CHEMICAL ENGINEERING TRANSACTIONS Volume 24, 2011
Editor Sauro Pierucci
 ISBN 978-88-95608-15-0 ISSN 1974-9791
DOI: 10.3303/CET1124002

The Effect of Co-Gasification of the Biomass Pellets with Gas on the Thermal Degradation of Biomass

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The major goal of the research is to develop a stable, effective and controllable biomass gasification process and produce an environmentally friendly energy resource – fuel gas, which can be used in internal combustion engines for energy production. A pilot scale stratified downdraft gasifier has been developed with the aim to provide a controllable process of gasification of wood and wheat straw pellets and their mixtures by varying the air supply rate and additional heat energy supply with propane flame flow into the gasifier. The composition of the produced fuel gas (CO and H_2) as well as the produced amounts of ash, chars and tars are estimated and analyzed taking into account the effect of operation condition variations on the gasification process.

1. Introduction

Biomass is a renewable energy resource (RES) applicable for clean energy production due to zero greenhouse carbon (CO_2) emissions and relatively low nitrogen oxide (NOx) emissions produced during the combustion (Balat, 2008). At the same time, the utilization of biomass as an energy source for the industrial energy production systems is highly limited because of dissimilar biomass structure, variations of elemental composition, moisture content and heating values of different types of biomass (Arena et al., 2010). One of the possibilities to provide a more effective utilization of biomass for clean and controllable energy production is to convert it into a liquid or a gaseous fuel with controllable fuel characteristics.

A well-developed method of different types renewable solid fuels conversion into gaseous fuels is biomass gasification (Knoef, 2008). Gasification is a promising technology for incomplete combustion of biomass and waste utilization with low environmental impact, resulting in the production of combustible gases (mixture of CO, H_2 with small addition of CH_4), containing up to 80% of the biomass energy and reducing global CO_2 emissions.

Besides the wood fuel residues, utilization of straw as a fuel offers another way to solve the energy problems. In Latvia utilization of straw did not exceed 0.03% of the total renewable energy resources that were consumed for the energy production in 2009. Straw application as a fuel in the energy sector is highly limited due to several reasons: straw has a high content of chlorine and potassium, which are undesirable in power plant fuels, because these cause corrosion, straw has high ash content – about 13.7% of the dry fuel. The major goal of the current study is to develop a stable, effective and controllable process of wood and straw pellets gasification to produce an

Please cite this article as: Suzdalenko V., Barmina I., Lickrastina A. and Zake M., 2011, The effect of co-gasification of the biomass pellets with gas on the thermal degradation of biomass, Chemical Engineering Transactions, 24, 7-12
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environmentally friendly energy resource – fuel gas (mixture of CO, H_2 and CH_4), which could be used in internal combustion engines for power production. The composition of the produced fuel gas as well as the amounts of ash, char and tars produced during biomass pellets gasification are estimated and analyzed with account of variations of the operation conditions – air supply rate (l/min) and additional heat energy supply rate (kJ/s) into the gasifier.

2. Descriptions of experiment

Wood and straw pellets were gasified in a downdraft gasifier, as it is the preferable set-up for dry biomass gasification to obtain as clean as possible fuel gas, which contains more than 80% of volatiles and produces less than 1% of tar (Reed and Das, 1988). A pilot scale stratified downdraft gasifier (Fig.1) is developed using a controllable additional heat energy supply into the bottom part of the biomass pellets (3) with a limited swirled air supply from the tangential air nozzles at the upper part of the gasifier (1). The airflow was ranged from 14 to 22 l/min, determining the fuel-rich conditions ($\alpha \approx 0.2$-0.3) for the biomass gasification.

