Available online at www.sciencedirect.com
ScienceDirect
Fuel 87 (2008) 1492–1502
FUEL
www.fuelfirst.com

Rapeseed residues utilization for energy and 2nd generation biofuels

A. Zabaniotou *, O. Ioannidou, V. Skoulou

Chemical Engineering Department, Aristotle University of Thessaloniki, Un. Box 455, 54124 Thessaloniki, Greece

Received 24 June 2007; received in revised form 28 August 2007; accepted 4 September 2007
Available online 29 September 2007

Abstract

Lignocellulosic biomass is an interesting and necessary enlargement of the biomass used for the production of renewable biofuels. It is expected that second generation biofuels are more energy efficient than the ones of first generation, as a substrate that is able to completely transformed into energy. The present study is part of a research program aiming at the integrated utilization of rapeseed suitable to Greek conditions for biodiesel production and parallel use of its solid residues for energy and second generation biofuels production. In that context, fast pyrolysis at high temperature and fixed bed air gasification of the rapeseed residues were studied. Thermogravimetric analysis and kinetic study were also carried out. The obtained results indicated that high temperature pyrolysis could produces higher yields of syngas and hydrogen production comparing to air fixed bed gasification.

Keywords: Rapeseed residues; Biofuels; Pyrolysis; Gasification; Kinetics

1. Introduction

Directive 2003/30/EC of the European Parliament and the Council of 8 May 2003 aims at promoting the use of biofuels or other renewable fuels to replace diesel or gasoline for transport in each Member State, with a view to contributing to objectives such as meeting climate change commitments, as well as promoting environmental-friendly security of supply and renewable energy sources. In this context, Member States should ensure that a minimum share of biofuels or other renewable fuels is placed on their markets and, to that effect, they shall set national indicative targets.

However, the first generation biofuels seem to create some scepticism to scientists. There are concerns about environmental impacts and carbon balances, which set limits in the increasing production of *biofuels of 1st generation*. Additionally, both biodiesel and bioethanol are expensive options for climate mitigation as compared to biomass for heat and power generation.

Bomb et al. [1] claimed that environmental impacts associated with energy crops require sustained investigation since the environmental impacts and carbon balances of biofuels depend on feedstocks and the way they are farmed, processed and distributed. *Biodiesel* and *bioethanol* in the EU has been calculated to result in 15–70% greenhouse gas savings when compared to fossil fuels [2], while bioethanol from Brazil results in over 90% greenhouse gas savings [3].

Frondel et al. [4] based on a survey of recent empirical studies, found that the energy and greenhouse gas balances of *rapeseed-based biodiesel* is clearly positive but it appears to be unclear whether the overall environmental balance is also positive. Additionally, they claimed that biodiesel is not a cost-efficient emission abatement strategy. Thus, for the abatement of greenhouse gases, they recommend more efficient alternatives based on both renewable and conventional technologies.

Besides, the agricultural rapeseed production capacities for example in Germany, which is the country with the highest rapeseed production, are almost exhausted

* Corresponding author. Tel.: +30 2310 99 62 74; fax: +30 2310 99 62 09.
E-mail address: sonia@cheng.auth.gr (A. Zabaniotou).

0016-2361/$ - see front matter
doi:10.1016/j.fuel.2007.09.003

according to Bockey et al. [5]. During the recent years, Germany and Austria have been leading in the substitution of diesel with biodiesel and rapeseed-oil biofuels, while France, Spain and Sweden mainly substitute petrol with bioethanol. The market penetration of biofuels additionally has been driven by increasing costs for crude oil and fossil fuels. However, the increasing production clearly shows its first limits. In Germany, during 2005, about 1 million of hectares were used for the cultivation of rapeseed for the production of biodiesel [6]. To a certain extend the increasing demand may be satisfied by importing feedstock or biodiesel but, in the long term, it is necessary to enhance the diversity of raw materials [6].

