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3 **Pyrolysis of Rice husk and Corn stalk in Auger Reactor: Part 1.**  
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5 **Characterization of Char and Gas at Various Temperatures**  
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9 *(To be submitted to Energy and Fuels)*  
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33 **Abstract**  
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37 In the series study, rice husk and corn stalk have been pyrolyzed in an auger  
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39 pyrolysis reactor at various pyrolysis temperatures of 350, 400, 450, 500, 550 and  
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41 600 °C in order to investigate the effect of the pyrolysis temperature on the pyrolysis  
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43 performance of the reactor and physicochemical properties of pyrolysis products (this part focus  
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45 on the char and gas, the next part focus on the pyrolysis liquid). The results have shown that  
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47 the pyrolysis temperature significantly affects the mass yields and properties of the  
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49 pyrolysis products. The mass yields of pyrolysis liquid and char are comparable to  
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51 those reported for the same feedstocks processed in fluidized bed reactors. With the  
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53 increase of the pyrolysis temperature, the pyrolysis liquid yield shows a peak at  
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55 500 °C, the char yield decreases while the gas yield increases for both feedstocks. The higher

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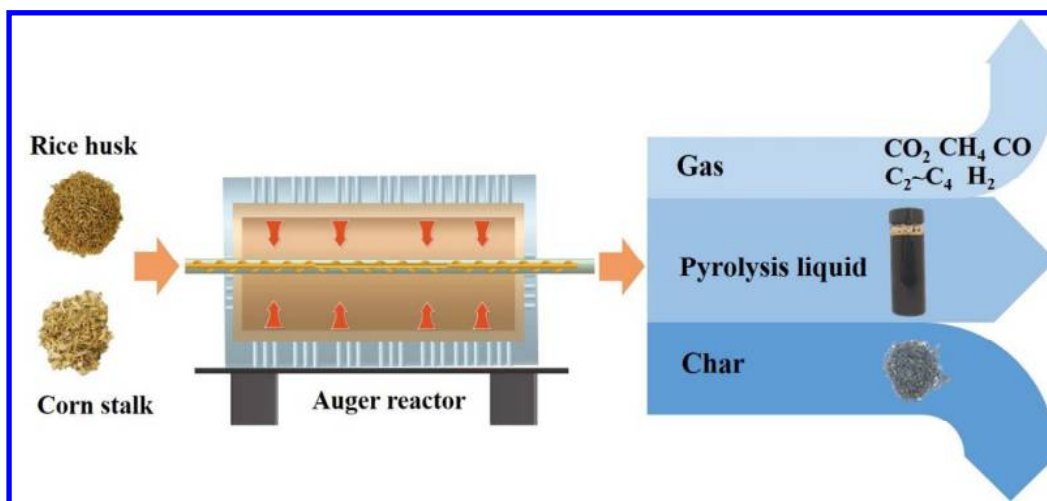
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heating value (HHV) and volatile matter content of char increase as the pyrolysis temperature increases from 350 to 600 °C. The gases obtained from the pyrolysis of rice husk and corn stalk mainly contain CO<sub>2</sub>, CO, CH<sub>4</sub>, H<sub>2</sub> and other light hydrocarbons, the molar fractions of combustible gases increase therefore their HHVs subsequently increase with the increase of the pyrolysis temperature.

**Key words:** Biomass Pyrolysis; Auger Reactor; Char; Pyrolysis Liquid; Gas

### Graphical Abstract



## 1 Introduction

Nowadays, China is in the period of rapid growth and development and the energy supply cannot meet the demand of energy consumption.<sup>1,2</sup> Except the import of petroleum from foreign countries, the development of renewable energy including biomass has received more and more attentions. Pyrolysis, the thermal decomposition process occurring in the absence of oxygen, has a great potential in converting biomass into high energy density products: pyrolysis oil, char and pyrolysis gas.<sup>3</sup> Pyrolysis is the precursor of combustion and gasification, however pyrolysis has the

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3 advantage of producing a liquid fuel which can be easily stored, transported, and used  
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5 for chemical products as well as heat and power generation.<sup>4</sup>  
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7 The yields and properties of the pyrolysis products vary over several factors  
8 including the type of feedstocks, pyrolysis processing conditions, and reactor type.<sup>5</sup>  
9 Fast pyrolysis in fluidized bed reactors is a relatively mature technology and it is  
10 frequently used in industrial-scale pyrolysis oil production. This process is  
11 characterized by very high heating rates ( $> 1000 \text{ }^\circ\text{C s}^{-1}$ ), short pyrolysis vapor  
12 residence time ( $< 2 \text{ s}$ ) and rapid condensation rate, thus the process can achieve high  
13 pyrolysis liquid yield up to 75 wt%.<sup>6</sup> However, this type reactor has limitations such  
14 as: (1) large space requirements as reactor vessels with a riser and downer over 10  
15 meters high in industry are often required for achieving satisfactory solid fluidization;  
16 (2) additional pumping power (thus higher energy costs) is needed to meet the  
17 requirement for suspension or circulation of solid fluidizing medium; (3)  
18 energy-intensive pre-treatment processes are required because of finely ground  
19 feedstock; (4) solid fluidizing medium may be present in solid product resulting in  
20 contaminated char product.<sup>7</sup>  
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33 Different pyrolysis reactor types present different arrangement, are established  
34 for different application purposes, and used to process different materials.<sup>8</sup> Among  
35 those configurations, auger reactor pyrolysis is one of the most popular technologies  
36 being evaluated nowadays, as does not require large volumes of carrier gases and it  
37 can process a wide range of biomass particles.<sup>9</sup> Due to these advantages, auger  
38 reactors were developed and commercialized by Renewable Oil International (RIO,  
39  $200 \text{ kg h}^{-1}$ ), and ABRI-TECH Inc. ( $1 \text{ dry ton d}^{-1}$ ).<sup>10</sup>  
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47 The use of auger reactor for pyrolysis of biomass has been reported in the  
48 literature. For example, Puy et al.<sup>11</sup> investigated the effect of the temperature, solid  
49 residence time, and feedstock flow rate, on the reactor performance and pyrolysis oil  
50 properties during the pyrolysis of forest residues in an auger reactor. The results have  
51 shown that the greatest yields of pyrolysis liquid and optimum product  
52 characterization were obtained at the pyrolysis temperature of  $500 \text{ }^\circ\text{C}$ , and under a  
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3 solid residence time longer than 2 min. In other work, Thangalazhy-Gopakumar et al.  
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5<sup>12</sup> performed the pyrolysis of pine wood in an auger reactor at different temperatures  
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7 and analyzed the physicochemical properties of pyrolysis oil. The results have shown  
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9 that 475 °C is an appropriate temperature for the production of pyrolysis oil from the  
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11 pyrolysis of pine wood in this particular reaction system. Also the pyrolysis oil  
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13 properties from a continuous auger reactor and a fluidized bed system were compared  
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15 by Ingram et al.,<sup>13</sup> using wood and bark as feedstocks. The results have shown that  
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17 auger reactor pyrolysis can produce pyrolysis oil comparable to that produced in  
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19 fluidized bed pyrolysis process either in mass yield or chemical composition.  
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21 Bhattacharya et al.<sup>14</sup> studied the co-pyrolysis of pine wood and three plastics at  
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23 different temperatures in a 2 kg h<sup>-1</sup> lab scale auger reactor. The obtained pyrolysis  
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25 liquids exhibited higher quality than pine bio-oil. Martínez et al.<sup>15</sup> investigated the  
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27 co-pyrolysis of forestry wastes and waste tyres in a continuous auger reactor and obtained that the  
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29 addition of waste tyres to the biomass blend was beneficial for the quality of the new bio-oils.  
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31 Veses et al.<sup>16</sup> performed the catalytic pyrolysis of forest pine wood in an auger reactor  
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33 using calcium-based catalysts and observed that the addition of low cost calcium  
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35 based catalysts could improve the bio-oil properties.

