

Influence of Urea Formaldehyde Resin on the Pyrolysis of Biomass Components: Cellulose, Hemicellulose, and Lignin

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Wood-based panels, which are often used and then abandoned, are a potential resource for energy recovery. To better understand the pyrolysis of wood-based panels, the effect of urea formaldehyde (UF) resin on the pyrolysis of the wood components (cellulose, hemicellulose, and lignin) was investigated. Thermogravimetric analysis (TGA), gas chromatography coupled with mass spectrometry (GC-MS), and an ultimate analysis were used to investigate the pyrolysis process and products of the biomass components mixed with 10% UF resin. The UF resin specifically inhibited the decomposition rate of cellulose and promoted the thermal decomposition of lignin. For xylan, the UF resin had little impact. The UF resin mainly affected the mass loss of C and O. Loss of both elements in lignin was promoted, but only C loss increased in cellulose. The nitric gases generated from the pyrolysis mixtures were HCN and NH₃, and N from the UF resin tended to transform into NH₃. Influence of the UF resin on the pyrolysis liquids was mainly seen on the N compounds. With the addition of the UF resin, more nitrogenous compounds were detected in the pyrolysis liquids. The relative contents of nitrogenous compounds in the pyrolysis liquids from cellulose and lignin were 12.8% and 64.3%, respectively.

Keywords: Cellulose; Hemicellulose; Lignin; Urea formaldehyde resin; Pyrolysis products; GC/MS

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INTRODUCTION

When considering energy and resources, it is known that major conventional fossil energy resources are on the verge of becoming extinct. As a lignocellulosic bioresource, waste wood-based panels show a great potential for providing raw materials for the production of renewable fuels and chemical feedstocks (Girods *et al.* 2009). The developing rate of wood-based panels in China increases by over 20% annually (Qian 2010), and the production of wood-based panels was 273 million m³ in 2014. This large consumption leads to nearly 10% of all wood-based panels and their relevant products being abandoned each year, which is a huge energy resource that can be recycled and reused (He and Mu 2008).

In recent decades, the pyrolysis of biomass is a new type of energy utilization, and has attracted the interest of many researchers. It enables the conversion of lignocellulosic biomass, such as forest rejectamenta or agricultural residues, into gas, liquid, and solid products. These products have a high energy density compared with raw materials, and can generate many chemicals (Cantrell *et al.* 2008). Depending on the pyrolysis technique, waste wood-based panels can be effectively utilized (Girods *et al.*

2008b).

However, there are some differences between the pyrolysis of wood-based panels and conventional biomass materials because of adhesives in the wood-based panels. These adhesives influence the pyrolysis characteristics and products. The pyrolysis temperature range of wood mixed with urea formaldehyde (UF) resin is considerably different from that of the raw material. Also, the gas products NH_3 and HCNO have been detected after pyrolysis of wood containing UF resin (Girods *et al.* 2008c). Adhesives with weak thermal stability have potential to reduce the thermal stability of the wood (Peng *et al.* 2011), and promote the pyrolysis of wood at lower temperatures (Feng *et al.* 2012; Chen *et al.* 2015). Compared with the pyrolysis products of wood, a large number of nitrogenous compounds have been detected, especially in the pyrolysis liquid from wood-based panels (Zhang *et al.* 2016). Furthermore, the UF resin in wood-based panels can produce the precursors of nitrogen oxides, such as NH_3 , HCN , and HCNO , during pyrolysis (Ahamad and Alshehri 2014). The emission of these nitrogen-containing gases is harmful to the atmospheric environment and human health (Ren *et al.* 2011). However, the study of wood-based panels so far has been limited to the effect of UF resin on wood rather than individual wood components.

As is well known, wood mainly composed of cellulose, hemicellulose, and lignin is a complex mixture. To explore the thermal behavior of biomass pyrolysis, the pyrolysis of cellulose, hemicellulose, and lignin were each separately studied, and the mechanism of biomass pyrolysis was determined (Yang *et al.* 2007; Qu *et al.* 2011; Yang *et al.* 2011; Lv and Wu 2012; Trubetskaya *et al.* 2015; Anca-Couce 2016). In a study on the additive effects on biomass pyrolysis, such as catalytic pyrolysis, the three main biomass components were each mixed with catalysts and then analyzed to understand the influence of the catalysts on the thermal behavior of the biomass char formation and pyrolysis products distribution (Nowakowski and Jones 2008; Case *et al.* 2015; Liu *et al.* 2015). However, In view of this, the purpose of present study was to explore the influence of UF resin on the pyrolysis of the main components of biomass, and the ultimate goal was to investigate the influence of UF resin thermal degradation of wood-based panels. In this paper, the pyrolysis of cellulose, xylan, and lignin separately mixed with UF resin was studied. Thermogravimetric analysis (TGA), gas chromatography coupled with mass spectrometry (GC-MS), and an ultimate analysis were used to evaluate the thermal characteristics and main components of the pyrolysis products.