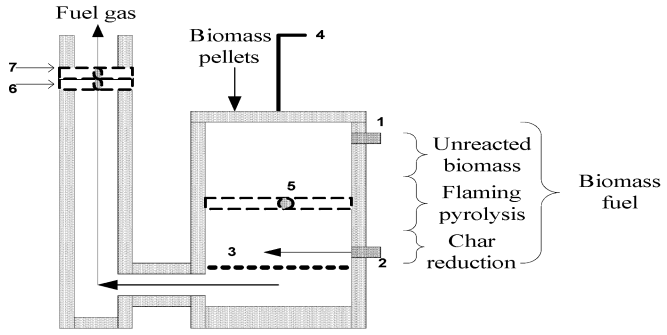

Figure 1: The pilot scale stratified downdraft gasifier: 1 – swirling air supply, 2 – propane flame flow injection, 3 – grate, 4 – sliding steel rod with a pointer, 5, 6 – orifices for thermocouples, 7– orifices for gas analysis.

The propane flame flow with controllable heat energy content was injected into the bottom part of the gasifier (2) from an external heat energy source and used to provide drying and heating of biomass up to 500-600 K to initiate the primary process of biomass gasification. As soon as the produced gas started to discharge from the gasifier, the external heat source was switched off. The duration of the propane flame supply into the gasifier was varied from 20 to 100 s, while the power of the propane flame flow was varied from 1 to 1.3 kJ/s. It allows studying the effect of additional heat energy supply by the propane flame flow in a range from 20 kJ up to 130 kJ, composing about 3-20% from the heat energy that must be supplied in order to initiate the endothermic process of biomass gasification at average equivalence ratio of air supply (α) $\alpha \approx 0.2$-0.3. The results show that a more stable and effective biomass gasification was obtained, when the additional heat energy supplied by propane flame flow exceeds 100 kJ and compiles

15% from the total energy content of the gasification. Below this limit the process of biomass gasification is quite unstable and indicates the high level of temperature and composition pulsations.

Discrete doses of biomass pellets (up to 200 g) were fed from the top of the gasifier and loaded on the steel grate in the bottom part (3). The average thickness (L, mm) of the biomass pellets in the gasifier at the initial stage of biomass gasification was about 100-120 mm, determining an average mass distribution of 1.7-2 g/cm downstream the gasifier. During the biomass gasification, the upper part of the biomass gradually moved down towards the bottom of the gasifier. Thus the thickness of the biomass layer in the gasifier gradually decreases and was controlled by a pointer attached to the sliding steel rod (4). The total length of the gasifier was 230 mm.

The experimental study of the biomass gasification included joint local on-line measurements of the temperature in the flaming pyrolysis zone, where charcoal and combustible gases (CO_2, H_2O, CO and H_2) were formed, as well at the outlet of the gasifier using a gas analyzer Testo-350XL. Local measurements of the temperature of the produced gas were carried out using Pt/Pt–Rh thermocouples. The first thermocouple (5) was inserted into the flaming pyrolysis zone at a distance of 50 mm above the grate. The second thermocouple (6) was inserted into the flow of produced gases at a distance of 170 mm from the gasifier outlet. The data were registered at one-sec intervals using a data plate PC-20. The effect of operating conditions on the formation of ash and tars is estimated from the weight measurements.

3. Results and discussion

The experimental study of biomass gasification has shown that the process of biomass gasification is sensitive to variations of the operating conditions – the rates of additional heat energy and air supply into the biomass. The primary process of biomass gasification starts with an endothermic process of biomass thermal degradation, which can be initiated by additional heat energy supply into the biomass. The resulting products from biomass gasification are gaseous products CO, CO_2, H_2, H_2O with a few percents of methane formed as well (Reed and Das, 1988):

$$C_{10}H_{14}O_6 + 4O_2 + heat \rightarrow 7CO + 3CO_2 + 6H_2 + H_2O \quad (1)$$

The time-dependent variations of the biomass gasification rate with correlating variations of the fuel gas composition indicate the formation of three main stages: biomass heating and drying at $t \approx 100\text{-}400$ s, devolatilization at $t \approx 500\text{-}1000$ s and char combustion/reduction at $t > 1000$ s. The duration of each stage is determined by the operating conditions as well as by the temperature and properties of the pelletized biomass (Nussbaumer, 2003).

