Bioresource Technology 102 (2011) 10441–10450

Contents lists available at SciVerse ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Integrated generation of solid fuel and biogas from green cut material from landscape conservation and private households

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ARTICLE INFO

Article history:
Received 20 May 2011
Received in revised form 22 August 2011
Accepted 29 August 2011
Available online 8 September 2011

Keywords:
Bioenergy
Biomass
Energy balances
Combustion
Waste

ABSTRACT

Green cut material is a potential source of renewable energy which is not fully exploited through conventional energy recovery systems. A new energy conversion process, the integrated generation of solid fuel and biogas from biomass (IFBB), which includes mechanical separation after hydro-thermal conditioning, was investigated. Ash softening temperature and lower heating value of the solid fuel were increased through the IFFB process in comparison to the untreated raw material. The net energy yield of IFBB at 40 °C conditioning temperature ranged between 1.96 and 2.85 kWh kg^{-1} dry matter (DM) and for the direct combustion between 1.75 and 2.65 kWh kg^{-1} DM. Conversion efficiencies for the IFBB system were 0.42–0.68 and for direct combustion 0.42–0.63. The IFBB system produces storable energy from material which is nowadays not used for energy conversion.

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1. Introduction

In order to reduce anthropogenic climate gas emissions and thus to act against the global climate change, the European Union has enacted the European Biomass Action plan to oblige its member states to reach specific amounts of renewable energy production (Anonymous, 2009). The European Union committed to produce 20% of its total primary consumption from renewable energy sources by the year 2020. Besides wind and solar energy, biomass is a major source of renewable energy, which is still not fully exploited. The intensified use of biomass from arable crops is limited as the cultivation of bioenergy crops requires agricultural land which leads to competition between food and bioenergy production (Johansson and Azar, 2007; Hoogwijk et al., 2003; Bergsma et al., 2007), eventually resulting in higher prices for food. From an ecological point of view, cultivation of energy crops is controversial. The use of agricultural crops for biofuel production can lead to higher climate gas emissions (Crutzen et al., 2008) and higher negative ecological impacts (Zah et al., 2007) than the use of fossil fuels. Due to the negative impacts of agricultural crops it was proposed to enhance the use of waste products to increase renewable energy production (Zah et al., 2007). Waste products can be industrial or agricultural residual products such as material from landscape conservation measures, road cut and railway cut as well as driftwood (Kern et al., 2010) or material from households, like kitchen residues and garden cuts. Up to now this material is mostly used to produce compost (Anonymous, 2008), which helps to close nutrient cycles and improves soil quality, but is also an energy requiring process (Edelmann and Schleiss, 2001). However, herbaceous biomass and especially green cut is a problematic material for energy production, as it is extremely heterogeneous (Hartmann, 2009), leading to difficulties in common ways of energy recovery from biomass, i.e. anaerobic digestion and combustion. Compared to wood, which is the most common solid biofuel, herbaceous materials contain more nitrogen (N), sulfur (S), chlorine (Cl), calcium (Ca), magnesium (Mg) and potassium (K) (Obernberger et al., 2006). As most of the N contained in fuels is converted into N_2 and NO_x, high N contents lead to increased NO_x emissions (Van Loo and Koppejan, 2008). High S and Cl contents lead to emissions as SO_2, HCl and cause corrosion problems, thus reducing the availability and lifetime of the combustion plant (Obernberger et al., 2006). High Cl contents can lead to increasing emissions of polychlorinated dibenzodioxins (PCDD) and polychlorinated dibenzofurans (PCDF) (Obernberger et al., 2006). K is also involved in corrosion processes in the furnace and leads to low ash melting temperatures, which in turn lead to slagging and fouling inside the combustion chamber (Van Loo and Koppejan, 2008).

Abbreviations: IFBB, integrated generation of solid fuel and biogas from biomass; DM, dry matter; PF, press fluid; PC, press cake; RM, raw material; RMC, raw material after conditioning; MF, mass flow; LHV, lower heating value; AST, ash softening temperature; DC, direct combustion; VS, volatile solids; AD, anaerobic digestion.

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0960-8524/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.biortech.2011.08.119

As green cut usually consists partly of wood and shrub material, it can be expected to be highly lignified. It is well known that anaerobic digestion of lignified material leads to low methane yields and conversion efficiencies (Shiralipour and Smith, 1984; Richter et al., 2009).

The University of Kassel has developed a system for energy production from heterogeneous and senescent plant material, the integrated generation of solid fuel and biogas from biomass (IFBB; Wachendorf et al., 2009). Its main principle is to subject biomass to hydrothermal conditioning and subsequent dehydration using a screw press, which results in a press fluid for biogas production and a press cake for combustion as solid fuel. Drying of the press cake with the waste heat from the biogas combustion is a key aspect of this procedure. This system is capable to produce energy from biomass of extensive grasslands, which causes difficulties in traditional anaerobic digestion or direct combustion as hay (Richter et al., 2009, 2010). The IFBB technique produces a storable solid fuel with improved combustion qualities and an easily digestible press fluid with high methane yields.

The aim of this study is to test the feasibility of the IFBB process to obtain renewable energy from green cut. Therefore, the objective was to investigate (i) the methane yield of press fluids from green cut and (ii) the quality of solid fuels from green cut, considering nutrient and mineral content, ash softening temperature and heating value and (iii) the energy balance of the IFBB system in comparison to direct combustion of green cut.