Therefore, it seems that energy crops are technically possible but that no single solution exists to cover every situation [7], pointed out that from a wider viewpoint, choices must maximize income, yield, quality characteristics, energy and technical tool savings, manpower, effects on soil, air and environment both at local and regional levels. In order to balance the cost of crops to biofuels options, it seems obvious that an aspect, which must be studied with particular care, is the economic exploitation of energy crops by-products determined by multi-functionality of many species [7] Electricity generation on the basis of crop residues for example, might be a relatively cheaper alternative in terms of abatement cost and an alternative income [4].

It seems then evident that an understanding of the relationship between production of grain and production of the biomass feedstock is important to support the emerging bioenergy technologies. Hoskinson et al. [8] have used a model – the DSS4Ag – in order to begin to understand the relationship between the production of grain and the production of biofeedstock, from the standpoint of the economics of simultaneously producing both. Many other computer models of bioenergy systems have been, also, developed. But none of them considered the economics of simultaneous production of an agricultural crop and its crop residue biomass.

Summarising, it is obvious that:

(1) Besides the biofuels derived from oil crops, grain and sugar crops, which are commonly called biofuels of the 1st generation, lignocellulosic feedstock can offer the potential to provide novel biofuels, the *biofuels of the second generation* (Table 1).
(2) *Electricity generation* on the basis of crop residues, might be a relatively cheap alternative in terms of abatement costs and an additional alternative income source and employment support measure for the agricultural sector.

In that respect, the present study being part of a research program aiming at the integrated utilization of rapeseed into Greece, attempting to contribute in the above problematic for the biodiesel production and parallel use of the residues for energy and 2nd generation biofuels production. Experiments that took place in Mediterranean region (Greece, Italy, Spain) under the EU program during the last decades showed positive results [9]. In Greece, rapeseed can be cultivated as a winter or spring annual crop and at the moment, its cultivation has been conducted on experimental and demonstration scale, with the first attempt of cultivation at real farmer's level through the proposed research program. The ability to grow at low temperatures, compared to the other oleiferous crops grown in Greece, is the most important feature of rapeseed cultivation.

Table 1
First and second generation biofuels from biomass

First generation biofuels		Second generation biofuels	
Type	Method-Source	Type	Method-Source
Bioethanol	Conventional	Bioethenol	Lignocellulosic
Biodiesel (FAME/FAEE)	From energy crops	BTL	Lignocellulosic
	From waste	Methanol	Synthetic fuels
Pure vegetable oils	Cold pressed	DME	Lignocellulosic
Biogas	Conventional	Biodiesel	NExBTL
Bio-ETBE	From energy crops	Biohydrogen	Lignocellulosic

The present research was conducted towards thermochemical conversion of rapeseed residues by means of high temperature pyrolysis and gasification for the production of a gas suitable for further energy production exploitation or syngas production for second generation biofuels production. Thermogravimetric analysis was also carried out for kinetic purposes.

2. Thermochemical conversion

There are two basic procedures to transform solid biomass into liquid or gaseous biofuels for the second generation biofuels production (Fig. 1). One aims at the thermochemical conversion of the total biomass into a high calorific value synthesis gas with subsequent production of various liquid and gaseous fuels. The other is to transform

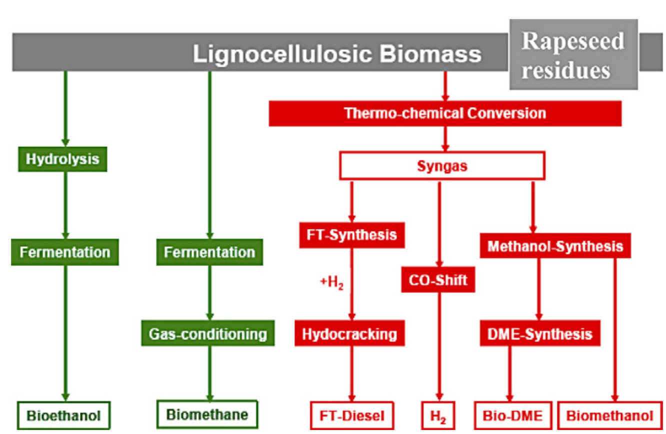

Fig. 1. Biofuels production from lignocellulosic feedstock.