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Research article

Development and validation of new methods for identification of bio-char as an alternative solid bio-fuel for power generation

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ABSTRACT

The aim of this study was to develop and validate a new rapid method for the qualitative analysis of solid biofuels obtained from a thermal treatment process. A new method for the qualitative confirmation of the second-generation solid bio-fuel origin was compared and assessed. The new method was compared with a method based on the concentration of ^{14}C carbon isotope in the studied material obtained from thermal conversion of a biomass. The developed method is intended to analyse the origin of the second-generation solid bio-fuels and is based on basic analytical fuel properties commonly measured in most laboratories. The process couples chemometric methods with proximate and ultimate analyses, heat of combustion and chemical composition of ash from second-generation solid bio-fuels.

In light of the current European regulations, the second-generation bio-fuels obtained by the thermal conversion of biomass, e.g., bio-chars or torrefied biomass, are not classified as biomass. Consequently, the energy generated by these biofuels is not classified as energy generated from a renewable energy source. The currently available method, i.e., analysis of the ^{14}C content in samples of interest, might not be sufficiently sensitive to characterise materials from the co-pyrolysis of biomass and non-biodegradable material. Prompted by this situation, a new method for the qualitative confirmation of the second-generation solid bio-fuel origin was proposed. The BioFuel Classifier for Power Generation (BFC-PowerGen) provides a rapid and accurate determination of the origin of a fuel and can be used for controlling the quality of fuel derived from the thermal conversion of biomass. This new classifier, which is based on a classification and regression tree model, delivers a classification accuracy of at least 96%.

1. Introduction

There has been increased interest in the development of solutions or systems that can produce valorised biomass fuels, i.e., torrefied biomass or bio-char, with desirable energy properties. Unfortunately, the current regulations regarding the qualifications of biomass for energy purposes are challenging for small- and medium-sized enterprises (SMEs) utilising thermal biomass conversion.

Currently, second-generation bio-fuels produced by SMEs do not meet the definition of biomass. In some European countries, the bio-char obtained from the thermal conversion of biomass cannot replace biomass in energy production from renewable sources because it is not classified as biomass. This is a direct interpretation of the directive [4], in which biomass is defined as "the biodegradable fraction of products, waste and residues with a biological origin of agriculture (…)" [1, 2]. Bio-char is not biodegradable because in the thermal conversion process, the structure of biomass is permanently changed by high temperature to the ordering structure. For this reason, SMEs and power plants cannot obtain financial support from the government for the production energy from OZE sources. The goal of the financial support is to encourage diversity in the structure of electricity suppliers to enable the use of domestic energy resources. However, methods to verify the origin of the materials, such as torrefied biomass or bio-char from biomass, are still lacking. Research laboratories employ analytical methods according to the European Standard, EN 15440:2011: 2011E. This standard concerns the determination of the biomass content in solid recovered fuels via two physicochemical methods: selective dissolution and a method based on the analysis of the ^{14}C carbon isotope concentration in the material. These methods are only suitable for the analysis of pure biomass and solid recovered fuels. Discrepancies between tested bio-char samples with a known amount of polymer impurities and the results from a ^{14}C analysis were published previously [3]. In that research and in almost all cases, the ^{14}C analysis wrongly classified a second-generation solid bio-fuel sample contaminated with plastics as a bio-char from pure (100%) biomass. For this reason, we conducted research intended to identify an appropriate analytical method that—combined with chemometric tools—will allow proper

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classification of such fuel. The developed tool, called the BioFuel Classifier for Power Generation (BFC-PowerGen), uses widely available data and typical laboratory analyses such as proximate and ultimate analysis, the heat of combustion and the chemical composition of ash of second-generation solid bio-fuels. BFC-PowerGen confirms >98% of the qualitative origin of solid fuels obtained from the thermal conversion of biomass and materials considered biomass.

1.1. Biomass availability and policy regulation

As of 2013, the worldwide consumption of energy is 532.997 EJ per year; this value is a 2.3% increase from the previous year. An analysis of the energy sector [4–11] indicates that the primary global energy demand will continue to grow steadily, and the demand will increase 41% by 2035. Because of the constantly rising fossil fuel prices, it is projected that renewable energy sources will become the second largest source of primary energy production in the world by 2035. The European Union (EU) encourages its members to increase the amount of renewable energy sources applied to power generation. These changes will contribute to an increase in the share of energy use in EU countries from 13% in 2012 to 32% by 2035 [4–11]. The current global energy produced from biomass is nearly 50% of all the energy from renewable sources; the energy produced and used in 2012 was 5.54 EJ. Co-firing with fossil fuels remains a popular form of energetic biomass application [13–15].

