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Influence of Particle Size, Reactor Temperature and Gas Phase Reactions on Fast Pyrolysis of Beech Wood

Li Chen, Capucine Dupont, Sylvain Salvador, Guillaume Boissonnet, and Daniel Schweich

Abstract

In the present work, a drop tube reactor (DTR) and a horizontal tubular reactor (HTR) were used to study the pyrolysis behaviour of beech wood particles of different sizes under the conditions encountered in industrial fluidized bed gasifiers, namely high external heat flux ($105 - 106 \text{ W.m}^{-2}$) and high temperature ($800 - 1000^\circ\text{C}$). The influence of the reactor temperature (800 and 950°C), of particle size (from $350 \mu\text{m}$ to 6 mm), and of gas residence time (from 1 to 10 s) were examined. Under the explored conditions, when pyrolysis is finished, more than $80 \text{ wt.}\%$ of virgin wood is converted into gas and less than $13 \text{ wt.}\%$ remains in solid. In the gas phase, CO is the main gaseous product ($50 \text{ wt.}\%$ of virgin wood), followed by H_2 (molar ratios of H_2/CO are between 0.35 to 0.55), H_2O , CO_2 and CH_4 . Species C_2H_2 , C_2H_4 , C_2H_6 and C_6H_6 are present in much lower amounts. The increase of temperature increases the rate of solid devolatilization and favours the cracking reactions of hydrocarbons. The increase of particle size increases the required time for completing pyrolysis. Meanwhile, the results obtained at 950°C show that the final products distribution at the end of pyrolysis is almost the same for the particles between 350 and $800 \mu\text{m}$. The increase of the particle size from $800 \mu\text{m}$ to 6 mm seems to have some influence on the final products distribution. The gas phase reactions mainly change the yields of light hydrocarbons and H_2 : the increase of gas residence time favours the cracking reactions of hydrocarbons and thus leads to a higher H_2 yield.

KEYWORDS: biomass, fast pyrolysis, drop tube reactor, horizontal tubular reactor, gas phase reactions, particle size, high temperature

1. Introduction

Biomass, as a renewable CO₂-neutral energy source, is widely available and increasingly used as an alternative to fossil fuel for energy supply. The thermochemical conversion of biomass to produce fuel gas (mainly CO and H₂) via gasification is considered as one of the most promising processes. The fluidized bed reactor constitutes a good option for large-scale applications of biomass gasification notably due to its high heat and mass transfer efficiency. Pyrolysis is the first step in the gasification process, and is of crucial importance since during pyrolysis up to 70-90 % of feed biomass can be converted into volatiles (Dupont 2006).

Biomass pyrolysis is a complex process including both physical and chemical phenomena. Some research efforts (Pyle and Zaror 1984; Chan, Kelbon et al. 1985; Simmons 1986; Peters and Bruch 2003) have been devoted to the study of the relative importance between heat transfer processes and chemical reactions during pyrolysis by using a characteristic times analysis that was initially proposed by Damköhler (1936). Recently, Dupont et al. (2007) estimated the characteristic times of these phenomena under the operating conditions encountered in fluidized bed gasifiers. Their results indicated that in the temperature range between 800 and 950°C, the pyrolysis of wood particles smaller than 100 µm was controlled by chemical reactions while the thermal regime was governing only for particles larger than 10 mm. For particles between 100 µm and 10 mm, the pyrolysis was found to occur in a transitional regime, in which both chemical reactions and heat transfer processes should be taken into account.

A lot of researchers (for example, (Brink and Massoudi 1978; Biagini, Fantozzi et al. 2004)) have used TGA to study the intrinsic kinetic of biomass devolatilization with small particles (~100 µm). Attention has also been paid to the pyrolysis of large particles (>10 mm) in thermal regime (Gronli 1996; Lu 2006; Bellais 2007). However, only few experimental results can be found in the literature (Zanzi, Sjoström et al. 1996; Dupont 2006; Xiu, Li et al. 2006; Couhert 2007; Lehto 2007) concerning the pyrolysis of particles between 100 µm and 10 mm, under the typical heating conditions encountered in fluidized gasifiers, namely high heat flux ($10^5 - 10^6 \text{ W.m}^{-2}$) and high temperature (> 800°C).

For this reason, this paper deals with an experimental study on the pyrolysis behaviour of beech wood particles covering a large range of sizes (350 µm; 500 µm; 700 µm; 800 µm; 2 mm; 6 mm) under atmospheric pressure, high external heat flux, and temperatures of 800 and 950°C.

The experiments were performed in a drop tube reactor (DTR) with particles between 350 and 800 µm. For larger particles, the solid residence time is

too limited in this reactor configuration so that a horizontal tubular reactor (HTR) was used with particles between 800 μm and 6 mm to complete the study.

2. Experimental section

2.1. Materials

Beech wood was selected as the biomass sample in present work. The particles smaller than 1 mm were sieved and classified to obtain fractions of uniform particle size. The large particles were classified through their thickness (Table 1).