At constant duration of the additional heat energy supply into the biomass (100 s) the most intensive release of CO and H_2 emissions is observed at the biomass devolatilization stage (Fig.2-a, b), promoting a sharp loss of the biomass weight at an average rate of 0.17-0.3 g/s and correlating temperature decrease in the flaming pyrolysis zone from 1400 K to 700-800 K. That confirms the development of

endothermic reactions of CO and H_2 formation (2, 3) (Butterman and Castaldi, 2008), (Knoef, 2008):

$$C + CO_2 \rightarrow 2CO \quad (164.9 \text{ kJ/mol}) \tag{2}$$

$$C + H_2 0 \rightarrow CO + H_2 \quad (122.6 \text{ kJ/mol}) \tag{3}$$

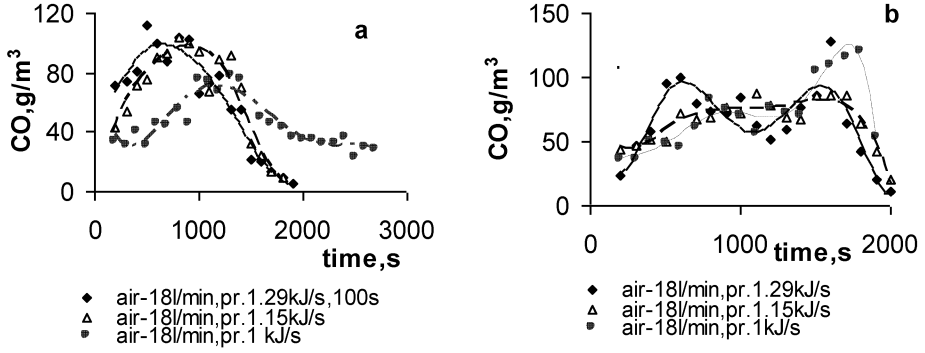

Figure 2: The effect of additional heat supply (kJ/s) on the formation of CO during the enhanced gasification of wood (a) and wheat straw (b) pellets.

By increasing the additional heat supply rate into the biomass during this stage of gasification in a range of 1-1.29 kJ/s at the constant rate of air supply, the peak amount of CO emissions for wood pellets can be increased from 78 g/m^3 to 104 g/m^3, while the average amount of CO in the produced gas flow increases from 73 g/m^3 to 97 g/m^3, so promoting a faster gasification of the wood pellets (Fig.2-a). The peak amount of H_2 in the products under the given conditions increases from 5.2 g/m^3 to 7.6 g/m^3 with an average amount of H_2 ranging from 4.7 g/m^3 to 6.7 g/m^3. Similar variations of the peak and average values of CO and H_2 are observed during the enhanced devolatilization of wheat straw pellets (Fig.2-b), when the increase of the additional heat energy supply into the biomass promotes an increase of the average value of CO emission of about 36%, while the average value of H_2 emission can be increased by 26%. As follows from Fig.2-b, for wheat straw pellets, the most intensive gasification is observed during the final stage of char combustion/reduction at t > 1000 s with a correlating increase of the average temperature in the pyrolysis zone up to 1300 K.

With the constant rate of additional heat energy supply, the processes of biomass gasification as well as the formation of main products (CO, H_2) are sensitive to the variations of the air supply rate into the gasifier (1). Under the given conditions, the equivalence ratio of the air supply increases in a range of 0.2-0.3 and the biomass gasification develops under the fuel-rich conditions ($\alpha < 1$). As follows from Fig.3-a,b, increasing the air supply rate from 14 l/min to 22 l/min increases the average amount of CO in the produced fuel gas from 56 g/m^3 to 80 g/m^3, while the average amount of H_2 increases from 4.5 g/m^3 to 6.4 g/m^3.

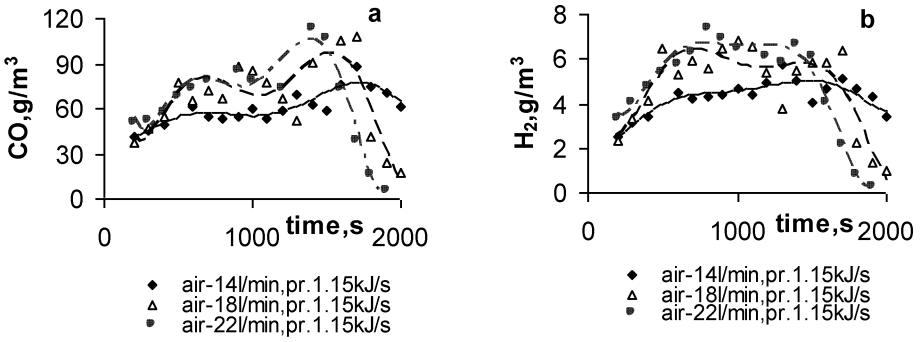

Figure 3: The effect of the air supply rate (l/min) on the formation of CO (a) and H_2 (b) during the gasification of wheat straw pellets.