EXPERIMENTAL

Materials and Preparation

Cellulose (C, microcrystalline cellulose, CAS: 9004-34-6), xylan (X, CAS: 9014-63-5), and lignin (L, alkali lignin, CAS: 8068-05-1) were purchased from Sigma-Aldrich Chemie GmbH (Buchs, Switzerland). Cellulose was in a powder fibrous form, and the lignin was alkali lignin in the form of a brown powder. Commercial hemicellulose is difficult to purchase, but xylan has been widely used as a representative component of hemicellulose during pyrolysis (Yang *et al.* 2007; Qu *et al.* 2011; Yang *et al.* 2011). The particle size of the UF resin, cellulose, xylan, and lignin was approximately 50 μm . The commercial wood adhesive used in this experiment, UF resin with a molar ratio (F/U) of 1.08, was provided by Beijing Wood Factory (Beijing, China). The weight percentage in wt.% (on dry basis) of each sample was 90% wood component (C, X, and L) and 10%

UF resin. Cellulose, xylan, and lignin were evenly mixed with 10 wt.% UF resin, and the samples were labelled as C+UF, X+UF, and L+UF, respectively. Neat samples were used as the controls. Samples were crushed until they were smaller than 0.2 mm in size and then dried in an oven at 103 °C for 3 h before the experiments were performed.

Thermogravimetric Analysis

The pyrolysis experiments were performed using a Metter Toledo TGA/SDTA851e thermogravimetric analyzer (Herisau, Switzerland). During the experiments, approximately 5 mg of the sample were placed in a ceramic crucible and heated from room temperature to 800 °C at a heating rate of 20 °C/min with nitrogen as the carrier gas at a constant flow rate of 40 mL/min.

Pyrolysis Reactor

The experimental setup, shown in Fig. 1, consisted of a quartz tubular reactor with a regulated electrical furnace controlling the temperature. Ten-gram samples were placed in the quartz sample boat in the furnace, where the temperature can reach 1200 °C. The C, C+UF, L, L+UF, and UF resin were pyrolyzed in a laboratory scale tubular furnace reactor at a linear heating rate of 20 °C/min from ambient to 600°C, and maintained for 2 h. The carrier gas was nitrogen with a flow rate of 100 mL/min in order to achieve an inert atmosphere. The gas flow of the device was controlled by flowmeters. Char and pyrolysis liquids were obtained for later analysis. Pyrolysis liquids were collected by using cold water to trap the condensable products. Each experiment was repeated three times.

All of the pyrolysis gases were run through gas washing bottles, in which nitrogen compounds were collected during the run. The collecting solutions consisted of 5 wt.% H₂SO₄ in the NH₃ collection bottles and 5 wt.% NaOH in the HCN collection bottles. Three bottles were used for each collection. When the system was tested, most of the NH₃ was found in the first two bottles, while the third bottle contained a negligible amount of NH₃. This was similar to results of the HCN collection. The NH₃ and HCN were analyzed with Kjeldahl titration.

