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Comparison between physical properties and chemical composition of bio-oils derived from lignocellulose and triglyceride sources

T. Stedile [a], L. Ender [a], H.F. Meier [a], E.L. Simionatto [b], V.R Wiggers [a,*]

[a] Chemical Engineering Department, Regional University of Blumenau (FURB), Blumenau, SC, Brazil
[b] Chemistry Department, Regional University of Blumenau (FURB), Blumenau, SC, Brazil

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ABSTRACT

Biomass can be used in the production of alternative liquid fuels and other chemicals through the pyrolysis process. The types of biomass used to obtain bio-oils can be divided into two main groups: lignocelluloses (LCs) and triacylglycerols (TAGs). However, although the liquid fraction obtained from the pyrolysis of these biomasses has different physical and chemical properties, the distinction between them is not yet clear in the literature. In this context, the main goal of this paper is to provide a summary of several research studies dealing with the measurement of the physicochemical properties of a range of bio-oils obtained from biomass based on lignocellulose and triglyceride sources. The aim is to shed light on the main differences between these two types of bio-oil in order to highlight their most appropriate applications as fuels or chemical precursors, by providing a comprehensive review on their physical and chemical properties.

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* Corresponding author.
E-mail address: vwiggers@furb.br (V. Wiggers).

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1. Introduction

Currently, with increasing environmental concerns, biomass is considered to be a promising resource for the production of biofuels as an alternative source of energy [1].

Biomass sources that can be used as feedstock for the production of biofuels cover a wide range of materials such as plant matter (including agricultural crops and residues), animal waste, municipal waste and industrial effluents [2]. Biomass has insignificant contents of sulfur and nitrogen, leading to lower emissions of SO_2 and NO_x than in the case of conventional fossil fuels. Also, since the CO_2 can be recycled by plants through photosynthesis, quantitatively, the net emission of CO_2 is zero [3].

The large-scale production of agriculture products, forestry products and livestock occurs in many countries. For instance, in Brazil, the production of nine cultures (sugarcane, soybean, rice, maize, cotton, orange, wheat, cassava and tobacco) was 895.59 million tonnes in 2009/2010. This is associated with the generation of 405.47 million tonnes of residues. In the same period, the level of livestock (poultry, swine and bovine) production was 22.88 million tonnes with the generation of 19.11 million tonnes of animal waste [4]. Forest harvesting and the wood processing industry produce around 41 million tons of timber waste annually [5]. The production of vegetable oil was 8.93 million tonnes in 2012 [6]. Thus, in Brazil, residues generated from biomass represent a great potential source of raw materials for energy production to replace the fossil fuels and address the issue of climate change.

Several different technical processes can be used to convert biomass into various forms of energy depending on the raw material characteristics and the type of energy required. Thus, a wide variety of conversion schemes have been developed to produce liquid fuels. Pyrolysis is one of the methods through which fuels and other chemicals can be produced from biomass materials. The liquid products, known as bio-oils, have been regarded as promising candidates to replace petroleum fuels for power generation, heat and the extraction of valuable chemicals [7].

Pyrolysis is an age-old technology which involves the thermal decomposition of biomass by heat in the absence of oxygen and, in some cases, in the presence of a catalyst, which results in the production of charcoal (solid), bio-oil (liquid) and gaseous fuel products [2,8]. The yield and properties of the product formed are strongly affected by process parameters such as the pyrolysis reactor design, reaction parameters (temperature, heating rate, residence time, pressure and catalyst) and biomass type and characteristics (particle size, shape and structure) [9]. Different reactions occur in the pyrolysis process according to the type of biomass used, which leads to a complex variation in the composition and properties of the bio-oils produced [10].

The direct substitution of petroleum fuels and chemical feedstocks with bio-oil is not possible due to the high viscosity, high water and ash contents, low heating value, instability and high corrosiveness of bio-oil. Consequently, bio-oil needs to be upgraded prior to its use as a liquid fuel or chemical feedstock [1,7], a process which is hindered by the complexity of the bio-oil composition [1]. There are several reviews on the upgrading of bio-oil and various technologies have been developed for this purpose [1,3,7,11–13].

The characterization of bio-oil is important for defining design parameters, developing kinetic models, scaling up and decision making related to the production of byproducts and upgrading [1,14]. Many research studies have addressed the conversion of various types of biomass into bio-oil, but a clear distinction between the differences in the physicochemical characteristics of these bio-oils is not provided in the literature. This article comprehensively reviews the differences between the bio-oils obtained from lignocellulosic and triglyceride biomass sources.

2. Biomass: Source type and composition

Biomass can generally be defined as any hydrocarbon material which mainly consists of carbon, hydrogen, oxygen and nitrogen, although sulfur is also present in lesser proportions. Inorganic species can also be present in significant proportions in some types of biomass. Biomass resources include various natural and derived materials, such as wooden and herbaceous species, wood wastes, bagasse, agricultural and industrial residues, waste paper, municipal solid waste, sawdust, biosolids, grass, waste from food processing, animal wastes, aquatic plants (including algae) [15], vegetable oils, animal fats and other waste materials [16].

It is possible to divide the types of biomass used for the production of bio-oil into two main groups: lignocellulose (LC) and triacylglycerol (TAG) sources. The liquid fraction obtained in both cases is called bio-oil, but the products present differences in terms of their physical properties and chemical composition [17].

2.1. Lignocelluloses (LC)

The chemical structure and major organic components in biomass are extremely important in the development of processes for producing fuels and chemicals. The major organic components of biomass can be classified as cellulose, hemicellulose and lignin, in addition to extractives (tannins, fatty acids and resins) and inorganic salts [15,18,19]. Typical lignocellulose biomass contains around 40–47 wt% cellulose, 25–35 wt% hemicellulose and 16–31 wt% lignin and the content of each component varies with the type of biomass [18]. Lignocellulose biomass used to obtain bio-oil can originate from forests, crops and industrial wastes, which are attractive mainly because of the low cost of the raw materials [10].

Plants convert carbon dioxide and water into primary and secondary metabolite biochemicals, through the photosynthesis process. Primary metabolites are carbohydrates (simple sugars, cellulose, hemicellulose, starch, etc.) and lignin (known as lignocellulose), which are present in high volumes in biomass. This lignocellulosic biomass can be converted into biofuels. The secondary metabolites are biochemicals of high value, such as gums, resins, rubber, waxes terpenes, terpenoids, steroids, triglyceride, tannin, plant acids and alkaloids, which are present in low volumes in the plants. They can be used in the production of high value chemicals, such as food flavors, pharmaceuticals, cosmeceuticals, and nutraceuticals, applying integrated processing techniques [8].

A bio-oil obtained from a lignocellulosic biomass typically has a high oxygen content and a low H/C ratio. The compounds and physical properties of a bio-oil are mostly dependent on the type of biomass used and the severity of the process. There are three major families of compounds: (i) small carbonyl compounds, such as acetic acid, acetaldehyde, acetone, hydroxyaldehydes, hydroxyketones, and carboxylic acids; (ii) sugar-derived compounds, such as furfural, levoglucosan, anhydrosugars, furan/pyran ring-containing compounds; and (iii) lignin-derived compounds, which are mainly phenols and guaiacols. Oligomers with molecular mass ranging from 900 to 2500 are also found in significant amounts [18].

The degradation of cellulose takes place via two pathways: one leads directly to certain small molecular products, such as furan, levoglucosan, glycolaldehyde and hydroxyl acetone, while in the other oligomers with a low degree of polymerization (DP) are formed. The oligomers with a low DP can be broken down further to form furan, light oxygenates, char, permanent gases, and