Thermal properties of biomass tar at rapid heating rates

Abstract: Gasification of biomass tar from by the biomass pyrolysis and gasification is a valuable resource for renewable energy, providing chemicals, a precursor to carbon material precursor and could be potentially a raw material of for liquid fuel. In this research, experimental studies of via thermal gravimetric analysis (i.e., TGA) of biomass tar have been carried out under were implemented at three rapid heating rates (i.e., 10k / min, 50k / min, 100 k / min, respectively) and in a nitrogen atmosphere. Based On the basis of analysis analytical methods utilized in thermal dynamics and physical chemistry, the results showed that the thermogravimetric curve (i.e. TG) of the biomass tar has moved to in a high-temperature direction with the an increase of in the heating rate. The greater the heating rate, the steeper the curve and the lower the resolution, the lag phenomenon of the temperature was being more significant. At the same time Concurrently, a differential thermal analysis (i.e. DTA) was one of thermal analysis the methods employed to study on the relationship between the temperature difference and the temperature or time of the tested substance and a reference substance. The peak temperature and maximum reaction rate of the differential thermal analysis curve (i.e. DTA) increases increased as the heating rate, the volatiles and molecules the molecular residence time of the biomass tar could be was shortened at a higher heating rate, and could thereby potentially inhibiting the generation of carbon and enlarge increasing the production of liquid fuel and increase the yield of liquid fuel.

Keywords: biomass tar, rapid heating rate, thermal dynamics, thermal weightlessness *1 [English Editor's Note #1: All keywords should appear in the Abstract.]

1 Introduction

Energy is the a basic material base of in national economy, [\leftarrow delete comma] economies and also the a basic primary condition of for human survival. Biomass is a renewable energy source with having advantages of fossil fuel properties, [<<u>delete</u> comma] such as storage capacity, renewable renewability, transformation transformability, and pollution-free, etc freedom from pollution ^[1,2,3]. Green plants convert solar energy into chemical energy by the use of photosynthesis in their chlorophyll-containing [*c*notice inserted hyphen] cells and subsequently store this energy in the biomass, where each mole of carbon fixed carbon represents about 470 kJ of energy absorbed ^[4,5] (Yuan et al., 2005; Zhang et al., 2002). The exploitation and utilization of biomass has been widely attentioned in the received much world-wide attention, and it occupies occupying an important position in the energy systems, wherein it is only weaker than only coal, oil and natural gas in primary energy, which is [are] considered the world's fourth-largest *2 [\leftarrow notice inserted hyphen] energy source[s] ^[6]. Biomass is generally composed of carbon, hydrogen, oxygen, nitrogen and other components of the complex hydrocarbons derived from plant, animal and microorganism renewable organics organic microorganisms ^[7,8,9](Serder 2004; Yang et al., 1994; Sheng et al., 1997). At present, the biomass conversion technology mainly includes direct combustion technology, biological conversion technology and thermo-chemical conversion technology. In recent

years, [\leftarrow insert comma] biomass gasification technology is has developed into a reliable biomass utilization technology developing rapidly in recent years, [\leftarrow delete comma] utilizing thermo-chemical treatments, [\leftarrow notice inserted comma] which use Biomass gasification technology is a thermo-chemical treatment technologies ,Thermochemical treatment techniques is the use of small amounts of air and oxygen as gasifying agents at elevated temperatures to convert the organic matter in the process of into combustible gas^[10,11,12]. Through thermochemical transformation, including pyrolysis and gasification, biomass generates gases, liquids and solid fuels which can partially be the serve as partial substitutes for fossil fuels. However, tar is an inevitable by-product in the biomass conversion process, [\leftarrow insert comma] and the presence of which may cause operating problems like such as blockages and corrosions which that reduce the efficiency of biomass in production^[13] (López et al. 2010). [Begin new paragraph]

* <u>English Editor's Note #2</u>: What is the noun that "which is" refers to? Is it "coal" or "oil" or "gas"? If the referent is plural, the verb must be revised to "are"; however, referring to more than one of the aforementioned nouns as "fourth-largest" does not make good sense as you have worded it. Do you mean that these three fossil fuels, *as a group*, constitute the "fourth-largest energy source"?

