



Biohydrogen production from kitchen based vegetable waste: Effect of pyrolysis temperature and time on catalysed and non-catalysed operation



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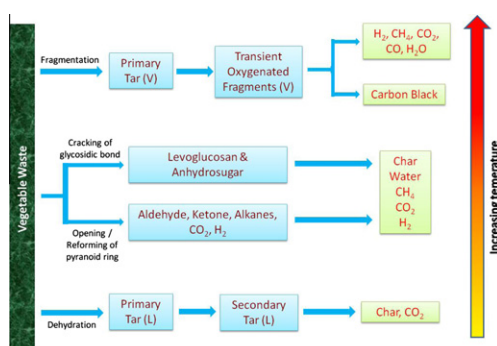
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HIGHLIGHTS

- ▶ High temperature favors high H₂ yield in vegetable waste pyrolysis.
- ▶ The catalyst presence reduced the CO₂ percentage in the bio-gas.
- ▶ Presence of sand as catalyst increases the methane yield considerably.
- ▶ Presence of silica based catalyst improves the calorific value of bio-gas.

GRAPHICAL ABSTRACT



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ABSTRACT

Pyrolysis of kitchen based vegetable waste (KVV) was studied in a designed packed bed reactor. The effect of process parameters like temperature, time and catalyst on bio-gas yield and its composition was studied. The total bio-gas yield was found to be maximum with non-catalysed operation (260 ml/g) at 1073 K (180 min). Higher hydrogen (H₂) yield with non-catalysed operation (32.68%) was observed at 1073 K (180 min) while with catalysed operation the requisite temperature (873 K) and time (120 min) reduced with both silica gel (33.34%) and sand (41.82%) thus, saving energy input. Methane (CH₄) yield was found to be highest (4.44 times than non-catalysed and 1.42 with silica gel) in presence of sand (71.485 ml/g) at medium temperature (873 K) and time (60 min). The catalyst operation reduced the carbon dioxide (CO₂) share from 47.29% to 41.30% (silica gel catalysed) and 21.91% (sand catalysed) at 873 K.

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1. Introduction

Rapid urbanization, industrialization and population growth have led to severe waste management problems in several cities of developing or under developed worlds. Due to uninterrupted relocation from rural and semi-urban areas to towns and cities the share of urban population has increased from 10.84% (1901

to 30.24% (March, 2012) in India (CPHEEO, 2000; MoSPI, 2012). The per capita waste generation rate depends on the size of the city (0.2–0.87 kg/d) (MoF, 2009). Municipal solid waste (MSW) has long posed threats to environmental quality and human health. Thus, the utilization of MSW for energy generation would suggest a solution of this problem (Singh et al., 2011). In India, most of the MSW is constituted of biomass (about 45–50%) waste generated in kitchens, agriculture, gardening, etc.

Hydrogen (H₂) is currently produced from natural gas, liquid hydrocarbons and coal by various chemical process like steam

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reformation (Trane et al., 2012), gasification (He et al., 2009) as well as by dark/photo fermentation processes, etc. (Srikanth et al., 2009; Venkata Mohan, 2009; Chandra and Venkata Mohan, 2011). Production of H₂ and other useful products by thermochemical treatment of waste biomass is an attractive alternative to fossil based route and has several advantages like reduced CO₂ emission, saving the cost of treating MSW, etc. (Balat, 2010). Even though anaerobic digestion was considered to be a matured process for the solid waste remediation, still there exist certain persistent limitations (Bouallagui et al., 2005; López Torres et al., 2008). Pyrolysis facilitates thermal decomposition of solid biomass at a temperature of 650–800 K at 1–5 bar in an inert atmosphere to yield gaseous compounds, oils and char. During pyrolysis, operating parameters such as particle size, temperature, heating rate, residence time and catalyst strongly affect the yield pattern and properties of products. These parameters can be regulated by selecting appropriate reactor types and heat transfer modes, such as gas–solid convective heat transfer and solid–solid conductive heat transfer (Saxena et al., 2008). Different types of wastes ranging from agricultural waste such as cotton cocoon shell (Demirbas, 2002), olive husk (Demirbas, 2002), switchgrass (Imam and Capareda, 2012), cassava plantation residue (Pattiya and Suttibak, 2012), corncob (Lu et al., 2011; Demiral et al., 2012), risk husk (Lu et al., 2011) to waste paper (Wu et al., 2003), forest biomass residues (Luik et al., 2007), wood waste (Phan et al., 2008), bark residue (Senoz, 2003), polymers (Singh et al., 2012; Mitan et al., 2008) and solid waste (He et al., 2010) have been used for pyrolysis. A considerable amount of work is done on catalysed pyrolysis of biomass with various types of catalysts, like, ZSM-5 (Bakar and Titiloye, 2012), K₂CO₃ (Barbooti et al., 2012), commercial NiMo/Al₂O₃ catalyst (Qinglan et al., 2010) and dolomite (He et al., 2010). In this context, kitchen vegetable waste (KVW) was considered as feed-stock for H₂ production and an attempt was made to elucidate the effect of pyrolysis temperature and retention time on the bio-gas production employing non-catalysed and catalysed pyrolysis. Silica gel and sand were used as catalyst in the catalysed pyrolysis. The biogas composition as a function of experimental variation was studied and discussed.

