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GASIFICATION OF WASTE WOOD BIOMASS

This paper presents the results of the gasification of sawmill waste – pine sawdust, deciduous sawdust, bark pine, wet sawdust and wood pellets. The moisture content of the waste in the test varied from 9 to 48%. The higher the moisture of biofuels, the lower the quality of the energy. This was confirmed by the results of the fuel property analysis, which are presented in the paper. The wood biomass gasification process was carried out in a compact bed gasifier with a power of 5 kW. The gasifying factor was the air fed to the bed through a grid sieve from the bottom of the gasifier. The research showed that the shares of flammable components in the resulting gas generator varied, resulting in differing calorific contents. Studies have shown that the gasification of wood biomass (even with a large moisture load, allows it to be transformed into a low-calorie fuel gas. The gasification of wood waste with a moisture content level of 9-11% only resulted in a larger share of combustible components in the gas generator. In the case of the pellets, the syngas contained 30% carbon monoxide, 12% methane and 8% hydrogen.

Keywords: wood waste, gasification, syngas

Introduction

Of the many types of biofuel, plant-based biomass is the most important, particularly forest biomass. However, this use of forest biomass should only apply to waste biomass. When such waste has a significant moisture load, it is classified as “difficult”.

Methods for the use of biomass for energy include, among others, direct combustion in boilers and co-combustion with coal. Some of the technologies used to convert biomass-based energy are gasification processes. They are the most technologically advanced. The agent used for biomass gasification is usually air. It creates a low or medium calorific generator gas, which can be used as a substrate for chemical syntheses, a fuel in gas-steam systems, motor fuel,

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and as a reburning gas to reduce NO_x in power boilers. During the gasification of biomass using air, a gas which comprises large amounts of nitrogen is obtained, which reduces the heat of the gas combustion to a value of 4-7 MJ/Nm³. Gasification using pure oxygen produces a gas with a calorific value of 10-12 MJ/Nm³. The use of steam as a gasifying agent increases the amount of hydrogen in the gas [Piskowska-Wasiak 2011]. The process achieves good results with improvements in the construction of the gasification chambers (furnaces) e.g.: gasification in chambers with a fluidized bed [Li et al. 2010], double-layer gasification [Wang et al. 2007], and gasification in a cyclone chamber [Guo et al. 2009]. The gasification of Brazilian *Pinus elliottii* in a downdraft gasifier with air as the gasification agent was studied by Mendiburu et al. [2014]. The input parameters considered were: (a) equivalence ratio (0.28-0.35); (b) moisture content (5-20%); (c) gasification time (30-120 min) and carbon conversion efficiency (80-100%). Gasification can become more efficient with the use of catalysts to increase the reactivity of the components involved in the process [Brown et al. 2008; Zhu et al. 2008]. The increased efficiency of the biomass gasification process can also be achieved by using various organic additives, among others, resin biomass pine [McKendry 2002]. The fuel additives used do not act as catalysts but as additional fuel substrate involved in the thermal change processes which occur in the reaction chamber of the thermal gasifier. Abroad biomass gasification technologies have been developing at a rapid pace due to constantly diminishing fossil fuel resources along with a constant increase in the demand for electricity. In contrast to the Polish market, gas generators are commercially produced overseas and occupy a stable position as heating elements [Kirkels and Verbong 2010]. In research by Gunarathne et al. [2014], bio-coal pellets were gasified in an updraft high-temperature agent gasification unit with air preheated to 900°C in order to study the performance of the air gasification of hydrothermal carbonized biomass. Through the process of biomass carbonization, the share of coal rose from 46 to 66% and the calorific value increased from 19 to 29 MJ/kg. The calorific value of the syngas reached 7.9 MJ/Nm³.

The aim of this study was to gasify various types of waste wood biomass in a laboratory gasifier with a capacity of 5 kW and with a compact bed, where the gasification agent was air. The process was conducted under atmospheric pressure. The gasification test results indicate the differences in the composition and calorific value of the gas produced from different types of wood biomass, with varying degrees of density and moisture load.