Table 1. Characteristics of the beech wood samples

Small particles	
Average particle size (μm)	Moisture (%)
350	6.5
500	6.5
700	7.2
800	7.5
Large particles	
Particle size (mm) (Length \times Width \times Thickness)	Moisture (%)
5 \times 2 \times 2	10.4
20 \times 10 \times 6	11.8

No significant differences were observed for the samples on the proximate and ultimate analysis except on moisture (see Table 1). Therefore only an average value of the analysis is given in Table 2.

Table 2. Proximate and ultimate analysis of the sample

Proximate Analysis (% Mass, Dry Basis)			Ultimate Analysis (% Mass, Dry, Ash-Free Basis)				
Volatile Matter	Fixed Carbon	Ash	C	H	N	S	O (by diff.)
85.3	14.3	0.4	49.2	6	0.5	0.02	44.3

2.2. Methods

2.2.1. Drop Tube Reactor (DTR)

The drop tube reactor (DTR) is depicted in Figure 1. It has already been previously described in detail by Van de Steene (1999) and Commandré (2002). This facility is designed to produce external heat fluxes at particle surface higher than about $1 \times 10^5 \text{ W} \cdot \text{m}^{-2}$. It consists of an alumina tube of $2000 \times 75 \text{ mm}$ (L \times i.d.), inserted in a vertical electric heater made of three independent heating zones, with a total isothermal reaction zone of 1000 mm.

Wood particles were continuously fed by a controlled weighing system and injected into the reactor with a transport N_2 stream through a water-cooled feeding tube. A dispersion dome was placed at the outlet of the feeding tube to distribute the wood particles over the reactor cross section. Another N_2 stream passed through a pre-heater to reach the reactor temperature and met the wood particles at the dispersion dome. A water-cooled sampling probe was inserted from the bottom of the reactor to collect solid and gas. The reaction zone length (and thus the residence time of solid and gas) could be varied by setting the sampling probe at different heights. A representative fraction (about 2/3) of the exhaust gas was sucked in the sampling probe, then passed through a char collection pot and a filter and a part of it was sent to the gas analysis system (see 2.2.3).

The flow rate of total N_2 stream, the sum of the cold transport stream and the pre-heated stream, were of 18.8 and $16.5 \text{ L} \cdot \text{min}^{-1}$ (at STP) at 800 and 950°C respectively, in order to keep the same N_2 velocity in the reactor. The flow rate of wood particles was of $0.5 \text{ g} \cdot \text{min}^{-1}$.