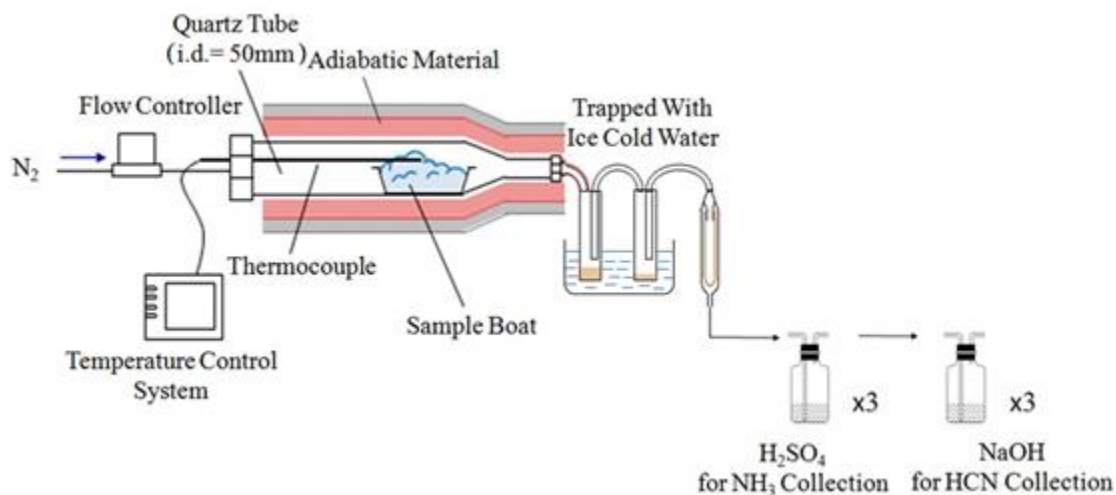


Fig. 1. Reactor used in the pyrolysis experiments

Elemental Analysis

The samples used during elemental analysis included both virgin samples and the char of the C, C+UF, L, and L+UF samples originated from pyrolysis experiment in pyrolysis reactor. An elemental analysis was done with an Elementar Vario EL III (Hanau Germany). The contents of C, H, and N were calculated using the mean value of the three tests. The content of O was obtained by calculating the difference of C, H, and N from 100%. The contents of C, H, N, and O of virgin samples was presented in Table 1.

Gas Chromatography-Mass Spectroscopy Analysis

The components of the pyrolysis liquids were analyzed using a QP201 gas chromatograph-mass spectrometer (GC-MS) (Shimadzu 2010, Kyoto, Japan). The gas chromatograph conditions were as follows: the RTX-5 column (30 m × 0.32 mm × 0.5 μm) was maintained at 50 °C for 2 min, the temperature was raised to 250 °C at a heating rate of 10 °C/min, and that temperature was then held for 5 min. Helium was used as the carrier gas. The injection was performed at 250 °C in the split mode of 30:1. The mass spectrometer was operated in the electron ionization (EI) mode with an ionization energy of 70 eV. The interface temperature was 250 °C. The scan interval was 0.5 s and the scan range for m/z was 33 to 500. The relative amount of the compounds were calculated using the area normalization method. The mass spectra obtained were compared with the mass spectra from the National Institute Standards Library (NIST).

RESULTS AND DISCUSSION

Thermogravimetric Analysis

The thermogravimetric (TG) studies were carried out at a temperature that ranged from room temperature to 800 °C. The data obtained were compared with calculations obtained from the expected results produced from the pyrolysis of the single component, a method widely used in other research of mixture (Zhou *et al.* 2014). From the TG and derivative thermogravimetric (DTG) curves, it was found that the UF resin had no influence on the pyrolysis behavior of the three components below 200 °C. As the temperature continued to increase, the UF resin mainly influenced the cellulose and lignin. The UF resin had little influence on the pyrolysis of xylan, and so no further experimental study on xylan was conducted in this research. Compared with theoretical curves, the UF resin inhibited the degradation rate of cellulose and promoted the thermal decomposition of lignin.

Table 1. Ultimate Analysis of the Samples

Sample	Elemental Analysis (wt.% on dry basis)			
	C	H	N	O ^a
Cellulose	43.36	6.67	0.00	49.97
Lignin	50.85	5.17	0.06	43.92
Xylan	37.85	5.40	0.16	56.59
UF resin	33.06	5.62	35.26	26.06

^a Determined by calculating the difference

Some studies have indicated that alkaline compounds have a strong catalytic effect on the dehydration reaction of cellulose (Niemelä 2010; Yan and Qi 2014). However, in our study, the UF resin may inhibit the depolymerization of cellulose, and had no dramatic effects on the pyrolysis of xylan in this experiment. It was speculated that the UF resin mainly affects formaldehyde, acetaldehyde, and other small molecular compounds in hemicellulose, and thus TGA failed to detect any effects on xylan. Lignin has a high thermal stability, with the main conversion step of lignin occurring over the large temperature range of 200 to 550 °C, and maximum conversion occurring at approximately 325 °C.