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37 The above studies mainly focused on the pyrolysis of woody biomass feedstocks  
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39 in auger reactors and the properties of pyrolysis oil under different circumstances  
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41 including different temperatures, co-pyrolysis with plastics and tyres, and catalytic  
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43 pyrolysis. However, up to now, there are very few researches investigating the effect  
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45 of the pyrolysis temperature and herbaceous biomass on the characteristics of char  
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47 and gas in auger reactors.

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49 Thus, the main aim of this series papers is to study the effect of the pyrolysis  
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51 temperature on the physicochemical properties of pyrolysis products from the  
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53 pyrolysis of biomass in an auger pyrolysis reactor. This part (Part 1) focuses on char  
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55 and gas, whereas the next part (Part 2) focuses on the study of the pyrolysis liquid.  
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57 The results of this work can be used to check if the thermal energy required for drying  
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59 and pyrolysis reaction can be supplied by gas and char.  
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## 2 Experimental Section

### 2.1 Feedstock Preparation

China is the largest agricultural country in the world and is rich in rice husk and corn stalk. According to Ji,<sup>17</sup> there is an annual production of about 40 and 72 million tons of rice husk and corn stalk respectively. Considering this wide availability, both rice husk and corn stalk were chosen as feedstocks for this investigation.

The rice husk and corn stalk samples used in this work were collected from Zhangzhou, Fujian Province and Datong, Shanxi Province in China, respectively. Rice husk sample was processed as received from the farm. The collected corn stalk sample was first ground into about 5 cm particles in a straw crusher with 1250 r min<sup>-1</sup> rotating speed. Further size reduction was accomplished by using a cutting mill with a 10 mm screen size. The particle size of the corn stalk sample was reduced to about 1 cm. **Figure 1** shows the corn stalk samples with different sizes and the as-received sample of rice husk. Both samples were dried before the pyrolysis experiments. The samples were spread out on a drying rack for air-drying to a moisture content below 20%. After treatment, the samples were stored at ambient conditions in sealed bags.



**Figure 1.** Rice husk sample and corn stalk samples with different sizes

The moisture, ash and volatile matter contents of the samples were determined in accordance with the ASTM standards E1756-08,<sup>18</sup> D1755-01,<sup>19</sup> and E872-82,<sup>20</sup> respectively.

The ultimate analyses of rice husk and corn stalk were carried out by using a Flash 2000 Organic Elemental Analysis CHON-S Meter (Thermo Fisher Scientific, USA). The oxygen content (dry and ash free basis) was calculated by difference.

The higher heating values (HHVs) of rice husk and corn stalk samples were measured by using an oxygen bomb calorimetry (XRY-1 A+, Shanghai Changji Geological Instrument Co., Ltd, China) in accordance with the ASTM standard D5865-13.<sup>21</sup>

The physicochemical analysis results of both feedstocks are shown in **Table 1**.

**Table 1.** Proximate and ultimate analysis results of rice husk and corn stalk

	Unit	Rice husk	Corn stalk
<i>Proximate analysis<sup>a</sup></i>			
Moisture	wt. %	16.7	17.6
Ash	wt. %	13.3	8.2
Volatile matter	wt. %	56.0	61.7
Fixed carbon <sup>b</sup>	wt. %	14.0	12.5
<i>Ultimate analysis<sup>c</sup></i>			
C	wt. %	48.78	47.09
H	wt. %	6.59	6.17
N	wt. %	3.73	9.14
S	wt. %	---	0.05
O <sup>d</sup>	wt. %	40.90	37.55
HHV	MJ kg <sup>-1</sup>	16.15	15.81