The Thermo-chemical conversion technology has been the principal focus in the study of biomass conversion, [\leftarrow delete comma & insert period \rightarrow]. In the process of biomass pyrolysis gasification or char conversion, [*insert comma*] have liquid residue generation occurs, [\leftarrow delete comma & insert period \rightarrow]. Biomass tar is the fluid residue from formed in the process of the during pyrolysis gasification or coking reaction conversion of biomass in the a furnace for combustible gas or straw char, under the condition in an environment of a small amount of air or oxygen is used as the gasification agent and furnace a temperature over above 600 $^{\circ}C^{[14]}$. In order to realize achieve liquid fuel conversion of biomass tar and its clean utilization, a deep clear understanding of the thermal its weightlessness of biomass tar and its combustion characteristics is particularly important. The biomass pyrolysis process contains includes a variety of chemical reactions and intermediate states, the reaction mechanism is being very complex, \leftarrow delete comma & insert period \rightarrow]. and Thermogravimetric and differential thermal analysis has been widely used by scientists as the an important research methods to methodology for studying the process and characteristics of biomass pyrolysis has been widely used by scientists. Besides In addition to the structure of biomass tar, the its thermal properties also play a crucial role in its successful control, conversion and further application for preparing carbon materials. Biomass tar decomposition mainly occurs due to cracking, steam reforming, dry reforming and carbon formation reactions^[15] (Li & Suzuki 2009b). Therefore, the thermal decomposition of biomass tar still has not been fully characterized and understood. [*insert period*] until now and Moreover, further systemic [systematic?] *3 study on tar is needed to reveal its complex thermal degradation mechanisms ^[16].

*<u>English Editor's Note # 3</u>: Compare the definitions of "systemic" [http://www.merriamwebster.com/dictionary/systemic] and "systematic" [http://www.merriamwebster.com/dictionary/systematic, (especially 3a & 3b)]. I think you mean "systematic" in this context.

In this paper study, the thermogravimetric experiments of on biomass tar under at various high heating rates have been were completed conducted by using the method of thermogravimetric and differential thermal analysis. The thermal weightlessness characteristics of biomass tar under the condition of at rapid heating rates has been were studied in order to provide a scientific reference for developing a technology for the clean conversion technology development of biomass tar to living organic material tar to

provide a scientific reference as a basis for further research. So Thus, the objective of this study research was to study the chemical composition and thermal degradation mechanism of biomass-derived tar in order to better control, separate and utilize this promising biomaterial.

1 Materials and methods

1.1 Samples

In this paper, The tar used in this paper study was collected from the pyrolysis gasification residue pool of at the Xigou Biomass Fuel Gas Plant of in Xihe town, Yangcheng County, Shanxi Province, China. The requisite temperature of for biomass pyrolysis gasification is 550 °C. Before the TGA experiments, the distilled tar was dried in a vacuum oven at 80°C for 4 hours, and then it was manually ground into small particles below 100 mesh (i.e. 254 micron). The Elemental and industrial analysis analyses of the maize straw biomass tar samples were tested by a Vario MACRO cube v2.0.9 type elemental analyzer, a GYFX-8000 type industrial analyzer and a ZDHW-5Z type automatic calorimeter, [←insert comma] all based on China's national standards: [←insert colon] GB476-1991 and GB/T212-2001. The results of the elemental and industrial analysis analyses of the maize straw biomass tar samples are shown in Table 1.

|--|

Weight/mg	Elemental analysis/wt%			Industrial analysis/wt%			/wt%	
-	Ν	С	Н	S	Moisture	Ash	Volatile	Fixed carbon
38.870	1.392	48.900	7.732	0.232	33.40	0.90	60.02	5.68
							Volatility	1