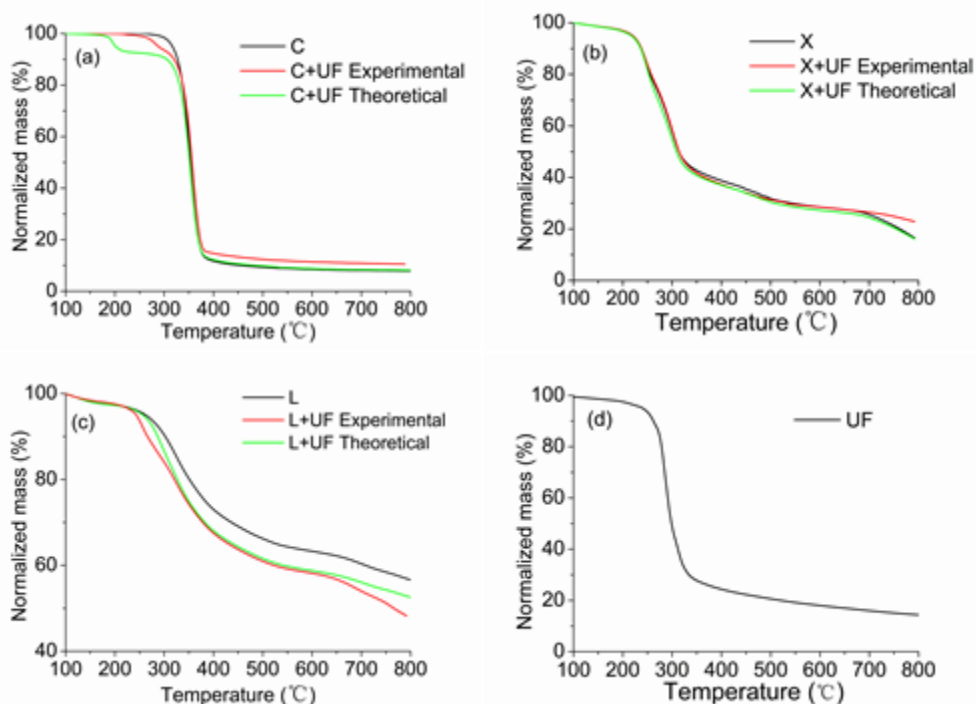


Fig. 2. TG curves of cellulose (a), xylan (b), and lignin (c)

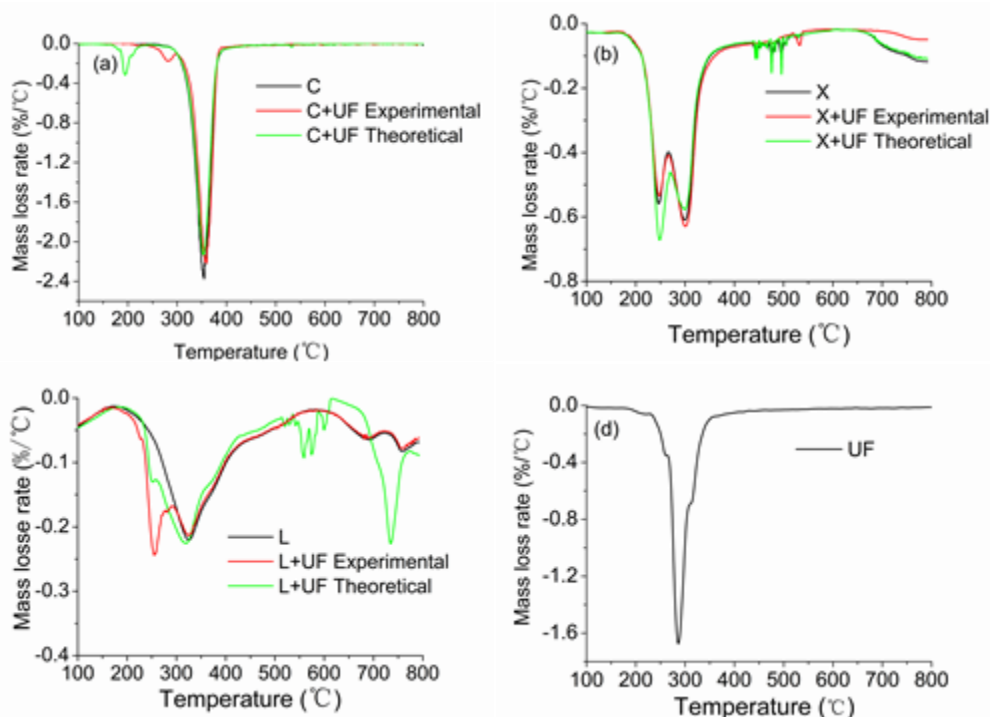


Fig. 3. DTG curves of cellulose (a), xylan (b), and lignin (c)

The cleavage reaction of lignin mainly occurs at higher temperatures. The maximum degradation rate of L+UF was remarkably higher than that of lignin (Fig. 3(c)). Therefore, it was speculated that the UF resin had a greater promoting effect on the pyrolysis of lignin, and was directly involved in the formation of various compounds.