<sup>a</sup> wet basis

<sup>b</sup> by difference

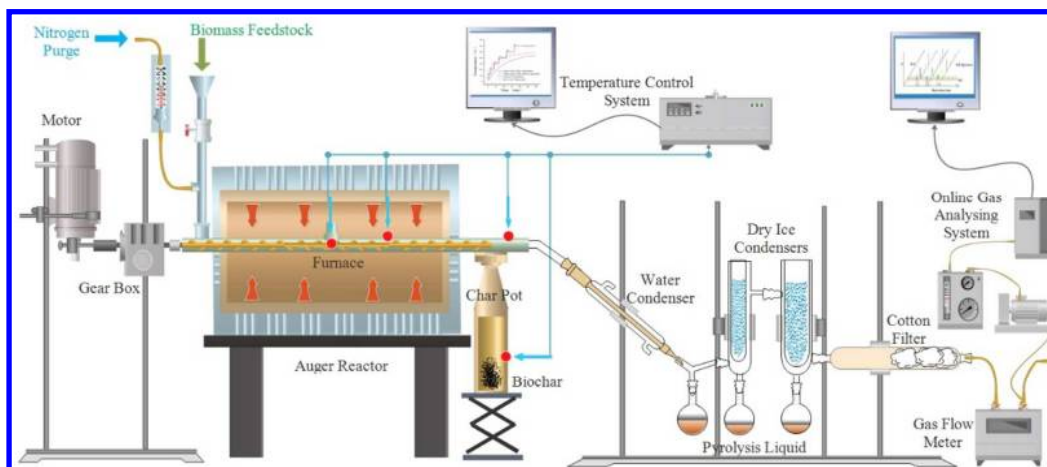
<sup>c</sup> dry ash-free basis

<sup>d</sup> by difference

## 2.2 Auger Pyrolysis System

The pyrolysis experiments were conducted in a  $350 \text{ g h}^{-1}$  stainless steel bench-scale auger pyrolysis system. This system was designed and constructed at the European Bioenergy Research Institute (EBRI), Aston University, UK. The auger reactor is compact, does not use a heat carrier and operates continuously.

**Figure 2** shows the schematic diagram of the auger pyrolysis system. The pyrolysis system consists of the following main components: biomass feeding sub-system, auger reactor sub-system, product recovery sub-system, data acquisition and control sub-system.



**Figure 2.** Schematic diagram of auger pyrolysis system

The main component of the biomass feeding sub-system is a simple volumetric screw feeder. The auger reactor system is completely constructed from stainless steel. The reactor kiln is 2.6 cm in diameter and 50 cm in length. A Carbolite VST 12/400 2kW electric furnace is used for providing heat for the pyrolysis reactor. The product recovery sub-system consists of one cool water condenser, two dry ice condensers, and a cotton filter. The data acquisition and control sub-system includes four thermocouples which are arranged at different positions (two of them were placed

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3 inside the auger reactor in order to monitor of the actual pyrolysis temperature, and  
4 another two were placed closely outside the wall of screw end and char pot,  
5 respectively), online gas chromatography, and gas flow meter.  
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9 The experiments were performed under six different pyrolysis temperatures (i.e.  
10 350, 400, 450, 500, 550 and 600 °C), in order to investigate the effect of temperature  
11 on both the product yields and the physicochemical properties of the pyrolysis  
12 products (char and gas in Part 1 and pyrolysis liquid in Part 2). For each experiment, a  
13 fixed amount of raw material was fed into the auger reactor at a constant feeding rate  
14 of 2 g min<sup>-1</sup>. The reactor was maintained under an inert atmosphere by purging  
15 nitrogen before the feedstock is fed into the reactor. The temperature in the reactor  
16 was heated to the desired temperature and held for 30 minutes to avoid the  
17 temperature gradient inside the reactor. The auger speed applied was 12 rpm, which  
18 corresponds to a solid residence time of 60 s. This is longer than the solid residence  
19 time in typical fluidized bed reactors.<sup>22</sup> However, pyrolysis volatiles move to the  
20 condenser within about 5 s. Therefore, the residence time of pyrolysis volatiles in this  
21 auger reactor are longer than that in fluidized bed reactors (about 2 s).<sup>23</sup> The samples  
22 from the feeding system was then passed to the reactor. The pyrolysis temperature  
23 inside the reactor was measured by two thermocouples. The pyrolysis temperature  
24 was maintained constant throughout each experiment. All liquids obtained from three  
25 condensers were mixed together to measure the total yield of pyrolysis liquid. The  
26 char was collected after cooling the reactor to room temperature. The gas produced  
27 during pyrolysis was filtered by cotton.  
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### 47 **2.3 Char analysis**

48 After each pyrolysis experiment, the cooled char was collected and weighted.  
49 Then it was placed in a sealed plastic bag for further physicochemical analysis. The  
50 collected char samples were dry, and therefore the properties of char samples were  
51 presented on a dry basis.  
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3 The ash and volatile matter contents of char was measured in accordance with  
4 the ASTM standard D1762 – 84.<sup>24</sup> The fixed carbon content of char was calculated  
5 by difference.  
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9 The ultimate analysis of char was carried out by using a Flash 2000 Organic  
10 Elemental Analysis CHON-S Meter (Thermo Fisher Scientific, USA). The oxygen  
11 content (dry and ash free basis) was calculated by difference.  
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14 The HHV of char was measured in an oxygen bomb calorimeter (XRY-1 A+,  
15 Shanghai Changji Geological Instrument Co., Ltd, China) in accordance with the  
16 ASTM standard D5865-13.<sup>21</sup>  
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## 21 22 **2.4 Pyrolysis Liquid Yield**

23 All pyrolysis liquid products were collected after each pyrolysis experiment and  
24 weighted.  
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27 The obtained pyrolysis liquid samples at different pyrolysis temperatures were  
28 placed in sealed brown containers and stored at 4 °C for further analysis.  
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31 The detailed properties of pyrolysis liquid were presented in Part 2 of this series.  
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## 35 **2.5 Gas analysis**