1.2 Experimental method

In this paper research, the thermogravimetric and kinetics kinetic characteristics of biomass tar samples were studied under non-isothermal conditions by using the a STA 6000 type synchronous thermal analyzer made in manufactured by PerkinElmer, [*insert* comma] Inc. According to In accordance with the thermogravimetric analysis analytical method, about 10 mg of the biomass tar sample was placed into a sample plate, [< delete comma & insert semi-colon \rightarrow]; and then, [\leftarrow insert comma] three heating rates were set by the temperature control unit of at 10 °C / min, 50 °C / min, [←insert comma] and 100 °C / min, [*ising the set by the temperature control unit respectively.* The carrier gases used in the experiment was were high-purity [< notice inserted hyphen] nitrogen and air, [*isert comma*] respectively, with the gas flow at 60 ml/min, the initial temperature at 30 °C, and the terminal temperature at 900 °C. The main performance parameters of the STA 6000 type synchronous thermal analyzer were within a temperature range of 15° C ~1000 °C, a heating rate of 0.1~100 °C/min, a sample capacity of 1500mg, a balance sensitivity of 0.1 ug, a calorimetry calorimetric precision accuracy of $\pm 2\%$, a temperature accuracy of ±0.5%, and a temperature repeatability of ±0.5%, etc.* *<u>English Editor's Note #4</u>: (a) It would be more *efficient* to list the aforementioned performance parameters in a Table, thereby eliminating the need for words such as "within," "a," "of" & "and." (b) The use of "etc." weakens a scholarly statement; therefore, avoid.

2 Results and discussion

2.1 The Chemical components of the biomass tar samples *

*<u>English Editor's Note #5</u>: It is permissible--and desirable for the sake of brevity--to use headline grammar in headers of sections & sub-sections and also in table & figure captions. Headline grammar omits definite articles that are required in normal prose.

The chemical components of the biomass tar samples was were determined by gas chromatography-mass spectroscopy (i.e. GC-MS) method, as shown listed in Table 2.

2.2 Gas Chromatography–Mass Spectrometry

The dried tar was dissolved in ethyl acetate with having a ratio of (tar:solvent=1g:10ml) $[\leftarrow \underline{delete} \text{ both parentheses}]$ at room temperature. The solution was centrifuged and the upper liquid fraction was collected and diluted to a weight concentration of 0.5% for the analysis by gas chromatography-mass spectroscopy (GC-MS) (Table2). An HP-3800 gas chromatograph equipped with a split/splitless injector and an HP-8410 automatic sampler with splitless injection was were used. The injector was maintained at 250°C, [*insert* commal and helium having a flow rate of approximately 1.0mL min-1 was used as the carrier gas with a flow rate of approximately 1.0mL min 1. The GC was equipped with a 30m (length) \times 0.25mm (inner diameter) Hewlett Packard HP-5MS capillary column with the a film of 0.25mm thickness. The oven temperature program was kept at 40°C for 3 min, [< delete comma] and then subsequently heated to 200°C at 15°C min-1, followed with by further heating to 280°C at 1°C min-1 and held at 280°C for 5min. The end of the column was directly introduced into the ion source of an HP 5970 mass selective detector (MSD) with in electron ionization (EI) mode. The mass spectrometer conditions were as follows: transfer line, [<insert comma] 270°C, [<<u>delete</u> comma & insert semi $colon \rightarrow$]; ion source, [\leftarrow insert comma] 250°C, [\leftarrow <u>delete</u> comma & insert semi-colon \rightarrow]; and electron energy, [*insert comma*] 70eV. The data acquisition was done accomplished with by HP-UX chemstation software using an HP-UNIX computer and an NBS mass spectra library database. The relative content of each component was obtained determined by dividing the individual peak area with by the total peak areas for in the chromatogram of the biomass tar.

Component	Formula	Molecular Weight	Relative Contents
			(%)
4-ethyl-phenol	C8H10O	122	9.44
Phenol	C6H6O	94	7.49
3-methyl-phenol	C7H8O	108	6.38
Naphthalene	C10H8	128	6.14
Acenaphthylene	C12H8	152	5.69
2,3-dihydro-Benzofuran	C8H8O	120	5.30
Anthracene	C14H10	178	4.61
2-methyl-phenol	C7H8O	108	3.51
4-ethyl-2-methoxy-phenol	C9H12O2	152	3.43
1-methyl-naphthalene	C11H10	142	3.26
2-methyl-naphthalene	C11H10	142	2.58
2,5-dimethyl-phenol	C8H10O	122	2.26
2-methoxy-4-vinylphenol	C9H10O2	150	2.24
2,4-dimethyl-phenol	C8H10O	122	2.22
4-ethyl-3-methyl-phenol	C9H12O	136	2.02
1H-phenalene	C13H10	166	2.02
Dibenzofuran	C12H8O	168	1.60
2-methoxy-phenol	C7H8O2	124	1.59