Influence of Urea Formaldehyde (UF) Resin on the Elemental Distribution in the Solid Samples

The three main elemental components of cellulose and lignin are C, H, and O. The elements C and O together comprise 90% of cellulose and lignin. The commercial lignin contained very little N, only 0.06 wt.%, while the UF resin contained 35.26 wt.%. As Fig. 4 shows, the comparison of the contents of the elements in the original sample and char multiplied by the char yield showed that there were losses. Although large amounts of C were lost during pyrolysis, C was the main element in the char and accounted for more than 60 wt.%, while the other elements were reduced in proportion. The influence of the UF resin on the C was minimal, but the content of O in the cellulose and lignin, especially in the char from lignin pyrolysis, decreased because of the addition of the UF resin. The loss of O was the highest, probably because O is fixed in the form of oxygenated compounds in the pyrolysis liquids and as CO and CO₂ in the gases released during pyrolysis.

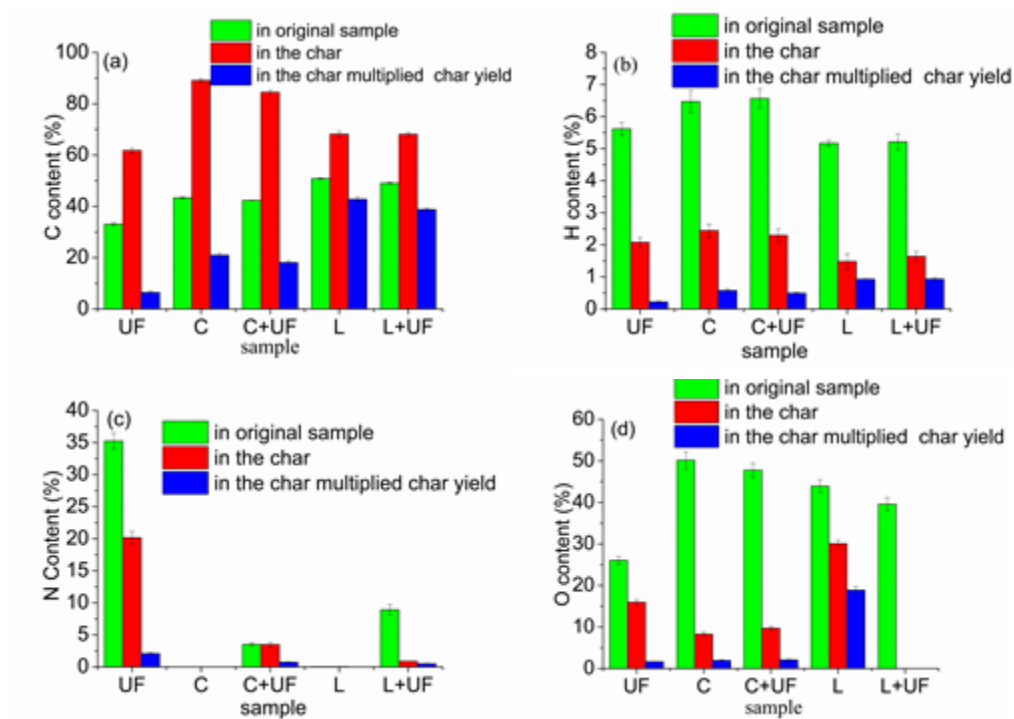


Fig. 4. Element contents of the solid samples before and after pyrolysis

The H content in the char was much lower than in the original samples and UF resin. During cellulose pyrolysis, the N contained in the UF blends was clearly introduced by the UF resin. There was no drop in the N content with the addition of the UF resin, and the N content in lignin was quite different from that in cellulose. It was speculated that N in the UF resin was more fixed in the solid products from the cellulose, and was less fixed when combined with the char from lignin pyrolysis, and in the gas and liquid products.

To investigate this further, the theoretical mass losses of the four main elemental components in the UF blends were calculated by the following equation, with the results shown in Fig. 5.

$$ML_{\text{blend}} = \chi_{\text{UF}} \times ML_{\text{UF}} + \chi_{\text{x}} \times ML_{\text{x}} \quad (1)$$

where χ_{UF} and χ_{x} are the weight percent of the UF resin and cellulose or lignin in the blend, respectively, and ML_{blend} , ML_{UF} , and ML_{x} are the mass losses of elemental components in the blend, UF resin, and cellulose or lignin (g), respectively.