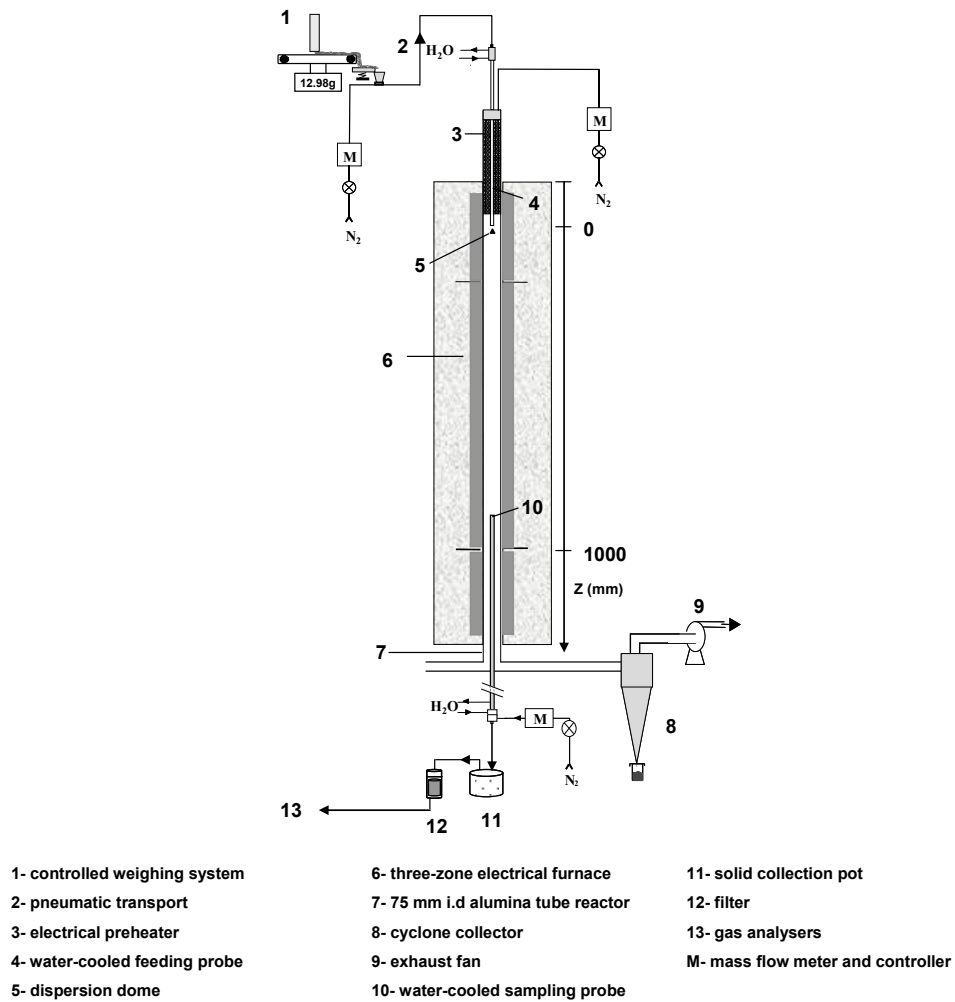


Figure 1. Scheme of the DTR

The main parameters studied in the DTR are listed in Table 3.

Table 3. Main parameters studied in the DTR

Parameters	Values
Particle size (μm)	350, 500, 700 and 800
Temperature ($^{\circ}\text{C}$)	800 and 950
Reaction zone length (m)	0.3, 0.5, 0.7 and 0.9

Under the explored conditions, the solid residence time was estimated to fall between 0.5 and 2.5 s for the sample of 350 μm , and between 0.3 and 0.7 s for the sample of 800 μm (Chen, Couhert et al. 2009).

2.2.2. Horizontal Tubular Reactor (HTR)

The horizontal tubular reactor (HTR) is depicted in Figure 2. It has been described in detail by Couhert (2007). This facility is designed to produce external heat fluxes at particle surface up to $5 \times 10^4 \text{ W} \cdot \text{m}^{-2}$ (Dufour 2007). It consists of a quartz tube heated by electrical resistances at temperatures up to 1000°C . A double envelop configuration is used to preheat the carrier gas before meeting the solid sample. The sizes of the outer and inner tube are $1290 \times 70 \text{ mm}$ (L \times i.d.) and $850 \times 55 \text{ mm}$ (L \times i.d.) respectively. The heated zone has a length of 620 mm. During the test, the isothermal gas phase reaction zone, i.e. the zone between the position of the sample holder and the end of the heated zone has a length of 320 mm.

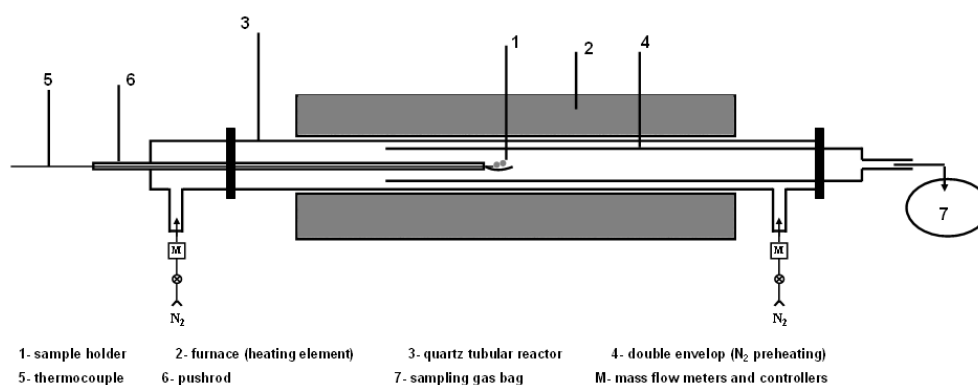


Figure 2 Scheme of HTR

Wood particles were weighed in a sample holder made of a stainless steel grid; the holder was driven by a pushrod and initially set in the cold zone of the reactor. The system was purged by N₂. 50 % of the injected N₂ was preheated through the double envelop, while the other 50 % of the injected N₂ remained cold in order to sweep the solid particles to avoid wood devolatilization before the beginning of the test. The temperature in the cold zone was not higher than 120°C during this stage. During the experiments, the outlet of the reactor was firstly connected to the gas analyzers to check the oxygen concentration. Once it was ensured that no oxygen remained, the reactor outlet was connected to a sampling

bag. The sample holder was then quickly pushed to the centre of the heated zone. At the end of the experiment, the sample holder was pulled back in the inert cold atmosphere to cool down, and then weighed. The sampling bag was connected to the gas analysis system (see 2.3.3) for the measurement of the gaseous components yields.

The solid residence time was set to 3 min in order to ensure that the pyrolysis was finished and that all the pyrolysis products completely left the reactor. The gas residence time in the isothermal gas phase reaction zone was controlled by the gas mass flow rate by assuming that the gas produced by pyrolysis could be negligible. The initial solid mass was of about 0.5 g for the sample of 800 μm , which was approximately placed as a monolayer of particles over the holder. It was of between 0.5 and 1 g for the samples of 2 and 6 mm, which consisted in several particles that could be considered as isolated on the holder.

Note that the samples were oven-dried before being placed in the sample holder in order to avoid any moisture evaporation during the N_2 purging stage before the experiment.

