

Biomass to syngas conversion by pyro-gasification process

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Abstract: - The results of experimental research pyro-gasification process applied to biomass products are presented in this paper. Both pyrolysis and gasification represent cutting edge processes for power generation or alternative fuel using biomass. Research focused on:

- Biomass quality improvement by pyrolysis process.
- Vapor-gasification for syngas production with increased hydrogen content.
- Parameters influence on process kinetics and products formation.

The aim of the research was the optimization of two-stage conversion process using a versatile bench tubular reactor and samples of about 30 grams. The conducted processes were low, medium and high temperature pyrolysis (500°C, 650°C and 800°C) and high temperature vapor-gasification of wood char (800°C – 1000°C).

Key-Words: - biomass, pyrolysis, vapor-gasification, syngas

1 Introduction

Increasing prices for natural gas and oil, growing demand of energy, the global warming process and rising production of organic wastes from various industries are some of the important factors that contributed to the biomass utilization as energy source. Although various technologies for thermo-chemical conversion of biomass (i.e. gasification, pyrolysis) were developed during the last years, the most used technique it is still based on combustion. The high air excess required for the complete cellulose wastes oxidation is the main cause of the combustion global energy efficiency limitation due to the process high outgoing hot gases flow ratio. Nevertheless, the high treatment temperatures and the massive presence of the oxygen facilitate the nitrogen toxic components and the flying ash transport, forcing the industrials to costly gases flue treatment utilities. The international policy on the CO₂ emissions forced the industrials from the energy sector to turn to alternative processes of pyrolysis and gasification. In the last decade many research centers started to reconsider alternative thermal treatment technologies as pyrolysis and gasification applied to biomass for alternative fuels production. Alternative biomass to energy conversion focused on thermal engines, gas engines and fuel cells. There is a real interest in maximizing the syngas LHW or the hydrogen content. Therefore our research focused on optimizing the vapor-gasification process. The results of biomass thermal

degradation can be applied on a large range of products with useful energy content (industrial and urban wastes, sludge etc.).

2 Experimental device

2.1 Installation

The installation used for this study is a tubular fix bed reactor (figure 1.), external electrically heated, for discontinuous treatment. The laboratory scale reactor consists in an external heated tube within the inner diameter is of 34 mm and 500 mm long. The active zone, heated one, is about 300 mm.

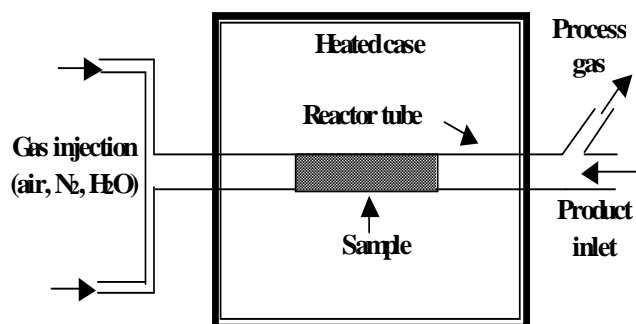


Fig. 1. Functional schema of the bench scale tubular reactor.

The tube reactor has two gas inlets for different experimental conditions: air, nitrogen or steam. The treated sample is introduced within a refractory steel tube. This device accepts quantities of about 3-50 grams for temperatures up to 1100 °C.

2.2 Biomass feedstock

Cherry wood was used during experimental campaign. The feedstock is characterized by its ultimate analysis as follows: 49.52 %wt C, 5.81 %wt H, 31.07 %wt O, 0.31 %wt N, 0.02 %wt S, 13.27 %wt H₂O (wet base). The ash content is 1.27 %wt and its chemical composition was approximated as a mixture of calcium oxide (CaO) and silica (SiO₂) in equal proportion. Including the moisture fraction, the LHV of the sample is 15,472 kJ/kg. The average weight of treated sample was around 30 – 35 grams.

