

Alkali-catalyzed hydrothermal treatment of sawdust for production of a potential feedstock for catalytic gasification

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HIGHLIGHTS

- The effect of temperature and catalyst loading on product distributions from HTT were investigated.
- The heating values of the produced slurry ranged from 12.0 to 16.4 MJ/kg.
- The product yield of solid residue ranged from 55.6 to 81.5 wt%.
- The highest combustibles were obtained with solid residue products.
- The yield of aqueous products ranged from 11.1 to 34.3 wt%.

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ABSTRACT

This study investigates the effects of reaction temperature and catalyst loading on product yields and fuel properties of produced slurry during the alkali catalyzed hydrothermal treatment (HTT) of pine sawdust. The yield of the liquid fraction, or the aqueous product (AP), at process temperatures of 180–260 °C obtained after solid/liquid separation of the slurry ranged from 11.1 to 34.3 wt% on a dry, ash free basis. The fuel quality of the produced slurry, such as the elemental composition and the higher heating value (HHV), was mainly affected by the catalyst loading. An increase in the catalyst loading caused the ash content to increase. Although the increase in temperature leads to a higher liquid fraction in the slurry making it more homogeneous, its contribution to the elemental composition of the whole slurry was limited. HHV of the produced slurry ranged from 12.0 to 16.4 MJ/kg. These values are comparable to that of black liquor (BL), which has previously been shown to be a promising feedstock for gasification in a pilot scale entrained flow gasifier. These results imply the possibility of a fuel switch from BL to the HTT slurry for entrained flow gasification though its gasification reactivity and conversion characteristics must be investigated further.

1. Introduction

Fuel switching from conventional fossil fuel to renewable energy sources has been given increased attention to mitigate the global warming caused by greenhouse gas (GHG) emissions from fossil fuel combustion. In addition, the diversification of energy sources and the increase in the energy self-sufficiency rate by developing renewable sources have become critical issues for each nation to form a secure

society with stable energy supply.

Waste biomass is one of the promising renewable sources due to its CO₂ neutrality. Its combustion does not contribute to increase in the net CO₂ concentration in the atmosphere. The released CO₂ during combustion will be absorbed by plant during photosynthesis. Therefore, the usage of biomass has a closed carbon cycle.

Gasification is one of the thermochemical pathways to convert biomass into valuable products. Syngas (hydrogen and carbon

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monoxide) can fuel gas turbines and engines to generate electricity with a high efficiency. Alternatively, syngas can be upgraded into liquid transportation fuels, such as methanol (MeOH), dimethyl ether (DME) and Fischer Tropsch (FT) diesel via catalytic conversion [1]. Therefore, biomass gasification process has big potential to contribute to sustainable biofuel generation for industrial and transportation sector.

Black liquor (BL), a by-product from pulping, is a promising biomass feedstock for entrained flow gasification process due to its high reactivity of the inherent alkali catalyst [1]. Luleå University of Technology (LTU), Sweden, operates a 3 MW pilot scale entrained flow gasifier coupled with the DME synthesis process, which has been successfully operated for more than 25,000 h to convert BL into DME for the demonstration of fleet tests of 10 heavy-duty trucks [2]. The feasibility of black liquor gasification (BLG) has been evaluated by many researchers through lab-scale and pilot scale experiments [2,3,4] as well as the techno-economic analysis [5,6]. Bach-Oller et al. [7,8,9] investigated co-gasification of BL and pyrolysis oil (PO) to effectively utilize the saturated alkali catalyst in BL. Their results showed comparable gasification reactivity and syngas yield of BL/PO mixture to pure BL, suggesting the possibility of fuel substitution. Co-gasification of BL and petroleum coke was also conducted to investigate the catalytic gasification process of solid fuel [10]. Zhan et al. [11] found that the impregnation method which brought the best catalytic activity was the wet grinding method, in which petroleum coke and BL solution were ground together in a ball-mill and then dried. According to those studies, the key for the efficient gasification is not only the amount of catalyst but also the uniformity of the fuel which leads to better catalyst dispersion and better catalyst contact with organic fraction in the fuel.

Within the current paper, we demonstrate a novel biomass energy conversion process, in which alkali catalyzed hydrothermal treatment (HTT) is used as a pretreatment process to generate a slurry feedstock intended for the catalytic gasification in an entrained flow gasifier. To our knowledge, there is no research investigating the effect of the reaction temperature and the catalyst loading during the catalytic hydrothermal treatment of woody biomass on the fuel properties of the produced slurry feedstock. For this purpose, alkali catalyzed hydrothermal treatment (HTT) was carried out as a pretreatment method of pine sawdust for catalytic gasification in an entrained flow gasifier. It is expected that catalytic HTT can produce slurry feedstock containing alkali catalysts which is pumpable that can be used in the downstream gasification process [12]. Moreover, the alkali compound acts as a catalyst in the gasification process.