2. Methods

The green cut material used in this study was collected at the composting facility of the city of Baden–Baden with an annual amount of green cut of about 3200 Mg DM. Baden–Baden is a town in the south-western part of Germany with 53,260 inhabitants and has extended sanatorium and spa facilities with high amounts of green cut from parks and private gardens.

2.1. Separation chopping and ensiling of raw material

Since green cut is heterogeneous, the material was sorted into four fractions: herbaceous, shrub, wood and soil material (Fig. 1). The soil fraction was used for conventional composting, and larger wood pieces were chopped and used for combustion. Therefore only herbaceous material and shrub cuttings were processed according to the IFBB approach. The shrub fraction, containing smaller wood, branches, roots, leaves and small amounts of grass, was chopped (Willibald SR5000, Willibald Ltd., Wald–Sentenhart, Germany) to a particle length of 5–10 cm and milled with a hammer mill using a 20 × 20 mm sieve (B. Maier Zerkleinerungstechnik Ltd., Bielefeld, Germany) prior to ensiling. The herbaceous material, containing grass, leaves, hay, straw, fine hedge cut, lawn cut and small amounts of wood, was directly chopped and ensiled. The comminuted material was compacted and closed air tight in 50 l polyethylene barrels. The herbaceous and the shrub material were ensiled both in pure non-mixed fractions (S0 and S100, respectively) and in mixtures containing 0.33, 0.50 and 0.67 of shrub-fraction (S33, S50 and S67, respectively). Samples were taken at two dates, 26.08.2008 and 31.10.2008, for all fractions and mixtures (S0, S33, S50, S67, S100). The ensiling should provide a secure conservation of the raw material without losses due to decomposition processes. As an accessory benefit, the low pH and the activity of bacteria during the ensiling process should enhance the disintegration of the plant material and thereby promote the later use in the process by enhancing the massflow (MF) of minerals and nutrients into the press fluid (PF).

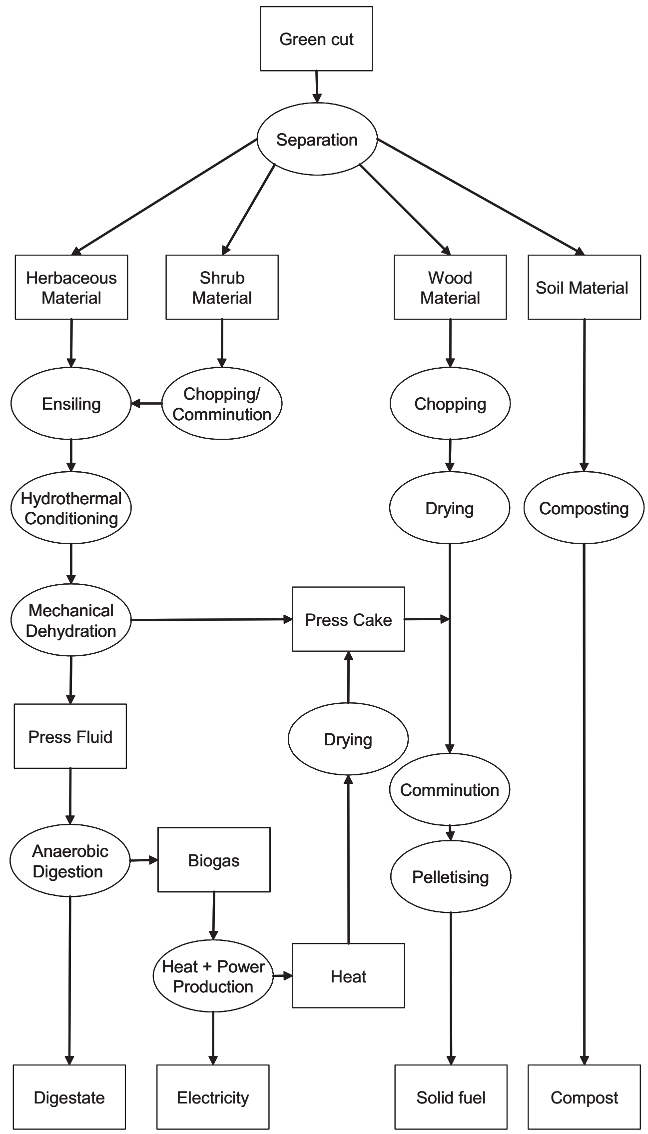

Fig. 1. Flow chart of separation and processing of green cut material as applied in this study.

2.1.1. Hydrothermal conditioning and mechanical dehydration

After ensiling, the samples went through a hydrothermal conditioning process. Two process temperatures, 40 and 60 °C, were investigated. The hydrothermal conditioning took place in a modified concrete mixer, which was filled with raw material (RM) and water in a proportion of 1:4 (RM:water). The material was heated by gas burners and continuously stirred for 15 min, followed by mechanical dehydration using a screw-press (Type Av, Anhydro Ltd., Kassel, Germany). The conical screw had a pitch of 1:6, the rotational speed was 6 revolutions min^{-1} and the cylindrical screen encapsulating the screw had a perforation of 1.5 mm.

Samples of RM before and after conditioning, PF and press cake (PC) were analyzed for DM content after 48 h drying at 105 °C. Crude ash was determined through burning of an aliquot of the same sample in a muffle type oven at 550 °C.

2.2. Chemical analyses and mass flow calculation

Concentrations of potassium (K), magnesium (Mg), calcium (Ca), chlorine (Cl) and sulfur (S) in RM and PC were determined by X-ray fluorescence-analysis. The concentration of carbon (C),

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