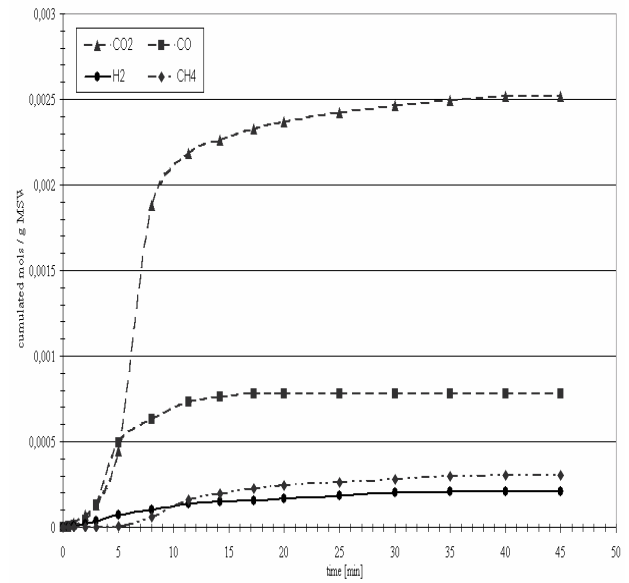
3 Experiment procedure and results

3.1 Pyrolysis stage

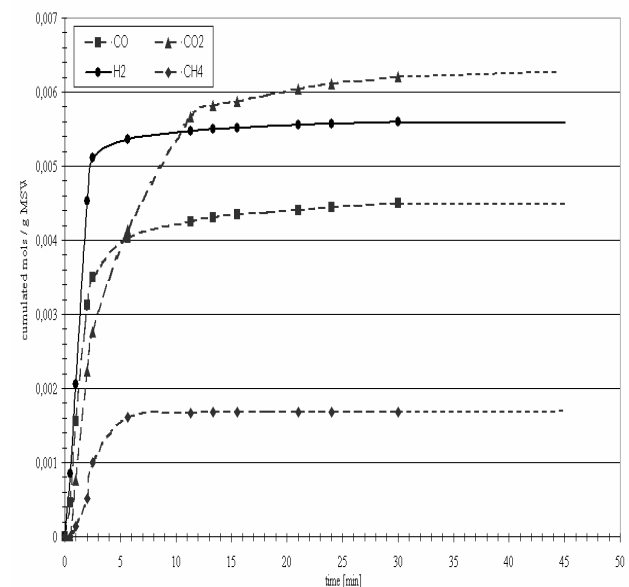
For the thermochemical processing we separated the drying and pyrolysis stage from the gasification one [1]. Therefore we first performed three types of atmosphere pressure pyrolysis under nitrogen environment. Nitrogen was injected inside the tube reactor 1 minute before the process start-up. A gas sample was analyzed to insure the inert atmosphere conditions required by the pyrolysis process. Analyze was performed using Agilent gas chromatographer.

In order to cover the main types of pyrolysis the process temperature was set to 500°C, 650°C and 800°C that correspond to low, medium and high temperature pyrolysis.

Figure 2 presents the generated gases evolution (average values) during the pyrolysis treatment. As we expected liberated gases: H₂, CO and CH₄ increase their content at higher temperature having a faster variation within the first 2 minutes, but the CO₂ quantity is quasi constant depending only on the O₂ concentration as we operate under auto-pyrolysis conditions (<2% oxygen) [2]. The instant hydrogen production increases 18 times from 0.0003 mol in 500°C pyrolysis to 0.0055 mol/1 gram of waste at 800°C. This phenomenon is related to the liberated tar cracking in gaseous phase [3]. The temperature of 500°C is insufficient to initiate the second gas phase reactions and consequently the volatiles and tars are evacuated in their initial form [4]. We noticed that pyrolysis kinetics at 650°C is similar to 800°C one.