2. Material and methods

2.1. Feedstock and catalyst

Pine sawdust was obtained from Norbotten County, Sweden, and used as feedstock. Prior to experiment, it was sieved to be in the size of 500–600 μm and dried at 105 $^{\circ}\text{C}$ overnight. Table 1 shows the result of the proximate and ultimate analyses of the sample. Its ash content was 0.03 wt% and the catalytic effect of metal species inherent in the parent biomass on HTT and following gasification can be neglected. Potassium carbonate (K_2CO_3) powder was purchased from Wako Pure Chemical, Japan (99.5%) and used as received.

Table 1
Ultimate and proximate analyses of pine sawdust.

Ultimate analysis (wt%, dry basis)				Proximate analysis (wt%, dry basis)		
C	H	N	O*	Volatile	Fixed carbon	Ash
50.5	6.7	< 0.03	42.8	88.4	11.6	0.03

* By difference.

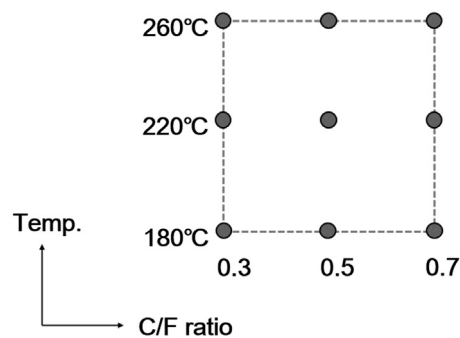


Fig. 1. 3×3 factorial design used in this study.

2.2. Experimental design

Two process conditions, the temperature and the catalyst to feedstock ratio (C/F), were chosen as variable parameters. Three levels were set for each variable with the same intervals. The temperature was set to be 180 $^{\circ}\text{C}$, 220 $^{\circ}\text{C}$, 260 $^{\circ}\text{C}$ and the C/F ratio was set to be 0.3, 0.5 and 0.7 on a mass basis. A 3×3 factorial design was used for this study, as shown in Fig. 1. The water to feedstock (W/F) ratio was set to be 5 on a mass basis throughout the experiments.

2.3. Experimental procedure

A 500 mL stainless steel batch reactor was used for the HTT experiments. It consists of a jacket heater, an outer reactor vessel, an inner stainless steel tube, a top cover, a temperature controller, a pressure gauge and a stirrer, as shown in Fig. 2.

For each experimental run, 15 g of the feedstock was used. The biomass was mixed with an alkaline catalyst by wet impregnation. A certain amount of alkali solvent with predetermined concentration was prepared beforehand based on the C/F and W/F ratios. The desired amount of the solvent and the feedstock were loaded into the reactor. It was sealed and purged with argon gas seven times to remove air inside the reactor. The initial pressure inside the reactor was atmospheric. The speed of the stirrer was set to approximately 120 rpm to ensure a good mixing. Reaction process was based on heating the reactor to the target temperature which took 30–40 min and then cooling down to room temperature without holding at target temperature. After the HTT experiments were completed, the reactor was cooled down to the room temperature with an electrical fan. The gas products were vented without collection.

The slurry in the reactor was collected and vacuum filtered using a

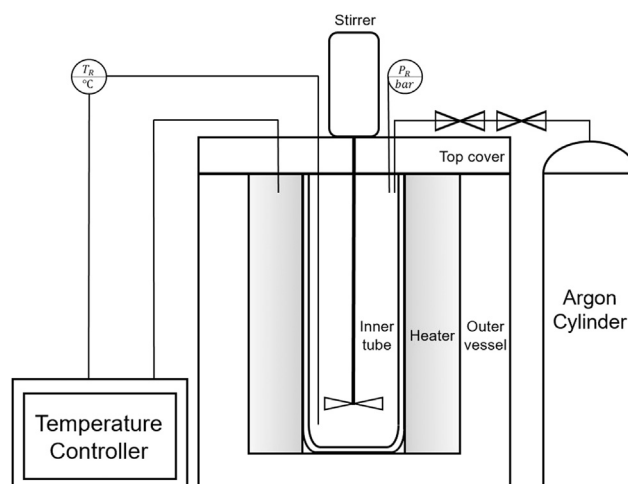


Fig. 2. Schematic diagram of the stainless steel batch reactor.

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