Table 2 Chemical components of the biomass tar by GC-MS analysis

2,3-Dimethylhydroquinone	C8H10O2	138	1.58
Biphenyl	C12H10	154	1.56
2,6-dimethoxy-phenol	C8H10O3	154	1.55
1,7-dimethyl-naphthalene	C12H12	156	1.53
Fluoranthene	C16H10	202	1.45
2,6-dimethoxy-4-(2-propenyl)-	C11H14O3	194	1.43
phenol			
1,1'-(1,3-butadiyne-1,4-diyl)bis-	C16H10	202	1.22
benzene			
2-ethenyl-naphthalene	C12H10	154	1.20
Phenanthrene	C14H10	178	1.11
2-ethyl-phenol	C8H10O	122	1.03
Others			14.56

Table 3.	The Melting point and	d boiling point <mark>s</mark> of	f main chemica	l components for	the in
		biomass ta	r		

Component	Melting point (°C)	Boiling point (℃)
4-ethyl-phenol	46	219
Phenol	40.6	181.9
3-methyl-phenol	10.9	202.8
Naphthalene	80.5	217.9
Acenaphthylene	92-93	265-275
2,3-dihydro-Benzofuran	-37	194
Anthracene	218	342
2-methyl-phenol	30-32	191
4-ethyl-2-methoxy-phenol	-30	153
1-methyl-naphthalene	-22	240-243

As can be seen listed from in Table 2, the main components of biomass tar is are 4ethyl-phenol, Phenol, 3-methyl-phenol, Naphthalene, Acenaphthylene; 2,3-dihydro-Benzofuran; Anthracene; 2-methyl-phenol; 4-ethyl-2-methoxy-phenol; and 1-methylnaphthalene and so on, [\leftarrow delete comma & insert period \rightarrow]. Which has The most abundant component the highest content is 4-ethyl-phenol of at 9.44% as 4-ethyl phenol, it's the having a melting point of 46°C, [\leftarrow delete comma] and a boiling point of 219°C,[\leftarrow delete comma & insert period \rightarrow]. Anthracene the formula for elements of (C8H10O) [\leftarrow insert parentheses & delete comma \rightarrow], Anthracene, also is a kind of another hydrocarbons hydrocarbon component, in biomass tar having a content of up to 4.61%.The chemical and physical properties of the biomass tar has have a greater influence on the thermal weight loss characteristics, especially the boiling point of Acenaphthylene, the highest of the components, [\boxtimes insert comma] reaches reaching to 265°C, [\boxtimes delete comma] which is the highest of the components. In addition Moreover, the analyzed biomass tar was a complex mixture, and it's the chemical composition of which had a significant influence in on the properties of tar thereof and it's the derived biomaterials.





* English Editor's Note #6: The bar-graph above is mislabeled. It should be revised to say "Figure 1."

Simultaneously Concurrently, the thermal decomposition process of the hydrocarbons was observed at within a wide temperature range at around from 250°C to 340°C, their the respective mass losses was being the fastest. Condensation and polymerization also occurred through the loss of side alky groups from the aromatic compounds. The higher the boiling point of the component, the more difficult it is to the gasification, [\leftarrow delete comma & insert period \rightarrow]. Therefore, [\leftarrow insert comma] the boiling points of the various components of which those boiling points in the thermogravimetric experiments should show different gasification trends in the condition of at rapid heating rates.