The main parameters studied in the HTR are listed in Table 4.

Table 4. Main parameters studied in the HTR

Parameters	Values
Particle size (mm)	0.8, 2 and 6
Temperature ($^{\circ}\text{C}$)	800 and 950
Gas residence time (s)	1, 4 and 11 at 800 $^{\circ}\text{C}$ 1, 3, and 10 at 950 $^{\circ}\text{C}$

2.2.3. Measurement

2.2.3.1. Analysis methods

The same gas analysis system was used for all the experiments. Note that to test the influence of the sampling method (direct sampling or sampling bag), Couhert (2007) carried out in the DTR a pyrolysis test during which she measured the gas yields by direct online measurement of the sampled gas and by analyzing a sampling bag after the pyrolysis test. The results were similar, which proved that the sampling method did not affect the results.

The gas analysis system is constituted of several analyzers, as shown in Table 5. The yields of all the main gaseous components except water vapour were measured by at least two different analyzers. Note that there is a high uncertainty on the H_2O value given by the mirror hygrometer due to the fact that the mirror

surface might be contaminated by the condensed components in the released gas. Hence, the yield of water vapour may only be considered as indicative. Its uncertainty is not negligible and may represent up to 6% as mass fraction in the total produced gas.

Table 5. Gas analysis system

	H ₂	CO	CO ₂	H ₂ O	CH ₄	C ₂ H ₄	C ₂ H ₂	C ₂ H ₆	C ₆ H ₆	O ₂
Micro GC	x	x	x		x	x	x	x	x	
FTIR ¹		x	x		x	x	x	x		
TCD ²	x									
FID ³					x					
NDIR ⁴			x							x
Mirror hygrometer				x						
Relative uncertainty ($\pm\%$)	10	5	10	20–50	10	20	10	20	20	10

1. Fourier Transform InfraRed spectrometer

2. Thermal Conductivity Detector

3. Flame Ionization Detector

4. Non-Dispersive InfraRed spectrometer

The methods for determining the solid mass loss were different for the experiments in the DTR and those in the HTR.

- the mass loss of solid pyrolyzed in the DTR was determined by the ash tracer method, the most common method used to determine the solid mass loss in the DTR (for example, see (Zanzi, Sjöström et al. 1996; Li, Xu et al. 2004; Xiu, Li et al. 2006)).
- the mass loss of solid pyrolyzed in the HTR was determined by directly weighing the sample before and after pyrolysis test.

Due to the lack of direct measurement, the tar yield was considered as equal to the difference between the virgin wood and the sum of the yields of gas and solid residue. Under the explored conditions, the tar yield may represent up to 10 – 15 wt.% of the initial wood at the end of pyrolysis, as explained in (Dupont 2006).

2.2.3.2. Repeatability

The result repeatability was checked by performing the same test on three different days.

- For the yields of gaseous components, it was found that for the experiments conducted in both reactors, the relative differences of results on each gaseous

component among these three tests was below 5% except for H₂O in which case it was of about 20%. This indicates that the experimental results were reliable.

- For the yields of solid, it was found that for the experiments conducted in the DTR, the relative differences of solid mass losses obtained among these three tests were up to 20%. This was mainly due to the small ash content in the virgin wood (about 0.3 wt.%). On the contrary, for the experiments in HTR, the relative differences of solid mass losses obtained among three tests were less than 5%. This indicates that the solid mass loss in the HTR was accurately determined.

3. Results and discussion

3.1. Results obtained in the DTR

3.1.1. Final products distribution

This paragraph aims to compare the results obtained in the present study with those reported by the former authors concerning the experiments conducted under similar operating conditions. Since only for the sample of 350 μm , the pyrolysis is finished under all the studied operating conditions (see Figure 3), the results of the sample of 350 μm are used to compare with literature results.

First of all, the comparison of final solid/gas/tar yields at 800°C is presented in Table 6.

Table 6. Comparison of final solid/gas/tar yields at 800°C with literature results

	Present study	(Dupont, Commandré et al. 2008)	(Zhang, Kajitani et al. 2006)	(Zanzi, Sjöström et al. 2002)
Sample	Beech wood	Mixture of pine and spruce	Cypress sawdust	Birch wood
Particle size (μm)	336	400	< 500	500 – 800
Solid yield (wt.%)	6	7 – 10	5	6
Gas yield (wt.%)	83	75	85	77
Tar yield (wt.%)	11	15 – 18	10	18

It can be seen that the results obtained in the present study are quite similar with these previous results on the final yields of solid residue, total gas and tar. The small differences, in particular on the yields of gas and tar may result from the

measurement uncertainty, the differences of biomass feedstock and of the reactor configuration.