36 The gas released during pyrolysis was analyzed every three minutes by an online  
37 gas chromatograph (VARIAN CP-4900, USA). The obtained GC data were processed  
38 by means of the software provided by the manufacturer of the online gas  
39 chromatography. The chemical composition of gas was obtained by the average of all  
40 collected data. The mass yield of gas was calculated by difference considering the  
41 yields of pyrolysis liquid and char.  
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48 The heating value of gas is contributed by the combustible components (i.e. CO,  
49 H<sub>2</sub>, CH<sub>4</sub>, and some other light hydrocarbons):  
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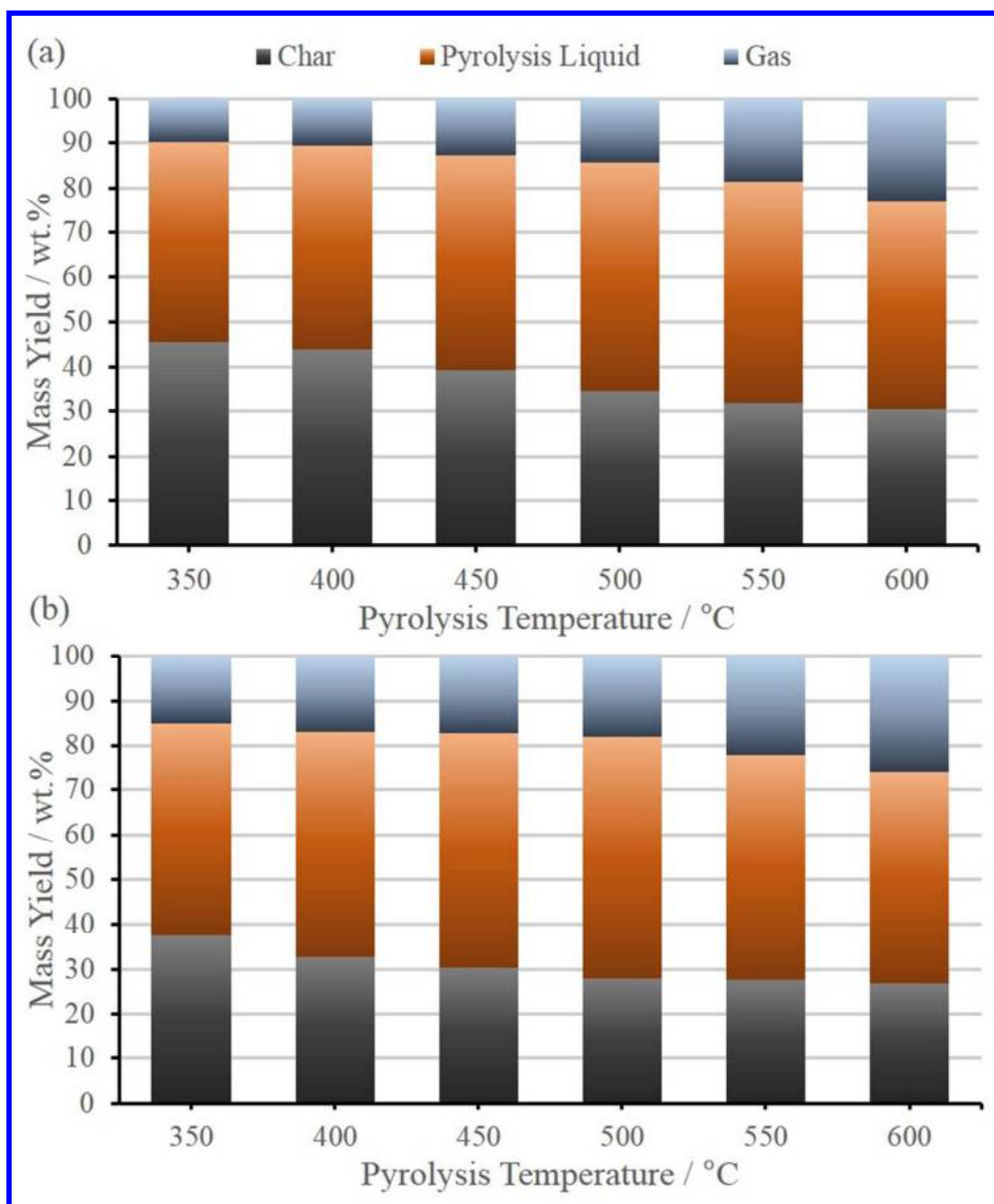
$$52 \text{HHV}_{\text{gas}} = X_{\text{CO}} \cdot \text{HHV}_{\text{CO}} + X_{\text{CH}_4} \cdot \text{HHV}_{\text{CH}_4} + X_{\text{H}_2} \cdot \text{HHV}_{\text{H}_2} + \sum (X_{\text{C}_n\text{H}_m} \cdot \text{HHV}_{\text{C}_n\text{H}_m}) \quad (1)$$

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3 where  $\text{HHV}_{\text{gas}}$ ,  $\text{HHV}_{\text{CO}}$ ,  $\text{HHV}_{\text{CH}_4}$ ,  $\text{HHV}_{\text{H}_2}$  and  $\text{HHV}_{\text{C}_n\text{H}_m}$  are the heating values  
4 of gas, CO, CH<sub>4</sub>, H<sub>2</sub>, and light hydrocarbon C<sub>n</sub>H<sub>m</sub>, and  $X_{\text{CO}}$ ,  $X_{\text{CH}_4}$ ,  $X_{\text{H}_2}$  and  
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9  $X_{\text{C}_n\text{H}_m}$  are the molar fractions of CO, CH<sub>4</sub>, H<sub>2</sub>, and light hydrocarbon C<sub>n</sub>H<sub>m</sub>.  
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### 11 12 13 **3 Results and Discussion**

