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Effect of Temperature and Duration of Torrefaction on the Thermal Behavior of Stem Wood, Bark, and Stump of Spruce

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Abstract

In this work the torrefaction of different parts of Norway spruce (stem wood, bark, and stump) was studied. Three different torrefaction temperatures were applied: 225, 275, and 300 °C with 30 and 60 minutes isothermal periods. The untreated and torrefied biomass materials were characterized by thermogravimetric analysis (TGA). The TGA results are interpreted in terms of the chemical composition determined by the cellulose, hemicellulose and Klason lignin content. The alkali ion contents of the samples were measured by ICP-OES technique. It was found that the effect of torrefaction temperature was greater than the effect of residence time up to 275 °C, while at 300 °C the residence time had a significant influence on the composition of the torrefied samples due to the intensive decomposition of cellulose.

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Keywords: torrefaction; thermogravimetry, spruce, cellulose, hemicellulose, lignin

1. Introduction

Lignocellulosic biomass is one of the most important renewable energy resources; however, in energetic applications the raw material has several disadvantages, such as the high oxygen content, low calorific value, low energy density, hydrophilic nature and high moisture content.

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Torrefaction is a promising mild thermal pretreatment method between 200 and 300 °C in an inert atmosphere for improving the mentioned disadvantages of lignocellulosic biomass [1]. The purpose of the pretreatment from a chemical point of view is the removal of water and the acidic groups of hemicelluloses or the whole hemicellulose fraction with minor degradation of cellulose and lignin in the biomass [2]. In order to maximize the effectiveness of the energy extraction, we need to characterize the biomass materials as much as possible.

The Norwegian national energy strategy has a goal of reducing Norway's greenhouse gas emissions by 30% before 2020 and by nearly 100% before 2050 [3]. This strategy indicates that the bioenergy utilization is going to increase over the next few years. Norway has considerable forest resources (more than 40% of the land is covered by forest) and the standing forest volume is increasing. Stem wood is the main harvesting product while the other parts of the tree (including bark and stump) are considered as by-products. These forest residues represent an abundant and underutilized source of renewable energy. Norway spruce is the most abundant wood species in Norway and in the Northern hemisphere. Many studies have been carried out on the thermal characteristics of Norway spruce stem wood [4-5], however only a few articles are available on the thermal decomposition of its bark and stump [6-7]. As a consequence of the difference in the relative amounts of cellulose, hemicellulose, lignin, extractives, and inorganic materials, the different parts of the tree are expected to behave differently during thermal decomposition. In this work, thermogravimetric (TGA) measurements and compositional analyses have been carried out to compare the thermal behavior of untreated and torrefied Norway spruce stem wood, bark, and stump.

2. Materials and Methods

Different parts of a representative single Norway spruce (*Picea abies*) tree were selected for the torrefaction study, namely: stem wood, bark, and stump. The samples originated from a Norway spruce forest in South Norway. After harvested, the trees were divided into three parts including trunk, stump, and forest residues. The trunk was further debarked to obtain stem wood and bark. The stem wood was first cut to strips, then further chopped into cubes with size of 1 x 1cm. The bark was chipped into pieces and those with length of around 5-7 cm were used for the torrefaction experiments. The stump was shredded into pieces and the pieces with size of 3-5 cm were torrefied.

The torrefaction experiments were carried out in a tube reactor placed in an electrical furnace in nitrogen atmosphere using flow rates of 1 l min^{-1}. About 80 g samples were treated in the tube reactor at 225 °C, 275 °C and 300 °C temperatures using 30 and 60 minutes isothermal periods. For further experiments the untreated and torrefied samples were ground by a cutting mill to <1 mm particle size.

The higher heating value was determined using an automatic IKA C 5000 bomb calorimeter. The combustion of about 0.5 g dried sample was performed in pure oxygen atmosphere under 30 bar pressure. The heat capacity of the calorimeter system was determined by benzoic acid calibration.

The amounts of the ashes have been determined using a CEN/TS 14775 EU standard method. The calcium, potassium, sodium and silicon contents of the ashes were determined by a Spectro Genesis ICP-OES (Spectro Analytical Instruments) with axial plasma observation.