Materials and methods

The research material consisted of a forest waste wood biomass in the form of bark, sawdust and wood pellets: (i) pine sawdust, wood sawdust from deciduous trees (except oak), and pellets from coniferous tree sawdust coming

from forest within the Podlasie Province; (ii) mixed wet sawdust, bark pine, wood pellets made from mixed sawdust – coming from the TRAK Timber Production Plant in Garbatka Długa, in Mazowieckie province.

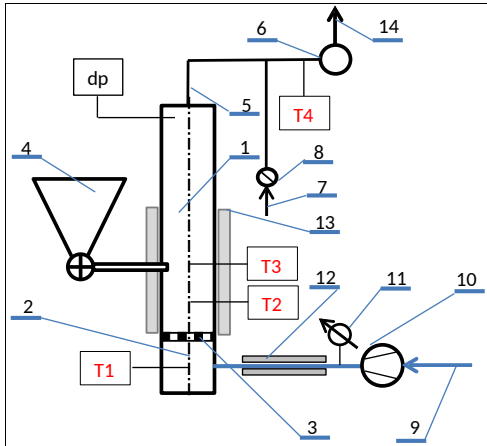
Table 1. Fuel properties of wood waste

Properties	Pine sawdust	Deciduous tree sawdust	Mixed wet sawdust	Coniferous tree pellets	Mixed wood pellets	Coniferous bark
Moisture content [%]	11.7	9.3	42.1	9.1	9.0	47.4
Flammable fraction* [%]	98.5	97.0	98.4	99.5	99.4	98.9
Ash* [%]	1.5	3.0	1.6	0.5	0.6	1.1
LHV* [kJ/kg]	19050	19101	17958	18151	18145	18680
LHV [kJ/kg]	17433	17542	8794	16170	16165	8031
Carbon** C [%]	48.54	51.70	45.07	49.1	48.93	47.86
Hydrogen** H [%]	6.10	6.10	6.26	6.32	6.48	6.16
Nitrogen** N [%]	0.32	0.21	1.44	0.20	0.93	1.27
Sulphur** S [%]	0.05	0.10	0.01	0.04	0.02	0.03
Chlorine** Cl [%]	0.11	0.10	0.16	0.07	0.01	0.12
Oxygen** O [%]	44.88	41.79	47.06	44.27	43.54	44.56

*Expressed on a dry free basis.

**Expressed on a dry ash-free basis.

Samples of the research material were collected according to the procedures used for sampling solids. After homogenization (in order to obtain representative samples), a fuel analysis was carried out. For this purpose, the following was determined: humidity, flammable and non-combustible parts, heat of combustion – in accordance with the PN-ISO standards [PN-Z-15008-02:1993; PN-ISO 1171:2002; PN-ISO 1928:2002] for the elemental composition of flammable substances - carbon, hydrogen, nitrogen, and sulphur by means of a Perkin Elmer 2400 series II CHNS elemental analyzer, and chlorine according to PN-ISO 587/2000. Mixed wet sawdust and coniferous tree bark are loaded with a substantial amount of moisture (42 and 47%, respectively). The combustion of these biofuels causes technical difficulties, and the fuel is known as “difficult”. In the gasification process, fuel moisture can be a factor advantageously influencing the process, however more than 40% of water in the fuel significantly decreases its calorific value. The ash content and elemental composition of the combustible substance of analyzed forest residue (sawdust, wood pellets, and bark) did not differ from the typical values for wood biomass. Fuels from waste pulp with the characteristics of the fuel shown in table 1 were converted into heat in the gasification process, in order to obtain combustible generator gas.