The biomass available in Europe for energy purposes can be divided into three main classes [10]:

- Biomass from agricultural land:
  - o energy crops,
  - o agricultural crop residues, and
  - o manure.

- Forest biomass:
  - o forest biomass,
  - o residues and forestry residues, and
  - o waste from the timber industry.

- Waste biomass:
  - o waste from the food industry and
  - o other biodegradable waste.

Energy and heat can be produced using perennial plants (hemp, linen, reed canary grass, willow, and poplar) and residues from the harvests of annual plants, such as cereal plants. Second-generation biofuels, such as torrefied biomass and bio-char, require the use of perennial fuels, including lignin-cellulose or woody fuels (hemp, linen, willow, poplar, and *Miscanthus*). The majority of the EU is cultivated with *Miscanthus* (15,542–17,622 ha), willow (30,600–36,480 ha), and poplar (14,865–15,085 ha). In Finland, 18,700 ha are intended for reed canary grass.

Biomass use in Poland currently exceeds 82% [4–11] (Fig. 1) of the total renewable energy used to produce primary energy.

More systems for biomass valorisation, e.g., torrefaction or pyrolysis of biomass, are appearing in the energy markets. The torrefaction process enables the production of new biomass fuels with good energy properties. Unfortunately, SMEs producing second-generation solid fuels cannot meet the legal regulations regarding the qualifications of biomass for energy purposes. These bio-char fuels do not match the traditional definition of biomass (which must be characterised as having a sufficient degree of biodegradability); therefore, the governmental support, particularly the support that has the goal of diversifying the energy structure to encourage the use of domestic energy resources, cannot be directly applied to SMEs.

2. Materials and methods

2.1. Currently available methodology for verifying biomass origin

The currently available research and quality control laboratory methods to verify biomass origin are presented in the European standard EN 15440: 2011 [12], which specifies the degree of biodegradability of solid secondary biomass based on two physicochemical methods:

- chemical selective dissolution and
- analysis of the ^{14}C content in the material.

These methods are adapted to the biomass analysis, which does not contain a non-biodegradable substance to an extent deviating from the known natural properties of the particular type of biomass. For example, the substance does not contain any added non-biodegradable substances that do not occur naturally (e.g., paints, varnishes, or sealers) or any substances that occur in amounts exceeding the known naturally occurring quantities in the biomass [1,2,16–19].

The selective dissolution method cannot be used for testing solid fuels, such as torrefied biomass and bio-char, because of the chemical conditions. The basis of this technique is the digestion or decomposition

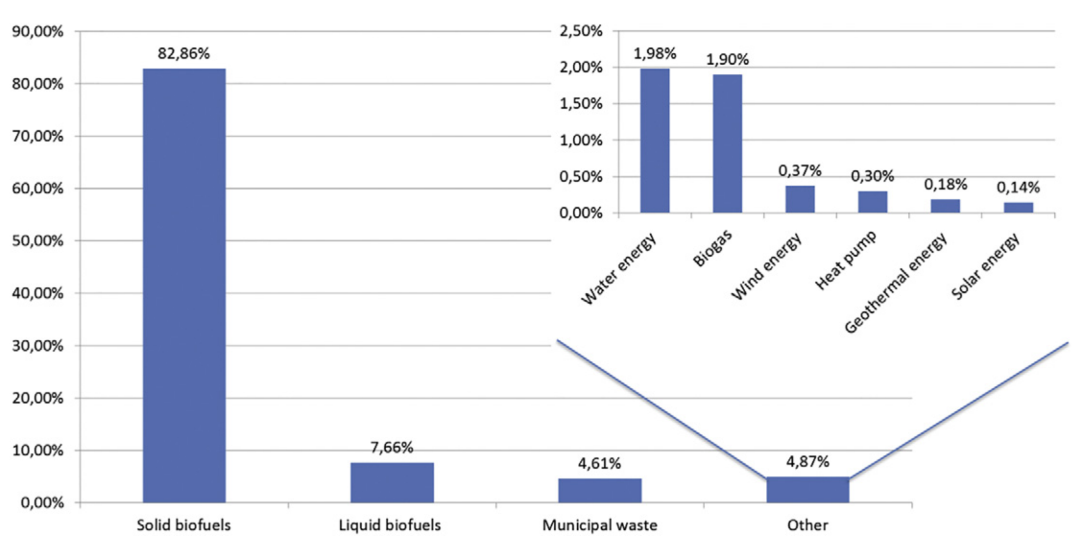

Fig. 1. Biomass in the production of primary energy in Poland [8].