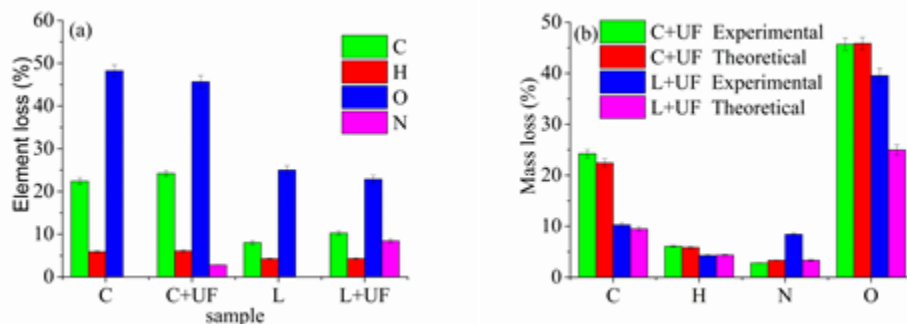


Fig. 5. Influence of the UF resin on the mass loss of elements in the samples during pyrolysis

As can be seen in Fig. 5, with the addition of the UF resin, the mass loss of C in cellulose increased from 22.40 to 24.24 wt.%, and in lignin increased from 8.03 to 10.27 wt.%. Similar trends for the mass loss of O were observed. However, the UF resin had mildly negative effects on the mass loss of H. It was seen in Fig. 5(b) that the mass losses of N from C+UF and L+UF were different. The experimental mass loss of N in C+UF decreased by 18 wt.%, while that in L+UF increased by 153 wt.% compared with the theoretical mass loss. The changes that were observed could have possibly been because of a reaction between the UF resin and lignin during co-pyrolysis. However, compared with the theoretical results, the experimental mass of O in C+UF was different by a small amount, and that in L+UF increased by 58 wt.%. This was likely because the UF resin had catalytic effects on the pyrolysis of cellulose and lignin, and especially affected the release of small molecular compounds. Li *et al.* (2014) discovered that the addition of UF resin promoted the formation of water and carboxylic acid during cellulose pyrolysis. It was speculated that the UF resin was involved in the pyrolysis of cellulose and lignin by fostering the breaking of chemical bonds in cellulose and promoting the decomposition of lignin.

Conversion of N to NH₃ and HCN during Pyrolysis Experiments

In the slow pyrolysis process, NH₃, HCN, and HCNO are precursors of NO_x. Because the detection method of HNCO is still not perfect, the formation of HNCO during pyrolysis was not very clear. Because of the absorption solution to detect gas-phase nitrogen compounds, HNCO could have hydrolyzed into NH₄⁺ and was mistaken for NH₃, and therefore HNCO was not detected.

As shown in Table 2, with the addition of the UF resin, NH₃ and HCN in the gas products were detected. It was observed that the NH₃ yields from the samples were higher than the HCN yields. Additionally, the HCN yields were all approximately the same for all of the samples. Some studies determined that the pyrolysis of UF resin can release a large amount of HCN (Ahamad and Alshehri 2014; Jiang *et al.* 2014). During the UF resin pyrolysis process in this study, 44.77 and 0.10 wt.% of N in the UF resin were converted into NH₃ and HCN, respectively. There are competing reactions for the generation of NH₃ and HCN (Leppälähti and Koljonen 1995). Because the pyrolysis temperature of this experiment was 600 °C, the HCN yield remained small at low temperatures, and occasionally the generation of HCN was not detected at all (Girods *et al.* 2008a). As seen in Table 2, it was interesting to observe that both the NH₃ and HCN yields from C+UF and L+UF were noticeably smaller than from the UF resin. Additionally, the production of NH₃ and HCN from L+UF was much higher than from

C+UF. N contained in the UF resin during pyrolysis was most likely bonded to the matrix or converted to liquid phase products. It was speculated that the UF resin combined with some groups in the lignin and promoted the release of NH_3 at lower temperatures. Compared with the structure of lignin, cellulose is composed of crystalline and amorphous phases, which could have affected the reactivity of cellulose with the UF resin. The release characteristics of N from different chemical structures are different. Abelha *et al.* (2008) suggested that N in ring structures have better thermal stability than straight chain nitrogen. Leppäläht and Koljonen (1995) found that N in ring structures are usually more stable during bark pyrolysis, and most N remains in the char. It is speculated that the reaction of lignin with UF resin can generate some kind of unstable nitrogenous structure, which leads to the transformation of N and degradation of lignin.

Table 2. Conversion of N to NH_3 and HCN during the Pyrolysis Experiments

Sample	N% in NH_3	N% in HCN	N% in NH_3 and HCN
UF	44.77	0.10	44.87
C	-	-	-
C+UF	0.08	0.05	0.13
L	0.05	0.04	0.09
L+UF	0.80	0.05	0.85