Secondly, in the gas phase, it is found that CO is the main gaseous product (50 wt.% of virgin biomass), followed by H₂ (the molar ratio of H₂/CO is between 0.35 and 0.55), H₂O, CO₂ and CH₄. Species C₂H₂, C₂H₄, C₂H₆ and C₆H₆ are present in much lower amounts. These results are in accordance with those observed by several earlier researchers working under similar operating conditions (Wei, Xu et al. 2006; Dupont, Commandré et al. 2008; Couhert, Commandré et al. 2009).

3.1.2. Influence of the particle size

The mass yields of solid residue, total gas, and tar corresponding to four reaction zone lengths at two temperatures are illustrated in Figure 3.

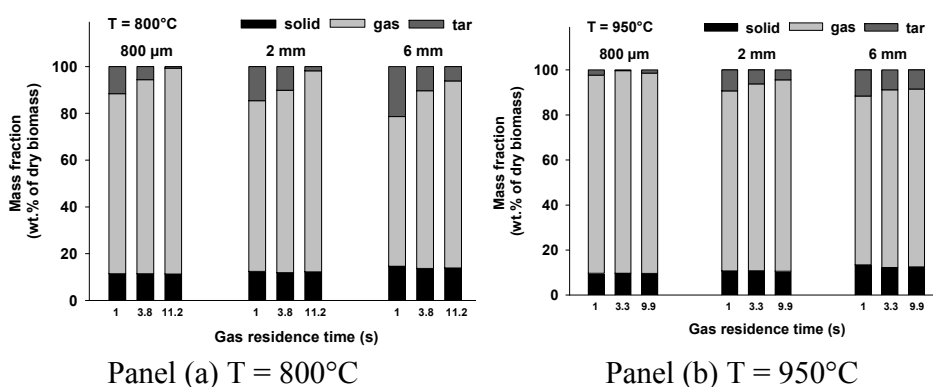


Figure 3. Mass yield of total gas, solid residue and tar (by diff.) in the DTR

Three different pyrolysis progress levels can be observed at 800°C (Figure 3 (a)) for the different particle sizes:

- For the sample of 350 μm, the yields of solid residue, total gas, and tar almost remain constant. This indicates that the pyrolysis is already finished after a reaction zone length of 0.3 m.
- For the sample of 500 μm, the yield of solid residue slightly decreases from 10 to 6 wt.% when the reaction zone length increases from 0.3 to 0.9 m. Meanwhile, the yield of total gas significantly increases from 63 to 83 wt.%, and the yield of tar significantly decreases from 27 to 11 wt.%. This indicates that the wood devolatilization is almost finished at a reaction zone length of 0.3 m, while the cracking reactions of the primary tar produced by wood

devolatilization are still in progress with the increase of the reaction zone length from 0.3 to 0.9 m.

- For the samples of 700 and 800 μm , the yields of solid residue significantly decrease from 36 to 10 wt.% and from 50 to 21 wt.% respectively. The yields of total gas significantly increase from 42 to 71 wt.% and from 37 to 59 wt.% respectively. This indicates that in this case the wood devolatilization is still in progress in reaction zone lengths from 0.3 to 0.9 m.

From these observations, it appears that the increase of particle size under the explored range (350 – 800 μm) significantly decreases the apparent pyrolysis rate and therefore increases the required time for completing pyrolysis reactions.

Secondly, the influence of the particle size on the final products distribution at the end of pyrolysis can be analyzed. This analysis is performed on the results obtained at 950°C and at a reaction zone length of 0.9 m because under these conditions, the pyrolysis can be considered as finished for all the samples. From Figure 3 (b), it can be seen that with the increase of the particle size from 350 to 800 μm , the total solid yield slightly increases from 4 to 8 wt.% and the total gas yield slightly decreases from 85 to 79 wt.%. Taking into account the experimental uncertainty, it seems that under the explored conditions, the particle size has no significant influence on the final yields of solid and gas.

It is also interesting to see whether the particle size affects the final yields of the main gaseous component (Figure 4).

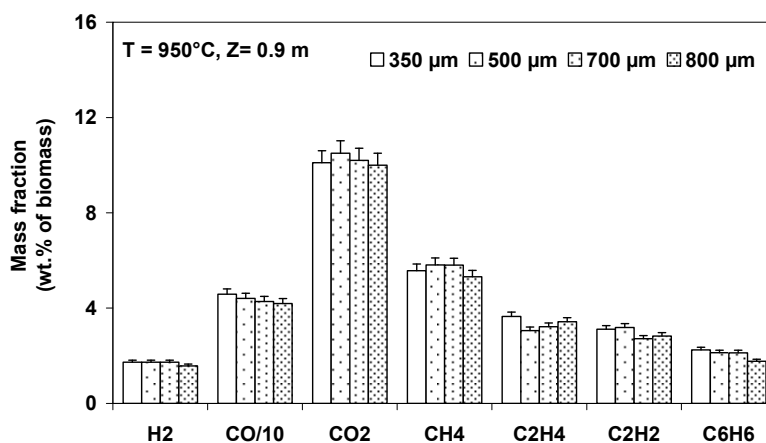


Figure 4. Yields of the main gaseous components in the DTR ($T = 950^\circ\text{C}$)

These results plotted in Figure 4 reveal that the particle size does not have significant influence on the yields of gaseous components.