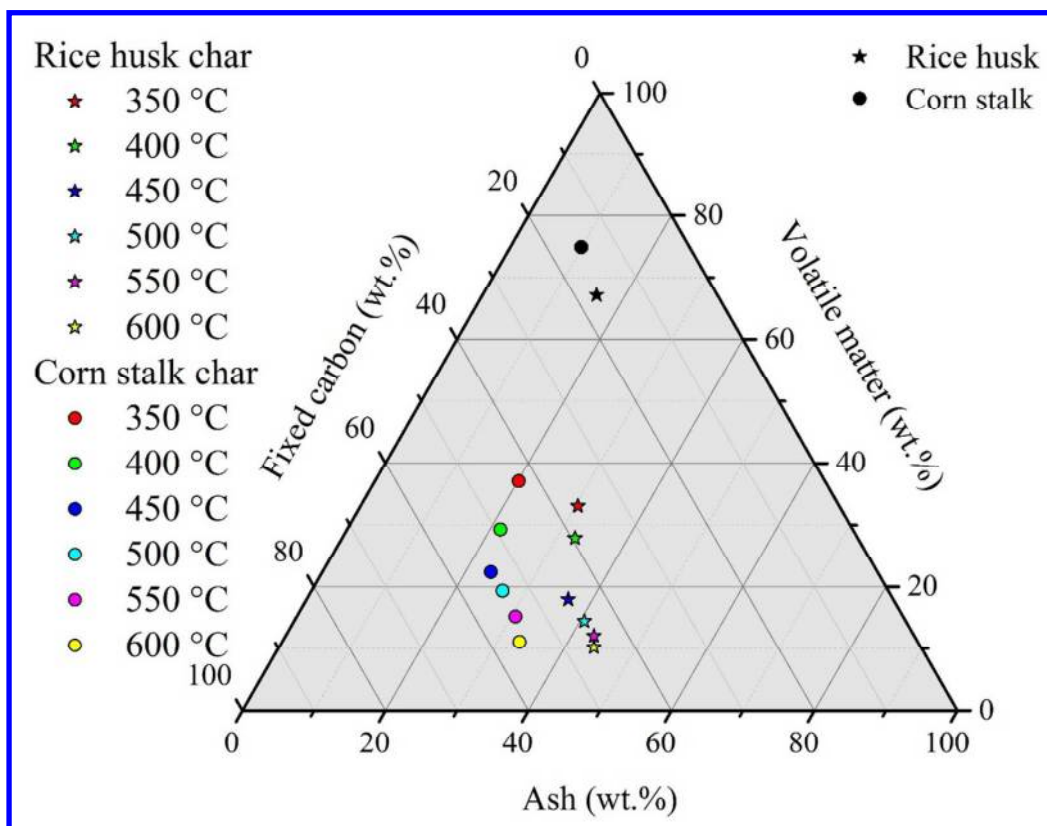
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15 The mass yields (on wet feed basis) of pyrolysis products (char, pyrolysis liquid  
16 and gas) from the pyrolysis of rice husk and corn stalk at various pyrolysis  
17 temperatures are presented in **Figure 3**. From Figure 3 it can be observed that the  
18 pyrolysis temperature significantly affects the mass yields of pyrolysis products for  
19 both feedstocks. It is also observed that the general char yields from rice husk are  
20 higher than those from corn stalk. This is largely due to the fact that there is higher  
21 ash content and higher lignin content<sup>25</sup> and less volatile matter content in rice husk  
22 than in corn stalk. With the increase of the heating temperature, the yield of char  
23 decreases (from 46 wt.% at 350 °C to 31 wt.% at 600 °C for rice husk and from 38 wt.%  
24 at 350 °C to 27 wt.% at 600 °C for stalk) while the yield of gas increases (from 10 wt.%  
25 at 350 °C to 23 wt.% at 600 °C for the pyrolysis of rice husk and from 15 wt.% at  
26 350 °C to 26 wt.% at 600 °C for the pyrolysis of corn stalk). The higher temperature  
27 can lead to the intensification of secondary reactions in pyrolysis vapors and therefore  
28 the production of more gas.<sup>26</sup> The yield of pyrolysis liquid shows a peak, 51 wt.% for  
29 the pyrolysis of rice husk and 54 wt.% for the pyrolysis of corn stalk, at the pyrolysis  
30 temperature of 500 °C. The above results obtained indicate that the auger reactor is  
31 able to achieve good results on the yields of pyrolysis liquid and char. For comparison  
32 purpose, the mass yields of products obtained from rice husk and corn stalk processed  
33 in fluidized bed reactor at 500 °C were presented and taken from the literature.<sup>27,28</sup>  
34 Due to shorter residence time of pyrolysis vapor, fluidized bed reactors produce a  
35 little higher pyrolysis liquid yield (54 wt.% for rice husk at 500 °C<sup>27</sup> and 61 wt.% for  
36 corn stalk at 500 °C<sup>28</sup>) and a little lower char yield (29 wt.% for rice husk at 500 °C<sup>27</sup>  
37 and 17 wt.% for corn stalk at 500 °C<sup>28</sup>).  
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**Figure 3.** Mass yields of char, pyrolysis liquid and gas from pyrolysis of (a) rice husk (b) corn stalk at various pyrolysis temperatures

**Figure 4** shows the proximate analysis results of rice husk and corn stalk and their pyrolysis chars obtained at different pyrolysis temperatures. From Figure 4, it can be observed that (1) the volatile matter content of char is lower than the raw material, (2) the fixed carbon content of char is higher than the raw material, (3) the ash content of char is affected mainly by the raw material, so the ash content of rice husk char is higher than that of corn stalk char, (4) with the increase of pyrolysis temperature (from 350 to 600 °C), the volatile matter content of char decreases (from

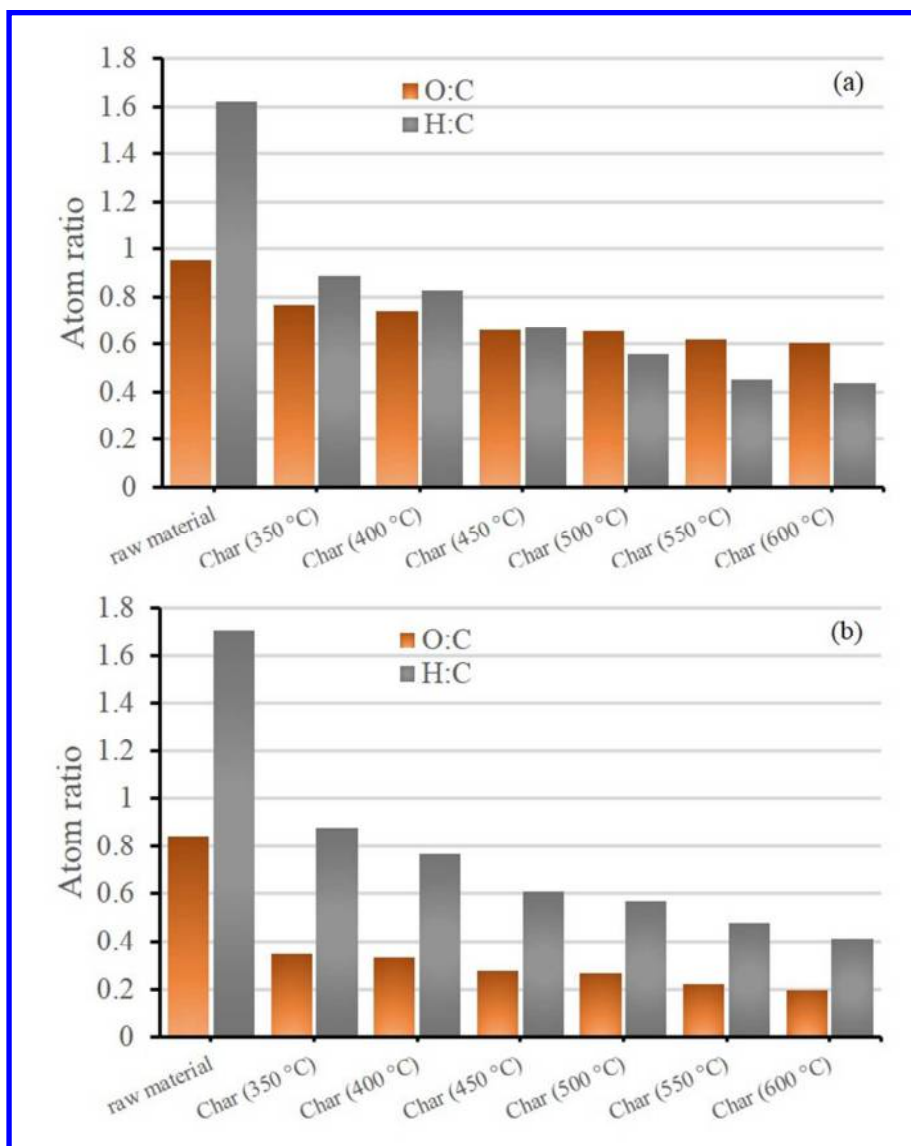
33% to 10% for rice husk char, from 37% to 11% for corn stalk char) and the ash content of char increases (from 30% to 44% for rice husk char, from 20% to 33% for corn stalk char) due to the increased thermal degradation rate.