Influence of the UF Resin on the Components of the Pyrolysis Liquids

The main components of C and C+UF and L and L+UF that were determined by GC-MS are shown in Tables 3 and 4, respectively. As Table 3 presents, the components of the pyrolysis liquid from cellulose were furfural (22.68%), 5-methyl-2-furaldehyde (22.06%), o-Xylene (18.38%), 2-methyl-1-propylene (17.64%), and 2-acetylfuran (16.68%). During pyrolysis, the cleavage of glycosidic bonds in cellulose led to the formation of a high proportion of anhydro-oligosaccharides and anhydro-saccharides (Lu *et al.* 2011; Patwardhan *et al.* 2011; Liu *et al.* 2013), and the dehydration reaction of the anhydrosugars produced furfural and furan derivatives. Because aromatic structures do not exist in cellulose, aromatics detected in the pyrolysis liquid from cellulose may have resulted from the polymerization reaction of small molecular compounds (Morf *et al.* 2002; Wei *et al.* 2006). From Table 3, it was seen that the components of the pyrolysis liquid from C+UF was very complex. It consisted of multiple components, such as aldehydes, aromatics, furan derivatives, esters, carboxylic acid, ketones, and nitrogenous compounds. The major component was 2-oxobutyl acetate with a relative content of 18.53%. Other ketones, such as 2-methyl-2-cyclopenten-1-one (5.33%) and 6-methyl-3,4-dihydro-2-pyranone (5.31%), were also detected in the pyrolysis of C+UF, while esters, carboxylic acid, ketones, and nitrogenous compounds were not found in the pyrolysis liquid from cellulose.

Table 3. Main Components of the Pyrolysis Liquids from Cellulose Before and After Being Mixed with UF Resin

Species	Compound	Relative Amount (%)	
		C	C+UF
Aldehydes	furfural	26.68	10.48
	5-methyl-2-furaldehyde	22.06	-
Aromatics	o-Xylene	18.38	0.09
Others	2-methyl-1-propylene	17.64	-
	2-acetylfuran	16.68	1.75
	butyrolactone	-	5.51
Carboxylic acid	2-hydroxy-2-methylbutyric acid	-	5.24
Ketones	2-oxobutyl acetate	-	18.53
	6-methyl-3,4-dihydro-2-pyranone	-	5.31
	3-Methyl-1,2-cyclopentanedione	-	4.10
	diacetone alcohol	-	3.46
	2,5-dihydro-3,5-dimethyl-2-furanone	-	3.02
	5-methyl-2(5H)-furanone	-	2.64
	2,3-dimethyl-2-cyclopenten-1-one	-	2.43
	4-hydroxy-2,5-dimethylfuran-3-one	-	2.05
	2-methyl-2-cyclopenten-1-one	-	5.33
Nitrogenous compounds	N-methyl-2-ynyl-1-amine	-	4.14
	2,4,4-trimethyl-5H-1,3-oxazole	-	8.71

Table 4. Main Components of the Pyrolysis Liquids from Lignin Before and After Being Mixed with UF Resin

Species	Compound	Relative Amount (%)	
		L	L+UF
Aromatics	phenol	31.69	-
	2-methoxy-phenol	23.34	0.13
Ketones	diacetone alcohol	27.72	28.59
	4-methyl-3-penten-2-one	17.25	5.26
	4-amino-4-methyl-2-pentanone	-	6.26
	2,2,6,6-tetramethylpiperidin-4-one	-	5.49
Nitrogenous compounds	N,N,N,N-tetramethyl-1,4-diamino-2-butene	-	42.51
	4-amino-4-methyl-2-pentanone	-	6.26
	2,2,6,6-tetramethylpiperidin-4-one	-	5.49
	1-methyl-3-(1,1-dimethyl-ethyl)-pyrrole	-	4.32
	N-methylcyclopentanamine	-	2.99
	(3S)-amino-5-methyl-(2R)-hexanol	-	2.75

Table 4 shows that the components of the pyrolysis liquid from lignin were simple and included phenol (31.7%), 2-methoxy-phenol (23.3%), diacetone alcohol (27.7%), and 4-methyl-3-penten-2-one (17.2%). The addition of the UF resin resulted in the formation of nitrogenous compounds and increased the variety of compounds in the

