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Stump torrefaction for bioenergy application

Khanh-Quang Tran [a,*], Xun Luo [b], Gulaim Seisenbaeva [c], Raida Jirjis [b]

[a] Department of Energy and Process Engineering, Norwegian University of Science and Technology, NO-7491 Trondheim, Norway
[b] Department of Energy and Technology, Swedish University of Agricultural Sciences, Box 7032, SE-75007 Uppsala, Sweden
[c] Department of Chemistry, Swedish University of Agricultural Sciences, Box 7015, SE-75007 Uppsala, Sweden

HIGHLIGHTS

- First study on torrefaction of stump for bioenergy application.
- Stump can achieve higher energy densification factors.
- Torrefied stump requires longer grinding time than torrefied wood.

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ABSTRACT

A fixed bed reactor has been developed for study of biomass torrefaction, followed by thermogravimetric (TG) analyses. Norway spruce stump was used as feedstock. Two other types of biomass, poplar and fuel chips were also included in the study for comparison. Effects of feedstock types and process parameters such as torrefaction temperature and reaction time on fuel properties of torrefied solid product were investigated. The study has demonstrated that fuel properties, including heating values and grindability of the investigated biomasses were improved by torrefaction. Both torrefaction temperature and reaction time had strong effects on the torrefaction process, but temperature effects are stronger than effects of reaction time. At the same torrefaction temperature, the longer reaction time, the better fuel qualities for the solid product were obtained. However, too long reaction times and/or too higher torrefaction temperatures would decrease the solid product yield. The torrefaction conditions of 300 °C for 35 min resulted in the energy densification factor of 1.219 for the stump, which is higher than that of 1.162 for the poplar wood samples and 1.145 for the fuel chips. It appears that torrefied stump requires much longer time for grinding, while its particle size distribution is only slightly better than the others. In addition, the TG analyses have shown that untreated biomass was more reactive than its torrefaction products. The stump has less hemicelluloses than the two other biomass types. SEM analyses indicated that the wood surface structure was broken and destroyed by torrefaction process.

1. Introduction

Bioenergy has been becoming more and more widely recognized as one of the most promising renewable energy alternatives, which would sustainably replace fossil energy and meet the need in the increasing world energy demand as well as for abatement with climate change. Consequently, the extraction of logging residues (tree tops and branches) has become a common practice in the forests of northern Europe and North America [1]. In Sweden, a country of no fossil energy resources, forestry and agriculture are of considerable significance for energy supply. Already, about 20% of energy currently used comes from forestry [2].

Sweden is one of the forest-rich countries, with 22.7 billion m^3 (stem volume over bark from stump to tip) [3]. The most common species, Norway spruce and Scots pine contribute 41% and 38% of the standing volume, respectively [3]. With an annual final felling area of around 200.000 ha, the harvested volume per year reached 87 million m^3 between year 2005 and 2007 [4]. It was reported that Swedish forest industries are expected to face the threat of shortage of wood [5]. The first time this was forecasted was in the 1960s, when a lack of wood in the 1990s was predicted [5]. However, such a deficit had never occurred. In the 1960s, the development of nuclear power plants was in full blast in Sweden and very few people discussed about the shortage of petroleum oil and oil prices. But now again a new deficit is being predicted, exacerbated by the damage caused by the storms in January 2005 [5]. Today people even

* Corresponding author. Tel.: +47 73 59 36 25; fax: +47 73 59 35 80.
E-mail address: khanh-quang.tran@ntnu.no (K.-Q. Tran).

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fear a competition for wood between the paper industry and the energy industry [5].

One way to meet the growing demand of forest biomass for energy application, without increasing the annual harvesting volume of stem wood, is to utilize stumps. By definition, the stump is all belowground and aboveground wool and bark mass of a tree beneath the merchantable timber cross-section [6]. The stump, including roots thicker than 5 cm, constitutes 23–25% of the stem volume [7]. Stump wood has been utilized during different period of various purposes, such as tar and pulp production. Today, stumps are not used for either of these purpose and be a potential source of energy. In Sweden the use of stump as fuel resource become more and more interesting [3]. The Swedish Forest Agency has estimated that stump harvesting would respond to an annual energy supply of 57 TWh/year in Sweden [4]. Furthermore, it is reported that when stumps and small roundwood from thinning are used to replace fossil fuels, the potential CO_2 reduction will be about four times as great as when only logging residues are used with a traditional chip system [8]. However, stumps have not been recognized as a bioenergy resource. It is interesting to note that although the research activity related to the use of stumps as fuel in Sweden was quite active during the last couple of years [3,8–15] no study of thermal pretreatment of stumps for energy application has been reported. Suitable methods for pretreatment of stump biomass are probably of great importance to make it accepted as fuel. It is therefore rewarding to carry out an investigation in this area for stumps.