a) pyrolysis 500°C



b) pyrolysis 800°C

Fig. 2. Pyrolysis gases production

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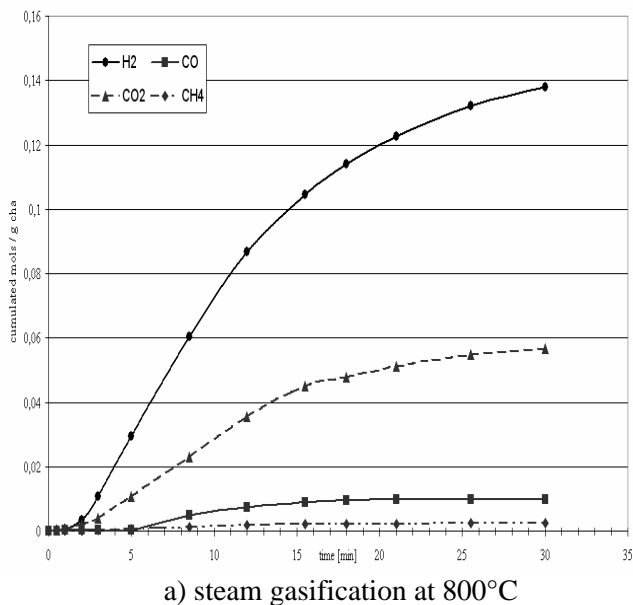
3.2 Vapor-gasification stage

For the process second stage, the gasification, we used as agent saturated steam at atmospheric pressure. As gasification product we used char from biomass pyrolysis at 500°C and 650°C with higher carbon content compared to 800°C pyrolysis char

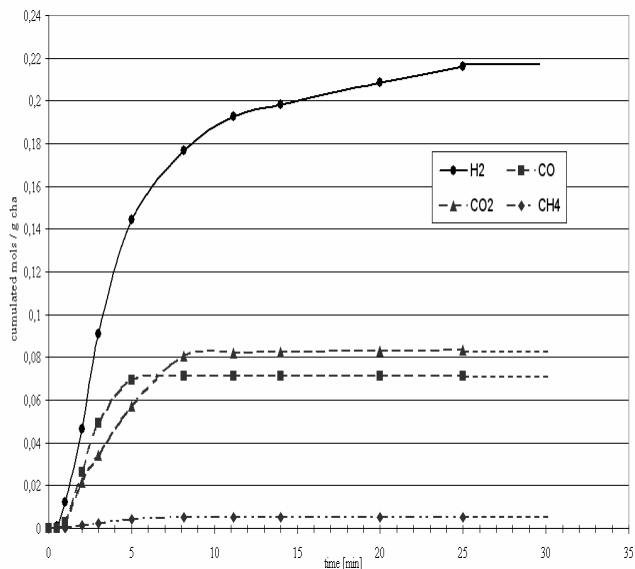
[1]. We introduced steam into the tube reactor using nitrogen as vector gas. The operating conditions were: temperature – 800°C and 1000°C; steam flow - 1 to 3 grams / minute for 5 grams of char. The carbon in the char obtained at 500°C is practically double as compared to the other sample issued from the 650°C pyrolysis. The carbon quantification was made through the char subsequent complete combustion and ash content determination.

3) and imposes also the transition period to the steady state. The hydrogen quantity doubles meanwhile the CH₄ content remains constant, being influenced only by the process pressure. As we expected, a higher temperature maximizes the H₂ production and the next step of the study was the gases production variations with the steam / carbon ratio at 1000°C [5].

Figure 4. presents the steam mass flow influence on the gas production in mol/1 gram of waste.