To sum up, the above results seem to indicate that under the explored conditions in the DTR, the increase of initial particle size from 350 to 800 μm

mainly increases the required time for completing pyrolysis, but do not significantly shift the final products distribution. Several former studies (Chan, Kelbon et al. 1985; Di Blasi 1996) concerning the influence of particle size in a higher range ($> 10 \mu\text{m}$) showed that a larger particle size gives a higher solid yield and a low gas yield due to the fact that under the same external heat flux conditions, the change of particle size changes the temperature-history inside the particle and therefore changes the products distribution. However, in the present study, the influence of the particle size on the final products distribution is not significant, which implies that under the explored conditions, the effect of the heat transfer processes could not be effective.

3.1.3. Influence of the reactor temperature

From the comparison between Figure 3 (a) and (b), it can be seen on the samples of 700 and 800 μm that the increase of temperature from 800 to 950°C logically increases the pyrolysis rate. On the contrary, it can be seen on the sample of 350 μm that the increase of temperature from 800 to 950°C has very little influence on the final solid/gas/tar yields.

One can furthermore investigate the influence of temperature on the final yields of the main gaseous components. Since it has been shown in the previous section that for the sample of 350 μm the pyrolysis is finished at all the studied operating conditions, the results on the sample of 350 μm at 800 and 950°C are taken for the comparison (Figure 5).

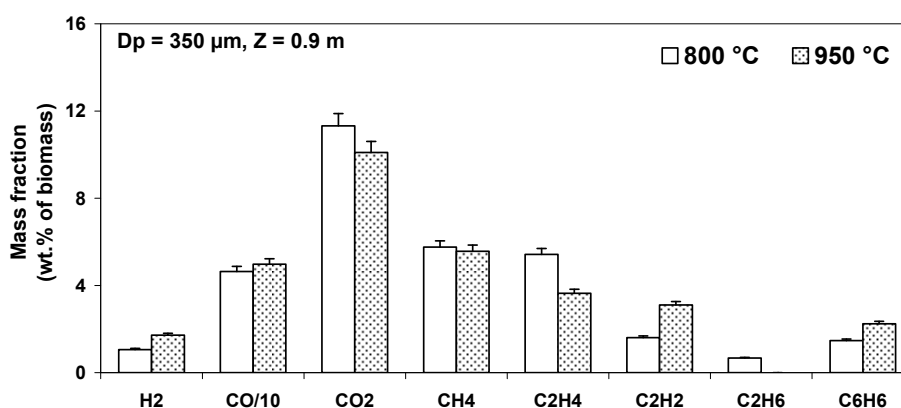


Figure 5. Influence of the temperature on the final yields of gaseous components at the end of pyrolysis in the DTR

It can be observed that with the increase of temperature from 800 to 950°C, the yield of H₂ increases significantly (from 1% to 1.7 wt.% of virgin wood), accompanied with the increase of C₂H₂ and C₆H₆ and the decrease of C₂H₄ and C₂H₆. Note that this trend is similar with what was observed in earlier studies (Ekstrom and Rensfelt 1980; Nunn, Howard et al. 1985; Zanzi 2001). From this observation, it may be asserted that the increase of H₂ and C₂H₂ mainly comes from the cracking reactions of C₂H₄, C₂H₆, and tar components in the gas phase. This implies that under the explored conditions in the present study, the distribution of the main gaseous components at the end of pyrolysis is influenced by the gas phase reactions rather than the initial particle size.

3.2. Results of experiments in HTR

3.2.1. Influence of the particle size

Figure 3 reports the evolution of the yields of solid residue, total released gas, and tar versus the gas residence time for particles of different sizes at 800 and 950°C. It should be kept in mind that due to the long solid residence time (3 minutes), the solid devolatilization process is finished in all cases.

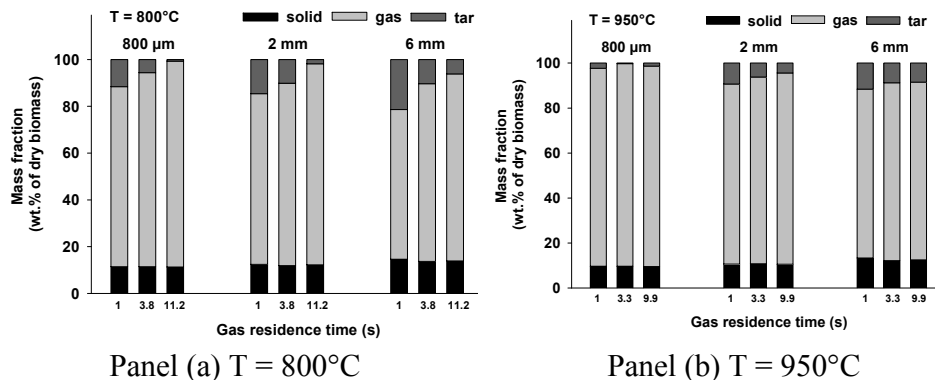


Figure 6. Mass yield of total gas, solid residue and tar (by diff.) in the HTR

It can be observed that whatever the temperature and gas residence time, the increase of particle size from 800 μm to 6 mm always increases the solid yield of about 2 – 3 wt.% of the initial dry wood and decreases the total gas yield of about 10%. Since the solid yield is accurately measured, this indicates that under the explored conditions in the HTR, the increase of particle size increases the solid yield.