pyrolysis liquid. During pyrolysis, the cleavage of lignin molecule chains and rearrangement of fragments led to the formation of phenolic compounds, which were the major pyrolysis products from lignin. The phenolic compounds in the pyrolysis liquid from lignin had a methoxy chain, which resulted from the existence of methoxy groups in the lignin structure. With the addition of the UF resin, the major constituent of the pyrolysis liquid from L+UF was N,N,N,N-tetramethyl-1,4-diamino-2-butene with a relative amount of 42.5%. Other nitrogenous compounds, such as 4-amino-4-methyl-2-pentanone (6.26%), 2,2,6,6-tetramethylpiperidin-4-one (5.49%), and 1-methyl-3-(1,1-dimethyl-ethyl)-pyrrole (4.32%), were also detected in the pyrolysis liquid from L+UF. These nitrogenous compounds were generated by the concerted reaction of the lignin and UF resin. The chemical structure of the lignin mainly consisted of phenyl propane monomers, followed by many branched chains, such as methoxy and aliphatic hydroxyl groups. Under the pyrolysis conditions, these branched chains, such as aliphatic hydroxyls, and C-C and C-O bonds, were cleaved because of the relatively poor thermal stability of the chains, while the C-C and C-O bonds of the aromatic nuclei were relatively stable. Reaction with open rings does not occur easily. With the addition of the UF resin, the relative content of 2-methoxy-phenol decreased from 23.3% to 0.13%, and phenol was not detected. However, a large amount of piperidine and pyrrole derivatives were found in the pyrolysis liquid from L+UF. It was inferred that the UF resin promoted the ring-opening reaction in lignin.

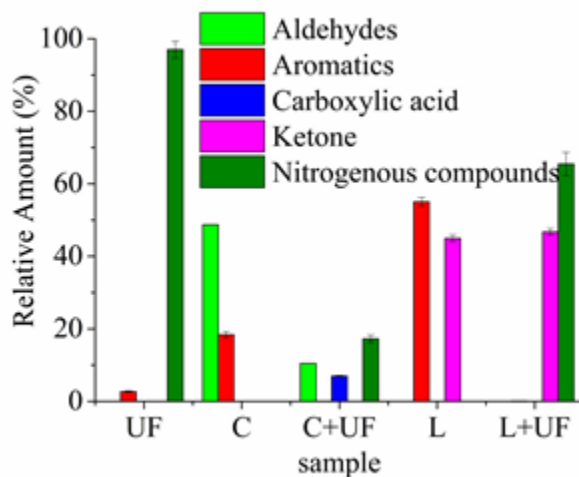


Fig. 6. Various species of compounds in the pyrolysis liquids from the UF resin, and cellulose and lignin before and after being mixed with the UF resin

Zhang *et al.* (2014) discovered that the UF resin pyrolysis liquid mainly consisted of nitrogen-containing substances, in which the major compound was N-formyl amine. Other components in the liquid included hexahydroxy N-containing heterocyclic compounds and pentabasic N-containing heterocyclic compounds, such as pyridine, pyrimidine, and piperazine. Figure 6 shows the relative amounts of compounds in the pyrolysis liquids from cellulose and lignin before and after being mixed with the UF resin. With the addition of the UF resin, the relative contents of the aldehydes and aromatics dramatically decreased, and carboxylic acid and nitrogenous compounds, which did not exist in the pyrolysis liquid from cellulose, were detected. The relative

contents of carboxylic acid and nitrogenous compounds were 5.2% and 12.8%, respectively. With the addition of the UF resin, the relative content of the ketones was almost unchanged, but the number of ketone species in the pyrolysis liquid from lignin increased. The UF resin had a remarkable influence on the relative contents of aromatics and nitrogenous compounds. It was found that the relative content of nitrogenous compounds reached up to 64.3%, whereas the relative content of aromatics was reduced from 55.0% to 0.13%. The nitrogenous compounds in the L+UF pyrolysis liquid did not only originate from the pyrolysis products of the UF resin, and may have been produced by the concerted reaction of the UF resin and lignin. It was speculated that the process of biomass component pyrolysis was influenced by interaction between the biomass components.

The antibacterial components of wood biomass pyrolysis liquids are generally carboxylic acid and phenols (Ma *et al.* 2011). The pyrolysis liquids of wood-based panels made the antimicrobial activities of the panels more obvious (Nakai *et al.* 2007). The nitrogenous heterocyclic compounds in the pyrolysis liquid had unique biological activities, such as low toxicity and good environmental compatibility, which could play an important role in the synthesis of pharmaceuticals and pesticides.

CONCLUSIONS

1. The influence of UF resin on the pyrolysis of biomass components was studied by thermogravimetric, elemental, and component analyses. Of the three main components in biomass, the UF resin specifically inhibited the decomposition rate of cellulose and promoted thermal decomposition of lignin. For xylan, the UF resin had little impact.
2. The influence of the UF resin on the elemental mass loss focused on C and O. The loss of both elements was promoted in lignin, but only the loss of C increased in cellulose.
3. The nitric gases generated during pyrolysis were HCN and NH₃, as N in the UF resin tended to become transformed into NH₃, and HCNO was not detected.
4. The influence of the UF resin on the pyrolysis liquid from C+UF and L+UF mainly affected the nitrogen compounds. Based on the results of the influence of UF resin on the pyrolysis of three components, there should be further investigation into the transformation mechanisms of nitrogen.

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