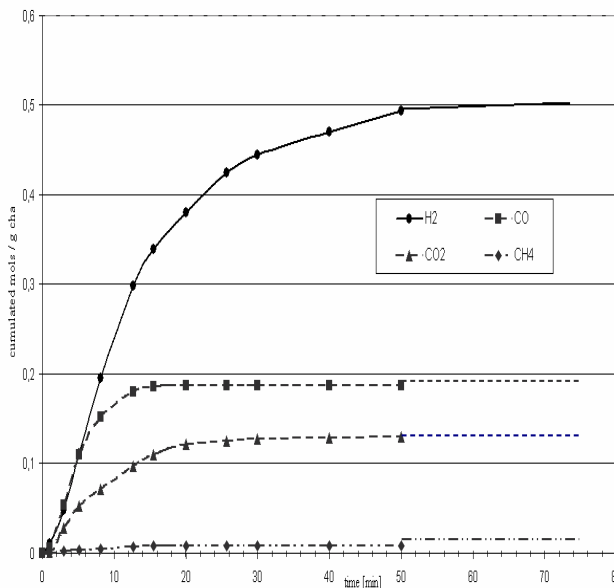


a) steam gasification at 800°C

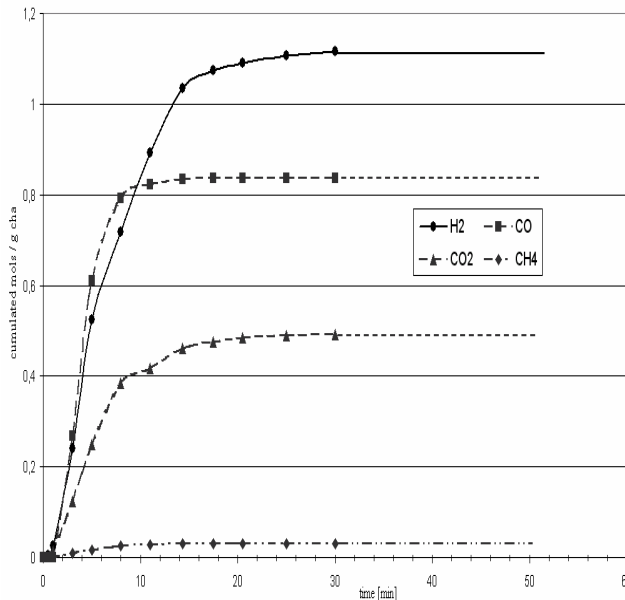


b) steam gasification at 1000°C
 Fig. 3. Gasification temperature influence on the gases production from 500°C pyrolysis char

The gas production is obviously influenced by the temperature, that generates a sensitive higher content at 1000°C compared to 800°C-850°C (figure



a) steam mass flow – 1g/min



b) steam mass flow – 3g/min
 Figure 4. Steam flow influence on the 650°C pyrolysis char gasification at 1000°C

Reaction speed increases and the period to reach the steady state is reduced to about 10 minutes. The combustible char fraction mass conversion rate varies from 93% to 98% due to H₂O/C ratio increase. The amount of H₂ is for 2.2 times higher when using a triple quantity of steam. In the same time the CO and CO₂ quantity increases four times. Performing complete combustion and ash content determination on the gasification residue we noticed the complete fixed carbon conversion at 1000°C. The residue issued from the 800°C gasification still contained 3% carbon [6].

To maximize the gasification gases production the interest is for a low temperature pyrolysis that enhances the char carbon content. The result is immediate: 0.22 molH₂/1gram of char at 650°C versus 0.5 molH₂/1gram of char at 500°C.

4 Conclusion

The option for separating the gasification process in two stages, integrated or independent: pyrolysis and gasification, can be dictated by biomass type (non-stable such as: agriculture waste, sludge, farm discharge, meat industry) and storage conditions, as well as electric and thermal consumer demand. If the product is characterized by fast degradation and cannot be processed on site, pyrolysis represents the first option in thermal-chemical conversion chain. For gasification stage low pyrolysis temperature char is required with higher fixed carbon content.

The temperature increase accelerates the gasification process and the CO + H₂ production under atmospheric pressure treatment conditions. The amount of hydrogen doubles for the same char sample gasified within the temperature range of 800 – 1000°C. The increase of the steam mass flow from 1g/min to 3g/min for 5 grams of char leads to a 40% enhancement of the fixed carbon conversion speed rate as well as the gas production. Thus, it is interesting to operate with a steam / biomass char ratio of about 2.6 at temperatures ranging between 950–1000°C under atmospheric pressure using low temperature pyrolysis 450°C – 525°C.

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