2.2 Thermogravimetric Analysis

The thermal decomposition process of the tar was characterized by a TA thermogravimetric analyzer (TGA Q50) with a resolution of 0.1µg. The experiment was carried out implemented at in the non-isothermal conditions from 30°C to 800°C at variable heating rates of 10, 50, and 100K min-1. The sample was grinded ground into powder to avoid the effect of heat transfer during the thermal decomposition process. [\leftarrow insert period] and A weight of 5mg was selected for thermal analysis under in a nitrogen atmosphere at the a flow rate of 60ml min-1. At least three samples were run for at each heating rate to guarantee the repeatability and reliability of the data obtained. The weight loss curves (TG) and differential thermogravimetric curves (DTG) against the temperature of the samples were recorded for thermal kinetic analysis. In order to avoid the effect of adsorbed water on the thermal decomposition process, all the samples were dried in a vacuum at 80°C for 48h. The thermogravimetric and differential thermal analysis curve of biomass tar.

2.3 The Thermogravimetric and differential thermal analysis curves of biomass tar

The thermogravimetric (TG) and differential thermal analysis (*DTA*) curves of biomass tar from corn stover in at different heating rates had been were determined by a synchronous thermal analyzer, as shown plotted on the graphs in Figure 2.

English Editor's Note #7: WHY did you use the acronym "*DTA*" in the above text but "*DTG*" in the legend of the graphs below? The discrepancy should be corrected.







(b)



(C)

Fig.2 Thermal analysis curves of biomass tar at different heating rates

As can be seen indicated from in the Figure 2(a) and figure 2(c), the shapes of the TG curves under the condition of in a nitrogen atmosphere and at two different rapid heating rates (i.e. 10k / min, 100 k / min, respectively) was were basically the same very similar, but their the starting reaction time for each reaction was different. Figure 2 shows that the Figure 2(a) also indicates that the starting reaction temperature of the thermal weightlessness was about 100 $^{\circ}$ C when the heating speed rate was slower. When the pyrolysis reaction temperature of biomass tar was at reached 350 °C, the change trend of the change in weight loss was linear with the an increase of in temperature. Figure 1 [←WHICH Figure number?] shows that the phenomenon of weight loss was very significantly significant at about 150 °C when the heating speed rate was faster, but the change changing trend of in weight loss begun began to slow down decelerate after reaching 400 °C; [←insert semi-colon] and moreover, [←insert comma] the change of in weight loss was approximately linear with the increase of in temperature. It showed is significantly significant that the progress of biomass pyrolysis has been was affected by two different heating rates, [\leftarrow delete comma & insert semi-colon \rightarrow]; and moreover, [<insert comma] the influence of the heating rate was larger greater especially in the late reaction process. [<insert period] of late reaction especially

The Figure of 2 shows that the DTG curve had two peaks, [\leftarrow delete comma & insert semi-colon \rightarrow]: the first, [\leftarrow insert comma] peak was a rush, [\leftarrow delete comma & insert semi-colon \rightarrow]; the second, [\leftarrow insert comma] peak was wider and more obvious as the speed rate increases increased. For example, when the heating rate was 50°C/min, the thermal weightlessness process of biomass tar could be divided into four stages. [\leftarrow delete period & insert colon \rightarrow]:

(1) First Weightlessness stage below 100 $^{\circ}C$, [\leftarrow insert comma] was in which drying stage occurred. [\leftarrow delete period & insert semi-colon \rightarrow];

(2) The second Weightlessness stage between 100 °C to and 150 °C, [\leftarrow insert comma] was a very obvious peak, [\leftarrow <u>delete</u> comma] that was the in which burning stage but occurred, [\leftarrow insert comma] producing only produced water and CO₂, which was the same as completely when the heating rate was under less than10 °C / min; [\leftarrow insert semi-colon] and in this stage the cracking rate of the differential thermal analysis curve also reached its maximum at 100 °C, [\leftarrow insert comma] at this which point, [\leftarrow <u>delete</u> comma] the weight loss is was about 20%. [\leftarrow <u>delete</u> period & insert semi-colon \rightarrow];

(3) The third Weightlessness stage between 150 °C to and 400 °C, [\leftarrow insert comma] was a very wide and flat peak, that was the characterized by volatile volatility and cracking stage of the main macromolecular compounds. [\leftarrow delete period & insert semi-colon \rightarrow];

(4) The forth Weightlessness stage between 400 $^{\circ}$ C and 900 $^{\circ}$ C, [\leftarrow insert comma] was a closely smooth and straight closely, and in which the cracking rate began to reduce and the weightlessness leveled off.

