzed for their physical and chemical characteristics.

2.3. Analytical methods

Hydrochar samples were analyzed for energy content using a bomb calorimeter (AC500, Leco, USA), proximate analysis (moisture, volatile matter (VM), fixed carbon (FC), and ash contents) using a thermogravimetric analyzer (TGA701, Leco, USA), ultimate analysis (carbon, hydrogen, nitrogen, and sulfur) using a CHNS analyzer (Truspec, Leco, USA), and surface morphology using a scanning electron microscope (SEM) (S-3400N, Hitachi, Japan).

Porosity characteristics of the hydrochar samples were analyzed by nitrogen adsorption analysis at 77 K in a BELSORP-mini II volumetric adsorption analyzer (BEL Japan Inc., Japan). The adsorbents were degassed for 2 h at 378 K in vacuum condition to remove residual moisture. The specific surface area was analyzed using Brunauer-Emmett-Teller (BET) analysis with adsorption isotherm data in a relative pressure (p/p_0) range of 0.05–0.3. The pore size distribution analysis was done using the Barrett-Joyner-Halenda (BJH) model with the adsorption and desorption branches of the isotherm.

Liquid samples were analyzed for total organic carbon (TOC), chemical oxygen demand (COD), biochemical oxygen demand (BOD), total nitrogen (TN), total phosphorus (TP), phenol and volatile fatty acids (VFA) concentrations using the high temperature combustion method (TOC-V CPH, Shimadzu, Japan), closed dichromate reflux method, 5-day BOD test, persulfate method, colorimetric method, direct photometric method, and distillation method (APHA/AWWA/WEF, 2005), respectively.

Gas samples were analyzed for CO_2, CH_4, O_2, and N_2 using a gas chromatograph (GC 7890A, Agilent, USA) equipped with a flame ionization detector. H_2S and CO were measured using a Multitec 540 instrument with infrared sensors (Sewerin, Germany). Total volatile organic carbon (VOC) was measured with a VOC analyzer (MiniRAE 2000, RAE systems, USA).

3. Results and discussion

Through the HTC process, FS with high moisture content can be converted into value-added products such as hydrochar as well as liquid and gas products. Therefore, the HTC could be considered as a potential technology for treating FS and producing hydrochar for uses as solid fuels and other value-added products. HTC product characteristics and applications, which depend on process conditions, are explained in the following sections.

3.1. Hydrochar

The produced hydrochar was a solid with a brown color, insoluble in water, and easily pulverized into powder. The SEM images

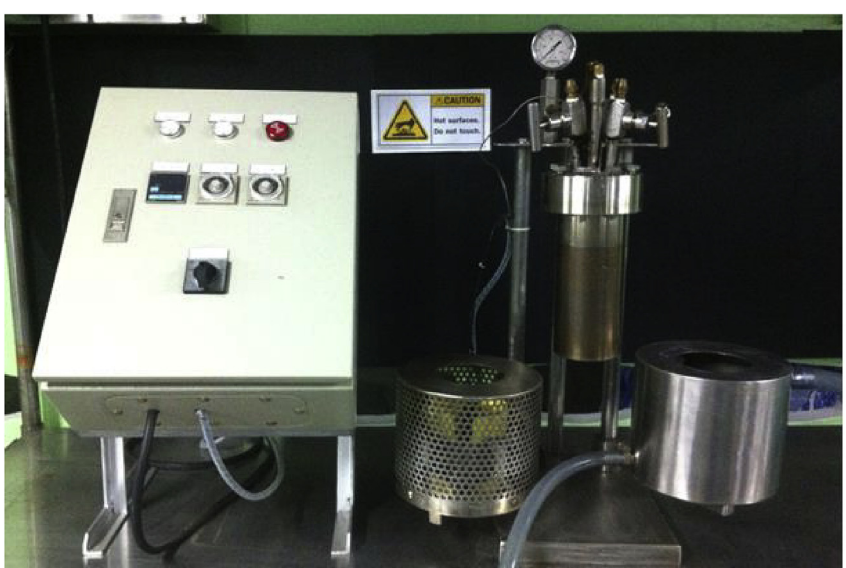

Fig. 1. Photograph of HTC reactor.

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