2. Methods

2.1. Experimental setup

The pyrolysis of KVW was conducted in a pyrolysis reactor designed and fabricated in the institute (Fig. 1). The set-up broadly consists of three parts: pyrolysis reactor, furnace and condenser. The length of the reactor was 18" (1" diameter; 3 mm thick; SS316) with one end welded to a 6 mm pipe (SS316) and the other to a 3 mm thick flange of 2" diameter (SS304). The former serves the inlet and the latter as outlet. The flange joints are closed by 1" bolts with an asbestos packing. The reactor was placed inside a furnace (16" × 4") with 14" heating zone insulated with glass wool through ceramic tube. Heating coil (3 KW) was wound around the ceramic tube. Inlet and outlets were connected to nitrogen cylinder and the ice-bath condenser, respectively. The ice-bath condenser was used to cool the gas produced and to separate the condensable gases.

2.2. Catalysts

Two types of catalysts viz., powdered silica gel (assay: 99.96%; 60–120 mesh; Himedia laboratories Ltd., India) and coarse sand (0.63–1 mm; acquired from construction site) were used in the experiments. The most common constituent of sand is silica in form of quartz. This is because of its chemical inertness, hardness and resistant to weathering.

2.3. Feed stock

The feedstock viz., KVW used for pyrolysis experiment was collected from institute canteen, CSIR-IICT. It was composed of peelings and choppings of raw vegetables and fruits. Prior to use KVW was dried under direct sun light for three days to remove the unbound moisture content. 10 g of shredded KVW was loaded for each experiment packed in between glass wool (Fig. 1).

2.4. Experimental methodology

The effect of pyrolysis temperature, retention time and catalysts on pyrolysis of KVW was evaluated employing the following experimental methodology. Each of the experiment was performed twice and the average figures were presented.

2.4.1. Non-catalysed pyrolysis

The non-catalysed pyrolysis experiments were carried out in nitrogen rich atmosphere in a pyrolysis reactor on batch mode basis. A fixed amount of dry waste KVW (10 g) sample was packed in the reactor and purged with pure nitrogen for two minutes. The reactor with the waste was then heated at a rate of 12 K/min. The decomposition of KVW was evaluated at various temperatures (673 K, 773 K, 873 K and 1073 K) and retention time (60 min, 120 min and 180 min). The volatile substances evolved during pyrolysis were passed through ice-bath condenser to separate the condensable gases from the non-condensable ones.

2.4.2. Catalysed pyrolysis

The catalysed pyrolysis experiments were carried out in nitrogen rich atmosphere in a pyrolysis reactor on a batch mode basis. A fixed amount of dry KVW (10 g) was mixed with silica-gel/sand catalyst (10% wt. basis) and packed in the reactor. Subsequently, the reactor was purged with pure nitrogen gas (99%) for two minutes and then heated at a rate of 12 K/min. The decomposition of KVW was studied at various temperatures (673 K, 773 K and 873 K) and retention time (30 min, 60 min and 120 min). The volatile substances evolved during the pyrolysis were passed through ice-bath condenser to separate the condensable gases from the non-condensable ones.

2.5. Analysis

The volume of bio-gas evolved from pyrolysis was measured through water displacement technique whenever required. The compositional analysis of bio-gas was evaluated by gas chromatograph (NUCON 5765) using thermal conductivity detector (TCD) with 1/8" × 2 m Heysep Q column employing nitrogen as carrier gas. The injector and detector were maintained at 60 °C each and the oven was operated at 40 °C isothermally. The bio-gas was quantified with the calibration gas supplied by Spangas & Equipments Ltd., Navi Mumbai, India. The ultimate analysis and volatile matter content of KVW were estimated using CHNS analyser (Vario Micro Cube) and thermo-gravimetric analyser (TGA; Mettler Toledo TGA/SDTA 851^e) respectively.

2.6. Principal component analysis (PCA)

The XLSOFT software was used for the analysis and evaluation of the data which generates observation plots and biplots in MS excel. The pyrolysis temperature and time were set as variables, while the two catalysts and one non-catalysed pyrolysis were set as samples.

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