The solid residue is was approximately 20% at the a temperature of 900 °C. In both the TG and the DTG, their the change rule was similar, but their the initial cracking temperature was very different. The greater the heating rate, the higher the temperature, [\leftarrow delete comma & insert semi-colon \rightarrow]; whereas, [\leftarrow insert comma] the lower the temperature, [\leftarrow insert comma] * [insert missing words: the (comparative adjective: lower?) the (noun phrase: heating rate?)]. In the cracking process of biomass tar, the reaction was exothermic reaction after reaching the pyrolysis temperature,. [\leftarrow delete comma but keep period]

* English Editor's Note #8: I am not a mind-reader! However, my suggested words do seem reasonable in this context: the lower the heating rate.

2.4 The Influence of heating rate to on thermal weightlessness characteristics of biomass tar

The contrastive analysis of the *TG* and *DTA* curves of biomass tar from corn stover in at different heating rates (i.e. 10 °C / min, 50 °C / min, 100 °C / min, [\leftarrow insert comma] respectively) were are as shown plotted in Figure 3.





(c)

Fig. 3 The Contrastive analysis of TG and DTG curves under at different heating rates

As illustrated in Figure 3, the thermal weightlessness process of biomass tar under in a nitrogen atmosphere mainly included four main phases, [$\leftarrow delete \text{ comma & insert colon} \Rightarrow$]: i.e. (1) drying stage, (2) fast release stage of surface volatile volatility, (3) an interim stage, and (4) slow release stage of internal volatile volatility.

In the drying stage, the heating rate had a smaller influence on the evaporation of water. The *TG* curves of the three heating rates were coincidence basically coincidentally within the a temperature range from between 0°C to and 35 °C, [\leftarrow insert comma] and at 100 °C, [\leftarrow delete comma] which changed with a different heating rate. [\leftarrow insert period] From Among the DTG curves, the slope and weight loss ratios of DTG- was were the largest of all. That is to say I.e., when the reaction temperature was within the range of 35 ~ 100 °C, biomass tar the process was consisted of not only an the evaporation process of water but also including included an initial volatile starting release process, [\leftarrow delete comma & insert period \rightarrow]. and Thus, [\leftarrow insert comma] the greater the heating rate is, the more obvious the volatile releases.

In the fast-release [< notice inserted hyphen] stage of surface volatile volatility, the surface volatile of biomass tar firstly first began to cracking with the rising of rapid increase in temperature quickly, when in which the macromolecular of biomass tar

consistency was cracked into smaller molecules and generated biomass fuel gas. Therefore, there was an obvious weightlessness of in the biomass tar as in the continuous volatile escape of gas from the surface volatile continuously.

The *TG* curves showed indicate, [\leftarrow delete comma] that the weight loss of in the biomass tar gradually increased to the maximum, and the slopes of TG the curves is being approximately to linear. As can be seen from The DTG curves indicate, [\leftarrow delete comma] that the temperature of at the highest weight-loss [\leftarrow notice inserted hyphen] rate was about 100 °C when the heating rates was were at 10 °C / min and 50 °C / min, [\leftarrow insert comma] respectively. The temperature of at the highest weight-loss [\leftarrow notice inserted hyphen] rate was about 150 °C when the heating rate was at 100 °C / min. The release stage of the surface volatile volatility was a strongly endothermic process because there was an obvious peak in the DTG curves.

In The interim stage, [\leftarrow delete comma] this was the one of coexistence stage characterized by both of the a fast release of surface volatile volatility and the a slow release of internal volatile volatility. The weight loss of in the TG curves began to decrease gradually and it was a parabolic curve parabolically. The weight-loss [\leftarrow notice inserted hyphen] rate of in the *DTG* curves began to decrease approximately linearly from the maximum with as the temperature increasing increased. The changes of in the three *DTG* curves was were different, [\leftarrow delete comma & insert colon \rightarrow]: and the higher the heating rate, the steeper the slopes of *DTG* curves are.