**Figure 4.** Proximate analysis results of rice husk and corn stalk and their pyrolysis chars at different pyrolysis temperatures (on dry basis)

The atom H:C and O:C ratios of rice husk and corn stalk chars as a function of pyrolysis temperatures are shown in **Figure 5**. From Figure 5, it can be obviously observed that the atom H:C and O:C ratios of char are lower than the raw material, and that both atom H:C and O:C ratios decrease with the increasing of the pyrolysis temperature. The above results indicates that with the increase of the pyrolysis temperature, char loses relatively more oxygen and hydrogen when compared to carbon. This similar result was also reported by Angin.<sup>29</sup> This is because the increase in the pyrolysis temperature, intensifies the dehydration and decarboxylation reactions

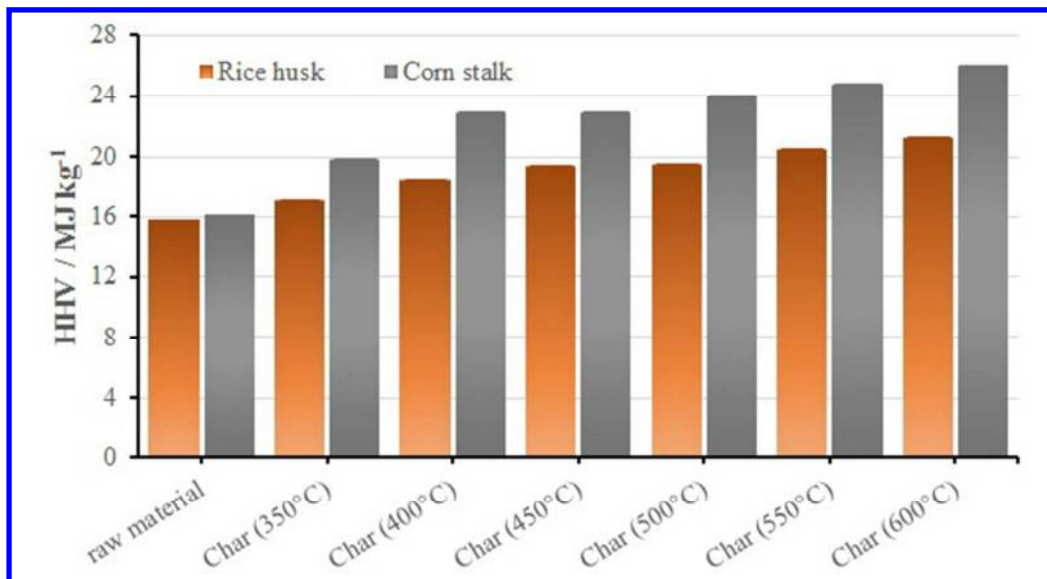
during the pyrolysis process.<sup>30</sup> The decrease in the atom H:C ratio with the increase of the pyrolysis temperature may be also related to the increase in the aromaticity of char, as reported by Xiao et al.<sup>31</sup>



**Figure 5.** Atom H:C and O:C ratios of chars from pyrolysis of (a) rice husk and (b) corn stalk at various pyrolysis temperatures

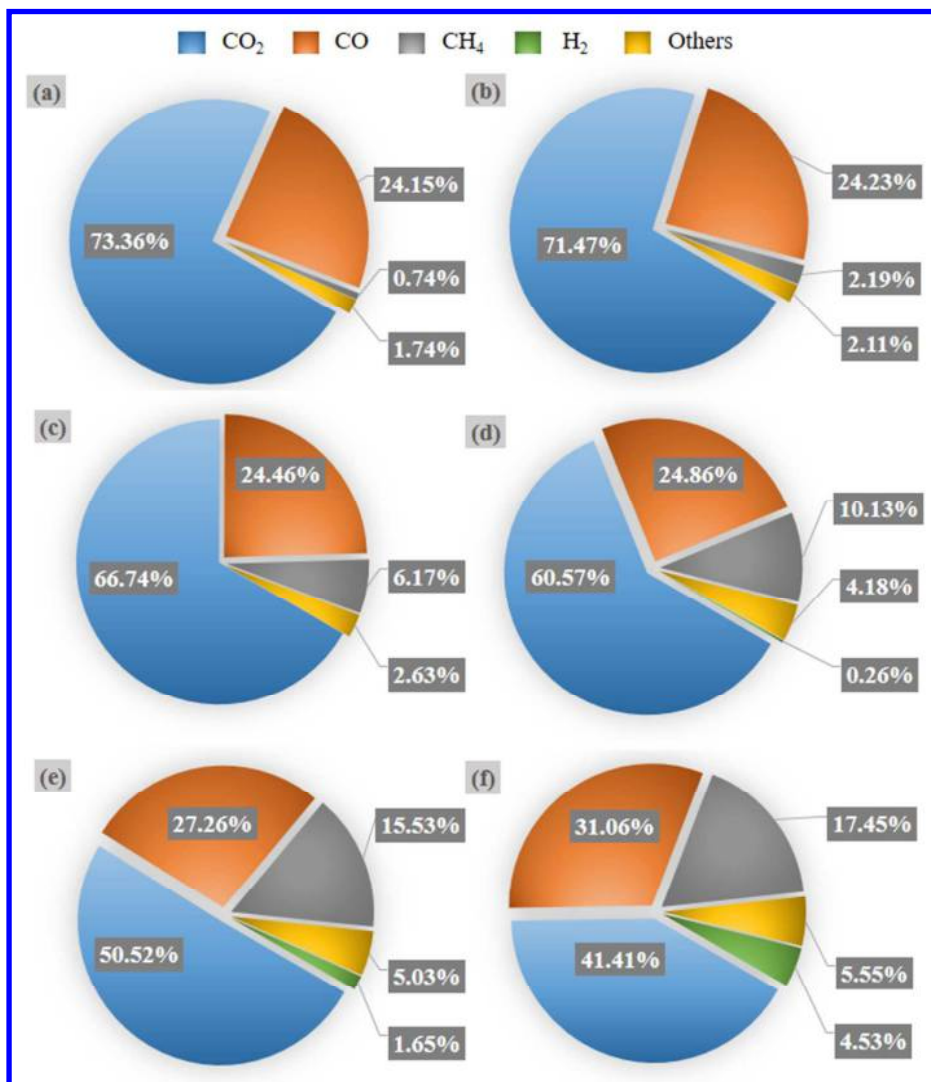
**Figure 6** shows the HHVs of rice husk and corn stalk as well as those of their chars produced at various pyrolysis temperatures. From Figure 6, it can be observed that (1) the HHV of char is more than that of the raw material, (2) the HHV of corn

