Fuel Processing Technology 130 (2015) 20–30

Contents lists available at ScienceDirect

Fuel Processing Technology

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

Effect of fatty acid composition in vegetable oils on combustion processes in an emulsion burner

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ARTICLE INFO

Article history:
Received 30 June 2014
Received in revised form 24 September 2014
Accepted 27 September 2014
Available online 12 October 2014

Keywords:
Fatty acid composition
Vegetable oils
Combustion
Emulsion burner

ABSTRACT

The use of vegetable oils as a fuel in burners is an alternative which offers certain advantages over the use of vegetable oils in engines. The present work explores the use of four oils: rapeseed, sunflower, soya, and a commercial mixture-seed as heating fuel oil (HFO). The article relates the composition of the fatty acids in the various vegetable oils to the combustion products obtained in an emulsion burner. The work has been carried out in three stages. Firstly, describing the use of vegetable oils as a fuel and determining the fatty acid composition by proton NMR. Secondly, combustion of the vegetable oils studied is performed using an emulsion burner, varying the burner adjustments, and analysing combustion gases. Thirdly, exploring the link between the fatty acids contained in each oil and the combustion efficiency and combustion gas concentration for each oil type. Due to the fatty acids they contain, not all the oils behave equally, even though their description as fuels is very similar.

1. Introduction

Through directive 2009/28/EC, the European parliament target for 2020 is for 20% of final energy to be renewable [1]. According to this directive, biomass is the renewable energy which most contributes to achieving this goal. The Commission considers three principles which all European policies on biomass sustainability must adhere to:

- Efficiently addressing problems affecting the sustainable use of biomass.
- Economic efficiency when pursuing the goals.
- Consistency in other existing policies.

The use of vegetable oils as alternatives to fossil based liquid fuels enables the sustainable use of biomass and is fully efficient in economic terms as it requires no investment. Oil is extracted in existing plants and combustion is performed in conventional facilities, which proves consistent with other policies such as the Common Agricultural Policy (CAP) and rural development laws.

Vegetable oils are considered to be bioliquids since they are liquid fuels obtained from agricultural products, animal fats, and marine plants. Broadly speaking, a bioliquid is any liquid which may be used in a power plant in place of fossil fuels [2].

Numerous studies have investigated biomass combustion and bioliquid combustion. Prominent amongst these are the study by Obermberger who conducted a thorough review of the technologies linked to each type of biomass for its use in heating [3], the studies carried out into co-combustion [4] at the Research Centre for Energy Resources and Consumption (CIRCE) at the University of Zaragoza, and the reference review carried out by Spliethoff [5].

Other works exploring the use of biomass for heating purposes include Batey [6] on biodiesel combustion and mixtures of oil and diesel in residential combustion facilities, Vanlaningham [7] who studies the combustion of soya seed oil for heating, and San José Alonso [8] who analyses the combustion of mixtures of soya, rapeseed, and sunflower oils with diesel in different proportions and with different combustion parameters in a pressure pulverisation burner. The latter author also studies the combustion of biodiesel which does not meet the specifications to be a biofuel [9], and the combustion of mixtures of biodiesel/gasoil as a fuel in a domestic 26.7 kW burner [10].

A number of comparative studies analysing the efficiency and combustion emissions of biodiesel and vegetable oils has been conducted by professor Afshin Ghorbani at the Petroleum University of Technology in Iran [11,12]. Other prominent works include those of Bemtgen, exploring combinations in biomass combustion and fossil fuels [13], and Tizane Daho [14] who researches optimisation of atomisation and granulometry in a modified burner.

If a combustion process is to prove optimal, it is important to know the physical characteristics (density, viscosity, etc) and composition of the fatty acids of the oils to be used. Analysing the chemical composition of the oils allows the stoichiometry of the combustion process to be established, and permits the stability and reactivity of these biofuels to be estimated, enabling measures to be taken to prevent the formation of deposits, corrosion or obstruction of parts of the burner, thereby enhancing the operability and durability of the combustion system.

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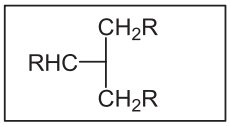
http://dx.doi.org/10.1016/j.fuproc.2014.09.036
0378-3820/

Table 1
Physical and chemical characteristics of VRO, VSO, RSfO, and RSO.

	Unit	Test method	VRO	VSO	RSfO	RSO
Density at 15 °C	kg/m^3	ISO 3675	922.0	911.6	922.4	922.4
Density at 35 °C	kg/m^3	ISO 3675	908.5	898.3	908.9	908.8
Density at 60 °C	kg/m^3	ISO 3675	891.7	880.8	892.0	892.0
Kinematic viscosity at 40 °C	mm^2/s	ISO 3104	36.78	20.02	32.84	32.82
Kinematic viscosity at 100 °C	mm^2/s	ISO 3104	8.05	5.27	7.6	7.71
C (%)	kg/kg	ASTM 1552	77.1	78.2	077.6	77.5
H (%)	kg/kg	ASTM 5291	11.5	11.7	11.4	11.4
N (%)	kg/kg	ASTM 5291	<0.05	<0.05	<0.05	<0.05
S (%)	kg/kg	ASTM 1744	0.06	0.05	0,36	0,28
O (%)	kg/kg	ASTM 240	11.3	10.0	10.6	10.8
Ashes (%)	kg/kg	ASTM 240	0.023	0.027	0.01	0.006
Water (ppm)	mg/kg	ASTM 240	589	470	337	298
H.H.V.	kJ/kg	ASTM 5291	2,239.2	2,276.6	2,255.3	2,258.4
L.H.V.	kJ/kg	ASTM 5291	2,099.8	2,134.7	2,117.0	2,120.1