1 – reaction chamber, 2 – air chamber, 3 – grate, 4 – fuel feeder, 5 – syngas pipeline (syngas sampling point), 6 – fan, 7 – air cooling syngas, 8 – air regulation, 9 – air channel, 10 – air blower, 11 – air flow measurement kg/s, 12 – starting heat-air, 13 – starting heater, 14 – gas torch; T1 – air temperature, T2 – -temperature in the fuel bed, T3 – temperature over the fuel bed, T4 – temperature cooled syngas, dp – pressure sensor

Fig 1. Laboratory test stand – gasifier

Gasification was carried out in a laboratory reactor with a fixed bed (fig. 1). The maximum heat output of the gasifier was 5 kW. The gasifying agent was air (0.56-0.93 g/s), which was fed to the bed through the sieve grate from below the gasifier. Fuel was supplied to a feeder and then transported to a reactor using a screw conveyor. The air was heated by a system of electric heaters. Self-ignition of the fuel layer was initiated by heating the reactor chamber with air to a temperature of 320°C. Gasification was carried out at 375-435°C – the temperature of the fuel layer. In contrast, above the bed, in the gas phase, the temperature was 870-940°C. At a temperature of 375-435°C, the autothermal process occurred in the fuel layer. The intensive evaporation of high-calorific condensing substances, including tar, took place. It is suggested that these high-calorific compounds were burned over the layer of the fuel, in the atmosphere (in the lower layer) of unreacted oxygen, which resulted in a temperature increase to the value $T = \sim 940^\circ\text{C}$. The lack of high-calorific C_nH_m hydrocarbons in the generated gas indicated this. Once the temperature in the reaction chamber was stabilized, the gas was collected from the upper part of the chamber using an aspirator. Having passed through the scrubber system, the gas was transported to the analyzer. Measurement of the concentrations of gaseous products was carried out using a GAS 3000 synthesis gas analyzer.

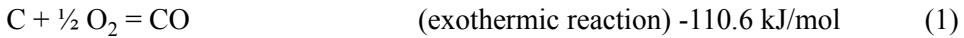
The ash was removed during the process by blowing it out of the gasification chamber with a stream of air from the exhaust fan. The ash was deposited in the bottom part of the secondary combustion chamber. The resulting gas was burned in a secondary combustion chamber and before using the exhaust fan, the exhaust gases were cooled to a temperature of ca 180°C. For cooling, ambient air was sucked through the flue exhaust duct. The gas generator and channel air blower were equipped with an electrical heating system, which was used to

provide warmth to the reaction zone. The stabilization process was performed by regulating the flow of fuel and the gasification air flow.

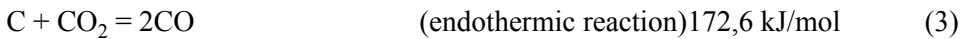
Results and discussion

Gasification is a complex chemical process and the main reactions leading to the formation of gaseous flammable products are [Littlewood 1997]:

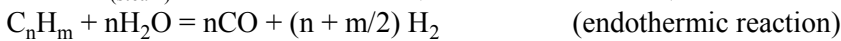
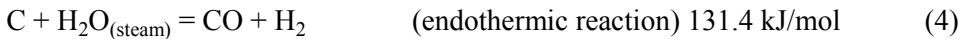
Oxidation reactions:



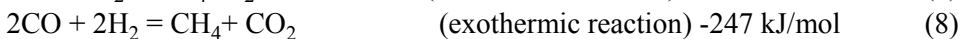
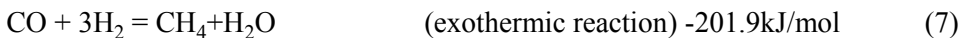
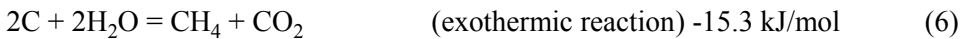
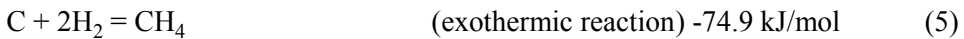
Boudouard reaction:



Steam gasification:



Methanation reactions:



The results of the gasification of the wood biomass in variable inlet air, refer to the composition of the produced generator gas. The change in the air flow in the conducted experimental studies was obtained by adjusting the air blow. Figs. 2a-2f show the volume fractions in % of the flammable components of the syngas: carbon monoxide CO, hydrogen H₂, and methane CH₄, as a function of the oxygen content ratio O₂[%_{vol}] in the oxidizer (blast) and carbon C share (mass fraction) in the fuel. The quality (calorific value) of the generated gas is decided by the share of flammable components.