In Figure 7, the influence of particle size on the final yields of the main gaseous components at 800°C is examined.

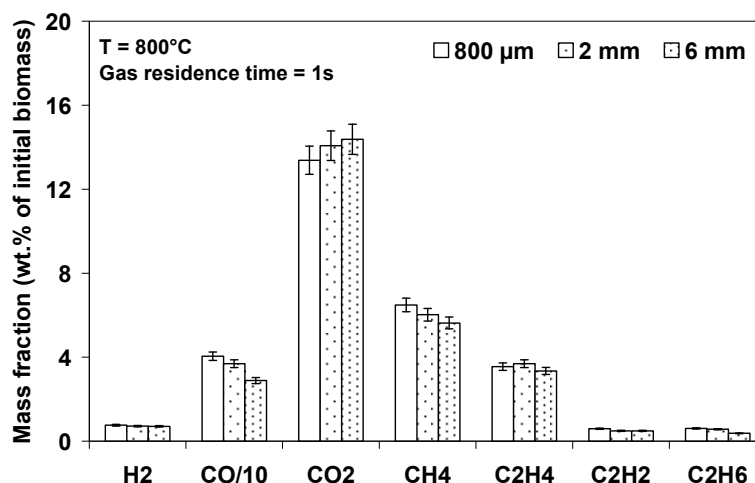


Figure 7. Influence of particle size on the final yield of the main gaseous components

From this figure, it can be seen that the decrease of the total gas yield with the increase of the particle size is mainly due to the decrease of the CO yield. Note that the same impact of particle size has also been observed at 950°C.

3.2.2. Influence of the gas residence time

The influence of the gas residence time on the solid/total gas/tar yields can be deduced from the results shown in Figure 3. First of all, it can be observed that the increase of the gas residence time does not influence the yield of solid residue. This means that wood devolatilization behaviour is not influenced by the change of the gas velocity at the solid surface and therefore the change of mass/heat transfer conditions at solid surface. Secondly, it can be observed that at 800°C, for all the samples, the increase of the gas residence time from 1 to 11 s increases the total gas yield by about 10-15 wt.% (of dry wood). A similar evolution was observed by Zhang et al. (2007) using the same type of reactor. This trend may be due to fact that longer gas residence time favours the cracking reactions of tar components and other light hydrocarbons. Finally, it can be observed that at 950°C, the increase of the gas residence time has almost no influence on the total gas yield for all the samples. This may be explained by the fact that at higher

temperature, the rate of the cracking reactions increase and that as a consequence, the cracking reactions are almost finished in 1 s at 950°C.

One can furthermore investigate the influence of the gas residence time on the yields of the main gaseous components. In fact, the influence of the gas residence time has been found to be the same for all the samples used in this study, hence only the results for the sample of 6 mm are given as an example (Figure 8).

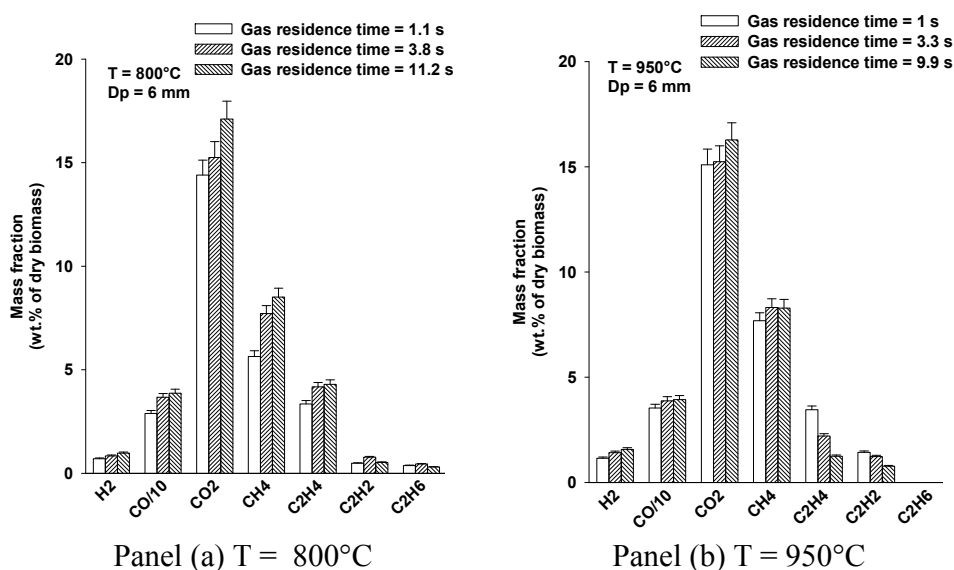


Figure 8. Influence of the gas residence time on the yields of the main gaseous components