stalk char is more than that of rice husk char produced at the same pyrolysis temperature, which may be attributed to the rice husk char contains more ash, (3) with the increase of the pyrolysis temperature from 350 to 600 °C, the HHV of char increases gradually from 17.15 MJ kg<sup>-1</sup> to 21.32 MJ kg<sup>-1</sup> for rice husk char, and from 19.89 MJ kg<sup>-1</sup> to 26.05 MJ kg<sup>-1</sup> for corn stalk char.

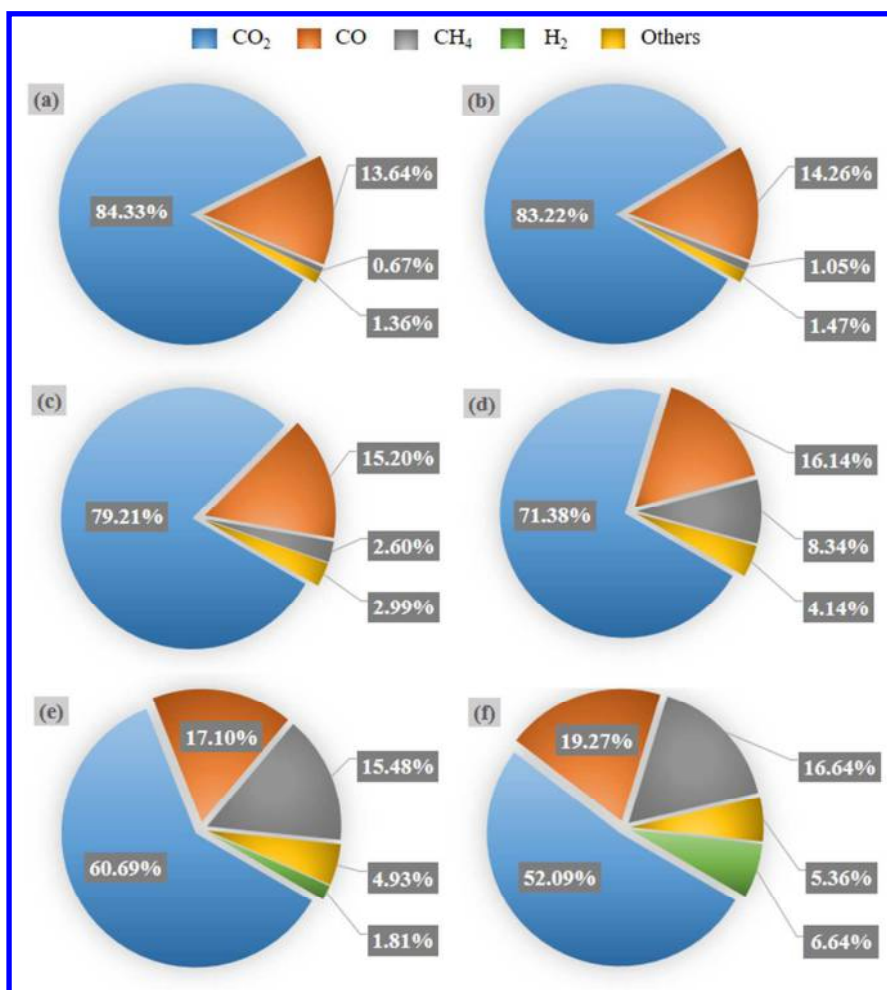


**Figure 6.** HHVs of chars from pyrolysis of rice husk and corn stalk at various pyrolysis temperatures

The collected online gas chromatography data was processed and the chemical compositions of the gases from the pyrolysis of rice husk and corn stalk were obtained. The results have shown that the gases from the pyrolysis of both feedstocks mainly consist of CO<sub>2</sub>, CO, CH<sub>4</sub>, H<sub>2</sub> and some other light hydrocarbons (mainly including C<sub>2</sub>H<sub>4</sub>, C<sub>2</sub>H<sub>6</sub>, C<sub>3</sub>H<sub>6</sub>, C<sub>3</sub>H<sub>8</sub> and n-C<sub>4</sub>H<sub>10</sub>). The molar fractions of the gas components from the pyrolysis of rice husk and corn stalk at various pyrolysis temperatures are shown in **Figures 7 and Figure 8**, respectively.



**Figure 7.** Molar percentages of components of gas from the pyrolysis of rice husk at various temperatures (a) 350 °C, (b) 400 °C, (c) 450 °C, (d) 500 °C, (e) 550 °C and (f) 600 °C.



**Figure 8.** Molar percentages of components of gas from the pyrolysis of corn stalk at various temperatures (a) 350 °C, (b) 400 °C, (c) 450 °C, (d) 500 °C, (e) 550 °C and (f) 600 °C.