Torrefaction is a thermochemical treatment employed to improve fuel properties of solid biomass fuel, which may be defined as a mild pyrolysis process within the temperature window of 200–300 °C, in the absence of oxygen and relatively low heating rates (<50 K/min) [16,17]. The process involves heating of the feedstock for drying, torrefaction and cooling. Similar to pyrolysis, the chemical structure of plant biomass is changed during the torrefaction. Biomass torrefaction results in products found in three phases: solid, liquid, and gas. The solid is the main product of biomass torrefaction and called torrefied biomass which has very low moisture contents and higher calorific values compared to the feedstock. Other improved fuel properties of torrefied biomass compared to the feedstock includes grindability and hydrophobicity. By cooling the exhaust steam released from biomass torrefaction processes, liquid of yellowish color is obtained from condensable gases. Non-condensable gases leave the process in the gas phase, which include carbon monoxide, carbon dioxide and little amount of methane. Typically, 70% of the feed mass is retained after torrefaction in the forms of solid products, which contain 90% of the initial energy [18]. The rest of 30% of the feed mass contains only 10% of the initial energy. The energy densification factor is commonly used to prove the improvement in energy density of torrefied solid product by torrefaction, for which the typical value is 1.3 [18].

Advantages of torrefaction of biomass for bioenergy application have been addressed in a number of published papers [16,18–21]. Prins and co-workers [16] found that it is more efficient biomass gasification via torrefaction. Li et al. [20] showed that torrefaction is able to provide a technical option for high substitution ratios of biomass in the co-firing system, up to 100% torrefied biomass without obvious decreasing of the boiler efficiency. More positively, the net CO_2 and the NO_x emissions significantly reduced with increasing of biomass substitutions in the co-firing system [20]. On the other hand, Ming and co-workers [19] demonstrated that bio-oils produced from torrefied wood have improved oxygen-to-carbon ratios compared to those from the original wood with the penalty of a decrease in bio-oil yield. The extent of this improvement depends on the torrefaction severity. It was considered that torrefaction could be a potential upgrading method to improve the quality of bio-oil, which might be a useful feedstock for phenolic-based chemicals [19]. Furthermore, in combination with pelletisation, torrefaction also aids the logistic issues that exist for untreated biomass [18].

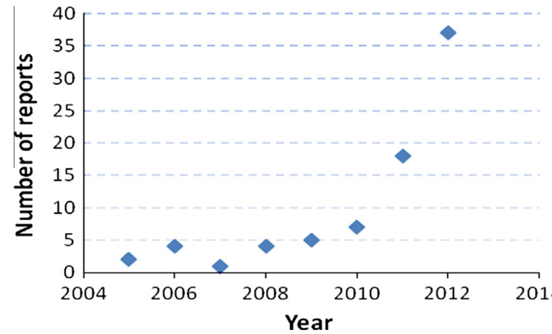

Fig. 1. Number of recent reports in biomass torrefaction by Sciencedirect.

Due to the aforementioned advantages of torrefaction, research and development activities in biomass torrefaction for energy applications worldwide were very active in the last couple of years, [18,22–36]. A quick search for the number of reports in Sciencedirect.com made by 25 September 2012, using the keyword of "torrefaction" restricted to "Abstract, Title, Keywords" fields gave the results presented in Fig. 1 on the year basis since 2005. The exponentially increasing trend of the number of reports proves the attractiveness of the technology for energy application. Different study methods and various feedstock types employed for research and development in torrefaction have been reviewed [21,37–39]. Tested feedstocks include wood, wood residues, energy crops (miscanthus, switchgrass, reed canary grass), short rotation coppice willow and poplar, and bamboo biomass material. However, none has been reported for stumps.

This present paper report results from an experimental study of biomass torrefaction, followed by thermogravity analysis basically for Norway spruce stump. Two other types of biomass, poplar wood and fuel chips (logging residues) were also included in the study for comparison.

2. Experimental

2.1. Experimental setup for biomass torrefaction

Fig. 2 represents the experimental setup used for biomass torrefaction in this study, which basically includes a tubular reactor placed in an electric muffle furnace, a nitrogen gas supply system with a heating element (not shown in the figure) for gas preheating, and an water-cooled condenser connected to the outlet of the reactor. The reactor made of stainless steel was designed to fit the existing furnace, Nabertherm LH 30/12, which can be operated within a temperature range of 30–3000 °C. The main body of the reactor is about 400 mm long, and consisted of two cylinders which are assembled centrically together by a sealing mechanism on top.

The reactor is introduced into the furnace through an opening on top of the furnace, placed and held in the right position as shown in Fig. 2a by the sealing flanges. The diameter of the outer cylinder (The red color part with a closed[1] end at the bottom in Fig. 2a) is 70 mm, and that of the inner cylinder tube (Fig. 2a, the green color part with an opened end at the bottom) is 50 mm. A removable stainless steel sample cup (Fig. 2a, the blue color part)

[1] For interpretation of color in Fig. 2, the reader is referred to the web version of this article.