It can be observed that the increase of gas residence time has a significant influence on the yields of the main gaseous components: the yields of H₂, CO and CH₄ increase at the two temperatures; the yields of C₂H₂ and C₂H₄ increase at 800°C but decrease at 950°C; a small amount of C₂H₆ is found at 800°C while no C₂H₆ is detected at 950°C. These trends suggest that the gas phase reactions are still under progress under these conditions: the increase of the gas residence time favours mainly the tar cracking reactions at 800°C to increase the production of light hydrocarbons, while at 950°C it favours the not only the cracking reactions of tar components, but also those of light hydrocarbons.

3.2.3. Comparisons between results obtained in the DTR and in the HTR

Since the sample of 800 μm has been used for the experiments in the DTR and in the HTR, a direct comparison of the two reactors is possible. The experiments were carried out at the same temperature (950°C) and for the same gas residence time (about 4 s, corresponding to a reaction zone length of 0.9 m in the DTR). It is worth noticing that due to the different reactor configurations, there are two main differences between the experiments:

- In the DTR the particles could be thought as isolated and in motion, while in the HTR the particles are in contact with each other and also in contact with the sample holder. Thus, the external heat transfer conditions at particle surface in two reactors are different.
- In the DTR the solid is always in contact with the released gaseous components, while in the HTR the released gaseous components are rapidly drawn away from the particle surface.

The comparison of the yields of the main gaseous components is listed in Table 7.

Table 7. Comparison between the yields of the main gaseous components in the DTR and in the HTR

Operating condition	T=950°C Gas residence time = 4 s	
	DTR	HTR
Mass yield (wt. % of dry biomass)		
H ₂	1.7	1.4
CO	48.4	45.5
CO ₂	10.1	14.8
CH ₄	5.7	9.1
C ₂ H ₄	3.7	2.7
C ₂ H ₂	3.1	1.0
C ₂ H ₆	0.4	0.0
Total gas	73	75

Globally speaking, despite the differences between the two reactors, the results on the yields of the main gaseous components obtained in these two reactors are very close. When having a more detailed look at the results, it can be noticed that the yields of CO₂ and CH₄ are found to be higher in the HTR than in the DTR, while for the others, the yields in the DTR are a little higher than in the HTR. However, these differences remain minor. This indicates that the differences of reactor configuration and heating conditions between DTR and HTR do not play an important role in the production of the main gaseous components. Consequently, it seems reasonable to use these two reactors conjointly to study the influence of the particle size on the sample pyrolysis behaviour.

4. Conclusions

The pyrolysis behaviour of beech wood particles between 350 μm and 6 mm was investigated under representative conditions of fluidized bed gasifiers, i.e. atmospheric pressure, high external heat flux ($10^5 - 10^6 \text{ W.m}^{-2}$) and high temperatures (800 and 950°C). A drop tube reactor (DTR) was used to study the pyrolysis of particles between 350 and 800 μm , and a horizontal tubular reactor (HTR) was used to complete the study with larger particles (800 μm – 6mm) and to study the influence of the gas residence time (1 to 10 s).

Generally speaking, under the operating conditions studied in the present work, at the end of pyrolysis, more than 80 wt.% of virgin wood is converted into gas and less than 13 wt.% remains in solid. In the gas phase, CO is the main gaseous product (50 wt.% of virgin wood), followed by H₂ (the molar ratio of H₂/CO is between 0.35 to 0.55), H₂O, CO₂ and CH₄. Species C₂H₂, C₂H₄, C₂H₆ and C₆H₆ are present in much lower amounts, which is found in accordance with previous experimental results in similar conditions.

Under the explored conditions in the present study, the increase of the particle size significantly increases the required time for pyrolysis. However, the particle size has only a limited influence on the final products distribution of pyrolysis. Indeed, the increase of particle size from 350 to 800 μm does not significantly affect the products yields at the end of pyrolysis while a little influence can be seen with the increase of the particle size from 800 μm to 6 mm, i.e. increasing the yield of solid residue by about 3 wt.% (of dry wood) and decreasing the yield of total gas by about 10 wt.% (mainly CO yield).

The increase of temperature from 800 to 950°C logically increases the apparent pyrolysis rate. Moreover, the change of temperature changes the yields of the main gaseous components, i.e. higher temperature favours the cracking reactions and increasing significantly the yield of H₂.

Finally, it has been shown that the final yields of the main gaseous components obtained under similar conditions in the two different reactors are very close. Thus the potential differences between the two reactors do not significantly affect the results. This confirms that it is reasonable to use them conjointly in the study.

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