The calorific value of the generated gas was calculated using the following formula (its source is found in the instruction manual for the analyzer):

$$LHV_{\text{syngas}} = 126 [\%CO] + 108 [\%H_2] + 359 [\%CH_4] + 665 [\%C_n H_m] \text{ [kJ/Nm}^3\text{]} \quad (9)$$

The greatest number of combustible components were found in the generated gases resulting from the gasification of the pellets - mixed and pine (figs. 2a and 2b): carbon monoxide CO at up to ca 28-30%, 11-14% methane CH₄, and 5-6% hydrogen H₂. This gas composition was reflected in the calorific

value (fig. 3) – 7600 to 8700 kJ/Nm³. The gasification of the sawdust regardless of its type (figs. 2c-2e) resulted in a gas production with a share of flammable components lower by more than half, and half the calorific value. A significant amount of methane in the gas (up to 14% when gasified pellets) was also observed. It should be noted that in the gasification of wood biomass in the compact fixed-bed gasifier, the share of methane in the synthesis gas is approx. 2-3% and the heating value of synthesis gas typically reaches a level of

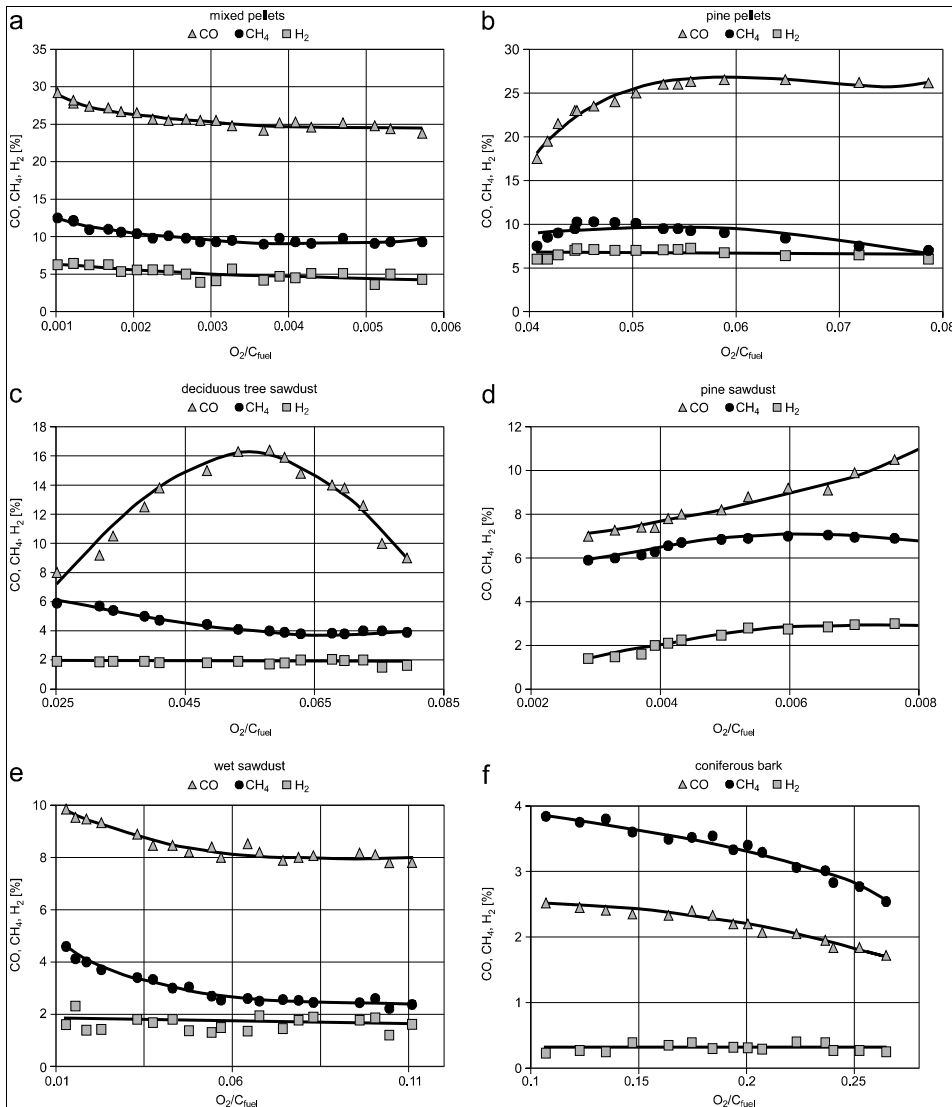


Fig. 2. [%_{vol}] CH₄, H₂, CO = f(O₂/C_{fuel}): a – mixed pellets, b – pine pellets, c – deciduous tree sawdust, d – pine sawdust, e – wet sawdust, f – coniferous bark

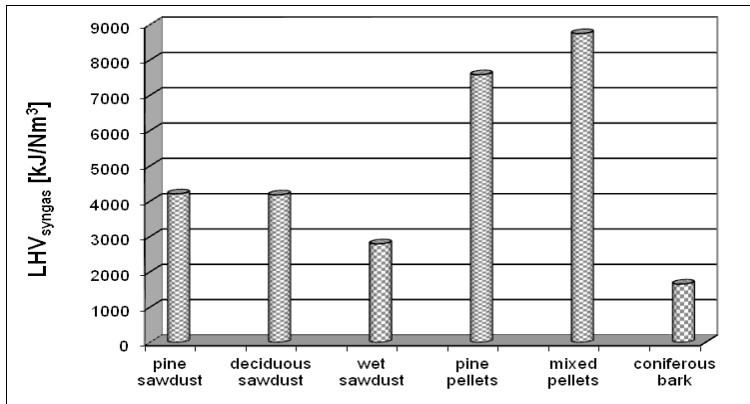


Fig. 3. The calorific value of gas generated from the gasification of wood

2000 kJ/Nm³ to 4000 kJ/Nm³ [Saravanakumar et al. 2007]. The bark of conifers (fig. 2f) proved to be the worst fuel for gasification. Several percentages of methane and carbon monoxide, and a fraction of hydrogen in the gas, resulted in a low calorific value of ca 1600 kJ/Nm³. Here, the process occurred at the highest values of O_2/C_{fuel} (>0.1). Gasification of the mixed pellets and pine sawdust was carried out under conditions with the least oxygenation – O_2/C_{fuel} 0.001-0.008. Research on waste wood material gasification enabled the production of low-calorific gases (fig. 3).