In the slow-release [\leftarrow notice inserted hyphen] stage of internal volatile volatility, only a small amount of internal the volatile matter was slowly released by pyrolysis due to the already completed fast-release [\leftarrow notice inserted hyphen] process of surface volatile volatility has been finished. In the later stage of pyrolysis process, biomass tar only remained coke, ash content and a small amount of volatile matter remained in the biomass. Therefore, the release rate of volatile matter was lower as a result that of the very small volatile content was very little in this stage. As can be seen from indicated by the TG curves, the weight loss of in the biomass tar was reduced very gently. The end temperature of the pyrolysis was about 690 °C when the heating rate was 10 °C / min, [\leftarrow delete comma] and about 800 °C when the heating rate was at 50 °C / min or 100 °C / min. The weight-loss [\leftarrow notice inserted hyphen] rate of biomass tar was gradually reduced gradually until the same as it became equivalent with that shown in the DTG curves.

Conclusion

(3) The An experimental study consisting of a thermal gravimetric analysis (i.e. *TGA*) of biomass tar has been completed under at three conditions of heating rates (i.e. 10k / min, 50 k/ min, 100 k / min, respectively) and in a nitrogen atmosphere has been completed. The results showed the following conclusions.

(1) GC-MS techniques were used to characterize the complex structure of the biomass tar. [\leftarrow delete period] The tar was mainly composed of phenols and polycyclic aromatic hydrocarbons, [\leftarrow insert comma] and some of them which were substituted by ethyl or methoxyl. The main components in biomass tar of this study studied were the phenols and the PAH, which were similar to the compositions of tar components from in other previously studied biomass resources such as wood and bamboo ^[17](Ku & Mun 2006; Mun & Ku 2010), although the weight fraction proportions of specific chemical compounds are distinguished with each other mutually distinguishable.

(2) From Table 2 can show lists the low molecular-weight [\leftarrow notice inserted hyphen] components of the biomass tar volatized at the beginning stage of a thermal-chemical conversion process, [\leftarrow delete comma] and in which the phenols and polycyclic aromatic

hydrocarbons lost their side chains with the increasing temperature and even large molecular-weight [\leftarrow notice inserted hyphen] hydrocarbons formed by the polymerization and condensation reactions. The absorption bands at 1265cm⁻¹ and 1036cm⁻¹ were asymmetrical, [\leftarrow insert comma] and but symmetrical stretching vibrations of aryl-alkyl ethers were associated with aromatic rings. A number of hydrogen atoms were located on the aromatic rings, [\leftarrow insert comma] indicated by the bands at 830cm⁻¹ and 750 cm⁻¹, [\leftarrow insert comma] attributed to C-H out-of-plane [\leftarrow notice inserted hyphens] bending vibrations in the aromatic rings. In addition, the IR stretching frequency of the carbonyl groups at 1686cm⁻¹ was lower than the typical stretching frequency that of carbonyl at 1715cm⁻¹ in ketone, which was a phenomenon probably caused by the conjugation of carbonyl groups with the aromatic structures and the delocalization of π electrons^[18] (Silverstein et al. 2005).

The results obtained showed prompted the following conclusions generalizations.

(4 1)The thermal weightlessness process of biomass tar under in a nitrogen atmosphere mainly included consists of four main phases, [\leftarrow delete comma & insert colon \rightarrow]: i.e. (1) drying stage, (2) fast release stage of surface volatile volatility, (3) an interim stage, and (4) slow release stage of internal volatile volatility.

(5 2)The TG curves of biomass tar moved move to high temperatures with increases of in the heating rate. The greater the heating rate is, the steeper the curve and the lower the resolution are. The lag phenomenon phenomena of the respective temperatures was are more serious.

(6 3)The peak temperature and maximum reaction rate of *DTA* curves increase with the heating rate.

(7 4)The volatiles volatility and molecules molecular residence time of biomass tar are shortened at higher heating rates.

Acknowledgments

[Redacted for anonymity]

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English Editor's Note #9: I am stopping my annotated corrections of capitalization and punctuation at this point. It is obvious that the typist(s) neglected to carefully observe the reference style exemplified on page 5 in the...Author Guidelines.... It is very tedious and time-consuming to make this kind of corrections—a task which the typist(s) **ought** to be able to do without editorial assistance.

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