R = R_1, R_2, R_3 or R_4

R_1 = saturated acyl groups (S): -O-CO-$CH_2(CH_2)_nCH_3$ (n = 14 or 16, palmitic or stearic acyl groups respectively)
R_2 = oleic acyl group (O): -O-CO-$CH_2(CH_2)_7CH{=}CH(CH_2)_7CH_3$
R_3 = linoleic acyl group (L): -O-CO-$CH_2(CH_2)_7CH{=}CHCH_2CH{=}CH(CH_2)_4CH_3$
R_4 = linolenic acyl group (Ln): -O-CO-$CH_2(CH_2)_7CH{=}CHCH_2CH{=}CHCH_2CH{=}CHCH_2CH_3$

Fig. 1. Representative structure of vegetable oil with the most common acyl groups in a TAG.

Bazzooyar [15] studies oil coking problems in the cooler parts of the combustion chamber due to thermal decomposition and polymerisation under certain temperature conditions.

The present article seeks to determine the fatty acid composition of four vegetable oils (virgin soybean, virgin rapeseed, refined sunflower, and refined mixture-seed [16] oils) and to study their relationship with energy efficiency and gas emissions in a combustion process. For this purpose, a facility equipped with an emulsion pulverisation burner and a combustion chamber which operates under stationary conditions has been used.

2. Describing vegetable oils as bioliquids

Physical and chemical characterisation of oils is useful for: a) the stoichiometric study of combustion, which enables the air-flow and flue gas per unit of bioliquid mass to be determined and excess air in combustion to be established, b) gauging the energy efficiency of the bioliquid combustion to be studied in terms of its Lower Heating Values (LHV), and c) establishing the pulverisation/vaporisation mechanism to be used depending on the viscosity and density of the bioliquid.

Table 1 specifies the test method and the equivalent international regulations together with the values obtained at the Castille and Leon Regional Fuel Laboratory (LARECOM) for the following oils: virgin rapeseed oil (VRO), virgin soybean oil (VSO), refined sunflower oil (RSfO), and refined seed oil (RSO).

As is well known, oils are basically comprised of triglycerides (TAGs) with different substitution patterns, lengths, and saturation degrees of the chains, as well as other minor components. The major fatty acids present in triacylglycerols from oils are unsaturated oleic, linoleic, and linolenic acids, followed by saturated acids, mainly palmitic and stearic

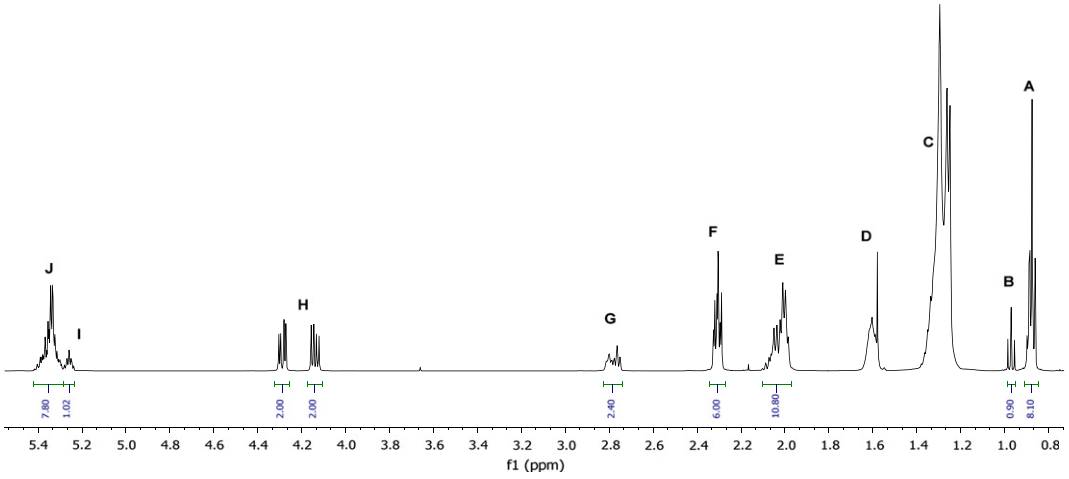


Fig. 2. 1H NMR spectra of an oil sample containing a known trilinolenin, trilinolein, triolein and tristearin mixture (10:20:60:10). Integration values are indicated under each signal (500 MHz, 8 scans, 90 degrees, 25 s relaxation delay, CDCl3).