Conclusions

1. Wood waste is a solid fuel which, during the gasification process, can be converted into a gaseous fuel.
2. The type of biomass determines the conduct of the process and affects the performance of the gasification products.
3. The concentrated wood waste (pellets) were characterized by the highest calorific value. In the gasification process in a compact fixed-bed gasifier, the heating value of the synthesis gas was 7600 and ~ 9000 kJ/Nm³, while the CH₄ content ranged from 11 to 14%. The gas obtained using this technology - due to its calorific value - may be used to drive gas turbines.
4. The gasification of poorly carbonized fuels (and wood waste is an example), characterized by a high moisture level (wet sawdust and coniferous bark), does not require the introduction of steam to the generator, however excess water often interferes with the process and needs to be evaporated off.
5. An increase in the methane and hydrogen content in the syngas is obtained using fluidized gasification technologies and dual-layer gasification technology, which are complicated from a construction point of view.

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List of standards

- PN-ISO 587/2000** Oznaczanie zawartości chloru z zastosowaniem mieszaniny Eschki (Determination of chlorine using Eschka mixture)
- PN-ISO 1171:2002** Oznaczanie popiołu (Determination of ash)
- PN-ISO 1928:2002** Oznaczanie ciepła spalania metodą spalania w bombie kalorymetrycznej i obliczanie wartości opałowej (Determination of gross calorific value by the bomb calorimetric method, and calculation of calorific value)
- PN-Z-5008-02:1993** Oznaczanie wilgotności całkowitej (Determination of moisture content)

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