With the constant rates of additional heat energy supply and air supply, the process of biomass gasification is influenced by variations of the biomass composition, determining the variations of CO emission and temperature during the gasification.

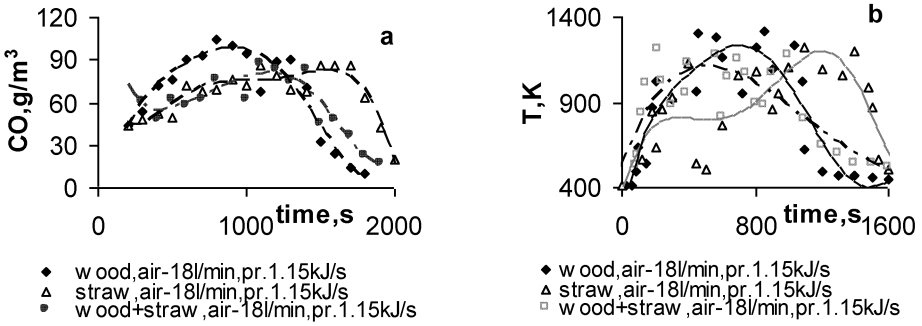

Figure 4: Time-dependent variations of CO emissions (a) and temperature (b) of the flaming pyrolysis zone for different types of biomass pellets.

When comparing the composition of the produced fuel gas during the wood and wheat straw pellets and their mixture (1:1) gasification (Fig.4-a, b), it was found that a faster gasification with a higher average value of the temperature in the pyrolysis zone can be obtained for wood pellets. The formation of the peak value of CO emissions (up to 104 g/m^3) for wood pellets takes place at the devolatilization stage. A longer gasification is observed for wheat straw pellets with the peak values of CO production (up to 108 g/m^3) and temperature at the char combustion stage. For the wood and wheat straw mixture, the peak value of CO emissions (up to 88 g/cm^3) and the peak value of the average temperature slightly decrease, and the formation of the peak value of CO is observed at the end stage of the devolatilization of wood pellets, i.e. between the stages of wood devolatilization and wheat straw char combustion.

Finally, it should be emphasized that the variations of the operation conditions and composition of biomass affect the formation of tar and ash. Increasing the additional heat energy supply in a range from 50 kJ up to 115 kJ promotes a slight increase of the average temperature in the pyrolysis zone of the downdraft gasifier from 750K up to 940K that promotes the enhanced thermal cracking of tars composed of carbohydrates and lignin's with correlating decrease of the mass of tars from 5.44 g to 1.5 g. With the constant rate of additional heat energy supply, the tar formation can be reduced by increasing the air supply into the gasifier, while the tar formation in the gasifier completely disappears at the air supply rate 0.4 g/s, when the average air excess ratio approaches to $\alpha \approx 0.27\text{-}0.3$ with correlating increase of the temperature during the gasification of the pelletized biomass. In addition, increasing the additional heat energy and air supply promotes a decrease of the ash production below 2% for wood pellets and below 3.5% for wheat straw pellets.

4. Conclusions

- Variations of the additional heat energy supply into the biomass allow controlling the process of biomass gasification with direct impact on the composition of the produced gas as well as on the formation of ash and tars.
- The gasification of pelletized biomass can be additionally controlled by varying the air supply rate into the gasifier, while the additional heat energy supply being constant. Under these conditions the increase of CO and H_2 production with the limited production of ash and tars can be obtained.

Acknowledgments

The authors would like to express our appreciation for financial support from the European Regional Development Funding Nr.2010/0241/2DP/2.1.1.1.0/10/APIA/ VIAA/006.

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