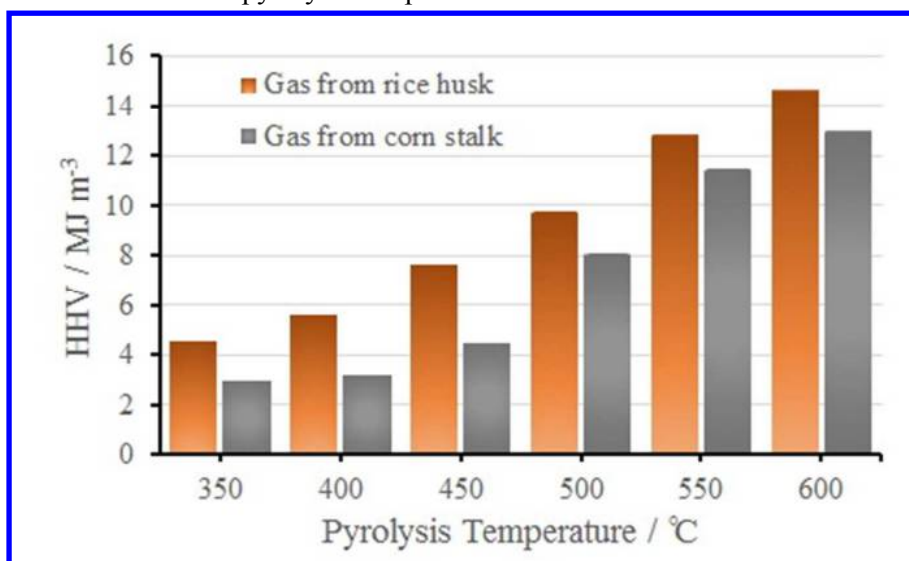
From **Figures 7 and 8**, it can be found that (1) with the increase of the pyrolysis temperature (from 350 to 600 °C), the molar fraction of CO<sub>2</sub> decreases relatively sharply (from 73.4 vol.% to 41.4 vol.% for rice husk gas and from 84.3 vol.% to 52.1 vol.% for corn stalk gas), the molar fraction of CO increases slowly (from 24.2 vol.% to 31.1 vol.% for rice husk gas and from 13.6 vol.% to 19.3 vol.% for corn stalk gas), the molar fraction of CH<sub>4</sub> increase relatively sharply (from 0.7 vol.% to 17.5 vol.% for rice husk gas and from 0.7 vol.% to 16.6 vol.%), (2) H<sub>2</sub> is negligible at low pyrolysis temperatures (< 500 °C for rice husk and < 550 °C for corn stalk) and when the pyrolysis temperature is high enough, the molar fraction of H<sub>2</sub> increases sharply



with the increase of the pyrolysis temperature (from 0.3 vol.% at 500 °C to 4.5 vol.% at 600 °C for rice husk gas and from 1.8 vol.% at 550 °C to 6.6 vol.% at 600 °C for corn stalk gas).

CO<sub>2</sub> is mainly produced from the cracking of partially oxygenated organic compounds (e.g. cellulose and hemicellulose).<sup>32</sup> At the auger reactor, the gas residence time is relatively long, the following reactions may occur at high temperatures:<sup>33-35</sup>  $C + 2H_2O \rightarrow CO_2 + 2H_2$  ,  $C + CO_2 \rightarrow 2CO$  , and  $3H_2 + CO \rightarrow CH_4 + H_2O$ . The releasing of CH<sub>4</sub> and other light hydrocarbons may be due to the reforming and cracking of heavier hydrocarbons in the pyrolysis vapors, which are commonly called as secondary reactions. On the other hand, part of H<sub>2</sub> can also be produced by the cracking of hydrocarbons at higher temperatures, due to the fact that it requires more energy.<sup>36</sup>

From the above results, it can be concluded that the combustible gas fractions in pyrolysis gas increase gradually with the increase of the pyrolysis temperature. According to Equation (1), the HHVs of gases produced at various temperatures from the pyrolysis of rice husk and corn stalk were calculated and shown in **Figure 9**. From Figure 9 it can be observed that the HHV of the gas increases relatively sharply with the increase of the pyrolysis temperature.



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3 **Figure 9.** HHVs of gases from rice husk and corn stalk at various pyrolysis  
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#### 10 **4 Conclusions**

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13 (1) The pyrolysis of rice husk and corn stalk in an auger pyrolysis reactor have  
14 been carried out at six different pyrolysis temperatures (350, 400, 450, 500, 550, and  
15 600 °C). The pyrolysis liquid and char yields in the auger reactor are comparable to  
16 those reported for the same feedstocks in fluidized bed reactors. The pyrolysis  
17 temperature significantly affects the mass yields of the pyrolysis products. Using an  
18 auger reactor, rice husk produces more char at the same pyrolysis temperature than  
19 corn stalk. With the increase of the pyrolysis temperature (from 350 to 600 °C), the  
20 char yield decreases while the gas yield increases. The maximum pyrolysis liquid  
21 yield is obtained at the pyrolysis temperature of 500 °C for both feedstocks (51 wt.%  
22 of rice husk and 54 wt.% of corn stalk).  
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32 (2) The proximate analysis results of chars from the pyrolysis rice husk and corn  
33 stalk show a decrease in volatile matter and an increase in ash content with the  
34 increase of the temperature. Both atom H:C and O:C ratios of char decreases with the  
35 increase of the pyrolysis temperature (from 350 to 600 °C) for both feedstocks. The  
36 HHV of rice husk char increases from 17.2 MJ kg<sup>-1</sup> to 21.3 MJ kg<sup>-1</sup> while that of corn  
37 stalk char increases from 19.89 MJ kg<sup>-1</sup> to 26.05 MJ kg<sup>-1</sup> as the pyrolysis temperature  
38 increases from 350 to 600 °C.  
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46 (3) The gases from the pyrolysis of rice husk and corn stalk show a similar  
47 tendency: the molar fractions of combustible gas including CO, CH<sub>4</sub> and other light  
48 hydrocarbons increase gradually while the molar fraction of CO<sub>2</sub> decreases with the  
49 increase of the pyrolysis temperature (from 350 to 600 °C). H<sub>2</sub> is detectable at 500 °C  
50 and 550 °C for the pyrolysis of rice husk and corn stalk, respectively. When the  
51 pyrolysis temperature is high enough, the molar fraction of H<sub>2</sub> increases sharply with  
52 the increase of the pyrolysis temperature for the pyrolysis of both feedstocks. The  
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3 HHV of gas increases with the increase of the pyrolysis temperature for both  
4 feedstocks.  
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